TESIS DE LA UNIVERSIDAD DE ZARAGOZA

2020

11

Gabriel Lozano Berges

Interacción del tipo de bota y superficie de juego en la salud ósea de niños y niñas futbolistas

Departamento
Fisiatría y Enfermería

Director/es
Casajús Mallén, José Antonio
Vicente Rodríquez, Germán

ISSN 2254-7606

Prensas de la Universidad
Universidad Zaragoza

ISSN 2254-7606

Tesis Doctoral

INTERACCIÓN DEL TIPO DE BOTA Y SUPERFICIE DE JUEGO EN LA SALUD ÓSEA DE NIÑOS Y NIÑAS FUTBOLISTAS

Autor

Gabriel Lozano Berges

Director/es

Casajús Mallén, José Antonio
Vicente Rodríquez, Germán

UNIVERSIDAD DE ZARAGOZA
Fisiatría y Enfermería

2018

Tesis Doctoral Internacional *[International Doctoral Thesis]*

Curso Académico 2018-2019

INTERACCIÓN DEL TIPO DE BOTA Y SUPERFICIE DE JUEGO EN LA SALUD ÓSEA DE NIÑOS Y NIÑAS FUTBOLISTAS

INTERACTION OF FOOTWEAR TYPE AND PLAYING SURFACE ON BONE HEALTH IN MALE AND FEMALE YOUNG FOOTBALL PLAYERS

GABRIEL LOZANO BERGES

Departamento de Fisiatría y Enfermería

Facultad de Ciencias de la Salud y del Deporte

Universidad de Zaragoza

Interacción del tipo de bota y superficie de juego en la salud ósea de niños y niñas futbolistas.

Interaction of footwear type and playing surface on bone health in male and female young football players.

GABRIEL LOZANO BERGES

A mis directores, Germán y José Antonio

A mis compañeros del grupo GENUD

A mi familia y amigos

Gracias por vuestra ayuda y apoyo incondicional

Nuestra recompensa se encuentra en el esfuerzo y no en el resultado.

Un esfuerzo total es una victoria completa

Mahatma Gandhi

El fracaso es parte de la vida; si no fracasas, no aprendes

y si no aprendes, no cambias

Paulo Coelho

Interacción del tipo de bota y superficie de juego en la salud ósea de niños y niñas futbolistas.

Interaction of footwear type and playing surface on bone health in male and female young football players

DIRECTORES DE TESIS:

Prof. José A. Casajús Mallén
Facultad de Ciencias de la Salud
Universidad de Zaragoza

Dr. Germán Vicente Rodríguez
Facultad de Ciencias de la Salud y del Deporte
Universidad de Zaragoza

MIEMBROS DEL TRIBUNAL:

Presidente
Dr. Ignacio Ara Royo
Facultad de Ciencias del Deporte Toledo
Universidad de Castilla-La Mancha

Secretaria
Dra. Nuria Garatachea Vallejo
Facultad de Ciencias de la Salud y del Deporte
Universidad de Zaragoza

Vocal
Dra. Charlotte Apps
School of Science and Technology
Nottingham Trent University

Suplente 1º
Dr. Gerardo Rodríguez Martínez
Facultad de Medicina
Universidad de Zaragoza

Suplente 2º
Dra. Silvia Bel Serrat
National Nutrition Surveillance Centre
University College Dublin

Universidad Zaragoza

1542

Prof. Dr. JOSÉ ANTONIO CASAJÚS MALLÉN

Catedrático de Universidad

Departamento de Fisiatría y Enfermería

Facultad de Ciencias de la Salud

Universidad de Zaragoza

JOSÉ ANTONIO CASAJÚS MALLÉN, CATEDRÁTICO DE LA UNIVERSIDAD DE ZARAGOZA, CERTIFICA:

Que la Tesis Doctoral titulada *"Interacción del tipo de bota y superficie de juego en la salud ósea de niños y niñas futbolistas."* que presenta D. **GABRIEL LOZANO BERGES** al superior juicio del Tribunal que designe la Universidad de Zaragoza, ha sido realizada bajo mi dirección durante los años 2014-2018, siendo expresión de la capacidad técnica e interpretativa de su autor en condiciones tan aventajadas que le hacen merecedor del Título de Doctor, siempre y cuando así lo considere el citado Tribunal.

Fdo. José A. Casajús Mallén

En Zaragoza a 20 de agosto de 2018

Dr. GERMÁN VICENTE RODRÍGUEZ
Profesor Titular de Universidad

Departamento de Fisiatría y Enfermería
Facultad de Ciencias de la Salud y del Deporte
Universidad de Zaragoza

GERMÁN VICENTE RODRÍGUEZ, PROFESOR TITULAR DE LA UNIVERSIDAD DE ZARAGOZA, CERTIFICA:

Que la Tesis Doctoral titulada *"Interacción del tipo de bota y superficie de juego en la salud ósea de niños y niñas futbolistas."* que presenta D. **GABRIEL LOZANO BERGES** al superior juicio del Tribunal que designe la Universidad de Zaragoza, ha sido realizada bajo mi dirección durante los años 2014-2018, siendo expresión de la capacidad técnica e interpretativa de su autor en condiciones tan aventajadas que le hacen merecedor del Título de Doctor, siempre y cuando así lo considere el citado Tribunal.

Fdo. Germán Vicente Rodríguez

En Zaragoza a 20 de agosto de 2018

Listado de publicaciones *[List of publications]*

La presente Tesis Doctoral es un compendio de trabajos científicos previamente publicados, aceptados para publicación o sometidos a revisión. A continuación, se detallan las referencias de cada uno de los artículos que componen este documento:

I. **Lozano-Berges G**, Matute-Llorente A, González-Agüero A, Gómez-Bruton A, Gómez-Cabello A, Vicente-Rodríguez G, Casajús JA. Soccer helps build strong bones during growth: a systematic review and meta-analysis. **Eur J Pediatr**. 2018 Mar; 177(3): 295-310. https://doi.org/10.1007/s00431-017-3060-3

II. **Lozano-Berges G**, Matute-Llorente A, Gómez-Bruton A, González-Agüero A, Vicente-Rodríguez G, Casajús JA. Is playing football more osteogenic for females before the pubertal spurt? **J Hum Kinet**. *Submitted*.

III. **Lozano-Berges G**, Matute-Llorente A, Gómez-Bruton A, González-Agüero A, Vicente-Rodríguez G, Casajús JA. Bone geometry in young male and female football players; a peripheral quantitative computed tomography (pQCT) study. **Arch Osteoporos**. 2018 May; 13(1): 57. https://doi.org/10.1007/s11657-018-0472-2

IV. **Lozano-Berges G**, Clansey AC, Casajús JA, Lake MJ. Lack of impact moderating movement adaptation when soccer players perform game specific tasks on a third-generation artificial surface without a cushioning underlay. **Sports Biomech**. *Submitted*.

V. **Lozano-Berges G**, Matute-Llorente A, Gómez-Bruton A, González-Agüero A, Vicente-Rodríguez G, Casajús JA. Is plantar pressure intensity associated with bone geometry and strength in male adolescent football players? **J Sports Med Phys Fitness**. *Submitted*.

VI. **Lozano-Berges G**, Matute-Llorente A, Gómez-Bruton A, González-Agüero A, Vicente-Rodríguez G, Casajús JA. Influence of different playing surface on bone mass accretion in male adolescent football players. **Proc Inst Mech Eng P J Sport Eng Technol**. *Submitted*.

VII. **Lozano-Berges G**, Matute-Llorente A, Gómez-Bruton A, González-Agüero A, Vicente-Rodríguez G, Casajús JA. Body fat percentage comparisons between four methods in young football players: are they comparable? **Nutr Hosp**. 2017 Oct; 34(5): 1119-1124. http://dx.doi.org/10.20960/nh.760

VIII. **Lozano-Berges G**, Matute-Llorente A, Gómez-Bruton A, González-Agüero A, Vicente-Rodríguez G, Casajús JA. Accurate Prediction Equation to Assess Body Fat in Male and Female Adolescent Football Players. **Int J Sport Nutr Exerc Metab**. *Accepted*.

Tabla de contenidos

Table of contents

Proyecto de investigación

La Tesis Doctoral que se presenta a continuación, así como los artículos que la conforman, se enmarcan dentro del siguiente proyecto de investigación:

"*Efecto de la interacción entre el tipo de césped artificial y modelo de botas en la salud ósea de niños y niñas futbolistas. (Acrónimo: FUTBOMAS)*"

Este proyecto nacional de 3 años de duración fue financiado por el *Ministerio de Economía y Competitividad del Gobierno de España (DEP2012-32724)* y desarrollado en colaboración con la Federación Aragonesa de Fútbol, Mondo Ibérica y Podoactiva.

Investigador principal: ***José A. Casajús Mallén.***

Becas

Gabriel Lozano Berges recibió una beca destinada a la Formación de Profesorado Universitario del *Ministerio de Educación, Cultura y Deporte del Gobierno de España (FPU13/02111)*.

Research project

The present Thesis, as well as the manuscripts that are part of it, are within the frame of the following research project:

"*Effect of the interaction between the type of artificial turf and boots model of bone health in children football players (Acronym: FUTBOMAS).*"

This three-year national project was funded by the *Ministerio de Economía y Competitividad del Gobierno de España* (DEP2012-32724) in collaboration with *Federación Aragonesa de Fútbol*, *Mondo Ibérica* y *Podoactiva*.

Principal investigator: ***José A. Casajús Mallén.***

Grants

Gabriel Lozano Berges received a grant from the *Ministerio de Educación, Cultura y Deporte del Gobierno de España* (FPU13/02111).

Resumen general

El ejercicio físico y el deporte durante el crecimiento tienen un papel fundamental en la mejora de la masa y la estructura ósea; sin embargo, no todos los deportes tienen el mismo efecto en el hueso. El fútbol es un deporte de alto impacto que está asociado con una adquisición de hueso favorable tanto a nivel de contenido como de densidad mineral ósea durante el crecimiento. El estímulo osteogénico que recibe el deportista podría modificarse con el tipo de superficie de juego, quedando por aclarar muchos aspectos sobre sus efectos en el hueso de chicos y chicas futbolistas adolescentes. Los objetivos generales de esta Tesis Doctoral son ampliar el conocimiento existente sobre los efectos de la práctica del fútbol en la masa y estructura ósea de niños y adolescentes futbolistas, y analizar la interacción de diferentes tipos de botas de fútbol y superficies de juego en el desarrollo de la masa y estructura ósea.

La muestra de estudio estuvo compuesta por un total de 110 futbolistas (75 chicos con una edad media de 12,7 ± 0,7 años y 35 chicas con una edad media de 12,7 ± 0,6 años) y 45 controles normo-activos (23 chicos con una edad media de 13,2 ± 1,4 años y 22 chicas con una edad media de 12,7 ± 1,3 años). Los futbolistas recibieron aleatoriamente el modelo de bota Adidas Nitrocharge 3.0 con multitaco o con taco de goma. Se evaluó su composición corporal usando absorciometría fotónica dual de rayos X, tomografía axial computerizada periférica, pletismografía por desplazamiento de aire, impedancia bioeléctrica y antropometría; sus presiones plantares mediante un sistema de plantillas Biofoot, y su actividad física usando acelerometría. Asimismo, se evaluaron las características mecánicas de las superficies de juego siguiendo los criterios de calidad establecidos por el Comité Europeo de Normalización (EN 15330-1:2007). Además, en un estudio realizado en la universidad "Liverpool John Moores University" participaron 13

jóvenes futbolistas a los que se les evalúo su biomecánica con un sistema de captura de movimiento (cámaras, marcadores reflectantes y plataformas de fuerzas).

Los resultados de la presente Tesis Doctoral mostraron que las chicas futbolistas tenían mayor contenido y densidad mineral ósea que los chicos. Además, tanto las chicas como los chicos futbolistas post-puberales (Tanner IV y V) presentaron mayores valores de masa ósea que los peri-puberales (Tanner II y III). En relación con la estructura y fuerza ósea, las chicas futbolistas tenían mejor estructura ósea y mayor fortaleza ósea que los controles; sin embargo, los chicos sólo mostraron mejor estructura ósea que los controles. La práctica de fútbol durante un año incrementó significativamente la densidad mineral ósea de las extremidades inferiores en comparación con los controles. Aunque el tipo de bota no influyó en la adquisición de masa ósea, los futbolistas que jugaban en césped artificial de tercera generación sin sub-base elástica (baja absorción de impacto) mejoraron la densidad mineral ósea aparente en comparación con los que jugaban en una superficie de juego con mayor absorción de impacto (césped artificial de tercera generación con sub-base elástica). Por otra parte, se demostró que la inclusión de una sub-base elástica en el césped artificial de tercera generación redujo el impacto y la carga recibida por el futbolista.

En conclusión, la práctica de fútbol durante el crecimiento tiene un efecto positivo en la adquisición ósea, especialmente en las chicas. Debido a que las superficies de juego más duras aumentan el impacto y carga recibidos por el futbolista, la práctica de fútbol en estas superficies podría aumentar la adquisición ósea de estos deportistas.

General abstract

Physical exercise and sport during growth have a key role to improve bone mass and geometry; nevertheless, not all sports have the same effect on bone. Concretely, football is a high impact sport that is positively associated with bone mass acquisition during childhood and adolescence. The type of surface is capable of modifying the osteogenic stimulus that football players receive, but as of today, the influence of different surfaces on bone health in young football players is unknown. Therefore, the general aims of this Thesis are to enlarge the scientific knowledge in terms of the effects of football practice on bone mass and structure in children and adolescent football players, and to analyse the interaction of different footwear types and playing surfaces on the acquisition of bone mass and structure.

The sample for the present study consisted of 110 football players (75 boys and 35 girls) and 45 normo-active controls (23 boys and 22 girls). Football players randomly received Adidas Nitrocharge 3.0 footwear model with a turf stud or hard-ground stud design. Body composition was evaluated through dual energy X-ray absorptiometry, peripheral quantitative computed tomography, air displacement plethysmography, bioelectrical impedance analyses and anthropometry; plantar pressures were measured by Biofoot insoles; and physical activity was measured with accelerometry. Mechanical characteristics of the football field were performed according to the quality standards proposed by the European Committee for Standardisation (EN 15530-1:2007). Furthermore, another sample of 13 young football players participated in a study performed in Liverpool John Moores University. Their biomechanical data were assessed using a motion capture system (camera, reflective markers and force platforms).

The results of the present Thesis showed that female football players had higher bone mineral content and density compared to males. Moreover, both male and female

postpubertal football players (Tanner IV and V) presented greater bone mass compared to their peripubertal counterparts (Tanner II and III). In terms of bone structure and strength, female football players had better structure and greater bone strength in comparison with controls; nevertheless, male football players only showed higher bone structure compared to controls. A year of football practice significantly increased bone mineral density at the lower limbs in comparison with controls. Although footwear type did not affect bone mass, football players who trained in third-generation artificial turf without elastic layer (low shock absorption) improved apparent bone mineral density at the lumbar spine compared to those players who trained in a more cushioning surface (third-generation artificial turf with elastic layer). On the other hand, the inclusion of an elastic layer in a third-generation artificial turf reduced impact forces and loading received by football players.

In summary, football practice has a positive effect on bone acquisition during growth, specially in girls. As hard football surfaces increase the impact and loading received by players, football practice in surfaces with low shock absorption could improve bone acquisition of football players.

Listado de abreviaturas

ADP	Pletismografía por desplazamiento de aire
AF	Actividad física
ANCOVA	Análisis de las covarianzas
ANOVA	Análisis de las varianzas
BIA	Análisis de impedancia bioeléctrica
CEICA	Comité de Ética de la Investigación de la Comunidad Autónoma de Aragón
CEN	Comité Europeo de Normalización
CMO	Contenido mineral óseo
CSD	Consejo Superior de Deportes
DMO	Densidad mineral ósea de área
DMOv	Densidad mineral ósea volumétrica
DXA	Absorciometría fotónica dual de rayos X
ESTO	Organización europea de césped artificial
FIFA	Federación Internacional de Fútbol
ISAK	Sociedad Internacional para el Avance de la Cineantropometría
IMC	Índice de masa corporal
ISCD	Sociedad Internacional de Densitometría Clínica
NIH	Institutos Nacionales de la Salud
OMS	Organización Mundial de la Salud
pQCT	Tomografía axial computerizada periférica
SBR	Caucho estireno-butadieno
Triple A	Atleta artificial avanzado

List of abbreviations

aBMD	Areal bone mineral density
ADP	Air displacement plethysmography
ANCOVA	Analysis of covariance
ANOVA	Analysis of variance
BIA	Bioelectrical impedance analysis
BMC	Bone mineral content
BMD	Bone mineral density
DXA	Dual energy X-ray absorptiometry
ESTO	European Synthetic Turf Organisation
FIFA	Fédération Internationale de Football Association
ISAK	International Society for the Advancement of Kinanthropometry
ISCD	International Society of Clinical Densitometry
NIH	National Institutes of Health
pQCT	Peripheral quantitative computed tomography
SBR	Styrene-butadiene rubber
SPSS	Statistical Package for the Social Sciences

1. Introducción ***[Introduction]***

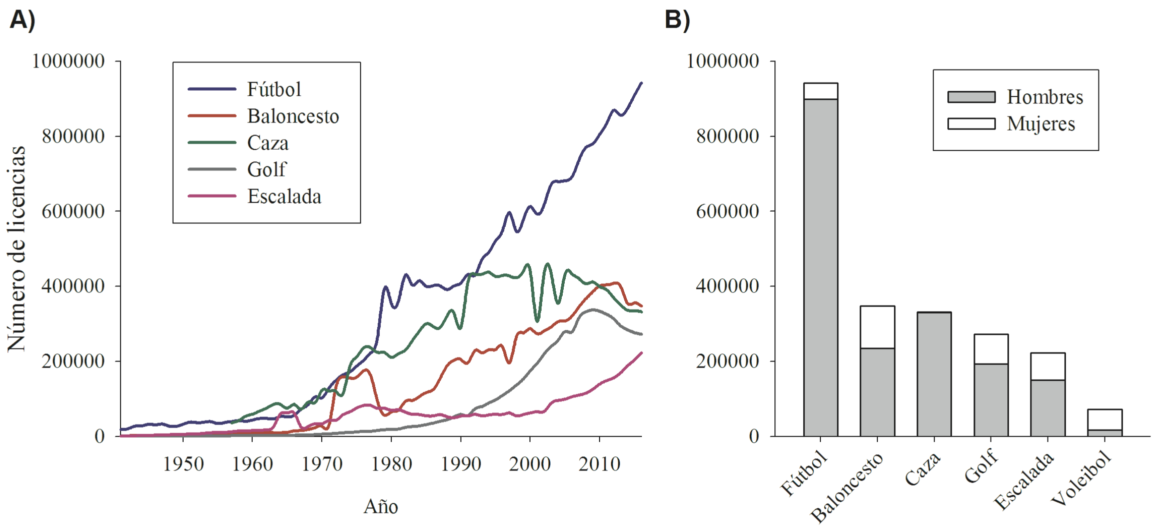
La presente Tesis Doctoral tiene como objetivo analizar la interacción del tipo de superficie y modelo de bota en la masa, estructura y geometría ósea de niños y niñas futbolistas. Por ello, la introducción se estructurará en los siguientes cuatro apartados: 1) historia del fútbol, 2) superficies de juego en el fútbol, 3) masa ósea en niños y adolescentes, y 4) efectos del fútbol en la masa ósea durante el crecimiento.

1.1 Historia del fútbol

El fútbol nació en Inglaterra en el año 1863 como resultado de la separación del *Rugby-Football* (rugby) y de la *Association Football* (fútbol) fundándose posteriormente, la *Football Association* (Federación Inglesa de Fútbol), primer órgano oficial de este deporte. Como consecuencia de la extensión del fútbol por otros países, en 1904, se fundó la *Fédération Internationale de Football Association* (FIFA) [1], asociación formada por siete federaciones de ámbito nacional. Concretamente, el *Madrid Club de Fútbol* representó a España ya que la Real Federación Española de Fútbol no fue constituida hasta el año 1909. En la actualidad, 211 federaciones están afiliadas a la FIFA.

En España, el Consejo Superior de Deportes (CSD) es un Organismo autónomo de la Administración General del Estado que reúne las federaciones deportivas españolas, entre ellas, la Real Federación Española de Fútbol. Los datos de licencias obtenidos del CSD de cada una de estas federaciones desde 1941 hasta la actualidad demuestran que el fútbol es, y ha sido, el deporte más practicado en España tanto en el siglo XX como en los inicios del siglo XXI (**Figura 1**). Curiosamente, en el año 2016, el número de licencias en el fútbol fue claramente superior al observado en el baloncesto, segundo deporte con mayor número de licencias (942.674 versus 347.017 licencias) [2]. Sin embargo, analizando estos datos en hombres y en mujeres por separado, se observa que solamente el 5% de las licencias en el fútbol (44.123 licencias) corresponden a mujeres. Así, el fútbol en mujeres es actualmente el quinto deporte con mayor número de licencias por detrás del baloncesto (112.265 licencias), golf (79.451 licencias), escalada (72.885 licencias) y voleibol (55.886 licencias; **Figura 1**). El elevado número de licencias en los hombres y el progresivo aumento en el número de licencias en las mujeres hace que este deporte sea uno de los más influyentes en España.

Figura 1. Licencias federativas de los deportes más practicados en España.



A) Histórico de licencias federativas de los deportes más practicados en España desde 1941 hasta 2016. B) Licencias de hombres y mujeres de los deportes más practicados en 2016.

1.2 Superficies de juego en el fútbol

1.2.1 Evolución de la superficie de juego en el fútbol

La evolución histórica del fútbol ha influido directamente en el cambio y desarrollo de la superficie de juego. En los orígenes de este deporte, los terrenos de juego eran praderas con una largura y anchura máximas de 182,9 m (200 yardas) y 109,7 m (120 yardas) respectivamente [3]. En el año 1891, se establecieron las dimensiones mínimas de los terrenos de juego en 91,5 m (100 yardas) de largo y 45,75 m (50 yardas) de ancho [3] y se consiguió que la mayor parte de estas superficies fueran de hierba natural. El resto de las superficies eran de tierra siendo más comunes en aquellas localidades o entidades desfavorecidas. El elevado coste que supone el mantenimiento de las superficies de hierba natural y el pobre reclamo para la práctica del fútbol de las superficies de tierra han impulsado la creación y el desarrollo de campos de fútbol con césped artificial. Este pavimento, además de replicar las características de la hierba natural y de mantener un nivel muy alto y estable a lo largo de la temporada [4], es capaz de soportar cambios climatológicos extremos y un uso elevado del mismo.

En los últimos años, el número de campos de fútbol de césped artificial en España en competiciones de nivel semiprofesional, regional y formativo (categorías alevín, infantil, cadete y juvenil) ha aumentado considerablemente. Por ejemplo, Burillo y col. [5] observaron que desde la temporada 2007/2008 a la temporada 2009/2010 el porcentaje de campos de césped artificial aumentó del 19% al 31% en 2ª División "B" (competición semiprofesional); y del 39% al 58% en 3ª División (competición regional). Hasta el momento, ningún equipo del fútbol profesional español (Liga Santander y Liga 123 formadas por 20 y 22 equipos respectivamente) juega sus partidos oficiales en campos de césped artificial. En lo que respecta al resto de competiciones europeas, la Organización

Europea de Césped Artificial [6] demostró que durante la temporada 2011/2012 varias competiciones de 1ª División (p.ej. las correspondientes a los países de Francia, Italia, Países Bajos) utilizaron al menos un campo de césped artificial (**Figura 2**). Concretamente, el número de campos de césped artificial es mayor en aquellos países con peores condiciones climatológicas (p.ej. Noruega, Rusia o Suiza). Por otra parte, los clubes más importantes de las ligas europeas han empezado a utilizar el césped híbrido, una superficie que aumenta la resistencia y estabilidad en comparación con el césped natural y que compuesta por un 96% de hierba natural y un 4% de fibra sintética. Aunque esta superficie se creó en los años 90, no fue hasta el mundial de Sudáfrica en 2010 cuando se utilizó el césped híbrido en competición oficial.

Figura 2. Número de equipos europeos que juegan en césped artificial.

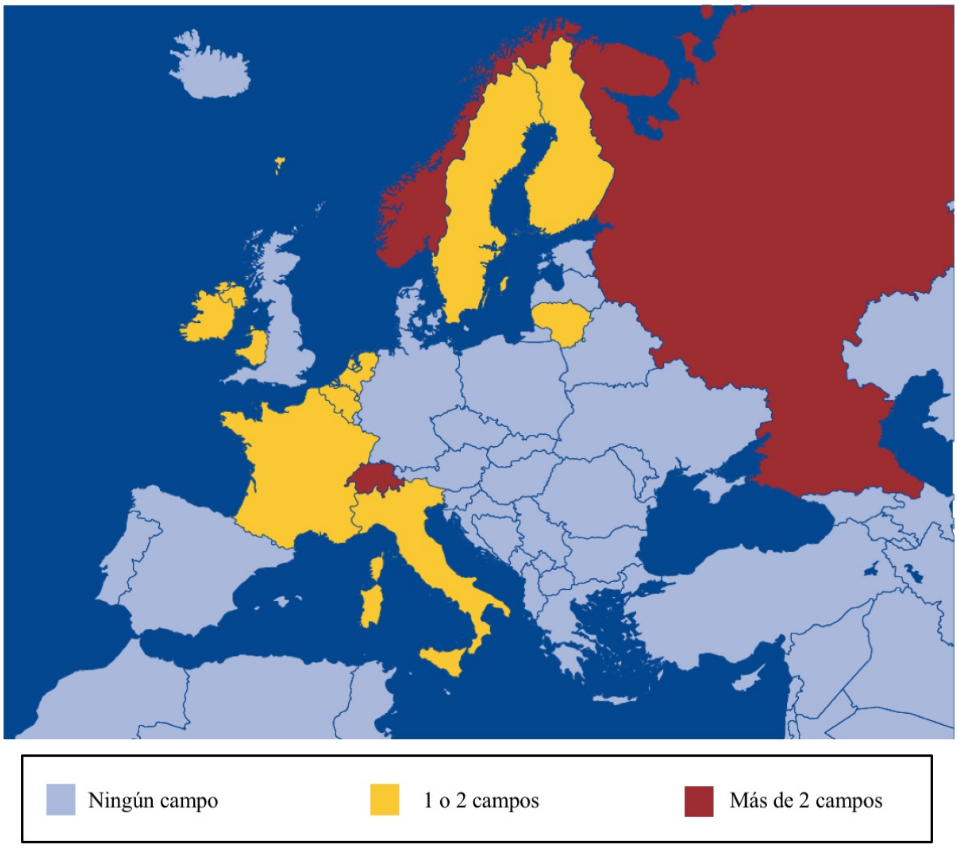


Imagen obtenida del informe realizado por la organización europea de césped artificial [6]

1.2.2 Tipos de césped artificial

El primer campo de césped artificial se construyó en el año 1966 en el estadio de fútbol americano Astrodome, situado en Houston (Texas, Estados Unidos). Sin embargo, no fue hasta el año 1973, cuando de la mano del arquitecto Díaz de Tejado se construyó el primer campo de césped artificial en España, destinado en esta ocasión al hockey. Este césped artificial estaba compuesto por densas alfombras de fibras de nylon (longitud de fibra entre 10-12 mm) monofilamento o fibrilada, que no incluían relleno entre las mismas ni sub-base elástica. Además, se caracterizaba por ser dura, muy abrasiva y que proporcionaba unos niveles elevados de tracción [7]. Debido al gran número de lesiones por abrasión en la piel, en los años 70 se modificó el nylon por el polipropileno, producto que proporcionaba las mismas propiedades que el nylon pese a ser menos resistente. Al mismo tiempo, se incluyó una sub-base elástica dando lugar a lo que hoy se conoce como césped artificial de primera generación (**Figura 3**).

Figura 3. Césped artificial de primera generación.

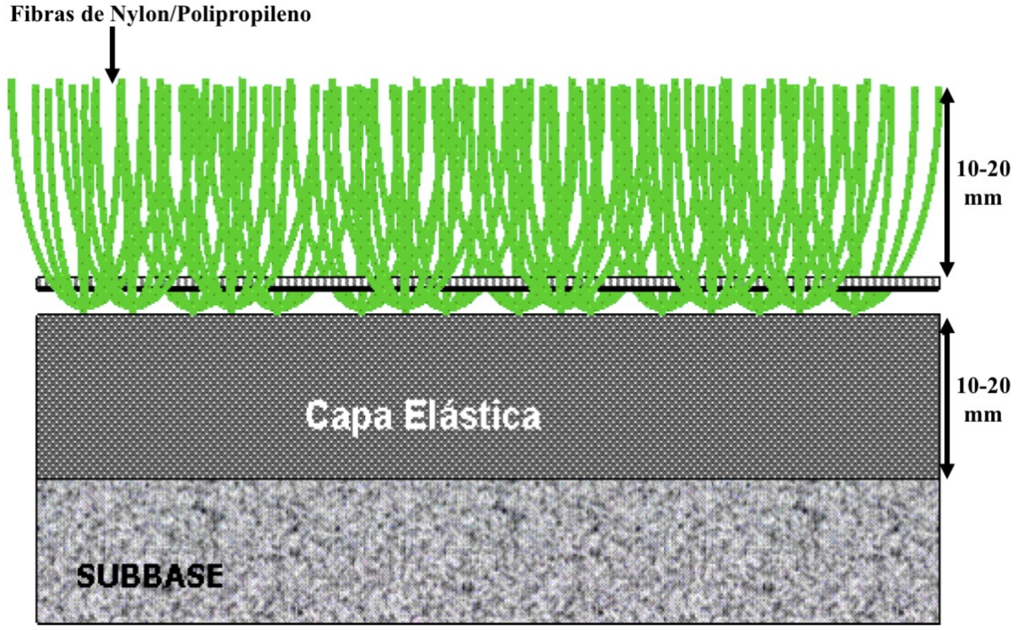


Imagen obtenida de la Tesis doctoral "Efectos de los componentes estructurales de soporte sobre el comportamiento mecánico y el rendimiento deportivo en los campos de fútbol de césped artificial" Sánchez-Sánchez [8].

A finales de la década de 1970 y como consecuencia del aumento de la longitud de la fibra hasta los 30 mm y la incorporación de arena como relleno, se creó el césped artificial de segunda generación (**Figura 4**). Además, se redujo el número de fibras y, por consiguiente, se aumentó el espacio para la colocación de la arena. Este hecho supuso, al mismo tiempo, una disminución en los costes de esta superficie. Por otro lado, la inclusión de la arena como relleno proporcionó estabilidad, redujo el aplastamiento de la fibra y favoreció la tracción del calzado con la superficie. Sin embargo, en lo que respecta al fútbol, este tipo de superficie todavía mostraba grandes diferencias en comparación con el césped natural (p.ej. uso de diferente tipo de bota, bote diferente del balón, mayor abrasión en el césped artificial) [9].

Figura 4. Césped artificial de segunda generación.

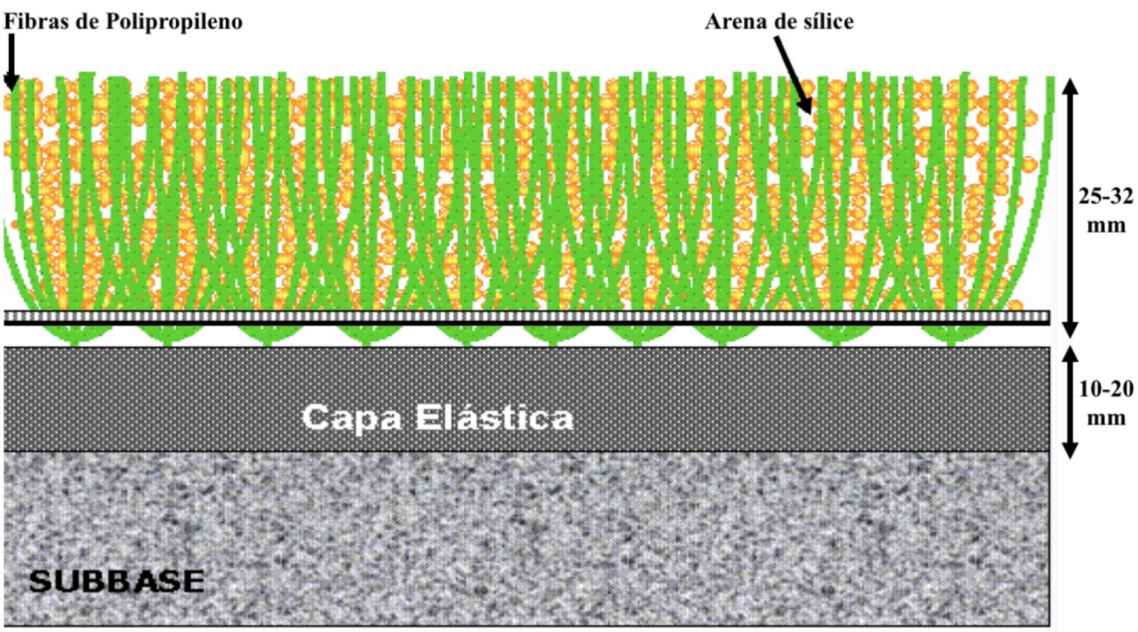


Imagen obtenida de la Tesis doctoral "Efectos de los componentes estructurales de soporte sobre el comportamiento mecánico y el rendimiento deportivo en los campos de fútbol de césped artificial" Sánchez-Sánchez [8].

Con el objetivo de mejorar las prestaciones del césped artificial y de simular lo mejor posible las características del césped natural, en la década de 1990 se desarrolló el césped artificial de tercera generación (**Figura 5**). En esta superficie la densidad de las fibras de polietileno monofilamento o fibriladas es baja, la longitud de las fibras se incrementa hasta 50-70 mm y se incluye, a la base de arena utilizada en el césped de segunda generación, un relleno de granulado de caucho (p.ej. SBR: caucho estireno-butadieno, caucho termoplástico Ecofill, etc.). Generalmente, el espesor del relleno se corresponde con dos tercios de la longitud de la fibra dejando así, una zona libre de relleno en la parte superior de la fibra que influye directamente en el rozamiento de la superficie y, por consiguiente, en la rodadura del balón sobre la misma [7]. Al mismo tiempo, el uso de fibras de polietileno lubricado reduce la abrasión y el gran espesor de relleno aumenta la absorción de impactos y permite a los futbolistas utilizar una bota con un tipo de taco al que están más acostumbrados. Cabe destacar que en ocasiones se incluye una base elástica

Figura 5. Césped artificial de tercera generación.

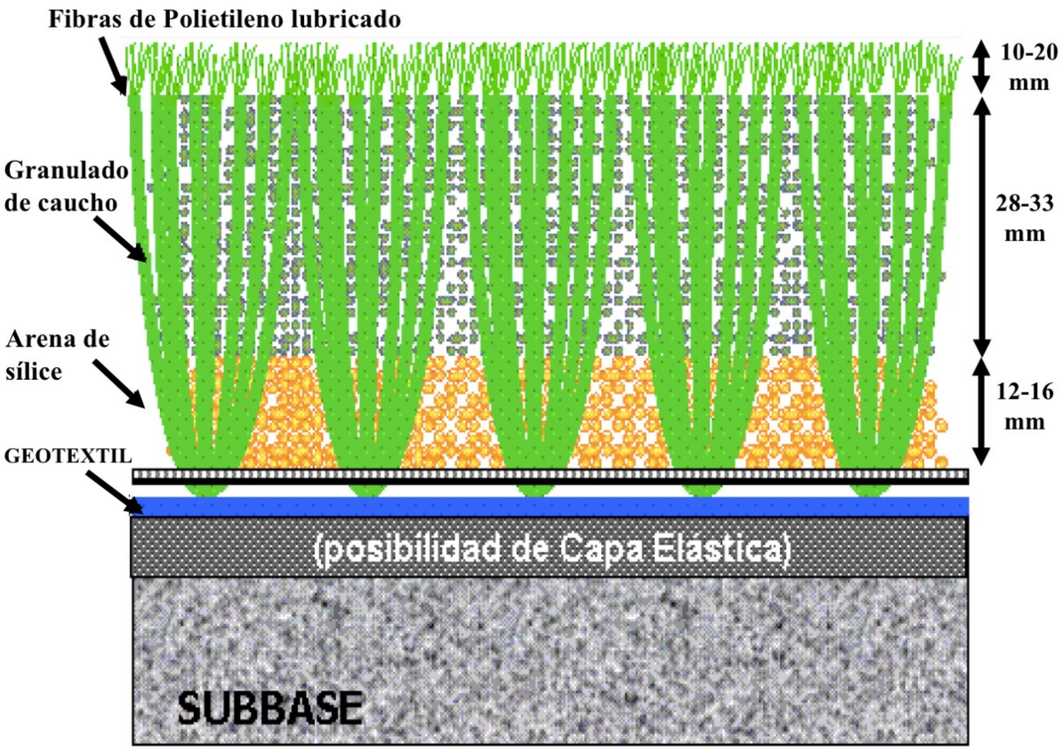


Imagen obtenida de la Tesis doctoral "Efectos de los componentes estructurales de soporte sobre el comportamiento mecánico y el rendimiento deportivo en los campos de fútbol de césped artificial" Sánchez-Sánchez [8].

debajo del césped artificial que es capaz de alterar la absorción de la superficie [10]. Esta evolución del césped artificial de tercera generación ha provocado que la FIFA haya desarrollado un batería de pruebas que permiten evaluar si el césped artificial replica las características del césped natural y si cumple los criterios mínimos de uso para la competición [4, 11].

Pese a que todavía no se ha desarrollado el césped artificial de cuarta generación, desde el sector del césped artificial se está trabajando en mejorar el sistema anterior. Estas innovaciones podrían estar relacionadas con una disminución de la cantidad de relleno, el uso de distintos tipos de fibras o la combinación de diferentes longitudes de fibras [7].

1.2.3 Características mecánicas del césped artificial

Todas las innovaciones del césped artificial tienen como objetivo principal replicar las propiedades del césped natural supliendo, al mismo tiempo, sus limitaciones. Es por ello que la FIFA [4, 11] desarrolló un conjunto de pruebas objetivas para evaluar las características mecánicas relacionadas con la función deportiva del césped artificial. Cabe destacar que la función deportiva de una superficie de césped artificial incluye las propiedades que afectan tanto a la interacción superficie-jugador como a la superficie-balón [11]. A continuación, se explicarán las características de la superficie qué componen ambas interacciones.

1.2.3.1 Interacción superficie-jugador

La interacción de la superficie con el jugador influye directamente en el riesgo de lesión y en el rendimiento del deportista [12]. FIFA [11] establece que las características de la superficie que afectan a esta interacción son las siguientes:

- *Absorción de impactos:* es la capacidad de disminuir las fuerzas de impacto a partir de la absorción y la disipación de energía.
- *Deformación vertical:* es la estabilidad de una superficie medida como la distancia que cede la superficie al recibir un impacto.
- *Tracción rotacional:* es la resistencia que ofrece una superficie al pie de apoyo del deportista (concretamente al taco utilizado) durante el giro, sin que se produzca deslizamiento o bloqueo del mismo.
- *Tracción lineal:* es la resistencia o el agarre del taco de la bota de fútbol en la superficie.
- *Abrasión de la piel:* es capacidad que tiene la superficie de dañar o quemar la piel durante un deslizamiento.

1.2.3.2 Interacción superficie-balón

Todo futbolista que va recibir el balón espera un bote, una velocidad y una dirección determinada del mismo [11], es por ello que la interacción de la superficie con el balón influye directamente en la jugabilidad y en el rendimiento del deportista. Las características que propone la FIFA para evaluar el rendimiento del balón sobre la superficie son las siguientes:

- *Rebote vertical:* es la altura que alcanza un balón tras la caída del mismo y su posterior contacto con el suelo.
- *Rodadura horizontal:* es la distancia recorrida por un balón sobre el césped artificial después de dejarse caer por una rampa.

1.2.4 Requisitos del césped artificial

Con el objetivo de establecer unos criterios de calidad del césped artificial en función de las características enumeradas anteriormente, tanto la FIFA como el Comité Europeo de Normalización (CEN), desarrollaron los requisitos que deben cumplir las superficies de césped artificial para obtener la certificación de calidad. Cabe destacar que la FIFA propone dos certificaciones: FIFA 1-Star destinada a las superficies de césped artificial que van a ser utilizadas a nivel amateur, y FIFA 2-Star destinada a aquellas que van a ser usadas a nivel profesional. Los requisitos de cada una de las normativas comentadas se muestran en la **Tabla 1**.

Tabla 1. Requisitos propuestos por la FIFA y CEN para evaluar las características mecánicas del césped artificial.

	FIFA		CEN
Características mecánicas	**FIFA 1-Star**	**FIFA 2-Star**	**EN 15330-1:2007**
Interacción superficie-jugador			
Absorción de impactos (%)	55 – 70	60 – 70	55 – 70
Deformación vertical (mm)	4 – 11	4 – 10	4 – 10
Tracción rotacional (Nm)	25 – 50	30 – 45	25 – 50
Interacción superficie-balón			
Rebote vertical (m)	0,60 – 1,00	0,60 – 0,85	0,608 – 1,012
Rodadura horizontal (m)	4 – 12	4 – 8	4 – 10

En resumen, debido a que el césped artificial se ha implantado de forma tan extensa en el fútbol base y a que cada superficie puede tener unas características mecánicas distintas, adquiere mayor importancia conocer cómo puede afectar el tipo de superficie en el impacto recibido por los jóvenes futbolistas y, por consiguiente, en el desarrollo óseo de los mismos.

1.3 Masa ósea

1.3.1 Definición y funciones del hueso

El hueso es el tejido más rígido del cuerpo humano debido a las sales minerales que contiene, principalmente calcio. Esta rigidez le permite realizar funciones corporales que no pueden ser ejecutadas por ningún otro tejido. Entre las funciones más importantes del hueso destacan las siguientes [13]:

- Sostener y dar forma al cuerpo.
- Proteger los tejidos subyacentes como los órganos vitales y el sistema nervioso central.
- Actuar como palanca mecánica en la producción de movimientos y servir de fijación para los músculos.
- Contribuir a la formación de las células sanguíneas.
- Actuar como reserva de sales minerales.

1.3.2 Osteoporosis, un problema de salud pública global

En el año 1993, la Organización Mundial de la Salud (OMS) definió osteoporosis como "*enfermedad esquelética sistémica caracterizada por una baja masa ósea y un deterioro de la micro-arquitectura del tejido óseo, con el consecuente incremento de la fragilidad ósea y de la susceptibilidad a la fractura*" [14]. Aunque esta definición destaca la importancia de la masa ósea en la osteoporosis, no tiene en cuenta la resistencia ósea, un factor muy importante en la aparición de las fracturas óseas. Por ello, en el año 2000, una reunión de expertos organizada por los Institutos Nacionales de la Salud (NIH) redefinió osteoporosis incluyendo este término "*enfermedad esquelética caracterizada por una* *resistencia ósea comprometida que predispone a un incremento del riesgo de fractura ósea*".

La OMS establece que una persona tiene osteopenia cuando su densidad mineral ósea (DMO) está entre -1,0 y -2,5 desviaciones estándar por debajo de la DMO media de un joven adulto (-1,0 > *T-score* > -2,5), y tiene osteoporosis cuando su DMO es inferior a -2,5 desviaciones estándar (-2,5 > *T-Score*). No obstante, Crabtree y col. [15], en la posición oficial de la Sociedad Internacional de Densitometría Clínica (ISCD), concluyeron que los términos osteopenia y osteoporosis no deben ser utilizados en niños y adolescentes. Al mismo tiempo, estos autores determinaron que aquellos niños o adolescentes con una DMO igual o inferior a -2 desviaciones estándar en comparación con la DMO media de un niño o adolescente a su edad (-2,0 > Z-Score) tienen que definirse como baja masa ósea o DMO.

La osteoporosis es una enfermedad que afecta a 75 millones de personas en Estados Unidos, Europa y Japón [16] causando 8,9 millones de fracturas anuales en todo el mundo [17]. La incidencia de esta enfermedad en personas mayores de 50 años es muy elevada y afecta directamente a su nivel de dependencia, con todos los gastos que esto supone para el sistema sanitario. Pese a que los riesgos asociados a esta enfermedad disminuyen considerablemente durante el crecimiento, tanto la niñez como la adolescencia son etapas trascendentales en la adquisición de masa ósea y, por lo tanto, en la prevención de esta enfermedad.

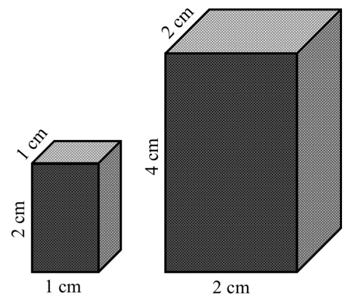
1.3.3 Resistencia ósea

El hueso tiene que ser ligero para facilitar el movimiento, rígido para resistir los impactos y, al mismo tiempo, flexible para deformarse sin agrietarse [18]. La resistencia o fortaleza del hueso está determinada a distintos niveles por la cantidad de hueso y su estructura [19]; en concreto, la cantidad de hueso es capaz de explicar el 60 – 80% de la resistencia ósea y la estructura ósea en torno al 20 – 40% de la misma.

La variabilidad de la cantidad y la estructura ósea entre grupos de población se explica por la influencia de una serie de factores clasificados en los siguientes grupos: factores no modificables (genética, maduración, sexo y raza) y modificables (actividad física y dieta). Aproximadamente el 80% de la cantidad y estructura ósea está predeterminado por factores no modificables entre los que destaca la genética. El porcentaje restante lo explican factores modificables como la actividad física y la dieta [20].

La salud ósea depende del contenido mineral óseo (CMO) y de la DMO. En niños y adolescentes la absorciometría fotónica dual de rayos X (DXA) es el método más utilizado para evaluar ambas variables. Esta técnica obtiene una imagen en dos dimensiones de la cual se calcula directamente el CMO (g) y el área ósea proyectada (cm^2), siendo ambas utilizadas en el cálculo de la DMO de área (g/cm^2). El principal inconveniente del DXA es que no puede medir la profundidad del hueso lo que provoca que se infraestime la DMO de los huesos pequeños y se sobreestime la de los huesos más grandes (**Figura 6**). Esta

Figura 6. Representación gráfica del efecto del tamaño en la DMO medida con el DXA.



CMO (g)	2,0	16,0
Volumen (cm^3)	2,0	16,0
DMO volumétrica (g/cm^3)	1,0	1,0
Área proyectada (cm^2)	2,0	8,0
DMO de área (g/cm^2)	1,0	2,0

El área proyectada se corresponde con la cara frontal sombreada en gris oscuro. Imagen adaptada del artículo "New approaches for interpreting projected bone densitometry data" realizado por Carter y col. [21]. Licencia: 4362011099134 limitación del DXA adquiere especial importancia en niños y adolescentes ya que durante el crecimiento los huesos cambian su tamaño, forma y densidad. Para reducir la influencia del tamaño sobre la DMO en este grupo de población, la ISCD [15] propone calcular la DMO aparente (DMO ajustado por la talla o el área) para cada zona evaluada. La Tabla 2 muestra algunas de las ecuaciones que se pueden utilizar para ajustar la DMO por el tamaño.

Tabla 2. Ecuaciones propuestas por el ISCD para calcular la DMO aparente en el cuerpo completo, columna lumbar y cuello femoral.

Autor/es	Zona evaluada	Ecuación
Katzman y col. [22]	Cuerpo completo	$BMC_{cuerpo\ completo}$ / (área ósea ^{2} / talla)
Carter y col. [21]	Columna lumbar	$BMC_{L1\text{-}L4}$ / área ósea$^{3/2}$
Carter y col. [21]	Cuello femoral	$BMC_{cuello\ femoral}$ / área ósea^{2}

La salud ósea también depende de la micro-arquitectura y geometría del hueso. La tomografía axial computerizada periférica (pQCT) es una de las técnicas más utilizadas para evaluar estas variables en niños y adolescentes, principalmente con una finalidad investigadora [23]. En comparación con el DXA, el pQCT es una técnica tridimensional, que no depende del tamaño del hueso y que permite evaluar la DMO volumétrica (DMOv). Además, es capaz de medir el hueso trabecular y cortical por separado, el área transversal de la zona del hueso evaluado y calcula parámetros de fuerza ósea a partir de las variables comentadas anteriormente. Cabe destacar que el hueso trabecular tiene una actividad metabólica aproximadamente 8 veces mayor que la observada en el hueso cortical [23] debido a que el hueso trabecular tiene mayor relación superficie-volumen que el hueso cortical [24]. Todo ello hace que los cambios en el hueso trabecular puedan ser mayores y se puedan detectar más rápidamente que en el hueso cortical.

1.3.4 Desarrollo óseo

El hueso empieza a desarrollarse en el crecimiento fetal y continúa hasta aproximadamente el final de la segunda década de vida [25]. Otras características óseas como la densidad cortical y la fortaleza ósea (ambas determinadas por la dimensión y grosor que tiene el hueso) pueden seguir aumentando hasta el final de la tercera década [20]. En términos de cantidad de masa ósea adquirida, se han observado patrones específicos en función de la edad y del sexo tal y como se muestra en la **Figura 7**. Durante la niñez, la masa ósea aumenta lentamente y, con el comienzo de la pubertad y de la

Figura 7. Evolución de la masa ósea durante el ciclo vital en hombres y mujeres.

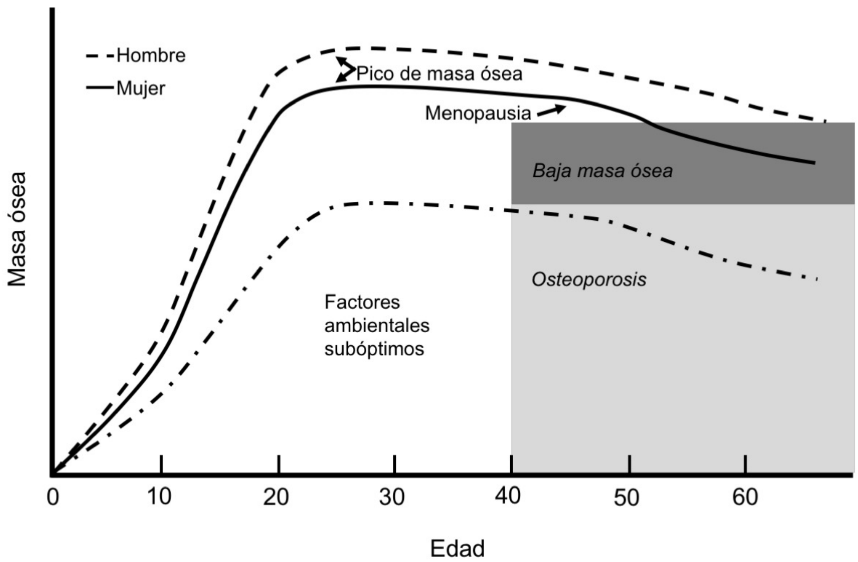


Imagen adaptada del artículo "The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations" Weaver CM y col. [20]. Licencia: Creative Commons Attribution-NonCommercial 4.0 International.

adolescencia, se alcanza el pico de crecimiento y de ganancia de masa ósea. Concretamente, el pico de ganancia ósea difiere entre sexos produciéndose a la edad de 12,5 ± 0,9 años en chicas y a la de 14,1 ± 1,0 años en chicos (**Figura 8**) [26]. Cinco años después de alcanzar este pico, la masa ósea adquirida en ambos sexos será aproximadamente el 95% del pico de masa ósea [27]. A partir de este momento, el hueso aumenta hasta alcanzar el pico de masa ósea a la edad de 25-30 años (**Figura 7**). Según Berger y col. [28] el pico de masa ósea se produce cuando la edad ya no influye positivamente en el hueso y se ha alcanzado un valor máximo.

Figura 8. Pico de crecimiento y de ganancia de masa ósea en chicos y chicas europeos.

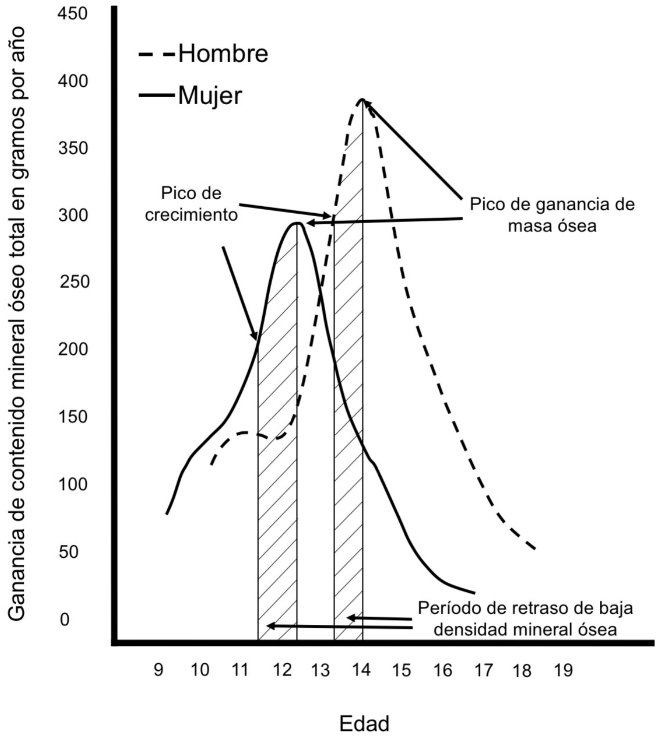


Imagen adaptada del artículo "The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations" Weaver CM y col. [20]. Licencia: Creative Commons Attribution-NonCommercial 4.0 International.

Los cambios en la estructura (tamaño y forma) y composición (cantidad de hueso trabecular y cortical) del hueso a lo largo del ciclo vital se producen a partir del modelado (construcción) y remodelado (re-construcción) óseo, ambos procesos influidos por el sexo y la edad (Figura 9). Durante la niñez, los huesos largos de los niños y niñas aumentan en longitud como consecuencia del modelado óseo en parte externa del hueso (periostio) y del remodelado óseo en la parte interna del hueso cortical (endostio). Los huesos también son progresivamente más anchos porque el modelado es superior al remodelado. Además, el agrandamiento del canal medular separa el hueso cortical del eje central del hueso y, por tanto, aumenta la rigidez ósea. Con la llegada de la pubertad, en las chicas, los estrógenos reducen el modelado óseo en el periostio y lo aumentan en el endostio limitando así el diámetro del hueso y ampliando el grosor cortical. En los chicos, los andrógenos incrementan la formación ósea en el periostio y, por consiguiente, el diámetro del hueso. Finalmente, en la edad adulta, se reduce ligeramente la formación ósea en el periostio y se mantiene la resorción del endostio [29]

Figura 9. Evolución de la estructura ósea durante el ciclo vital en hombres y mujeres.

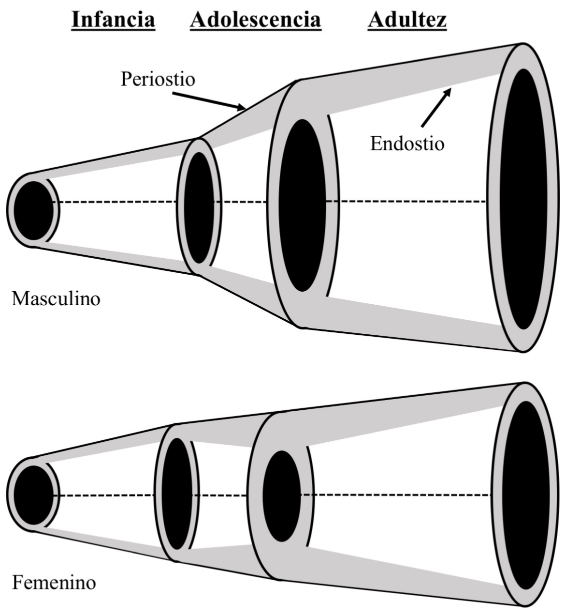


Imagen adaptada del artículo "Bone quality: the material and structural basis of bone strength" Seeman E [30].

1.3.5 Estrés mecánico, ejercicio físico y hueso

Carpersen y col. [31] definen actividad física como "*cualquier movimiento corporal producido por los músculos esqueléticos que exija gasto de energía*", y ejercicio físico como "*una variedad de actividad física planificada, estructurada, repetitiva y realizada con un objetivo relacionado con la mejora o el mantenimiento de uno o más componentes de la aptitud física"*. Por ello, uno de los objetivos de un programa de ejercicio físico podría ser la mejora o el mantenimiento de la masa y estructura ósea, ósea, ya que el Colegio Americano de Medicina del Deporte incluye la composición corporal como un componente más de la condición física [32].

El hueso es más sensible a los ejercicios y/o deportes que son dinámicos y que provocan cargas o impactos rápidos, no repetitivos, de moderada-alta intensidad y corta duración [33]. Estos impactos se producen en acciones como saltos, cambios de dirección o esprints y son capaces de activar las células óseas (osteocitos) y, por tanto, el remodelado óseo. Este mecanismo a partir del cual se transforma la carga mecánica en una respuesta ósea es conocido como "*Mecanotransducción*". Para iniciar la respuesta osteogénica, la magnitud del impacto debe alcanzar el umbral de deformación. Este umbral varía entre personas, regiones corporales, estadios madurativos y hábitos de actividad física o ejercicio físico [20]. En el año 1987, Frost desarrolló la teoría del "*Mecanostato óseo*" [34] y estableció los siguientes umbrales para diferenciar el efecto que tienen diferentes magnitudes de impacto en el hueso (**Figura 10**):

- Efecto trivial (< 200 micro tensiones (με)): La magnitud del impacto no estimula el hueso.
- Efecto fisiológico (200 – 2000 με): La magnitud del impacto estimula levemente el hueso manteniendo el modelado y remodelado óseo en un estado estable.
- Efecto de sobrecarga (2000 – 4000 με): La magnitud del impacto estimula el modelado óseo y, por lo tanto, se forma hueso nuevo.
- Efecto patológico (> 4000 με): La magnitud del impacto es muy elevada y se provocan micro-fracturas óseas. En esta zona, el hueso aumenta el riesgo de fractura ósea.

Las magnitudes de impacto están expresadas como cambio en porcentaje de la longitud del hueso (p.ej. hueso de 500 mm que experimenta una deformación de 0.5mm recibe una deformación de 0.001 o del 0.1% lo que es igual a 1000 με).

Figura 10. Umbrales de estimulación ósea propuestos por Frost [34].

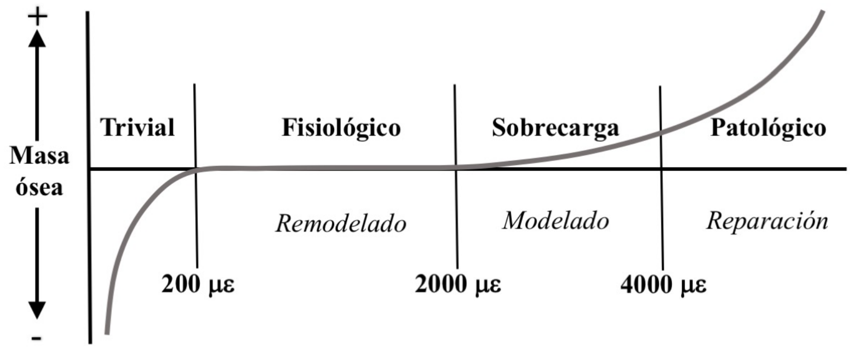


Imagen adaptada del artículo "Direct in vivo strain measurements in human bone—A systematic literature review" Al Nazer R y col. [35]. Licencia: 4363031017400.

1.4 Efectos del fútbol en la masa ósea durante el crecimiento

A continuación, se resumen los principales hallazgos relativos a la estructura y masa ósea de niños y adolescentes futbolistas. Debido al dimorfismo sexual existente en el desarrollo óseo durante el crecimiento [26], estos hallazgos fueron divididos por sexo. Cabe destacar que el artículo realizado por McCulloch y col. [36] fue el único que comparó la masa ósea entre chicos y chicas futbolistas sin encontrar diferencias significativas entre sexos.

1.4.1 Masa y estructura ósea en chicos futbolistas

La **Tabla 3** resume las características y los principales hallazgos de todos los estudios que evaluaron la masa y/o estructura ósea de los chicos futbolistas.

Gran parte de los estudios realizados en chicos futbolistas analizaron las diferencias óseas entre estos deportistas y controles. En el año 1992, se publicó el primer artículo que comparó la masa ósea de chicos futbolistas y controles sin reportar diferencias significativas entre los grupos [36]. Posteriormente, Vicente-Rodríguez y col. [37, 38] y Zouch y col. [39-41] demostraron el efecto positivo que tenía el fútbol durante el crecimiento en el CMO y DMO de las zonas corporales que soportan la carga como la columna lumbar, la cadera o las extremidades inferiores. Además, destacaron que los efectos positivos del fútbol en la masa ósea son más evidentes en aquellos futbolistas que habían alcanzado la pubertad. Un estudio realizado por Plaza-Carmona y col. [42] también reportó que los futbolistas que jugaban en superficies duras (tierra) y blandas (césped artificial) tenían mayores valores de CMO en las extremidades inferiores, pelvis, cuello femoral y zona intertrocantérea que los controles; sin embargo, no se encontraron diferencias significativas en las variables óseas entre los grupos de futbolistas que jugaban en diferentes superficies. Para reforzar los resultados positivos del fútbol en el hueso, dos estudios que utilizaron un sistema de ultrasonido cuantitativo para evaluar la densidad y estructura del hueso, mostraron mejor *velocidad del sonido* (variable relacionada con la densidad ósea) de la tibia en futbolistas que en controles [43, 44].

Algunos artículos también compararon los efectos del fútbol en el crecimiento con los obtenidos en otros deportes. Sanchis-Moysi y col. [45] demostraron que los futbolistas tenían mayor DMO en el cuello femoral que los tenistas; mientras que Vlachopoulos y col. [46] reportaron mejor estructura, índice de rigidez, CMO y DMO en la mayoría de las zonas corporales que soportan los impactos (cadera, cuello femoral, extremidades interiores) que los ciclistas y nadadores. Por otro lado, un estudio longitudinal realizado por Agostinete y col. [47] mostró que los jugadores de baloncesto aumentaron más la DMO del cuerpo completo y de los brazos que los futbolistas. Estos resultados revelan que las acciones específicas de cada deporte y el medio en el que se practican son variables que influyen directamente en la masa y estructura ósea de los propios deportistas.

Por otro lado, los estudios realizados por Mota y col. [48] y Anliker y col. [49] demostraron que la extremidad inferior no dominante de los futbolistas tenía mayores valores de masa y estructura ósea que la dominante. Estos resultados refuerzan la hipótesis de que la carga recibida por las extremidades inferiores en el fútbol es mayor en la no dominante [50] debido a que soporta las acciones de la dominante (p.ej. golpeos de balón).

Tabla 3. Estudios que evalúan la masa y/o estructura ósea en chicos futbolistas.

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
McCulloch y col. (1992) [36]*	FUT (23) NAD (20) CON (25)	15,3 ± 0,8 15,0 ± 1,1 14,9 ± 0,6	TR	-	10 18	TC SPA	Calcáneo Radio	No se observaron diferencias óseas entre grupos.
Vicente-Rodríguez y col. (2003) [38]	FUT (53) CON (51)	9,3 ± 0,2 9,3 ± 0,2	TR	1,8 ± 0,2	≥ 3	DXA	C.COM Cabeza EXT.SUP Pelvis EXT.INF C.LUM Cadera C.FEM WARD TROC INT.TROC	Los FUT mostraron valores superiores de DMO en EXT.INF, C.LUM, pelvis, C.FEM y TROC que los CON. Los FUT mostraron valores superiores en CMO en EXT.INF y TROC que los CON.
Vicente-Rodríguez y col. (2004) [37]	FUT (17) CON (11)	8,7 ± 0,4 9,4 ± 0,3	L (36)	1,8 ± 0,2	≥ 3	DXA	C.COM EXT.SUP EXT.INF C.LUM Cadera C.FEM WARD TROC INT.TROC	Los FUT mostraron valores superiores de CMO y DMO en C.COM, EXT.INF, C.LUM Y INT.TROC que los CG.
Zouch y col. (2008) [41]	FUT (39): CON (13)	11,7 ± 0,9 10,7 ± 0,6	L (10)	≥ 3	(4/2)	DXA	C.COM Cabeza EXT.SUP EXT.INF C.LUM Cadera	Los FUT que entrenaban 4 horas a la semana tuvieron valores inferiores de CMO en la cabeza que CON. Después de 10 meses de seguimiento, los FUT aumentaron significativamente el CMO en C.COM, EXT.INF y C.LUM.

Continúa…

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
Nebigh y col. (2009) [51]	FUT (23): TN1 (11) TN2-3 (54) TN4-5 (26) CON (61): TN1 (6) TN2-3 (38) TN4-5 (17)	13,4 ± 0,2 13,3 ± 0,2 13,5 ± 0,3 13,5 ± 0.3 13,3 ± 0,5 12,8 ± 1,1 13,4 ± 0,5 13,3 ± 0.4	TR	3,9 ± 0.8	8	DXA	C.COM EXT.INF Pelvis C.LUM C.FEM	Tanto en TN2-3 y TN4-5, los FUT mostraron valores superiores de CMO y DMO en C.COM, EXT.INF, pelvis, C.LUM y C.FEM que los CON.
Falk y col. (2010) [43]	Niños (90): FUT (26) HOCK (30) CON (34) ADO (92): FUT (30) HOCK (31) CON (31)	10-12 11,1 ± 0.5 11,2 ± 0,8 11,1 ± 0.7 14-16 15,2 ± 0,7 15,3 ± 0,9 15,2 ± 0.7	TR	 5,4 ± 1,0 4,7 ± 1,1 7,4 ± 2,3 9,0 ± 2,1	 5,6 ± 1,6 6,4 ± 1,3 6,7 ± 1,8 6,5 ± 1,6	Ultrasonido	Radio Tibia	Los niños y adolescentes FUT mostraron valores superiores de VS en la tibia que los CON. Los adolescentes FUT mostraron valores inferiores de VS en el radio que los HOCK.
Sanchis-Moysi y col. (2010) [45]	FUT (21) TEN (25) CON (22)	10,3 ± 0,2 10,6 ± 0,2 10,6 ± 0,2	TR	1,8 ± 0,2 4,1 ± 1,8	4-6	DXA	C.COM EXT.SUP EXT.INF C.LUM C.FEM	Los TEN mostraron valores superiores de área ósea, CMO y DMO en la diferencia de ambas EXT.SUP que los FUT y CON. Los FUT mostraron valores superiores de CMO y DMO en la diferencia de ambas EXT.INF que los CON. Los FUT mostraron valores superiores de CMO y DMO en C.LUM que los TEN.
Mota y col. (2010) [48]	FUT (71): Sub19 (12) Sub17 (20) Sub15 (39)	 < 19 ≤ 17 ≤15	TR	-	-	DXA	C.COM EXT.INF	Los FUT Sub17 mostraron valores superiores de DMO en la EXT.INF no dominante en comparación con la dominante.
Madic y col. (2010) [44]	FUT (32) CON (30)	10,7 ± 0,5 11,2 ± 0,7	TR	≥ 1	10-15	Ultrasonidos	Calcáneo	Los FUT mostraron valores superiores de VS en el calcáneo derecho e izquierdo que los CON.

Continúa…

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
Silva y col. (2011) [52]	FUT (10) NAD (12) TEN (10) CON (25)	14,7 ± 0,8 13,8 ± 2,5 14,1 ± 1.6 13,4 ± 2,0	TR	≥ 3	15,1 ± 0,8 17,3 ± 1,6 16,0 ± 0,8	DXA	C.COM C.LUM Cadera Izq. C.FEM WARD TROC INT.TROC	Los FUT mostraron valores superiores de DMO en Cadera Izq. que NAD y CON. Los FUT que estaban al final de la adolescencia (16-18 años) mostraron valores superiores de DMO en C.COM, C.LUM y C.FEM que los FUT que iban a iniciar la pubertad (10-12 años).
Seabra y col. (2012) [50]	FUT (117) CON (34)	13,8 ± 1,5 13,3 ± 1,3	TR	≥ 3	≈ 3	DXA	C.COM EXT.SUP C.LUM	Los FUT mostraron valores superiores de DMO en C.COM y EXT.INF que los CG.
Anliker y col. (2013) [49]	FUT (66)	15,1 ± 1,5	TR	9,1 ± 2,5	10,7 ± 2,0	pQCT	4, 14, 38 y 66% tibia	La EXT.SUP no dominante de los FUT mostraron valores superiores de masa y estructura ósea en el 4, 14 y 38% de la tibia que la dominante.
Zouch y col. (2014) [40]	PPUB (35): FUT (22) CON (13) PUB (41): FUT (26) CON (15)	 11,9 ± 0,8 11,7 ± 0,6 12,9 ± 0,8 12,5 ± 0,6	L (12)	≥ 3	≈ 2-5	DXA	C.COM Cabeza EXT.SUP EXT.INF C.LUM Cadera	Los FUT PPUB y PUB tuvieron valores superiores de CMO en la C.COM, EXT.SUP y cadera que CON PPUB y PUB. Los FUT PUB mejoraron más que los FUT PPUB el CMO en EXT:SUP, EXT.INF y C.LUM. Los FUT PPUB mejoraron más el CMO de la EXT.INF y cadera que los CON PPUB. Los FUT PUB mejoraron más el CMO de la EXT.INF y C.LUM que los CON PUB.
Plaza-Carmona y col. (2014) [42]	SD FUT (14) SB FUT (14) CON (14)	9,4 ± 0,2 8,9 ± 0,2 9,3 ± 0,1	TR	≥ 1	≥ 3	DXA	C.COM Cabeza C.FEM WARD TROC INT.TROC	Los SD FUT mostraron valores superiores de CMO en pelvis, C.FEM y INT.TROC que los CON. Los SD y SB FUT mostraron valores superiores de DMO en pelvis, C.FEM, TROC y INT.TROC que los CON. Los SB FUT mostraron valores superiores de CMO en EXT.INF, pelvis, C.FEM, TROC y INT.TROC que los CON.
Zouch y col. (2015) [39]	FUT (42) CON (23)	12,0 ± 0,8 11,7 ± 0,6	L (36)	≥ 3	≈ 2-5	DXA	C.COM Cabeza EXT.SUP EXT.INF C.LUM C.FEM	Al inicio del estudio, los FUT tuvieron valores superiores de DMO en la C.COM y EXT.SUP que CON. Después de 3 años, los FUT tuvieron valores superiores de CMO y DMO que CON en todas las zonas osteogénicas. Al final de 3 años, los FUT PPUB mejoraron más la DMO del C.COM, EXT.SUP, C.LUM y C.FEM que los CON.

Continúa…

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
Agostinete y col. (2016) [47]	FUT (18) NAD (16) BC (14) YUD (12) KAR (9) CON (13)	12,4 ± 1,9 13,5 ± 1,5 13,4 ± 1.2 13,1 ± 1,5 13,1 ± 1.8 11,9 ± 2,2	L (9)	41,5 ± 43,8 57,1 ± 32,1 32,2 ± 22,2 47,6 ± 39,3 41,1 ± 37,4 meses	-	DXA	C.COM EXT.SUP EXT.INF C.LUM	Después de 9 meses, los FUT mejoraron significantemente la DMO del C.COM, EXT.SUP, EXT.INF y C.LUM. Después de 9 meses, los BC mejoraron más la DMO del C.COM y EXT.SUP que los FUT.
Vlachopoulos y col. (2017) [46]	FUT (37) NAD (41) CIC (29) CON (14)	12,8 ± 0,9 13,4 ± 1,0 13,2 ± 1,0 12,3 ± 0,5	TR	≥ 3	10,0 ± 2,3 9,5 ± 5,1 5,1 ± 2,1	DXA HSA Ultrasonidos	C.SUB EXT.SUP Pelvis EXT.INF C.LUM Cadera C.FEM WARD TROC HSA variables	Los FUT mostraron valores superiores de CMO y DMO en C.SUB, pelvis, EXT.INF, cadera, C.FEM, WARD, TROC y EXT.INF que los CON. Los FUT mostraron valores superiores de DMO en cadera, WARD y TROC que los NAD y CIC. Los FUT mostraron valores inferiores de CMO y DMO en EXT.SUP que los NAD. Los FUT mostraron valores inferiores de área ósea en EXT.SUP y C.LUM que los NAD. Los FUT mostraron valores superiores de MI.TRANS que los CON. Los FUT mostraron valores superiores de sección que los CIC y CON. Los FUT mostraron valores superiores de A.TRANS que los NAD, CIC y CON. Los FUT mostraron valores superiores de IF.CAD que los NAD y CON. Los FUT mostraron valores superiores de I.RIG en la EXT.INF dominante que los NAD, CIC y CON. Los FUT mostraron valores superiores de I.RIG en la EXT.INF no dominante que los NAD y CON.

* El estudio de McCulloch y col. (1992) también comparó la masa ósea entre chicos y chicas futbolistas sin encontrar diferencias significativas.
ADO: adolescentes, A.TRANS: área transversal del cuello femoral, BC: jugadores de baloncesto, CIC: ciclistas, CON: controles, C.COM: cuerpo completo, C.FEM: cuello femoral, C.FEM.ANC: anchura del cuello femoral, C.FEM.DIA: diámetro del cuello femoral C.LUM: columna lumbar, C.SUB: cuerpo subtotal (sin incluir la cabeza), DXA: absorciometría fotónica dual de rayos X, EXT.INF: extremidad inferior, EXT.SUP: extremidad superior, FUT: futbolistas, HOCK: jugadores de hockey, HSA: análisis estrcutural de cadera, IF.CAD: índice de fuerza de cadera, INTROC: zona intertrocantérea, I.RIG: índice de rigidez, KAR: karateca, L(#): estudio longitudinal (número de meses de seguimiento), MI.TRANS: momento de inercia transversal del cuello femoral, NAD: nadadores, PPUB: prepuberal, PUB: puberal, SB: superficie blanda, SD: superficie dura, SPA: densitometría simple de rayos, TC: Tomografía computerizada, TEN: tenistas, TN: estadio madurativo de Tanner, TR: estudio transversal, TROC: trocánter, WARD: triángulo de Wards, YUD: yudocas.

1.4.2 Masa y estructura ósea en chicas futbolistas

La **Tabla 4** resume las características y los principales hallazgos de todos los estudios que evaluaron la masa y/o estructura ósea de las chicas futbolistas hasta el inicio de la presente Tesis Doctoral.

Pese a que el número de artículos realizados en chicas futbolistas (10 estudios) es menor que en chicos (17 estudios), los resultados son similares en ambos sexos. El artículo de Soderman y col. [53] fue el primero realizado en chicas futbolistas. Estos autores reportaron mayores valores de DMO en todas las zonas evaluadas (cuerpo completo, columna lumbar, cuello femoral, triángulo de Wards y trocánter) en las chicas futbolistas que las controles. Sin embargo, cuando dividieron la muestra en mayores y menores de 16 años, observaron que estas diferencias en DMO se mantenían en los grupos mayores de 16 años y se atenuaban entre los grupos menores de 16 años. Posteriormente, Plaza-Carmona y col. [54, 55] y Ubago-Guisado y col. [56] demostraron que las futbolistas tenían mayores valores de CMO y DMO en la mayoría de las zonas que soportan el impacto. Cabe destacar que el estudio de Ubago-Guisado y col. [56] también mostró que las diferencias óseas entre futbolistas y controles eran más evidentes en los estadios madurativos mayores.

Gran parte de los estudios realizados en chicas futbolistas tenían como objetivo analizar el efecto de diferentes deportes (p.ej. baloncesto, natación y balonmano) en la masa y estructura ósea. En concreto, los estudios transversales de Ferry y col. [57], Plaza-Carmona y col. [55], Bellew y col. [58] y Ubago-Guisado y col. [56] demostraron que las futbolistas tenían mayores valores en CMO y DMO de varias zonas osteogénicas (p.ej. cadera, cuello femoral o trocánter) que las controles. En comparación con otros deportes de impacto, las futbolistas demostraron valores superiores en CMO del cuello femoral que las jugadoras de baloncesto [56], y valores inferiores de CMO, DMO y área ósea en las extremidades inferiores que los saltadores de la comba [59]. Por otro lado, el estudio de Ferry y col. [60] es el único que ha evaluado los efectos longitudinales de ocho meses de práctica de fútbol y natación en la masa y estructura ósea de las chicas. A diferencia de los resultados obtenidos en las nadadoras, las futbolistas mejoraron la DMO (p.ej. cuerpo completo, columna lumbar, cadera, cuello femoral) y estructura ósea (p.ej. momento de inercia, sección transversal). Estos resultados justifican que las diferencias óseas entre deportistas están altamente influenciadas por el medio en el que se practican.

Un estudio realizado por Ubago-Guisado y col. [61] comparó la masa ósea entre futbolistas que jugaban y entrenaban en distintas superficies (tierra y césped artificial) demostrando que aquellas que jugaban en tierra tenían mayores valores de CMO y DMO en la cadera que aquellas que lo hacían en césped artificial. Los autores reportaron que la superficie de tierra tenía menos capacidad de absorber el impacto que la superficie de césped artificial, lo que sugiere que las futbolistas que jugaban en superficie de tierra recibieran un estímulo osteogénico más elevado.

Analizando los estudios que han evaluado la masa y estructura ósea de chicos y chicas futbolistas hasta el inicio de esta Tesis Doctoral, se han identificado las siguientes necesidades:

- Una revisión sistemática y meta-análisis que resuma los efectos del fútbol en la masa y estructura ósea de los chicos y chicas futbolistas.
- Estudios que analicen y comparen el efecto del fútbol entre sexos y estadios madurativos.
- Estudios que evalúen la estructura y fortaleza ósea con el pQCT en chicos y chicas futbolistas.

- Estudios que analicen la influencia de factores externos como el tipo de superficie o bota de fútbol en la masa y estructura ósea.
- Un mayor número de estudios longitudinales que ayuden a explicar el efecto de la práctica del fútbol en diferentes estadios madurativos.

Tabla 4. Estudios que evalúan la masa y/o estructura ósea en chicas futbolistas.

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
Soderman y col. (2000) [53]	FUT (51) ≤ 16 años (23) > 16 años (18) CON (41) ≤ 16 años (28) > 16 años (23)	16,3 ± 0,3 16,2 ± 1,3	TR	8,1 ± 2,1	5,0 ± 1,7	DXA	C.COM Cabeza C.LUM C.FEM WARD TROC	Los FUT mostraron valores superiores de DMO en todas las zonas medidas que los CON. Los FUT ≤16 años mostraron valores superiores de DMO en TROC que los CON. Los FUT >16 años mostraron valores superiores de DMO en todas las zonas medidas que los CON.
Pettersson y col. (2000) [59]	FUT (15) SAL (10) CON (25)	17,4 ± 0,8 17,8 ± 0,8 17,6 ± 0,8	TR	8,7 ± 2,2 11,5 ± 1,7	5,1 ± 2,2 6,1 ± 3,4 0,9 ± 1,1	DXA	C.COM Húmero Radio EXT.INF C.LUM C.FEM WARD TROC Fémur Tibia	Los FUT mostraron valores superiores de DMO en C.FEM, TROC, fémur y tibia que los CON. Los SAL mostraron valores superiores de DMO en C.COM (6,0%), C.LUM (10,3%) y húmero derecho (8,6%) que los FUT. Los SAL mostraron valores superiores de CMO en C.CMO, parte proximal de la tibia y diáfisis de la tibia que los FUT. Los SAL mostraron valores superiores de área ósea en el fémur, parte proximal de la tibia y diáfisis de la tibia que los FUT.
Bellew y col. (2006) [58]	FUT (16): NAD (29) PESO (19)	15,1 ± 1,2 12,0 ± 2,1 13,6 ± 1,3	TR	4,9 ± 1,8 5,2 ± 2,5 5,1 ± 2,4	9,8 ± 4,0 9,7 ± 5,0 9,2 ± 4,9	SPA	Calcáneo	Los FUT mostraron valores superiores de DMO en el calcáneo que los NAD. Los FUT mostraron valores superiores de DMO que los datos de adultos de la OMS.
Nichols y col. (2007) [62]	AI (93): FUT (22) ATL (29) SOF (15) VOL (11) TEN (10) LAC (6) RNI (68) COR (56) NAD (12)	TOT 15,7 ± 1,3 AI 15,6 ± 1,2 RNI 15,6 ± 1,3	TR	TOT 6,4 ± 3,4 AI 6,5 ± 3,4 RNI 6,1 ± 3,3	TOT 1,9 ± 0,4 AI 2,0 ± 0,4 RNI 1,9 ± 0,4	DXA	C.COM C.LUM Cadera C.FEM TROC	Las HI eumenorreicas mostraron valores superiores de DMO en cadera y TROC que las RNI eumenorreicas. Las HI eumenorreicas mostraron valores superiores de DMO en C.LUM y TROC que las RNI oligo/amerreicas. Las HI eumenorreicas mostraron valores superiores de DMO *Z-score* en C.LUM que las RNI eumenorreicas y oligo/amenorreicas. Las HI oligo/amenorreicas mostraron valores superiores de DMO *Z-score* en C.LUM que las RNI oligo/amenorreicas

Continúa…

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
Ferry y col. (2011) [57]	FUT (32): NAD (26) CON (15)	16,2 ± 0,7 15,9 ± 2,0	TR	≥ 7 ≥ 6	10	DXA HSA	C.COM EXT.SUP EXT.INF C.LUM Cadera DOM C.FEM WARD TROC INT.TROC HSA variables	Los FUT mostraron valores superiores de CMO y DMO en C.COM, C.LUM, y cadera que los NAD. Los FUT mostraron valores superiores de DMO *Z-score* en C.COM, C.LUM, cadera y C.FEM que los NAD. Los FUT mostraron valores superiores de MI.TRANS, C.FEM.ANC y shaft que los NAD.
Ferry y col. (2013) [60]	FUT (32): NAD (26) CON (15)	16,2 ± 0,7 15,9 ± 2,0	L (8)	≥ 7 ≥ 6	10	DXA HSA	C.COM EXT.SUP EXT.INF C.LUM Cadera DOM C.FEM WARD TROC INT.TROC HSA variables	Al inicio del estudio, los FUT mostraron valores superiores de DMO y DMO *Z-score* en C.LUM, cadera y C.FEM que los NAD. Al inicio del estudio, los FUT mostraron valores superiores de DMO en cadera, TROC e INT.TROC que los CON. Después de 8 meses, los FUT mejoraron la DMO de C.COM, C.LUM, cadera, C.FEM, TROC e INT.TROC. Después de 8 meses, los FUT mejoraron la estructura ósea de la cadera.
Plaza-Carmona y col. (2013) [55]	FUT (10) TEN (13) CON (10)	8,2 ± 0,1 8,5 ± 0,1 9,7 ± 0,2	TR	-	2	DXA	C.COM EXT.INF Cadera C.FEM WARD TROC INT.TROC	Los FUT mostraron valores superiores de CMO en C.COM, C.LUM, pelvis, EXT.INF TROC que los CON. Los FUT mostraron valores superiores de DMO en C.COM, C.LUM, pelvis, EXT.INF derecha, TROC e INT.TROC que los CON. Los FUT mostraron valores superiores de CMO en C.COM, C.LUM, pelvis y EXT.INF que los NAD. Los FUT mostraron valores superiores de DMO en pelvis, EXT.INF derecha, TROC y INT.TROC que los NAD.

Continúa…

Autor	Participantes (N)	Edad	Diseño	Años entreno	Horas semana	Metodología	Zonas medidas	Resultados
Ubago-Guisado y col. (2015) [56]	PPUB: FUT (20) NAD (20) BC (20) BM (20) CON (20) PUB FUT (20) NAD (20) BC (20) BM (20) CON (20)	 9,6 ± 1,0 9,2 ± 0,7 10,4 ± 0,5 9,9 ± 0,6 10,0 ± 0,5 12,3 ± 0,6 12,2 ± 0,6 13,1 ± 0,3 12,7 ± 0,9 12,1 ± 0.7	TR	 3,9 ± 1,8 4,9 ± 2,0 3,4 ± 1,5 3,4 ± 1,4 4,5 ± 1,7 4,1 ± 2,4 4,4 ± 1,4 3,9 ± 1,8	 3,0 ± 0,0 3,8 ± 1,9 2,9 ± 0,4 3,1 ± 0.2 3,6 ± 0,8 4,4 ± 2,7 3,1 ± 0.2 4,2 ± 2,8	DXA	C.COM EXT.SUP EXT.INF Cadera Pelvis C.FEM WARD TROC INT.TROC	Los FUT PPUB mostraron valores superiores de CMO en pelvis y TROC; y DMO en INT.TROC que los PPUB CON. Los FUT PPUB mostraron valores superiores de CMO en C.FEM y TROC; y DMO en C.FEM que los PPUB NAD. Los FUT PPUB mostraron valores superiores de CMO en C.FEM y TROC que los PPUB BC. Los FUT PUB mostraron valores superiores de CMO en C.COM, pelvis, C.FEM, WARD, TROC y EXT.INF; y DMO en C.COM, EXT.SUP, pelvis, cadera, C.FEM, WARD y INT.TROC que los PUB CON. Los FUT PUB mostraron valores superiores de CMO en C.COM, C.FEM, TROC y EXT.INF; y DMO en pelvis y cadera que los PUB NAD.
Plaza-Carmona y col. (2016) [54]	PPUB (20): FUT (10) CON (10) PEPUB (45): FUT (30) CON (15)	 8,2 ± 0.1 9,7 ± 0,2 11,7 ± 0,1 10,9 ± 0,2	TR	 2,5 ± 0,7 4,3 ± 1,8	2	DXA	C.COM EXT.INF Cadera Pelvis C.FEM WARD TROC INT.TROC	Los FUT PPUB mostraron valores superiores de CMO en C.FEM; y DMO en C.FEM e INT.TROC que los PPUB CON. Los FUT PEPUB mostraron valores superiores de CMO en C.COM, pelvis, WARD y TROC que los PEPUB CON. Los FUT PEPUB mostraron valores superiores de DMO en C.COM, cadera, C.FEM, WARD, and INT.TROC que los PEPUB CON.
Ubago-Guisado y col. (2016) [61]	PPUB FUT (20) TIE (11) CA (9) PUB FUT (20) TIE (11) CA (9)	 10,0 ± 0,9 9,1 ± 0,9 12,6 ± 0,6 12,0 ± 0,6	TR	 4,3 ± 1,4 3,3 ± 2,2 4,6 ± 1,4 4,3 ± 2,1	 3,0 ± 0,0 3,0 ± 0,0 3,5 ± 0,8 3,7 ± 0,7	DXA	C.COM EXT.INF Cadera Pelvis C.FEM WARD TROC INT.TROC	Los FUT PUB (TIE) mostraron mayores valores de CMO y DMO en la cadera que los FUT PUB (CA)

AI: alto impacto, ATL: atletismo, A.TRANS: área transversal del cuello femoral, BC: jugadores de baloncesto, BM: balonmano, CA: césped artificial, CON: controles, COR: correr, C.COM: cuerpo completo, C.FEM: cuello femoral, C.FEM.ANC: anchura del cuello femoral, C.FEM.DIA: diámetro del cuello femoral C.LUM: columna lumbar, DXA: absorciometría fotónica dual de rayos X, EXT.INF: extremidad inferior, EXT.SUP: extremidad superior, FUT: futbolistas, HSA: análisis estructural de cadera, IF.CAD: índice de fuerza de cadera, INTROC: zona intertrocantérea, I.RIG: índice de rigidez, L(#): estudio longitudinal (número de meses de seguimiento), LAC: lacrosse, MI.TRANS: momento de inercia transversal del cuello femoral, NAD: nadadores, PEPUB: peripuberal, PESO: levantadores de peso, PPUB: prepuberal, PUB: puberal, RNI: deportes repetitivos/sin impacto, SAL: saltadores de comba, SOF: softball, SPA: densitometría simple de rayos, TEN: tenistas, TIE: tierra, TR: estudio transversal, TROC: trocánter, VOL: voleibol, WARD: triángulo de Wards.

2. Hipótesis

La práctica del fútbol tiene una repercusión positiva en la masa y estructura ósea de los niños y niñas que lo practican.

La práctica del fútbol durante una temporada en una superficie con menor absorción de impacto provoca mayores aumentos en CMO, DMO y estructura ósea que la práctica en una superficie más blanda con mayor absorción de impacto.

---

2. Hypotheses

Football practice has a positive impact on bone mass and structure in male and female adolescent football players.

One season of football practice in a surface with lower impact absorption provokes higher bone mineral content (BMC), bone mineral density (BMD) and bone structure enhancements than football practice in a softer surface with higher impact absorption.

3. Objetivos

Los *objetivos generales* de la presente Tesis Doctoral son: ampliar el conocimiento científico sobre los efectos de la práctica del fútbol en la masa y estructura ósea de niños y adolescentes futbolistas, y analizar la interacción de diferentes tipos de botas de fútbol y superficies de juego en la adquisición de masa y estructura ósea.

Los *objetivos específicos* de cada uno de los ocho artículos que componen esta Tesis Doctoral son:

Artículo I. Resumir la literatura actual en relación con los efectos de la práctica del fútbol en la masa ósea de los niños y adolescentes futbolistas en función del sexo y el estadio madurativo.

Artículo II. Analizar la masa ósea de los futbolistas adolescentes, y evaluar la influencia del sexo y del estadio madurativo en CMO y DMO.

Artículo III. Examinar y comparar las variables de masa y estructura ósea evaluadas al 4 y 38% de la longitud de la tibia entre futbolistas y controles separados por sexo.

Artículo IV. Investigar la influencia de la inclusión de una sub-base elástica en el césped artificial de tercera generación sobre la biomecánica de jóvenes futbolistas (fuerzas de impacto, cinemática de las articulaciones y características del movimiento) durante una serie de acciones específicas del fútbol.

Artículo V. Comparar la estructura y fortaleza ósea entre chicos futbolistas con diferentes presiones plantares registradas durante una combinación de acciones específicas del fútbol.

Artículos VI. Comparar CMO, DMO, DMO aparente, estructura ósea y fortaleza ósea entre chicos futbolistas y controles, y evaluar la influencia de entrenar y jugar al fútbol en dos superficies diferentes, césped artificial de tercera generación con sub-base elástica y sin sub-base elástica, en las variables comentadas anteriormente.

Artículo VII. Comparar el porcentaje de grasa corporal calculado mediante el DXA, pletismografía por desplazamiento de aire, análisis de la impedancia bioeléctrica y antropometría en futbolistas adolescentes.

Artículos VIII. Determinar la precisión de las ecuaciones más utilizadas en chicos y chicas adolescentes en una muestra de jóvenes futbolistas, desarrollar una ecuación específica para chicos y chicas adolescentes futbolistas, y validar la nueva ecuación con otra muestra de las mismas características.

3. Aims

The general aims of the present Thesis are: to enlarge the scientific knowledge in terms of the effects of football practice on bone mass and structure in children and adolescent football players, and to analyze the interaction of different footwear types and playing surfaces on the acquisition of bone mass and structure.

The *specific aims* of each of the eight articles that compose this Thesis are:

Manuscript I. To summarize the current literature regarding the effects of football practice on bone mass in both sexes and different pubertal stages in children and adolescents.

Manuscript II. To assess bone mass in a group of adolescent football players; and to evaluate the influence of both sexes and pubertal status on bone mineral content and bone mineral density.

Manuscript III. To examine and compare bone mass variables and geometric variables at the 4 and 38% sites of the tibia length between adolescent football players and controls separated by sex.

Manuscript IV. To investigate the influence of a cushioning underlay on football player biomechanics (impact force, joint kinetics and movement characteristics) across a range of game-specific tasks.

Manuscript V. To compare bone geometry and strength between male adolescent football players with different maximum values of the average pressures registered during a combination of football-specific tasks.

Manuscript VI. To compare bone mineral content, areal bone mineral density, bone mineral apparent density, bone geometry and bone strength between young male football players and controls; and to evaluate the influence of training and playing football on two playing surfaces, third-generation artificial turf with and without elastic layer, on previous bone values.

Manuscript VII. To compare body fat percentage calculated by dual energy X-ray absorptiometry, air displacement plethysmography, bioelectrical impedance analyses and anthropometry in adolescent football players.

Manuscript VIII. To determine the accuracy of the most used anthropometric equation in male and female adolescent football players, to develop a specific equation for male and female football players, and to cross-validate this new equation with another sample of the same population.

4. *Material y métodos* ***[Material and methods]***

A continuación, se detalla la metodología general del proyecto de investigación "*Efecto de la interacción entre el tipo de césped artificial y modelo de botas en la salud ósea de niños y niñas futbolistas*" (DEP 2012-32724) al cual está adscrito la presente Tesis Doctoral. Sin embargo, en cada artículo aparece una descripción específica de la metodología utilizada en el mismo.

4.1 Comité de ética

El proyecto se llevó a cabo siguiendo las *Principios Éticos para las Investigaciones Médicas en Seres Humanos* reconocidas por la *Declaración de Helsinki de 1975* (revisado en las 64º Asamblea General en Fortaleza 2013, Brasil), y cumpliendo la legislación y la normativa legal española (ley 14/2007, de 3 de Julio, de Investigación Biomédica). Además, el *Comité de Ética de la Investigación de la Comunidad Autónoma de Aragón* (CEICA) en la reunión celebrada el día 19 de junio de 2013, Acta Nº CP12/2013 emitió un *dictamen favorable* a este proyecto (C.I. PI13/0091) (Anexo I). El proyecto también fue registrado en la base de datos pública "*ClinicalTrials.gov*" obteniendo el código de registro [NCT02399553] (Anexo II).

Previo a la participación en el proyecto se organizaron reuniones en cada uno de los clubes deportivos (*Real Zaragoza S.A.D., Los Molinos U.D., C.D. Marianistas, C.D. Transportes Alcaine* y *S.D. Ejea*) y centros escolares (*Colegio Salesianos "Nuestra Señora del Pilar"* y *Colegio Juan XXIII*) donde se explicaron los objetivos y procedimientos del mismo. Tanto los participantes como sus padres, madres o tutores legales recibieron una hoja de información que explicaba detalladamente las pruebas a realizar en el estudio, así como de los posibles riesgos y beneficios derivados de la participación en el mismo (Anexo

III). Finalmente, los padres, madres o tutores legales de los participantes tuvieron que firmar un consentimiento informado para que sus hijos e hijas pudieran participar en el proyecto (Anexo IV). Por otra parte, los participantes tuvieron que dar su asentimiento para confirmar su participación en el proyecto.

4.2 Diseño del proyecto

El presente proyecto tiene un diseño controlado aleatorizado por bloques. En el primer corte transversal (*Evaluación A, octubre-diciembre 2013*) se evalúo y se comparó la masa ósea de los futbolistas en función del sexo y del estadio madurativo. Posteriormente comenzó la fase de intervención que duró aproximadamente siete meses. En esta fase se suministró a cada participante un tipo de bota determinado (Adidas Nitrocharge 3.0, Herzogenaurach, Germany) con el que tenían que entrenar y jugar durante toda esa temporada. Aquellos futbolistas que entrenaban y jugaban en césped natural y tierra se les entregó este modelo de bota de fútbol con taco de goma (*hard-ground stud design*; **Figura 11**). Por otra parte, aquellos que entrenaban y jugaban en césped artificial fueron aleatorizados en dos grupos y recibieron el mismo modelo de bota de fútbol con distinto taco entre ellos (**Figura 11**): multitaco (*turf stud desing*) y taco de goma (*hard-ground stud design*). Después de la intervención se llevó a cabo la segunda evaluación (*Evaluación B, mayo-julio 2014*) que coincidió con el final de la temporada de los futbolistas y que sirvió para evaluar los cambios en la masa y estructura de los futbolistas en función de los diferentes tipos bota de fútbol y superficie de juego. Al final de la siguiente temporada se realizó la tercera evaluación (*Evaluación C, mayo-julio 2015*) para estudiar la perdurabilidad de los resultados óseos obtenidos.

Figura 11. Modelo de bota y taco utilizado en el presente proyecto.

A) B)

A) Adidas Nitrocharge 3.0 multitaco (turf stud desing) y B) taco de goma (hard-ground stud design).

4.3 Muestra

Los criterios de inclusión comunes a los futbolistas y controles de este estudio fueron los siguientes: (a) caucásico, (b) tener una edad comprendida entre 11 y 14 años, (c) no tener una enfermedad conocida, y (d) no estar tomando medicación que afecte al hueso en el momento de comenzar el proyecto ni durante los tres meses previos. Además, los futbolistas tenían que llevar al menos un año entrenando a fútbol y los controles no tenían que estar practicando ningún deporte de forma regular.

Ocho equipos de fútbol que competían a nivel provincial en su categoría de edad y dos colegios de Zaragoza (Aragón, España) fueron invitados a participar en este estudio. La totalidad de los futbolistas decidieron participar; sin embargo, sólo 45 de los 114 estudiantes decidieron participar. En consecuencia, la muestra inicial del proyecto estuvo compuesta por un total de 121 futbolistas (81 chicos y 40 chicas) y 45 controles (23 chicos y 22 chicas). Cabe destacar que 11 futbolistas no asistieron a las mediciones por lo que la muestra final del estudio fue 110 futbolistas (75 chicos y 35 chicas) y 45 controles (23 chicos y 22 chicas).

El **artículo I**, al tratarse de una revisión sistemática con meta-análisis, tiene una metodología propia y diferente a los estudios experimentales que está explicada en detalle en dicho artículo.

Los **artículos II y III** son transversales y cuentan con la muestra descrita en la *Evaluación A*. No obstante, existen pequeñas variaciones en el número de participantes debidas a valores perdidos en alguna de las variables de análisis.

El **artículo IV** es transversal y fue realizado con una muestra diferente de jóvenes futbolistas en la universidad "*Liverpool John Moores University*". Para la realización de este estudio se reclutaron 15 jóvenes futbolistas (10 hombres y 5 mujeres) que tenían que llevar al menos un año jugando al fútbol y no haber tenido ninguna lesión grave en las extremidades inferiores en los seis meses previos al comienzo del estudio. Debido a un problema en el registro de los datos de biomecánica, tres participantes tuvieron que ser excluidos del estudio. Finalmente, 12 futbolistas (9 hombres y 3 mujeres) fueron incluidos en los análisis.

El **artículo V** es transversal y cuenta con los datos medidos en la *Evaluación B*. La muestra de este estudio también disminuyó debido a que no todos los participantes del proyecto pudieron asistir a la medición de las presiones plantares (realizadas antes de finalizar la temporada 2013-2014) y a los criterios de inclusión establecidos para este estudio (p.ej. únicamente los chicos futbolistas).

El **artículo VI** es longitudinal e incluyó los datos de las *Evaluaciones A y B*. Este artículo estudio los efectos del tipo de superficie en la adquisición de masa y estructura ósea de los niños futbolistas. El número de participantes disminuyó debido a valores perdidos en alguna de las variables de análisis y a los criterios de inclusión establecidos para este estudio (p.ej. únicamente los chicos futbolistas que entrenaban y jugaban en césped artificial).

Los **artículos VII y VIII** son transversales y fueron realizados con los datos obtenidos en la *Evaluación B*. Existen variaciones en el número de participantes debidas a los valores perdidos en alguna de las variables de análisis. Por otra parte, se reclutó una muestra adicional de 28 futbolistas (21 chicos pertenecientes al *C. D. Oliver Urriti*, y 7 chicas pertenecientes al *C.D. Transportes Alcaine*) para realizar la validación de la ecuación antropométrica desarrollada en el artículo VIII.

4.4 Pruebas y valoraciones

Puesto queel proyecto FUTBOMAS es más amplio que lo reflejado en esta Tesis Doctoral, en este apartado únicamente se van a explicar aquellas pruebas y valoraciones que han sido utilizadas en alguno de los artículos incluidos. La **Tabla 5** resume las pruebas y valoraciones realizadas en cada uno de los artículos de esta Tesis Doctoral.

4.4.1 Valoración de la composición corporal

4.4.1.1 Absorciometría fotónica dual de rayos-X

El equipo DXA QDR-Explorer (Hologic Corp. Software versión pediátrica 12.4, Bedford, Massachusetts, EEUU) fue utilizado para la medición de la masa ósea, grasa y magra. Este dispositivo fue calibrado diariamente con un fantoma de espina lumbar y, siempre que el programa lo requirió, se realizaron dos calibraciones adicionales: la primera con un fantoma de pasos y la segunda mediante una prueba de uniformidad radiográfica de la camilla. Todas las calibraciones y valoraciones fueron realizadas por el mismo técnico siguiendo las recomendaciones del fabricante. Los coeficientes de variación para la determinación del CMO y DMO fueron calculados antes de comenzar esta Tesis Doctoral [63].

Se llevaron a cabo las exploraciones de cuerpo completo, columna lumbar y cadera no dominante. En todas las pruebas se colocó al participante en decúbito supino sobre la camilla. Para determinar la dominancia de la extremidad inferior, se preguntó a los participantes qué extremidad emplearían para golpear un balón [64]. De la exploración de cuerpo completo se midieron los valores de CMO (g), DMO (g/cm^2), área ósea (cm^2), masa grasa (g; %) y masa magra (g) del cuerpo entero y de las siguientes regiones: cabeza, cuerpo entero sin la cabeza, extremidades superiores, tronco y extremidades inferiores. Los valores de CMO (g), DMO (g/cm^2) y área ósea (cm^2) de las vértebras L_1-L_4 fueron medidos mediante la prueba de columna lumbar y, a través de la exploración de la cadera no dominante, se obtuvieron los datos de CMO (g), DMO (g/cm^2) y área ósea (cm^2) de las siguientes subregiones: cuello femoral, triángulo de Wards, trocánter, región intertrocantérica y cadera total. También se calculó la DMO aparente del cuerpo completo [22], columna lumbar y cuello femoral [21] usando las ecuaciones de la **Tabla 2**.

4.4.1.2 Tomografía axial computerizada periférica

El equipo Stratec XCT-2000 L (Stratec Medizintechnik, Pforzheim, Alemania) fue utilizado para la medición de la masa, estructura y fortaleza ósea de la tibia no dominante. EL pQCT fue calibrado diariamente con un fantoma que incluye tejidos de densidades similares al tejido magro. Las calibraciones y valoraciones también fueron realizadas por el mismo técnico siguiendo las recomendaciones del fabricante. El artículo realizado por

Gómez-Bruton y col. [65] reporta los coeficientes de variación del pQCT para cada variable.

Para evaluar la masa, estructura y fortaleza ósea de la tibia, se realizaron cuatro cortes transversales al 4, 14, 38 y 66% de la longitud de la tibia. Esta longitud fue medida con una regla de madera desde el punto más proximal del cóndilo medial de la tibia hasta el punto más distal del maléolo medial. Los participantes fueron colocados en una silla ajustable a sus proporciones corporales. Posteriormente, se posicionó el escáner en la parte distal de la tibia para obtener una vista previa de esta zona y así, colocar manualmente la línea de referencia en el punto medio de la placa terminal de la tibia (zona distal). Las variables de interés fueron el CMO, DMOv y áreas; diversos espesores como el cortical, periostio o endostio, y varios índices de fortaleza ósea. Para la realización de los artículos de esta Tesis Doctoral se han utilizado las variables del 4% de la longitud de la tibia para la valoración del hueso trabecular, y las del 38% de la longitud de la tibia para la valoración del hueso cortical.

Las imágenes del pQCT fueron analizadas con la versión 6.20 del software del fabricante. Para determinar el periostio se utilizó el modo "*Contour mode 1*" con un umbral de 180 mg/cm^3 (4% de la longitud de la tibia) o de 280 mg/cm^3 (38% de la longitud de la tibia). En el 4% de la tibia, el hueso trabecular se determinó a través de un área central correspondiente al 45% del área transversal total del hueso. En el 38% de la tibia, el hueso cortical se determinó a partir del "*Cortical mode 1*" con un umbral de 710 mg/cm^3. Además, se utilizó el "*Cortical mode 1*" con un umbral de 280 mg/cm^3 para calcular las variables de fortaleza ósea. Por otra parte, se asumió que la mineralización ósea era de 1200 mg/cm^3.

4.4.1.3 Pletismografía por desplazamiento de aire

La pletismografía por desplazamiento de aire (ADP; BOD-POD® Body Composition System, Life Measurement Instruments, Concord, CA, EEUU) se utilizó para evaluar el volumen corporal bruto (volumen corporal total y volumen pulmonar). Este dispositivo calculó la densidad corporal total basándose en la siguiente ecuación: DC = M / (BVraw + 0.40 * TGV – SAA); donde DC es la densidad corporal total, M es la masa corporal del participante (kg), BVraw es el volumen corporal total (L), TGV es el volumen pulmonar (L), y SAA es la superficie corporal calculada automáticamente por el software (m^2). El volumen pulmonar de cada participante fue estimado automáticamente por el software del ADP. Posteriormente, se utilizó la ecuación de Siri [66] para estimar el porcentaje de grasa corporal del participante a partir de la densidad corporal total calculada. El ADP fue calibrado diariamente con un cilindro de 50,378 L siguiendo las recomendaciones del fabricante. Además, todos los participantes fueron medidos en ropa interior y tuvieron que llevar un gorro de baño.

4.4.1.4 Análisis de la impedancia bioeléctrica

El análisis de impedancia bioeléctrica (BIA) fue realizado con un equipo de impedancia portátil de cuatro electrodos (TANITA BC-418, TANITA Corp., Tokyo Japón). Los participantes fueron medidos en ropa interior y descalzos. Con esta prueba se estimaron los datos de masa grasa y masa libre de grasa de los mismos.

4.4.1.5 Antropometría

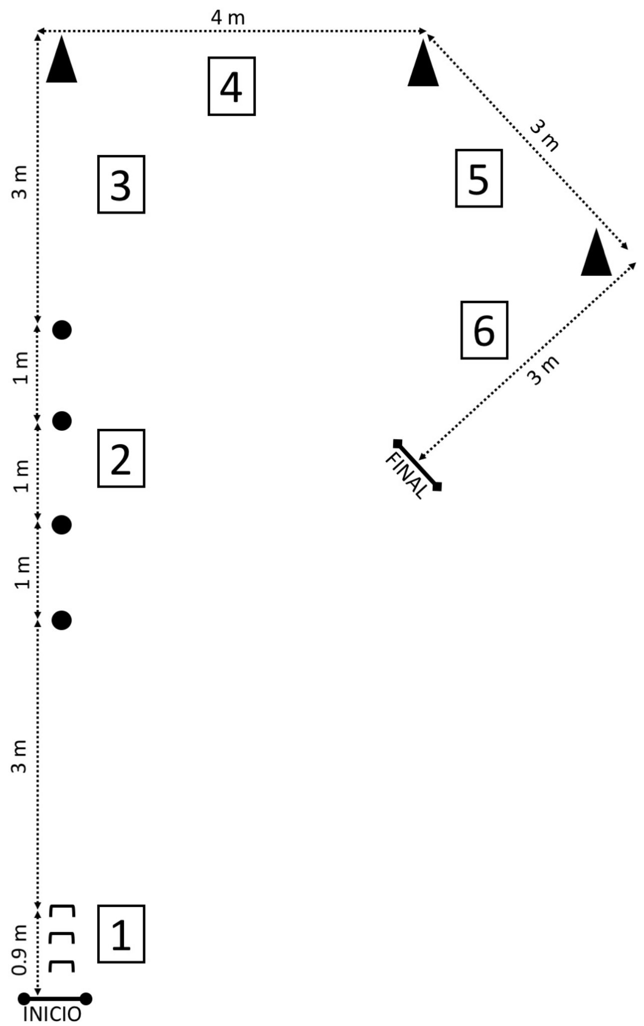
Todas las mediciones antropométricas fueron realizadas según las recomendaciones de la Sociedad Internacional para el Avance de la Cineantropometría (ISAK) [67] con los participantes en ropa interior y sin calzado. La talla se midió con un estadiómetro que tenía una precisión de 0,1 cm (SECA 225, SECA, Hamburg, Germany); mientras que, la masa corporal se midió con una báscula de 0,1 kg de precisión (SECA 861, SECA, Hamburg, Germany). El índice de masa corporal (IMC) fue calculado a través de la división de la masa corporal (kg) entre la talla (m) elevada al cuadrado.

Las medidas de los pliegues, perímetros y diámetros se realizaron por duplicado en el lado derecho del cuerpo con un calibre de pliegues de 0,2 mm de precisión (Holtain Ltd. Crymmych, UK), una cinta antropométrica de precisión 0,1 mm y un paquímetro de 0,1 mm de precisión (ambos Rosscraft S.R.L., Canadá). Se calculó la media de las dos mediciones y, en caso de necesitar una tercera medición, se registró la mediana de las tres mediciones. Se midieron los pliegues del bíceps, tríceps, subescapular, iliocrestal, supraespinal, abdominal, muslo anterior y pantorrilla; los perímetros del brazo relajado, brazo contraído, cintura, cadera, muslo medio y pierna; y los diámetros biepicondíleo del húmero y bicondíleo del fémur. Todas las mediciones fueron efectuadas por antropometristas nivel 2 de ISAK.

4.4.2 Valoración de las presiones plantares

El sistema Biofoot® (IBV, Valencia, España) fue utilizado para medir las presiones plantares de ambos pies de los participantes durante una combinación de acciones específicas del fútbol (**Figura 12**). Este sistema está compuesto por dos plantillas conectadas cada una de ellas a dos amplificadores colocados en la zona lateral de la pierna. Estos amplificadores se conectan con un módulo de transmisión situado en la cintura de los participantes (columna lumbar) y que envía telemétricamente los datos al ordenador. Las plantillas tienen un grosor de 0,7 mm, son flexibles, de polyester y están compuestas por 64 sensores piezoeléctricos distribuidos a lo largo de la planta del pie. La unidad de medida de este sistema es el kilopascal (kPa) y la frecuencia de registro es de 100Hz durante 15 s.

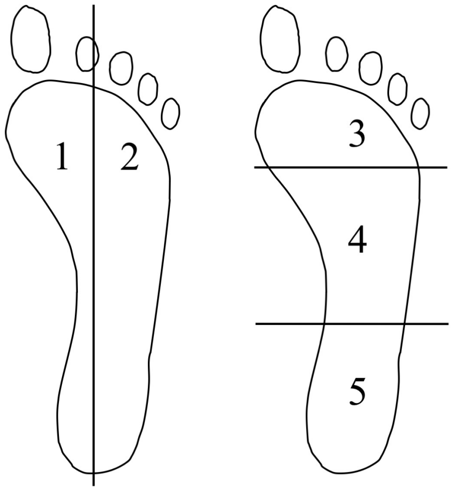
Figura 12. Combinación de acciones específicas del fútbol.



1) Tres saltos con los pies juntos de vallas de 30 cm de altura, 2) carrera en zigzag alrededor de cuatro picas, 3) esprint de tres m, 4) carrera lateral de cuatro m, 5) y 6) dos esprints de tres m separados por un giro de 90º.

Siguiendo las recomendaciones de la versión 6.1 del software, las presiones plantares fueron analizadas en las zonas del pie lateral, medial, antepié, mediopié y retropié (**Figura 13**). Para cada una de estas zonas, se seleccionó el máximo de la presión media definido por el sistema como el valor máximo de la presión media de la zona analizada. Estas valoraciones se pudieron llevar a cabo gracias a la colaboración de la empresa Podoactiva con este proyecto.

Figura 13. Zonas del pie analizadas.

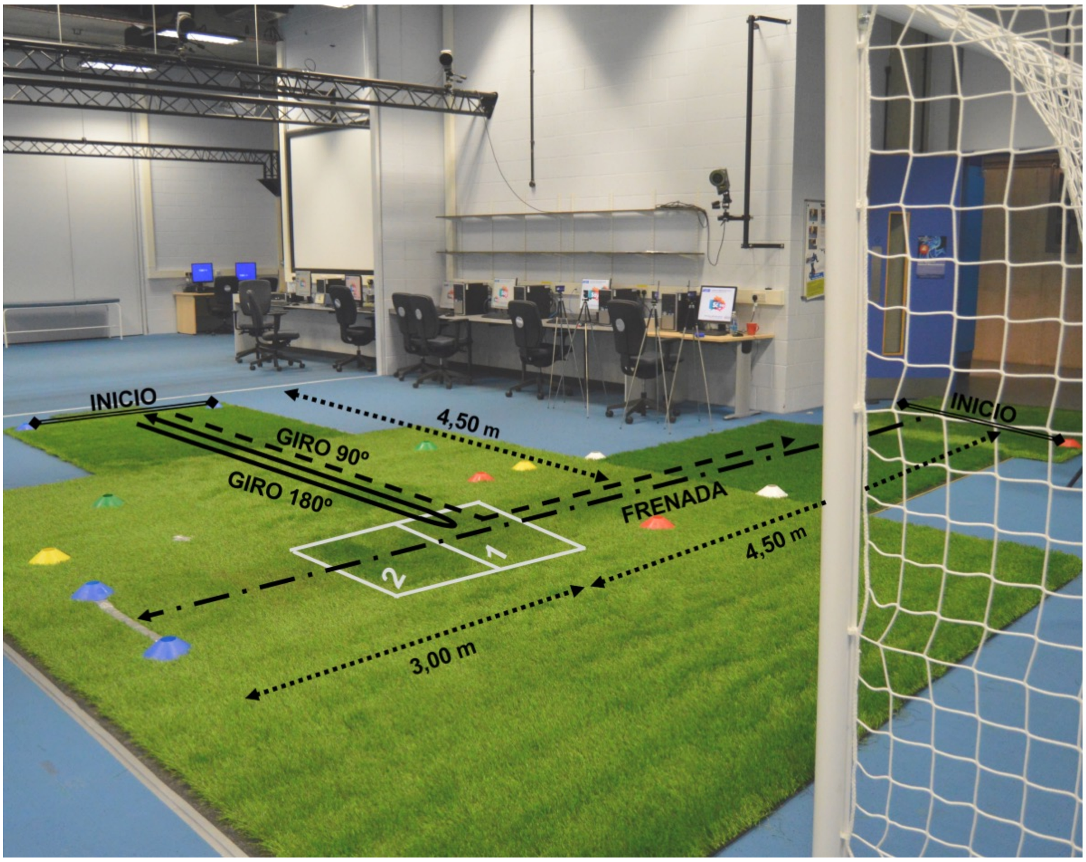


1) Zona medial del pie, 2) zona lateral del pie, 3) antepié, 4) mediopié, y 5) retropié

4.4.3 Análisis de la biomecánica

Diez cámaras optoeléctricas y el software Qualysis Track Manager (Oqus 400, Qualisys AB, Göteborg, Suecia) fueron utilizados para registrar los datos de cinemática del cuerpo del futbolista durante cuatro acciones específicas del fútbol (giro de 90º, giro de 180º, salto *drop jump* y frenada rápida; **Figura 14**). Las cámaras registran la posición de los marcadores reflectantes y esféricos (12 mm de diámetro). Concretamente, se colocaron 43 marcadores en los siguientes puntos corporales del participante: séptima vértebra cervical, manubrio esternal, espina iliaca posterosuperior (derecha e izquierda), cresta iliaca (derecha e izquierda), espina iliaca anterosuperior (derecha e izquierda), epicóndilos femorales lateral y medial (derecha e izquierda), maléolos tibial y peroneo (derecha e izquierda), talón proximal, distal y lateral, y la cabeza del quinto metatarsiano. Cuatro placas rígidas de plástico con cuatro marcadores cada una de ellas fueron colocadas en la parte lateral del muslo y de la pierna (derecha e izquierda). Además, se creó un punto de referencia en el primer metatarsiano de los pies derecho e izquierdo a través de un puntero digitalizado (C-Motion, Inc., Germantown, Maryland, EEUU). Posteriormente, se definieron cada uno de los marcadores con el software Qualysis Track Manager 2.11. Los datos de movimiento fueron registrados a una frecuencia de 500 Hz. Cabe destacar que este sistema también se sincronizó con dos plataformas de fuerza (90x60 cm, 9281B, Kistler Holding AG, Winterthur, Suiza) configuradas para registrar a una frecuencia de 3000 Hz y situadas en la parte central del laboratorio como se muestra en la **Figura 14**. Por otra parte, el programa Visual 3D (C-Motion, Inc., Germantown, Maryland, EEUU) fue utilizado para transformar los análisis del software Qualysis Track Manager en datos de imagen 3D y, así, poder crear los segmentos corporales, sus ángulos y sus rangos de movimiento.

Figura 14. Colocación del césped artificial en el laboratorio.



Las dos plataformas de fuerza (rectángulos grises 1 y 2) están situadas en el centro del volumen tridimensional, lugar donde se realiza la medición. La línea discontinua representa un giro de 90º, la línea continua representa un giro de 180º y la línea discontinua con puntos representa un sprint con una frenada rápida. Estas tres tareas se realizaron en la plataforma de fuerza 1. En la tarea de frenada rápida, los participantes comenzaron a frenar en la plataforma de fuerza 1 y, posteriormente, debían parar completamente en los dos pasos siguientes. El salto drop jump se realizó con el pie izquierdo en la plataforma de fuerza 1 y el derecho en la plataforma de fuerza 2.

4.4.4 Valoración de las propiedades mecánicas de los campos de fútbol

Las propiedades mecánicas de los campos de fútbol incluidos en el presente proyecto fueron evaluadas siguiendo los criterios de calidad establecidos por el CEN (EN 15530-1:2007). Esta normativa evalúa el rendimiento y la durabilidad de las superficies deportivas que van a ser usadas a un nivel amateur, educativo y/o recreativo. Los requisitos que debe cumplir una superficie para que pueda ser utilizada según el CEN se muestran en la **Tabla 1**. A continuación, se explica cómo han sido evaluadas las propiedades mecánicas incluidas en este proyecto.

El equipo utilizado para evaluar la *absorción de impactos* de las superficies incluidas en el presente proyecto fue el Atleta Artificial Avanzado (Triple A; **Figura 15.A**). Esta prueba consiste en dejar caer una masa conocida desde una altura determinada sobre un muelle que simula el efecto amortiguador del tobillo y la rodilla del futbolista. Se registra la fuerza máxima (N) con una célula de carga. Posteriormente, se calcula la absorción de impacto usando como referencia la fuerza máxima obtenida en un pavimento de hormigón con la siguiente ecuación: Absorción impacto (%) = $[1 - \text{Fuerza}_{pav} \text{ (N)} / \text{Fuerza}_{hor} \text{ (N)}] \times 100$.

La *deformación vertical* de la superficie también fue evaluada con el Triple A. En esta prueba, se deja caer una masa conocida desde una altura determinada sobre la superficie y unos sensores registran el desplazamiento de la superficie. Se evalúa tanto la fuerza máxima como el desplazamiento. La deformación vertical estándar se calcula con la siguiente ecuación: Deformación vertical (mm) = $[1500 / \text{Fuerza}_{pav} \text{ (N)}] \times$ deformación (mm).

Figura 15. Equipos utilizados para medir la absorción de impactos, deformación vertical (Triple A; A) y tracción rotacional (B) de las superficies.

A)

B)

A) Imagen realizada en el campo de fútbol "Estadio Municipal de Ejea de los Caballeros". B) Imagen obtenida del documento de Mondo Ibérica titulado "Campos de césped artificial: Diseño, tipos, construcción, normativa y mantenimiento" Catón, J. [68].

El equipo utilizado para evaluar la *tracción rotacional* se muestra en la **Figura 15.B**. Esta prueba consiste en dejar caer un peso de 46 kg desde una altura entre 5-7 cm de forma que los tacos se claven en la superficie. Posteriormente, se gira la herramienta hasta que cede el suelo. El parámetro evaluado es la resistencia al giro (Nm).

La prueba de *rebote vertical* consiste en dejar caer un balón desde una altura conocida de forma que un micrófono capta el sonido del primer y del segundo impacto del balón sobre el suelo (**Figura 16.A**). A través del tiempo entre el primer y el segundo impacto se calcula la altura de rebote vertical con la siguiente ecuación: Altura (cm) = [1,23 x (tiempo (s) – 0,025) x 100.

El equipo utilizado para medir la *rodadura horizontal* se muestra en la **Figura 16.B**. Esta prueba consiste en dejar caer un balón por una rampa con una inclinación establecida por la normativa del CEN. Se mide la distancia (m) desde el balón hasta el final de la rampa. Se realizará en tantas direcciones como pendientes tenga el campo.

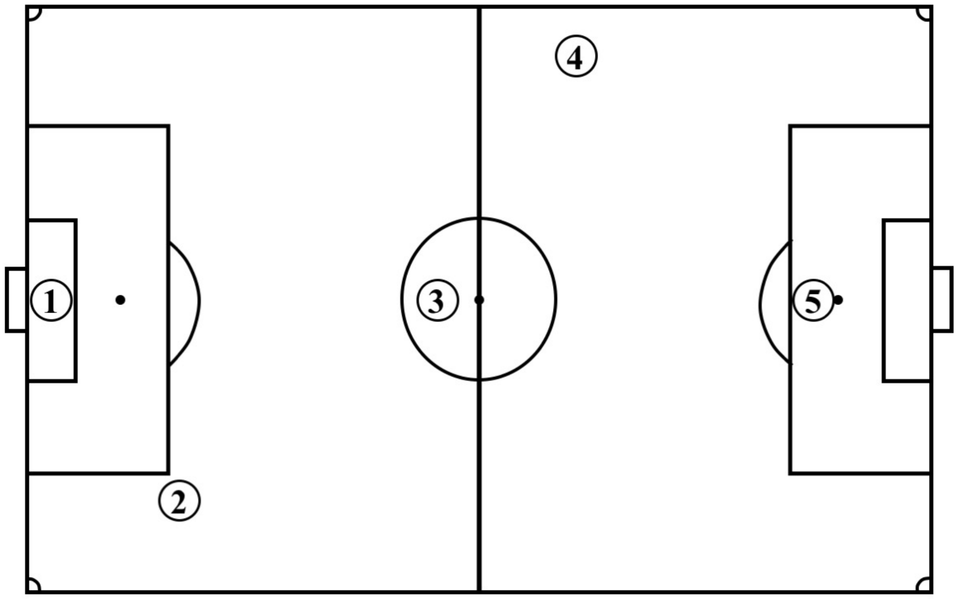
Figura 16. Equipos utilizados para medir el rebote vertical (A) y la rodadura horizontal (B) del balón sobre la superficie.

A) **B)**

Ambas imágenes fueron obtenidas del documento de Mondo Ibérica titulado "Campos de césped artificial: Diseño, tipos, construcción, normativa y mantenimiento" Catón, J. [68].

Estas características mecánicas fueron medidas en cinco zonas diferentes del campo de fútbol (**Figura 17**). Las pruebas de absorción de impactos, deformación vertical y tracción rotacional se repitieron tres veces en cada zona del campo; mientras que, el rebote vertical y la rodadura horizontal se repitieron cinco veces. Todas las pruebas se llevaron a cabo en unas condiciones meteorológicas estables (temperatura: 10 – 22 ºC, velocidad del viento: 0 – 1,2 m/s, y humedad: 45 – 60%) medidas con el dispositivo Pocket Weather Tracker 4000 (Kestrelmeters, Birmingham, UK). Cabe destacar que estas valoraciones se pudieron llevar a cabo gracias a la colaboración de la empresa Mondo Ibérica con este proyecto.

Figura 17. Zonas del campo donde se midieron las propiedades de los campos de fútbol.



Zonas determinadas por la normativa EN 15530-1:2007 del CEN.

4.4.5 Otros datos

4.4.5.1 Maduración sexual

Para evaluar la maduración sexual, se facilitó a todos los participantes una planilla con distintas imágenes de maduración sexual (Anexo V) para que se auto-evaluasen siguiendo los cinco estadios propuestos por Tanner y Whitehouse [69]. También se estimó el comienzo de la madurez en chicos y chicas a partir de las siguientes ecuaciones [70]:

- Chicos: Comienzo de la madurez (años) = -7,999994 + [0,0036124 x (edad x altura en cm)]
- Chicas: Comienzo de la madurez (años) = -7,709133 + [0,0042232 x (edad x altura en cm)]

4.4.5.2 Ingesta de calcio

Se utilizó un cuestionario validado de frecuencia de consumo de calcio para estimar los miligramos ingeridos diariamente por los participantes (Anexo VI) [71, 72].

4.4.5.3 Actividad física

La actividad física de los participantes fue medida con acelerómetros triaxiales (GENEActiv desarrollados por Unilever Discover, Colworth, Reino Unido; y distribuidos por ActivInsights Ltd., Kimbolton, Cambridge, Reino Unido). Estos acelerómetros han sido calibrados y validados en niños y adolescentes y en diferentes zonas corporales como en la muñeca derecha e izquierda [73]. Los participantes de este estudio llevaron el acelerómetro en su muñeca no dominante durante siete días. Debido a que los futbolistas no pudieron llevarlo durante los partidos oficiales, tenían que anotar en una hoja de registro el día y el tiempo que no lo llevaban (Anexo VII). Las aceleraciones se registraron a una frecuencia de 30 Hz y fueron analizadas en *epochs* de un segundo con el software Rstudio (versión de escritorio RStudio 1.0.153, Boston, EEUU) y el código desarrollado por Marín-Puyalto J. y col. Los minutos de tiempo válido sedentario y en las intensidades de actividad física ligera, moderada y vigorosa fueron calculados a partir de los puntos de corte propuestos por Phillips y col. [73] para la muñeca derecha (tiempo sedentario < 2,3 g·s, ligera 2,4 – 7,9 g·s, moderada 8,0 – 21,0 g·s, vigorosa >21,0 g·s) e izquierda (tiempo sedentario < 2,6 g·s, ligera 2,7 – 7,1 g·s, moderada 7,2 – 22,5 g·s, vigorosa >22,6 g·s).

Tabla 5. Pruebas y valoraciones realizadas en cada uno de los artículos de esta Tesis Doctoral.

Valoración	Método	Medición	Equipo utilizado	Artículos
Composición corporal	DXA	Cuerpo completo, cadera no dominante y columna lumbar.	QDR-Explorer	II, VI, VII y VIII
	pQCT	Tibia no dominante.	Stratec XCT-2000 L	III, V y VI
	ADP	Cuerpo completo.	BOD-POD®	VII
	BIA	Cuerpo completo.	TANITA BC-418	VII
	Antropometría	Pliegues: bíceps, tríceps, subescapular, iliocrestal, supraespinal, abdominal, muslo anterior y pantorrilla. Perímetros: brazo relajado, brazo contraído, cintura, cadera, muslo medio y pierna. Diámetros biepicondíleo del húmero y bicondíleo del fémur).	Compás de pliegues Holtain Cinta antropométrica Rosscraft Paquímetro Rosscraft	VII y VIII
Presiones plantares	Plantillas	Pie lateral, medial, antepié, mediopié y retropié.	Biofoot®	V
Biomecánica	Cámaras optoeléctricas Plataforma de fuerzas	Articulaciones de la cadera, rodilla y tobillo.	Qualysis Track Manager Visual 3D (C-Motion) Kistler Holding AG	IV
Propiedades mecánicas de los campos de fútbol	CEN	Evaluación de absorción de impactos, deformación vertical, tracción rotacional, rebote vertical y rodadura horizontal en cinco zonas de los campos de fútbol.	Normativa EN 15530-1:2007	VI
Maduración sexual	Cuestionario Ecuación	Desarrollo madurativo actual	Imágenes de Tanner y Whitehouse [69] Ecuaciones de Moore y col. [70]	II, III, V, VI, VII y VIII
Ingesta de calcio	Cuestionario	Ingesta diaria de calcio	Cuestionario validado Julián y col.[71]	III, V y VI
Actividad física	Acelerometría	Muñeca no dominante	GENEActiv	VI

ADP: pletismografía por desplazamiento de aire; BIA: análisis de impedancia bioeléctrica; CEN: Comité Europeo de Normalización; DXA: absorciometría fotónica dual de rayos X, pQCT: tomografía axial computerizada periférica.

4.5 Análisis estadísticos

A continuación, se resumen brevemente las pruebas estadísticas que se efectuaron para obtener los resultados de esta Tesis Doctoral; no obstante, en cada artículo incluido aparece una descripción más detallada de todos los análisis estadísticos realizados.

Los análisis estadísticos se realizaron con el paquete informático *Statistical Package for the Social Sciences* (SPSS versión 22.0 para Mac OS X, SPSS Inc., Chicago, IL, EEUU). En general, los datos se presentan como media ± desviación estándar, a menos que se indiquen otros estadísticos. En primer lugar, se estudió la normalidad en la distribución de las variables continuas mediante el test de *Kolmogorov-Smirnov*. Si la distribución de una variable era normal, las diferencias entre grupos se establecían mediante *el test para muestras independientes* (test *t* de *Student*) o con el *test de análisis de las varianzas* (ANOVA). En algunas pruebas estadísticas se utilizaron covariables para ajustar variables que pueden estar influenciadas por otras. En esos casos se efectuó el *test de análisis de las covarianzas* (ANCOVA) junto con el *test post hoc de Bonferroni*. Las variables nominales (estadio de maduración sexual de Tanner) se analizaron con *tablas de contingencia* aplicando el *test de Chi-cuadrado*.

Para analizar la influencia del tipo de superficie en el hueso, se estudiaron las interacciones *tipo de superficie x tiempo* con el *test de medidas repetidas de ANOVA*. Las asociaciones entre variables se estudiaron mediante *correlaciones bivariadas de Pearson* y *regresiones lineales*.

El tamaño del efecto de las pruebas estadísticas realizadas se evaluó mediante la *d* de Cohen (pruebas *t* de *Student*) y el eta-cuadrado (*partial eta squared*; η^2_p). Se usaron los puntos de corte establecidos por Hopkins y col. [74]: el tamaño del efecto de la *d* de Cohen puede ser trivial (0,0 – 0,2), pequeño (0,2 – 0,6), moderado (0,6 – 1,2), grande (1,2 – 2,0) o muy grande (> 2,0); y de la η^2_p puede ser pequeño (0,01 – 0,06), medio (0,06 – 0,14) o grande (> 0,14). El nivel de significación estadístico fue tomado, como norma general como $p < .05$.

5. Resultados y discusión

Uno de los objetivos iniciales de esta Tesis Doctoral era analizar la influencia de diferentes tipos de bota de fútbol en la masa y estructura ósea de los futbolistas. Sin embargo, los análisis realizados demostraron que los dos tipos de bota de fútbol incluidos en este estudio no influyeron en la adquisición ósea de estos deportistas (chicos: **Tabla 6;** chicas: **Tabla 7**). Por ello, no se han incluido estos resultados como un artículo científico en la presente Tesis Doctoral.

Los resultados y la discusión de la presente Tesis Doctoral se muestran como artículos científicos, siguiendo el formato en el que han sido publicados, aceptados o sometidos.

---

5. Results and discussion

One of the initial aims of the present Thesis was to analyze the influence of different footwear types on bone mass and structure in football players. Nevertheless, the statistical analyses showed that the footwear types included in this study did not influence bone acquisition (boys: **Table 6**; girls: **Table 7**). Therefore, these results have not been included in this Thesis as a manuscript.

Results and discussion of this Thesis are shown as research manuscripts, following the format in which they were published, accepted or submitted.

Tabla 6. Comparación de la masa, estructura y fortaleza ósea entre los chicos futbolistas que jugaron durante una temporada con diferente tipo de bota (multitaco y taco de goma).

				Medidas repetidas			
				Intra-grupo		**Interacción Grupo x tiempo**	
		Multitaco	**Taco goma**	**Multitaco**	**Taco goma**		
		N=21	**N=20**	η^2_p	η^2_p	***p***	η^2_p
DXA							
CMO (g)							
Cuerpo subtotal	T0	1220,399±222,992	1203,306±279,853				
	T1	1389,849±296,540	1363,284±339,730	0,654‡	0,616‡	,740	0,003
Columna Lumbar	T0	36,638±6,690	35,661±8,395				
	T1	41,525±9,032	40,462±10,349	0,543‡	0,522‡	,934	<0,001
DMO (g/cm^2)							
Ext. inferiores	T0	1,047±0,105	1,030±0,133				
	T1	1,132±0,116	1,124±0,134	0,630‡	0,666‡	,546	0,009
DMO aparente (g/cm^3)							
Cuerpo completo	T0	0,092±0,004	0,091±0,005				
	T1	0,095±0,004	0,095±0,004	0,126‡	0,259‡	,331	0,024
Columna lumbar	T0	0,106±0,007	0,108±0,009				
	T1	0,110±0,008	0,111±0,009	0,229‡	0,178‡	,766	0,002
Cuello femoral	T0	0,181±0,015	0,183±0,018				
	T1	0,184±0,016	0,185±0,018	0,060	0,040	,848	0,001
pQCT							
4% de la tibia							
DMOv (mg/cm^3)	T0	321,30±27,24	320,27±34,19				
	T1	321,22±24,86	319,90±28,49	<0,001	<0,001	,947	<0,001
DMOv trab (mg/cm^3)	T0	293,32±34,56	292,47±43,37				
	T1	292,47±32,61	290,32±37,36	0,001	0,005	,848	0,001
38% de la tibia							
CMO (g)	T0	2,98±0,32	2,94±0,40				
	T1	3,17±0,38	3,14±0,43	0,662‡	0,661‡	,898	<0,001
DMOv cort. (mg/cm^3)	T0	1049,08±23,85	1062,89±29,93				
	T1	1049,01±25,20	1060,32±28,87	<0,001	0,022	,521	0,011
Área cort. (mm^2)	T0	257±29	254±36				
	T1	274±33	272±37	0,580‡	0,610‡	,648	0,005
Espesor cort. (mm)	T0	4,72±0,37	4,77±0,47				
	T1	4,92±0,38	5,00±0,43	0,322‡	0,381‡	,618	0,006
FRC_X (N)	T0	3019,2±476,3	2938,1±597,7				
	T1	3238,5±533,6	3136,4±611,3	0,422‡	0,362‡	,724	0,003
SSI_POL (mm^3)	T0	1341,4±219,0	1307,9±274,8				
	T1	1455,8±229,0	1401,7±262,4	0,499‡	0,390‡	,438	0,015

Los datos se presentan como media ± desviación estándar. CMO: contenido mineral óseo; cort: cortical; DMO: densidad mineral ósea; DMO: densidad mineral ósea de área; DMOv: densidad mineral ósea volumétrica; DXA: absorciometría fotónica dual de rayos X; FRC_X: índice de fractura en el eje X; pQCT: tomografía axial computerizada periférica; SSI_POL: índice de tensión deformación; T0: inicio de la temporada; T1: final de la temporada; trab: trabecular; η^2_p: eta al cuadrado.
Cuando los análisis se ajustaron por los minutos al día que realizaban actividad moderada-vigorosa y la masa magra, no se encontró ninguna interacción tipo de bota por tiempo significativa ($p > .05$). No se encontraron diferencias significativas en ninguna de las variables entre los futbolistas que jugaban con diferente tipo de bota ni al inicio ni al final de la temporada ($p > .05$).
‡diferencias significativas intra-grupo entre el inicio y el final de la temporada.

Tabla 7. Comparación de la masa, estructura y fortaleza ósea entre las chicas futbolistas que jugaron durante una temporada con diferente tipo de bota (multitaco y taco de goma).

				Medidas repetidas			
				Intra-grupo		Interacción Grupo x tiempo	
		Multitaco	Taco goma	Multitaco	Taco goma		
		N=14	N=16	η^2_p	η^2_p	*p*	η^2_p
DXA							
CMO (g)							
Cuerpo subtotal	T0	1318,341±273,927	1272,391±313,824				
	T1	1442,364±282,304	1393,756±295,241	0,674‡	0,694‡	,906	0,001
Columna Lumbar	T0	45,722±10,192	40,483±11,676				
	T1	51,035±10,180	45,744±10,648	0,679‡	0,703‡	,957	<0,001
DMO (g/cm^2)							
Ext. inferiores	T0	1,052±0,101	1,078±0,119				
	T1	1,144±0,108	1,159±0,112	0,613‡	0,589‡	,596	0,010
DMO aparente (g/cm^3)							
Cuerpo completo	T0	0,093±0,004	0,091±0,005				
	T1	0,098±0,004	0,096±0,004	0,347‡	0,457‡	,621	0,009
Columna lumbar	T0	0,124±0,015	0,120±0,018				
	T1	0,128±0,016	0,124±0,013	0,203‡	0,301‡	,673	0,006
Cuello femoral	T0	0,187±0,030	0,204±0,037				
	T1	0,195±0,032	0,204±0,036	0,130	<0,001	,155	0,071
pQCT							
4% de la tibia							
DMOv (mg/cm^3)	T0	301,48±33,39	316,864±38,26				
	T1	312,52±36,69	327,850±38,37	0,301‡	0,327‡	,991	<0,001
DMOv trab (mg/cm^3)	T0	248,05±37,03	272,700±42,42				
	T1	252,54±38,24	273,322±39,99	0,057	0,001	,421	0,023
38% de la tibia							
CMO (g)	T0	3,01±0,42	2,93±0,48				
	T1	3,16±0,46	3,07±0,48	0,561‡	0,586‡	,946	<0,001
DMOv cort. (mg/cm^3)	T0	1105,23±31,79	1085,23±36,41				
	T1	1121,65±27,79	1107,70±29,06	0,470‡	0,655‡	,191	0,060
Área cort. (mm^2)	T0	250±35	243±41				
	T1	259±38	254±40	0,334‡	0,457‡	,566	0,012
Espesor cort. (mm)	T0	4,84±0,51	4,70±0,58				
	T1	4,95±0,50	4,92±0,52	0,126	0,352‡	,240	0,049
FRC_X (N)	T0	2945,7±615,7	2856,1±705,3				
	T1	3116,2±661,6	3070,3±691,9	0,337‡	0,479‡	,485	0,018
SSI_POL (mm^3)	T0	1284,4±248,8	1188,4±285,0				
	T1	1322,0±251,0	1286,2±262,5	0,073	0,381‡	,092	0,098

Los datos se presentan como media ± desviación estándar. CMO: contenido mineral óseo; cort: cortical; DMO: densidad mineral ósea; DMO: densidad mineral ósea de área; DMOv: densidad mineral ósea volumétrica; DXA: absorciometría fotónica dual de rayos X; FRC_X: índice de fractura en el eje X; pQCT: tomografía axial computerizada periférica; SSI_POL: índice de tensión deformación; T0: inicio de la temporada; T1: final de la temporada; trab: trabecular; η^2_p: eta al cuadrado.
Cuando los análisis se ajustaron por los minutos al día que realizaban actividad moderada-vigorosa y la masa magra, no se encontró ninguna interacción tipo de bota por tiempo significativa ($p > .05$). No se encontraron diferencias significativas en ninguna de las variables entre los futbolistas que jugaban con diferente tipo de bota ni al inicio ni al final de la temporada ($p > .05$).
‡diferencias significativas intra-grupo entre el inicio y el final de la temporada.

European Journal of Pediatrics
https://doi.org/10.1007/s00431-017-3060-3

REVIEW

Soccer helps build strong bones during growth: a systematic review and meta-analysis

Gabriel Lozano-Berges [1,2,3,4] • Ángel Matute-Llorente [1,2,3,4] • Alejandro González-Agüero [1,2,3,4] • Alejandro Gómez-Bruton [1,2,3,4] • Alba Gómez-Cabello [1,3,4,5] • Germán Vicente-Rodríguez [1,2,3,4] • José A. Casajús [1,2,3,4]

Received: 19 November 2016 / Revised: 27 November 2017 / Accepted: 29 November 2017

Abstract

The aim of this study was to analyze the effects of soccer practice on bone in male and female children and adolescents. MEDLINE, PubMed, SPORTDiscus and Web of Science databases were searched for scientific articles published up to and including October 2016. Twenty-seven studies were included in this systematic review (13 in the meta-analysis). The meta-analysis was performed by using OpenMeta[Analyst] software. It is well documented that soccer practice during childhood provides positive effects on bone mineral content (BMC) and density (BMD) compared to sedentary behaviors and other sports, such as tennis, weightlifting, or swimming. Furthermore, soccer players present higher BMC and BMD in most weight-bearing sites such as the whole body, lumbar spine, hip, and legs. Moreover, bone differences were minimized between groups during prepuberty. Therefore, the maturity status should be considered when evaluating bone. According to meta-analysis results, soccer practice was positively associated with whole-body BMD either in males (mean difference 0.061; 95%CI, 0.042–0.079) or in females (mean difference 0.063; 95%CI, 0.026–0.099).

Conclusion: Soccer may be considered a sport that positively affects bone mass during growth. Pubertal soccer players presented increased bone mass compared to controls or other athletes; however, these bone differences are minimized during the prepubertal stage.

Communicated by Mario Bianchetti

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00431-017-3060-3) contains supplementary material, which is available to authorized users.

✉ José A. Casajús
joseant@unizar.es

Gabriel Lozano-Berges
glozano@unizar.es

Ángel Matute-Llorente
amatute@unizar.es

Alejandro González-Agüero
alexgonz@unizar.es

Alejandro Gómez-Bruton
bruton@unizar.es

Alba Gómez-Cabello
agomez@unizar.es

Germán Vicente-Rodríguez
gervicen@unizar.es

1 GENUD “Growth, Exercise, NUtrition, and Development”, Universidad de Zaragoza, Zaragoza, Spain

2 Faculty of Health and Sport Science (FCSD), Department of Physiatry and Nursing, Universidad de Zaragoza, Huesca, Spain

3 Instituto Agroalimentario de Aragón-IA2-(Universidad de Zaragoza -CITA), Zaragoza, Spain

4 Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn), Madrid, Spain

5 Centro Universitario de la Defensa, Zaragoza, Spain

Published online: 28 December 2017

What is known:
• *It has been described that childhood and adolescence are important periods for bone mass and structure.*
• *Previous studies have demonstrated that soccer participation improves bone mass in male and female children and adolescents.*

What is new:
• *The differences between soccer players and controls are more marked during puberty than prepuberty.*
• *Weight-bearing sites such as lumbar spine, hip, femoral neck, trochanter, intertrochanteric region and both legs are particularly sensitive to soccer actions.*

Keywords Football · Sports · Bone mass · Bone tissue

Abbreviations

BMC	Bone mineral content
BMD	Bone mineral density
DXA	Dual-energy X-ray absorptiometry
pQCT	Peripheral quantitative computed tomography
QUS	Quantitative ultrasound system
SPA	Single photon absorptiometry
WHO	World Health Organization

Introduction

Osteopenia and osteoporosis are important diseases worldwide and are characterized by low bone mineral density (BMD) and microarchitectural deterioration [4]. These diseases appear mainly in the elderly causing morbidity, mortality, and high economic costs to society [8]. Nevertheless, childhood and adolescence have been described as critical periods to counteract them because 26% of the adult bone mineral content (BMC) is accumulated at the ages of approximately 12 and 14 years in females and males [5], respectively. Thus, appropriate bone mass accretion during growth seems fundamental to reduce the risk of suffering bone fractures in advanced age [32].

Both BMC and BMD are mainly determined by genetics [1]; nevertheless, lifestyle factors such as physical exercise [42] and nutrition [15] can also influence them. However, not all factors have the same relevance in this regard [45]; and similarly, not all physical exercises or sports have equal repercussions on bone tissue [38]. Different sport classifications have been proposed as follows according to their osteogenic stimulus: high/odd/repetitive/low-impact sports [26] or weight-bearing/non-weight-bearing sports [21]. Cycling and swimming are classified as non-weight-bearing sports, while others such as gymnastics or soccer are classified as high-impact sports [38].

Bone improvements are strongly correlated with high-impact and weight-bearing sports but not as correlated with non-weight-bearing ones. A continued practice of a high-impact sport such as soccer during growth could help to maintain these improvements and to attain high BMC and BMD [38].

Several studies have reported positive effects of soccer participation on bone mass either in male or in female children and adolescents [12, 28, 43, 49]; however, some authors such as Zouch et al. [48] and Seabra et al. [34] have not demonstrated this positive effect of soccer on bone mass. On the other hand, only one study is focused on gender differences during childhood or adolescence [21].

Therefore, the aim of this systematic review and meta-analysis was to investigate the effects of soccer practice on bone mass in both genders and different pubertal stages in children and adolescents.

Materials and methods

Data sources and search strategy

This review has been performed following the criteria and methodology established by the Preferred Reporting Items for Systematic reviews and Meta-Analyses Protocols (PRISMA-P) 2015 statement [22].

Journal articles were identified by searching in electronic databases and scanning references and lists of articles. The search strategy was applied to MEDLINE, PubMed, SPORTDiscus, and Web of Science up to and including October 2016.

The search strategy used to identify the articles in MEDLINE was as follows: (“Soccer”[Mesh] AND (“Bone Density”[Mesh] OR “Bone and Bones”[Mesh])) NOT “Soccer/injuries”[Mesh]. Moreover, “Humans” and “Child: birth-18 years” filters were applied. The search strategy used in PubMed was as follows: ((Soccer[Title/Abstract] OR Football[Title/Abstract]) AND (bone[Title/Abstract] AND (child*[Title/Abstract] OR adoles*[Title/Abstract] OR young[Title/Abstract] OR youth[Title/Abstract] OR *puber*[Title/Abstract] OR prepuber*[Title/Abstract]) NOT injur*[Title/Abstract]). The search strategy applied in SPORTDiscus was as follows: (Soccer[SU Subjects

(Descriptors)] AND (Bone density[SU Subjects (Descriptors)] OR Bone[SU Subjects (Descriptors)])) NOT soccer injuries[SU Subjects (Descriptors)]. The search strategy used in Web of Science was as follows: ((soccer AND ("bone density" OR "bone structure" OR "bone strength")) NOT "soccer injuries").

Two reviewers independently evaluated all studies. Titles and abstracts were examined, and full relevant articles were obtained and assessed using the inclusion and exclusion criteria described below. Inter-reviewer disagreements were resolved by consensus, and in some cases, a third reviewer was consulted to resolve disagreements.

The inclusion criteria

Languages of studies: English and Spanish.

Types of studies: Cross-sectional, randomized, and non-randomized controlled trials and longitudinal studies researching the effects of soccer practice on bone mass.

Types of participants: male and female soccer players (age range 6–18 years).

Types of outcomes: whole body, lumbar spine, leg, hip (femoral neck, trochanter, intertrochanteric region, and Ward's triangle subregions) BMC and BMD, bone architecture and ultrasound parameters (broadband ultrasound attenuation (BUA), speed of sound (SOS), and stiffness index).

The search summary

A total of 290 relevant articles were identified using the search strategies. Six additional articles were found through the reference lists. Following a review of titles and abstracts and excluding duplicates, the total number of articles was reduced to 40. Then, 27 articles met the inclusion criteria and were selected to be included in this review. On the other hand, the number of studies included in this meta-analysis, in comparison with the systematic review, were reduced from 27 to 13. Articles were excluded because of the following reasons: (1) DXA was not used [3, 7, 10, 17, 21]; (2) a control group was not included [23, 26, 40]; (3) whole-body BMD was not measured [33]; and (4) the same sample was included in different studies [12, 30, 43, 47, 48] (Fig. 1).

The characteristics of each study included in this systematic review were summarized in different sections following PICOS format [22]: participants (P), intervention (I), comparison between groups or control group (C), outcomes (O), and study design (S).

Quality assessment

Studies were assessed using two different quality assessment tools, one for the cross-sectional studies proposed by Hinckson et al. [13] and another for the longitudinal studies proposed by Tooth et al. [39].

The first tool consisted of ten criteria that were classified in four categories (descriptive information, external validity, internal validity, and clinical effects). All of them were scored as "Yes," "No," or "Not available." Afterwards, the final score of each article was obtained by the sum of the positive answers that were classified in a specific qualitative description (0–20%, bad; 21–40%, poor 41–60%, fair; 61–80%, good; and 81–100%, excellent).

In the second quality assessment tool [39], 33 criteria were assessed, scored as "Yes," "No," or "Not available" and classified in two categories: factors that could modify the effects and descriptive elements. Then, all positive scores were summed, and the average quality score of each item and study were independently calculated. However, a specific qualitative description was not available for these scores.

Statistical analysis

Statistical analyses were performed using OpenMeta [Analyst] software (OS X version obtained from http://www.cebm.brown.edu/openmeta/). Heterogeneity between studies was assessed by chi-squared test, expressed as inconsistency index (I^2) and interpreted as follows: $I^2 = 0$–25% no heterogeneity, $I^2 = 25$–50% moderate heterogeneity, $I^2 = 50$–75% high heterogeneity, and $I^2 = 75$–100% extreme heterogeneity. BMD mean differences between soccer players and controls and their 95% confidence intervals were calculated using a continuous random-effects model (DerSimonian-Laird method) due to significant heterogeneity between studies was found.

Results and discussion

Methodological quality

Supplementary Table 1 summarizes the details of the methodological quality assessment tool for cross-sectional studies. The average quality score was 77.6% (ranged from 60 to 100); therefore, the articles included in this review can be defined as good quality. Although two studies showed poor methodological quality, they were included in this review but their conclusions should be interpreted with caution.

In longitudinal studies, the average quality score was 17.8 out of 33 (ranged from 16/33 to 19/33) (Supplementary Table 2). However, all studies were included in this review, considering that the quality assessment used was described as "very demanding" by other authors such as Tooth et al. [39] who applied this tool and showed similar results (17/33). The inclusion of this information may be of interest to enhance the quality of future longitudinal studies.

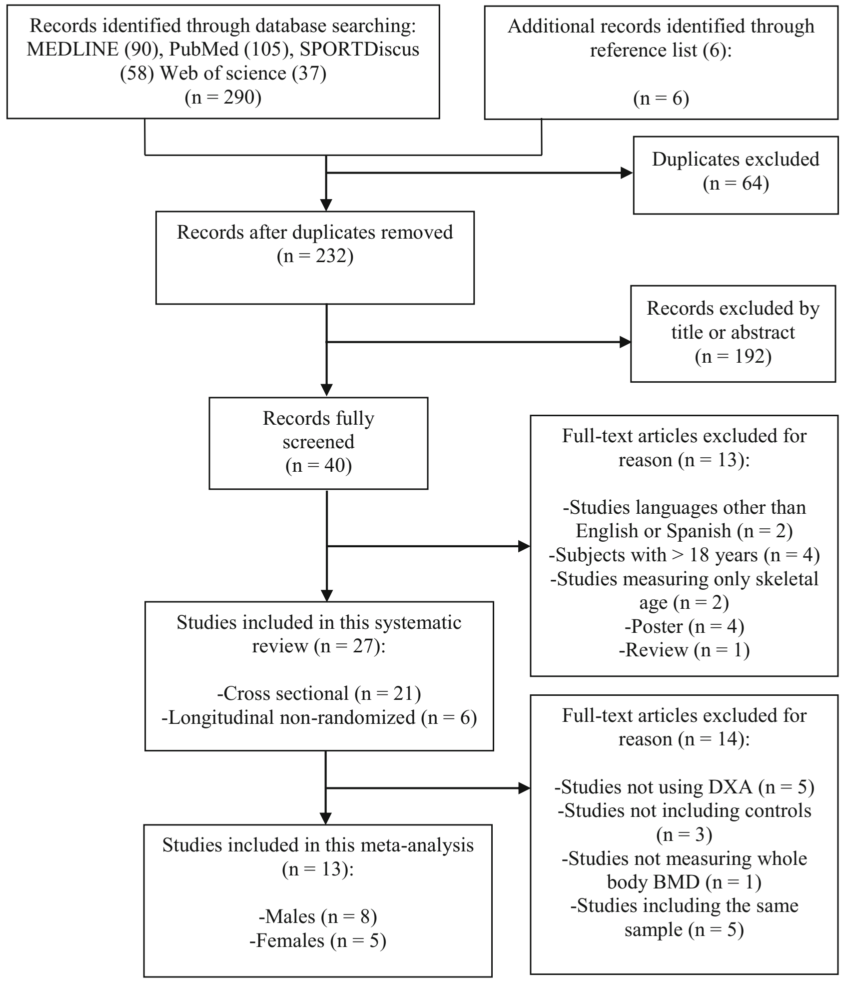


Fig. 1 PRISMA flow diagram of articles that were selected

Effects of soccer practice on bone mass in children and adolescent soccer players

Due to the clear sexual dimorphism in bone development during growth [5], the outcomes of this review have been divided by gender. Tables 1 and 2 summarize studies concerning males and females. In addition, the text has been distributed according to the comparison group: controls, athletes, and among themselves.

Gender differences

The only study evaluating gender differences in bone mass between male and female adolescent soccer players was performed by McCulloch et al. [21], finding no differences in BMC or in BMD between genders but showing a tendency towards higher bone mass in female soccer players compared to their male counterparts. These results could be explained by the fact that females accumulate BMC earlier than males [18, 19].

Males

Comparison between soccer players and controls The first study that reported on bone mass in male children and adolescent soccer players and age-matched controls was performed by McCulloch et al. [21]. They observed that BMD tended to be increased in children and adolescent soccer players compared with controls, but these differences were not significant. Moreover, Vicente-Rodríguez et al. [44] showed that prepubertal soccer players had increased BMC at lower limbs and trochanter and increased BMD at pelvis, legs, lumbar spine, proximal femur, femoral neck, and trochanter compared with the control group. Nebigh et al. [24] showed similar results in pubertal but not in prepubertal soccer players compared to controls. In addition, Seabra et al. [34] also showed increased whole-body and lower limb BMD in soccer players compared to controls but not in the lumbar spine. Even considering other possible confounders, soccer participation by itself seems to be associated with increased bone mass. Considering this, Plaza-Carmona et al. [31] studied the influence of the playing surface (soft vs. hard ground). Independent of the playing

Table 1 Effects of soccer training on bone mass in youth male soccer players

Study	Participants: Number	Sex	Age	Study design	Training experience (y)	Weekly training (h)	Data source	Measured areas	Outcome
McCulloch et al. [21]	SOC (23) SWI (20) CG (25)	M-F	15.3 ± 0.8 15.0 ± 1.1 14.9 ± 0.6	Cross-sectional	NA	10 18	CT SPA	Calcaneus Radius	No significant bone differences between groups.
Vicente-Rodriguez et al. [44]	SOC (53) CG (51)	M	9.3 ± 0.2 9.3 ± 0.2	Cross-sectional	1.8 ± 0.2	At least 3	DXA	WB Head Arms Pelvic Legs LSP Hip FNECK WTRI TROCH INTROCH	SOC showed higher both legs, LSP, pelvic, femur, FNECK, TROCH BMD than CG. SOC showed higher both legs and TROCH BMC than CG.
Vicente-Rodriguez et al. [43]	SOC (17) CG (11)	M	8.7 ± 0.4 9.4 ± 0.3	Longitudinal study	1.8 ± 0.2	At least 3	DXA	WB Arms Legs LSP Hip FNECK WTRI TROCH INTROCH	WB, both legs, LSP, FNECK and INTROCH BMC and BMD were significantly greater in SOC than CG.
Zouch et al. [47]	SOC (39): CG (13)	M	11.7 ± 0.9 10.7 ± 0.6	Longitudinal study	At least 3	(4/2)	DXA	WB Head Arms LSP Hip Legs	SOC who trained 4 h/week showed lower cranial BMC than CG. After 10 months of follow-up, SOC significantly increased WB, LSP, total hip kicking, and supporting leg BMC.
Nebigh et al. [24]	SOC (91): TN1 (11) TN2–3 (54) TN4–5 (26) CG (61): TN1 (6) TN2–3 (38) TN4–5 (17)	M	13.4 ± 0.2 13.3 ± 0.3 13.5 ± 0.3 12.5 ± 1.1 13.3 ± 0.5 12.8 ± 1.1 13.4 ± 0.5 13.3 ± 0.4	Cross-sectional	3.9 ± 0.8	8	DXA	WB Pelvis LSP FNECK Legs	SOC showed higher WB, pelvis, LSP, FNECK, and both legs' BMC and BMD than CG in early (TN2–3) and late puberty (TN4–5).
Falk et al. [10]	CHI (90): SOC (26) HOCK(30) CG (34) ADO (92): SOC (30) HOCK (31) CG (31)	M	CHI: 10-12 11.1 ± 0.5 11.2 ± 0.8 11.1 ± 0.7 14-16 15.2 ± 0.7 15.3 ± 0.9 15.2 ± 0.7	Cross-sectional	5.4 ± 1.0 4.7 ± 1.1 7.4 ± 2.3 9.0 ± 2.1	5.6 ± 1.6 6.4 ± 1.3 6.7 ± 1.8 6.5 ± 1.6	QUS	Mid-shaft tibia Distal 1/3 radius	SOC showed higher tibia SOS than CG in children and adolescents. HOCK showed higher radial SOS than SOC in adolescents.

Table 1 (continued)

Study	Participants: Number	Sex	Age	Study design	Training experience (y)	Weekly training (h)	Data source	Measured areas	Outcome
Sanchis et al. [33]	SOC (21) TEN (25) CG (22)	M	10.3 ± 0.2 10.6 ± 0.2 10.6 ± 0.2	Cross-sectional	1.8 ± 0.2 4.1 ± 1.8	4–6	DXA	WB Arms LSP FNECK Legs	TEN showed higher inter-arm asymmetry BA. BMC and BMD than SOC and CG. SOC showed higher inter-leg asymmetry BMC and BMD than CG. SOC showed higher FNECK BMC and BMD than TEN.
Mota et al. [23]	SOC (71): U19 (12) U17 (20) U15 (39)	M	 < 19 ≤ 17 ≤ 15	Cross-sectional	NA	NA	DXA	WB Legs	U17 SOC in non-dominant leg showed higher BMD than U17 SOC in dominant leg.
Madic et al. [17]	SOC (32) CG (30)	M	10.7 ± 0.5 11.2 ± 0.7	Cross-sectional	At least 1	10–15	QUS	Right/left calcaneus	SOC showed higher right and left calcaneus SOS than CG
Silva et al. [35]	SOC (10) SWI (12) TEN (10) CG (14)	M	14.7 ± 0.8 13.8 ± 2.5 14.1 ± 1.6 13.4 ± 2.0	Cross-sectional	At least 3	15.1 ± 0.8 17.3 ± 1.6 16 ± 0.8	DXA	WB LSP Left hip FNECK WTRI TROCH INTROCH	SOC showed higher left hip BMD than SWI and CG. SOC at the end of puberty (16–18 years) showed higher WB, LSP and proximal femur BMD than SOC at initial age of puberty (10–12 years).
Seabra et al. [34]	SOC (117) CG (34)	M	13.8 ± 1.5 13.3 ± 1.3	Cross-sectional	At least 3	≈ 5	DXA	WB LSP Lower limb	SOC showed higher WB and both lower limbs BMD than CG.
Anliker et al. [3]	SOC (66)	M	15.1 ± 1.5	Cross-sectional	9.1 ± 2.5	10.7 ± 2.0	pQCT	4, 14, 38, and 66% of tibia length	SOC in non-dominant leg showed higher bone mass and geometry at 4, 14, and 38% of tibia length than SOC in dominant leg.
Zouch et al. [48]	PPB (35): SOC (22) CG (13) PB (41): SOC (26) CG (15)	M	 11.9 ± 0.8 11.7 ± 0.6 12.9 ± 0.8 12.5 ± 0.6	Longitudinal study	At least 3	≈ 2–5	DXA	WB Head Arms LSP Hip Legs	PB SOC showed higher WB, total hip and both legs BMC than PB CG. PPB SOC showed higher WB, Hip and both legs BMC than CG PPB. PB SOC enhanced more marked LSP, FNECK, supporting leg and both arms BMC than PPB SOC. PPB SOC enhanced more marked hip and kicking leg BMC than PPB CG. PB SOC enhanced more marked LSP and both leg BMC than PB CG.
Plaza-Carmona et al. [31]	HG: SOC (14) SG: SOC (14) CG (14)	M	 9.4 ± 0.2 8.9 ± 0.2 9.3 ± 0.1	Cross-sectional	At least 1	At least 3	DXA	WB FHEAD WTRI TROCH INTROCH	HG SOC showed higher pelvis, FNECK and INTROCH BMC than CG HG and SG SOC showed higher pelvis, FNECK TROCH and INTROCH BMD than CG SG SOC showed higher pelvis, leg, FNECK, TROCH and INTROCH BMC than CG
Zouch et al. [49]	SOC (42) CG (23)	M	12.0 ± 0.8 11.7 ± 0.6	Longitudinal study	At least 3	2–5	DXA	WB Head Arms LSP FNECK	At baseline, SOC showed higher WB and both legs BMD than CG After 3 year follow-up, SOC showed significant BMC and BMD in all weight-bearing sites. During 3-year follow-up, SOC increased more in WB, LSP, FNECK and non-dominant arm BMD than CG.

Table 1 (continued)

Study	Participants: Number	Sex	Age	Study design	Training experience (y)	Weekly training (h)	Data source	Measured areas	Outcome
								Legs	During 3-year follow-up, SOC increased more in LSP, FNECK and non-dominant arm BMC than CG. During 3-year follow-up, SOC had less head %BMC and %BMD changes than CG.
Agostinete et al. [2]	SOC (18) SWI (16) BB (14) JUD (12) KAR (9) CG (13)	M	12.4 ± 1.9 13.5 ± 1.5 13.4 ± 1.2 13.1 ± 1.5 13.1 ± 1.8 11.9 ± 2.2	Longitudinal study	41.5 ± 43.8 57.1 ± 32.1 32.2 ± 22.2 47.6 ± 39.3 41.1 ± 37.4 months	NA	DXA	WB Arms LSP Legs	After 9-month follow-up, SOC enhanced BMD at WB, arms, LSP and legs. After 9-month follow-up, BB increased more in WB and arms than SOC.
Vlachopoulos et al. [46]	SOC (37) SWI (41) CYC (29) CG (14)	M	12.8 ± 0.9 13.4 ± 1.0 13.2 ± 1.0 12.3 ± 0.5	Cross-sectional	At least 3	10.0 ± 2.3 9.5 ± 5.1 5.1 ± 2.1 –	DXA HSA QUS	SB Arms Pelvis LSP Hip FNECK WTRI TROCH Legs Shaft FNECK_W FNECK_D CSA CSMI Section HIS SI	SOC showed higher SB, pelvis, hip, FNECK, WTRI, TROCH, legs, shaft BMC and BMD than CG. SOC showed higher Hip, WTRI and TROCH BMD than SWI and CYC. SOC showed lower arms BMC and BMD than SWI. SOC showed lower arms LSP and shaft BA than SWI. SOC showed higher CSMI than CG. SOC showed higher section than CYC and CG. SOC showed higher CSA than SWI, CYC, and CG. SOC showed higher HSI than SWI and CG. SOC showed higher SI at dominant foot than SWI, CYC, and CG. SOC showed higher SI at non-dominant foot than SWI and CG.

BA bone area, *BB* basketball, *BMC* bone mineral content, *BMD* bone mineral density, *CG* control group, *CSA* cross-sectional area, *CSMI* cross-sectional moment of inertia, *CST* circular strength training, *CT* computed tomography, *CHI* child, *DXA* dual-energy X-ray absorptiometry, *FNECK* femoral neck, *FNECK_W* femoral neck width, *FNECK_D* femoral neck diameter, *HOCK* hockey players, *HIS* hip strength index, *HSA* hip structural analysis, *INT* intervention, *INTROCH* intertrochanteric region, *JUD* judo, *KAR* karate, *L2* second lumbar vertebrae, *L4* fourth lumbar vertebrae, *LSP* lumbar spine, *M* male, *NA* not available, *NOR* normal training, *PB* pubescent, *PPB* prepubescent, *pQCT* peripheral quantitative computed tomography, *QUS* quantitative ultrasound system, *SB* subtotal body, *SOC* soccer players, *SOF* softball, *SOS* speed of sound, *SI* stiffness index, *SPA* single photon absorptiometry, *SUM* summer, *SWI* swimmers, *TEN* tennis players, *TN* tanner, *TOT* total sample, *TROCH* trochanter, *U15* under 15 years, *U17* under 17 years, *U19* under 19 years, *VOL* volleyball, *WB* whole body, *WHO* World Health Organization, *WIN* winter, *WLI* weightlifters, *WTRI* wards triangle

Table 2 Effects of soccer training on bone mass in youth female soccer players

Study	Participants: Number	Sex	Age	Study design	Training experience (y)	Weekly training (h)	Data source	Measured areas	Outcome
Soderman et al. [36]	SOC (51): ≤ 16 years (23) > 16 years (18) CG (41) ≤ 16 years (28) > 16 years (23)	F	16.3 ± 0.3 16.2 ± 1.3	Cross-sectional	8.1 ± 2.1	5.0 ± 1.7	DXA	WB Head LSP FNECK WTRI TROCH	SOC showed higher BMD in all weight-bearing sites than CG. Younger SOC (≤ 16 years) only showed higher TROCH BMD than CG. Older SOC (> 16 years) showed higher BMD in all weight-bearing sites than CG.
Pettersson et al. [28]	SOC (15) RSK (10) CG (25)	F	17.4 ± 0.8 17.8 ± 0.8 17.6 ± 0.8	Cross-sectional	8.7 ± 2.2 11.5 ± 1.7	5.1 ± 2.2 6.1 ± 3.4 0.9 ± 1.1	DXA	WB Humerus Radius LSP FNECK WTRI TROCH Femur Tibia	SOC showed higher FNECK, TROCH, femur, and lower limb subregions BMD than CG. RSK showed higher WB (6.0%), LSP (10.3%) and right humerus (8.6%) BMD than SOC. RSK showed higher WB, proximal tibia and tibia diaphysis BMC than SOC. RSK showed higher total femur, proximal tibia and tibia diaphysis BA than SOC.
Bellew et al. [7]	SOC (16) SWI (29) WLI (19)	F	15.1 ± 1.2 12.0 ± 2.1 13.6 ± 1.3	Cross-sectional	4.9 ± 1.8 5.2 ± 2.5 5.1 ± 2.4	9.8 ± 4.0 9.7 ± 5.0 9.2 ± 4.9	SPA	Calcaneus	SOC had significantly higher calcaneus BMD compared to WLI and SWI. SOC showed greater BMD than adult norms to normative data from the WHO.
Nichols et al. [26]	HI (93): SOC (22) SJT (29) SOF (15) VOL (11) TEN (10) LAC (6) RNI (68): RUN (56) SWI (12)	F	TOT 15.7 ± 1.3 HI 15.6 ± 1.2 RNI 15.6 ± 1.3	Cross-sectional	TOT 6.4 ± 3.4 HI 6.5 ± 3.4 RNI 6.1 ± 3.3	TOT 1.9 ± 0.4 HI 2.0 ± 0.4 RNI 1.9 ± 0.4	DXA	WB LSP Hip FNECK TROCH	Eumenorrheic HI showed higher total hip and TROCH BMD than eumenorrheic RNI. Eumenorrheic HI showed higher LSP and TROCH BMD than oligo/amenorrheic RNI. Eumenorrheic HI showed higher LSP BMD Z-scores than eumenorrheic and oligo/amenorrheic RNI. Oligo/amenorrheic HI showed higher LSP BMD Z-scores than oligo/amenorrheic RNI.
Ferry et al. [11]	SOC (32) SWI (26) CG (15)	F	16.2 ± 0.7 15.9 ± 2.0	Cross-sectional	At least 7 At least 6	10	DXA HSA	WB Arms LSP Dominant hip FNECK WTRI TROCH INTROCH Legs	SOC had significantly higher WB, LSP, and hip BMC and BMD than SWI. SOC showed higher WB, LSP, hip, and FNECK BMD Z-score than SWI. SOC had higher CSMI at NN, FS, and IT compared than SWI. SOC had lower BR at NN, FS, and IT compared than SWI

Table 2 (continued)

Study	Participants: Number	Sex	Age	Study design	Training experience (y)	Weekly training (h)	Data source	Measured areas	Outcome
								NANECK Shaft INTROCH	
Ferry et al. [12]	SOC (32) SWI (26) CG (15)	F	16.2 ± 0.7 15.9 ± 2.0	Longitudinal study	At least 7 At least 6	10	DXA HSA	WB LSP Dominant hip FNECK WTRI TROCH INTROCH NANECK Shaft INTROCH	At baseline, SOC showed higher LSP, hip, FNECK, TROCH, and INTROCH BMD than SWI. At baseline, SOC showed higher LSP, hip, FNECK, and BMD Z-score than SWI. At baseline, SOC showed higher hip, TROCH, and INTROCH BMD than CG. At baseline, SOC showed higher hip BMD Z-score than CG. After training season, SOC enhanced BMD at WB, LSP, hip, FNECK, TROCH, and INTROCH After training season, SOC enhanced BMD Z-score at WB After training season, SOC enhanced CSMI and BR at FS After training season, SOC enhanced Z-score in CSMI and Z at FS section.
Plaza-Carmona et al. [29]	SOC (10) SWI (13) CG(10)	F	8.2 ± 0.1 8.5 ± 0.1 9.7 ± 0.2	Cross-sectional	NA	2	DXA	WB Hip FNECK WTRI TROCH INTROCH	SOC showed higher WB, both ribs, LSP, pelvis, both leg, FHEAD, and TROCH BMC than CG SOC showed higher WB, LSP, pelvis, right leg, TROCH, and INTROCH BMD than CG SOC showed higher WB, pelvis, both leg BMC than SWI SOC showed higher pelvis, right leg, TROCH, and INTROCH BMD than SWI
Ubago-Guisado et al. [41]	PPB (20): SOC (20) SWI (20) BB (20) HB (20) CG (20) PB (20): SOC (20) SWI (20) BB (20) HB (20) CG (20)	F	 9.6 ± 1.0 9.2 ± 0.7 10.4 ± 0.5 9.9 ± 0.6 10.0 ± 0.5 12.3 ± 0.6 12.2 ± 0.6 13.1 ± 0.3 12.7 ± 0.9 12.1 ± 0.7	Cross-sectional	 3.9 ± 1.8 4.9 ± 2.0 3.4 ± 1.5 3.4 ± 1.4 4.5 ± 1.7 4.1 ± 2.4 4.4 ± 1.4 3.9 ± 1.8	 3.0 ± 0.0 3.8 ± 1.9 2.9 ± 0.4 3.1 ± 0.2 3.6 ± 0.8 4.4 ± 2.7 3.1 ± 0.2 4.2 ± 2.8	DXA	WB Arms Pelvis Hip FNECK WTRI TROCH INTROCH Legs	PPB SOC showed higher pelvis and TROCH BMC and INTROCH BMD than PPB CG. PPB SOC showed higher hip, FNECK and TROCH BMC, and FNECK BMD than PPB SWI. PPB SOC showed higher FNECK and TROCH BMC than PPB BB. PB SOC showed higher WB, pelvis, FNECK, WTRI, TROCH, and leg BMC and WB, arms, pelvis, hip, FNECK, WTRI and INTROCH BMD than PB CG.

Table 2 (continued)

Study	Participants: Number	Sex	Age	Study design	Training experience (y)	Weekly training (h)	Data source	Measured areas	Outcome
									PB SOC showed higher WB, FNECK, TROCH, and leg BMC and pelvis and hip BMD than PB SWI.
Plaza-Carmona et al. [30]	PPB (20):	F		Cross-sectional		2	DXA	WB	PPB SOC showed higher FNECK BMC than PPB CG.
	SOC (10)		8.2 ± 0.1		2.5 ± 0.7			Pelvis	PPB SOC showed higher FNECK and INTROCH BMD than PPB CG.
	CG (10)		9.7 ± 0.2					Hip	
	PEPB (45):							FNECK	PEPB SOC showed higher WB, pelvis, WTRI, and TROCH BMC than PEPB CG.
	SOC (30)		11.7 ± 0.1		4.3 ± 1.8			WTRI	
	CG (15)		10.9 ± 0.2					TROCH	PEPB SOC showed higher WB, hip, FNECK, WTRI, and INTROCH BMD than PEPB CG.
								INTROCH	
								Legs	
Ubago-Guisado et al. [40]	PPB (60)	F		Cross sectional			DXA	WB	PB SOC (G) showed higher hip BMC and BMD than PB SOC (AT).
	SOC (11/9)		10.0 ± 0.9		4.3 ± 1.4	3.0 ± 0.0		Pelvis	
	(G/AT)		9.1 ± 0.9		3.3 ± 2.2	3.0 ± 0.0		Hip	
	BB (14/6)		10.3 ± 0.6		3.1 ± 1.5	2.8 ± 0.5		FNECK	
	(SYN/PAR)		10.5 ± 0.3		4.0 ± 1.6	3.0 ± 0.0		WTRI	
	HB (12/8)		9.7 ± 0.6		3.3 ± 1.4	3.0 ± 0.0		TROCH	
	(SYN/SMO)		10.0 ± 0.7		3.5 ± 1.3	3.1 ± 0.4		INTROCH	
	PB (60)							Legs	
	SOC (11/9)		12.6 ± 0.6		4.6 ± 1.4	3.5 ± 0.8			
	(G/AT)		12.0 ± 0.6		4.3 ± 2.1	3.7 ± 0.7			
	BB (7/13)		13.3 ± 0.4		4.1 ± 2.0	3.2 ± 0.3			
	(SYN/PAR)		13.1 ± 0.3		4.5 ± 1.1	3.0 ± 0.1			
	HB (8/12)		13.0 ± 1.0		4.4 ± 2.2	6.5 ± 3.4			
	(SYN/SMO)		12.5 ± 0.8		3.6 ± 1.4	6.0 ± 2.4			

AT artificial turf, *BA* bone area, *BB* basketball, *BMC* bone mineral content, *BMD* bone mineral density, *BR* buckling ratio, *CG* control group, *CSMI* cross-sectional moment of inertia, *DXA* dual-energy X-ray absorptiometry, *G* ground, *F* female, *FHEAD* femoral head, *FNECK* femoral neck, *FS* the shaft, *HB* handball, *HI* high/odd impact, *HSA* hip structure analysis, *INTROCH* intertrochanteric region, *IT* intertrochanteric, *LAC* lacrosse, *LSP* lumbar spine, *NA* not available, *NANECK* narrow neck, *NN* narrow neck, *NS* not specify, *PAR* parquet, *PB* pubertal, *PPB* prepubertal, *PEPB* peripubertal, *RNI* repetitive/non-impact, *RSK* rope-skipping, *RUN* runners, *SJT* sprinters, jumpers, and throwers, *SMO* smooth concrete, *SOC* soccer players, *SOF* softball, *SPA* single-photon absorptiometry, *SWI* swimmers, *SYN* synthetic, *TROCH* trochanter, *VOL* volleyball, *WB* whole body, *WTRI* wards triangle, *Z* section modulus surface, prepubertal soccer players showed increased BMC and BMD in most weight-bearing sites compared to controls, and no differences were found between playing surface groups. Although most of the studies use DXA, the quantitative ultrasound system (QUS) is another method to measure bone properties related to bone density and structure such as speed of sound (SOS), broadband ultrasound attenuation, and stiffness index. Madic et al. [17] used QUS reporting increased calcaneus SOS in soccer players compared to those of control subjects. In addition, a recent study performed by Vlachopoulos et al. [46] also reported that soccer players demonstrated an increased stiffness index, BMC, BMD, and bone structure at most weight-bearing sited compared to controls.

Today, few longitudinal studies have evaluated the effects of soccer practice on bone tissue during growth. Vicente-Rodriguez et al. [43], in a 3-year follow-up longitudinal study, reported greater increases in BMC and BMD parameters at the whole body, lower limbs, lumbar spine, femoral neck, and intertrochanteric region as well as a hypertrophic effect on bone in soccer players compared to controls. Three longitudinal studies performed by Zouch et al. [47–49] compared the bone tissue between two different activity groups. In the first study [47], although no differences were shown at baseline between soccer players and controls, positive increments for BMC at whole body, lumbar spine, total hip, and lower limbs were found in soccer players after 10 months of training, with higher increases in those who trained for 4 h per week compared with those who trained for 2 h per week. In the second study [48], participants were split into prepubertal and pubertal groups and were followed up for 1 year. Similarly, at baseline, prepubertal soccer players and controls demonstrated no BMC differences; however, pubertal soccer players showed increased BMC compared to controls. After a 1-year follow-up, greater increases for BMC at whole body, total hip, and lower limbs were observed for prepubertal soccer players compared to controls, whereas pubertal players also showed greater increases at lumbar spine. When both groups of soccer players were compared, greater BMC increases were reported in pubertal players than in prepubertal players. The last study performed by Zouch et al. [49] demonstrated increased BMD in whole body and both legs at baseline. After 3 years, soccer players presented increased BMC and BMD gains at whole body, lumbar spine, total hip, and lower limbs compared to the control group. In contrast, a study performed by Agostinete et al. [2] found no BMD accrual differences between young soccer players and controls after 9-month follow-up. It is important to state that the previous study had the lowest duration of follow-up and the hours per week of training in each sport were not reported.

The high-impact actions in the lower limbs caused by soccer practice could explain the positive influence of this sport on different weight-bearing sites such as pelvis, lower limbs, lumbar spine, and proximal femur. However, BMC and BMD differences at hip should be cautiously interpreted because the hip is a site with high variability during bone development [9]. Moreover, these differences between soccer players and controls are more marked in pubertal than prepubertal soccer players. On the other hand, the number of hours and days of training should be considered, as prepubertal soccer players perform fewer hours of training and have a shorter history of practice compared to pubertal ones.

Comparison with other athletes McCulloch et al. [21] compared soccer players with other athletes (including swimmers) and showed no differences in BMD at calcaneus. In addition, Falk et al. [10] found no SOS differences at tibia but increases at the radius in hockey players compared to soccer players. In contrast, Sanchis-Moysi et al. [33] found that adolescent soccer players had increased femoral neck BMD compared to tennis players, but these results were not corroborated by Silva et al. [35], although they showed increased values in these two groups compared with swimmers. Compared with previous studies, Vlachopoulos et al. [46] reported that soccer players had better bone structure, stiffness index, and BMD at most weight-bearing sites compared to swimmers and cyclists. However, arms, lumbar spine, and shaft bone area and arms BMD and BMC were increased in swimmers compared to soccer players. In addition, a longitudinal study performed by Agostinete et al. [2] showed that basketball players increased more whole body and arms BMD than soccer players.

These studies revealed that the differences in bone tissue at each bone site evaluated are highly influenced by the environment and the type of specific actions of each sport, as has been previously suggested [14]. Moreover, finding that there were no bone differences in lower limbs comparing soccer with hockey and tennis could be explained by the greater number of years of practice and training among hockey and tennis players compared with soccer players.

Comparison between soccer players Mota et al. [23] studied adolescent soccer players comparing them in three age groups and reported that soccer players who were under 17 years old showed increased BMD in the non-dominant leg when compared to the dominant leg, while those under 19 and under 15 presented this tendency without a significant difference. In the study by Ankiler et al. [3] increased bone mass and better bone geometry was shown in the non-dominant leg compared to the dominant leg evaluated with peripheral quantitative computed tomography (pQCT).

These differences between both legs could be explained by the fact that the non-dominant leg performs the majority of jumps and supports the action of the dominant leg while kicking. Thus, the loading suffered by the non-dominant leg is higher than that experienced by the dominant leg [34].

Hormone levels Discrepancies between studies in the effect of soccer on bone tissue during growth could be influenced by bone mineral accrual differences during growth [6] and the increases of important secreted hormones that influence bone mass during puberty [20]. Nevertheless, Nebigh et al. [24] reported increased IGF-1 and IGFBP-3 concentrations in prepubertal soccer players compared to age-matched controls, although these authors showed no differences in BMC and BMD between groups. However, hormonal concentrations, BMC and BMD variables studied in the pubertal soccer players were increased compared to those reported in controls. Therefore, these bone improvements derived from soccer training could be influenced by the levels of hormones such as IGF-1, IGFBP-3, GH, and testosterone. Moreover, soccer training during prepubertal stage could increase these hormones and consequently promote bone improvements.

In summary, bone properties are slightly improved in prepubertal soccer players compared to older soccer players, but at the same time, these improvements are greater in prepubertal soccer players compared to control subjects [48]. These bone differences between development stages could also be explained by the fact that pubertal soccer players have probably been exposed to soccer strains for more years than prepubertal soccer players. Therefore, prepuberty and puberty are important stages in the bone development process where playing some high-impact sport such as soccer could be beneficial to improving bone mass.

Each sport could have different effects on bone tissue depending on the biomechanics and the type of specific actions executed [10, 27]. Soccer players suffer more strains in their lower limbs, while other athletes such as hockey and tennis players have more strains in their upper limbs because actions are made with an implement such as a stick or a racket. These differences are minimized between high-impact sports; therefore, it is not clear if soccer practice provokes increased bone changes at weight-bearing sites compared to other high-impact sports.

Females

Comparison between soccer players and controls Soderman et al. [36] first evaluated bone characteristics between female soccer players and control subjects, finding increased BMD in every studied variable. Dividing the sample into two age-groups (younger or older than 16), younger players only showed differences at trochanter BMD, while the older players presented increased BMD at whole body and all weight-bearing sites compared to the control group. Ubago-Guisado et al. [41] reported increased femoral neck and trochanter BMC and intertrochanteric region BMD in prepubertal female soccer players compared to controls. They also showed increased BMC and BMD at most weight-bearing sites in pubertal soccer players compared to controls. Moreover, a recent study by Plaza-Carmona et al. [30], which compared bone mass and divided the groups by pubertal status, found similar results.

These results support that the osteogenic effect caused by high-impact actions from soccer is more evident in older athletes. Although younger athletes showed no significant differences compared with controls, a tendency existed towards increased BMC and BMD compared to controls, suggesting that soccer may have a positive influence on bone mass during growth. As suggested for males, the greater benefits found in older soccer players could be because older soccer players have been exposed to soccer loads for more years.

Comparison between soccer players and other athletes Petterson et al. [28] compared female soccer players with rope skippers, and no raw differences between athletes were observed, but when adjusting for lean body mass, soccer players showed decreased total body, lumbar spine, and right humerus BMD compared to rope skippers. In addition, soccer players also showed decreased tibia and radius BMC and femur and tibia bone area compared to rope skippers. The high impacts that rope skippers receive need to be considered.

Ferry et al. [11] compared female soccer players and swimmers and positive bone effects were only reported in soccer players, as also suggested by Plaza-Carmona et al. [29], who found increased BMC at total body, hip, and legs in female soccer players compared to swimmers. Bellew et al. [7] showed increased BMD in female soccer players compared to swimmers and weight lifters. In addition, they compared these results to normative data and found that those values in female adolescent soccer players were higher than those expected in adult controls. Ubago-Guisado et al. [41] compared female practicing soccer, swimming, handball, and basketball in prepubertal and pubertal stages. Prepubertal soccer players presented increased hip, femoral neck, and trochanter BMC and trochanter BMD compared to swimmers and higher BMC at femoral neck and trochanter than basketball players. Pubertal soccer players showed increased whole body, hip, femoral neck, trochanter and legs BMC, and pelvis and hip BMD compared to pubertal swimmers.

The study performed by Ferry et al. [12] was the only longitudinal study evaluating the effects of soccer practice on bone tissue in female soccer players. These authors reported that soccer practice improved bone characteristics after 1 year of practice, supporting the cross-sectional findings, whereas 1 year of swimming practice caused neither changes nor enhancements in bone mass.

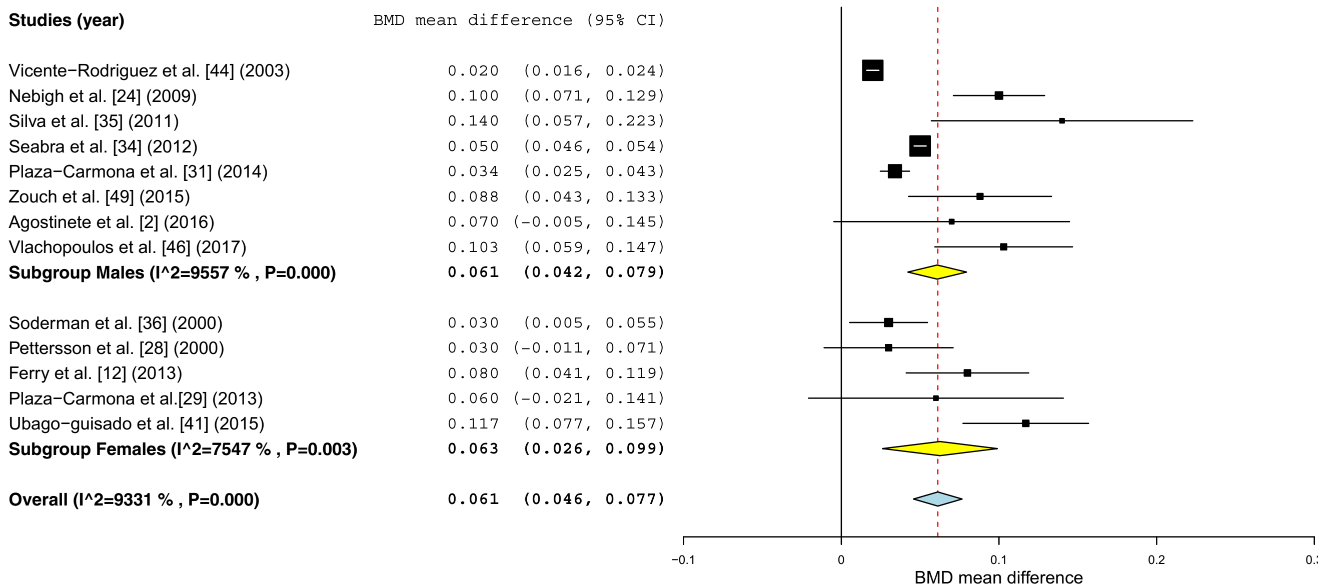


Fig. 2 Forest plot of whole-body BMD mean difference between soccer players and controls. *BMD* bone mineral density, *CI* confidence interval, I^2 inconsistency index

The differences between athletes that practice high-impact sports such as soccer, basketball, or rope-skipping remain unclear. Although these sports are composed of high-impact movements, the loading patterns seem to be different, especially in relation to the direction of the forces, being that compressive forces are more common during jumps and that tensile forces are more common during versatile movements [28]. Therefore, team sports characterized by dynamic and versatile movements such as soccer seem to be the most adequate sports to provoke the best effect on bone [16]. However, the existence of some sports or physical exercises, such as rope-skipping (characterized by compressive forces and a continue high-impact loads), which could be more osteogenic than soccer, should be considered.

Comparison between soccer players Ubago-Guisado et al. [40] compared bone mass between soccer players who trained on the ground and those who trained on artificial turf. Moreover, the comparisons were stratified according to maturity status. They only reported higher hip BMC and BMD in pubertal soccer players who trained on the ground when compared to their counterparts who trained on artificial turf. However, no differences were found between prepubertal soccer groups. These results could be explained by the fact that prepubertal soccer players trained and played for fewer years and hours per week than their pubertal peers. On the other hand, because ground is harder than artificial turf, those soccer players who trained on the ground could have a higher osteogenic stimulus.

Menstrual cycle Nichols et al. [26] evaluated the interaction between menstrual status and the type of load caused by several sports in female soccer players. All bone comparisons performed in the study demonstrated that normal menstrual status and the practice of high-impact sports are the best interaction for obtaining high BMC and BMD.

BMC and BMD are influenced by the practice of high-impact sports such as soccer; nevertheless, menstrual status during adolescence highly influenced the bone mineralization and should therefore be considered [26]. It has also been described that menstrual irregularities could negatively affect bone independently of the practiced activity [26], causing loss of BMD and stress fractures in these athletes [37].

In summary, although there are few studies regarding young female soccer players, most of the studies included in this review reported increased bone mass values compared to other athletes and age-matched control subjects [7, 12, 25, 29, 36, 41], with only Petterson et al. [28], reporting decreased BMD compared with rope-skippers. Both sports are characterized by high ground reaction forces, but the direction of the forces is different: compressive forces are caused during jumping, which is the most repeated action while rope-skipping, and tensile forces are caused during the versatile movements that are typically found in soccer. Although soccer practice with a dynamic loading regimen characterized by unusual movements could cause a greater effect on bone mass [16], rope skippers in this study were more exposed to high-impact strains than soccer players. Moreover, sport-specific exercise during soccer training should be registered because this training could be developed at a low intensity, without including so many high-impact actions such as jumps, kicks, starts or stops.

The effects of maturity stage on bone mass has been studied in young female soccer players, and the differences between soccer players and controls are more marked in pubertal than prepubertal soccer players. These results could be explained by the fact that bone development is more advanced in pubertal players than in prepubertal ones. Moreover, prepubertal soccer players have trained for fewer years than pubertal soccer player; therefore, the time of exposure is also lower, and this needs to be taken into account. In addition, those soccer players who had normal menstrual status and practiced high/odd-impact sports could be in the best condition to develop bone.

Meta-analysis results

A forest plot of whole-body BMD comparison between soccer players and controls separated by gender is shown in Fig. 2. Analyzing together the studies including male or female participants, BMD mean difference between soccer players and controls was 0.061 (95% CI, 0.046–0.077) associated with an extreme heterogeneity ($I^2 = 93\%$). Analyzing males and females separately, BMD mean differences between soccer players and controls was 0.061 (95% CI, 0.042–0.079) in males and 0.063 (95% CI, 0.026–0.099) in females. Both gender analyses presented extreme heterogeneity (males: $I^2 = 96\%$; females: $I^2 = 75\%$).

The results of this meta-analysis reinforced the positive effects of soccer practice on bone mass during growth demonstrated along this systematic review. Furthermore, these analyses highlighted that positive effects are similar independently of the gender.

Limitations

Some limitations of this review should be recognized. Studies in languages other than English or Spanish were not included in this review; therefore, a language bias may be present. The age range of this systematic review is wide, from 8 to 18 years old. It is possible that, if a smaller age range was included, different results might have emerged due to the known differences in bone development between childhood and adolescence. Moreover, there were few studies of growing soccer players that evaluated bone strength using pQCT or hip structural analysis (HSA). Finally, descriptive variables that could modify bone mass values such as hours per week of soccer training, years of soccer practice, and calcium intake were not evaluated in several studies included in this review.

Conclusion

Overall, positive effects of soccer practice on bone mass at most weight-bearing sites during prepubertal and pubertal stages have been highly demonstrated. However, these effects are more marked in pubertal compared to prepubertal soccer players partially because pubertal athletes presented a bone development that was more advanced, had been playing soccer for more years, and have consequently been exposed to soccer loadings for more time. Lumbar spine, hip, femoral neck, trochanter, intertrochanteric region, and both legs are particularly sensitive to the mechanical loads elicited by soccer actions in either prepubertal and pubertal soccer players or male and female athletes. Moreover, the majority of osteoporotic fractures during adulthood occur in these weight-bearing sites, especially at lumbar spine and hip. Thus, soccer practice could be an adequate sport to reduce future osteoporotic problems in adults. Therefore, beginning to play soccer at the prepubertal stage and continuing during puberty seems to be appropriate for improving bone health during those developmental stages and in the future.

Perspective

Although positive effects of soccer practice on bone tissue in children and adolescents have been demonstrated, some questions remain unanswered.

The optimal type and amount of training for achieving the greatest bone improvements are still unknown as well as the adequate age or range of ages (if any) to begin playing soccer. Other parameters, such as the types of surface and shoes, should be taken into account because they could affect bone accretion. Moreover, the effects of soccer training on bone mass during a season or several seasons have been scarcely studied as well as the differences on BMC and BMD between prepubertal and pubertal soccer players. Therefore, future studies should take these considerations into account and attempt to answer them.

Authors' Contributions All the authors have been actively involved in the planning and enactment of the study. JAC and GVR were the main researchers in the present study, and GLB was the first author. AML, AGA, AGB, and AGC were co-researchers. GLB and AML independently evaluated all studies, and AGA resolved inter-reviewer disagreements. GLB drafted the document, and AML, AGA, AGB, AGC, GVR and JAC critically reviewed the document. All authors have read and approved of the manuscript.

Funding This work was funded by the Spanish "Ministerio de Economía y Competitividad" (Project DEP 2012-32724). GLB received a Grant FPU 2013 (FPU13/02111) from the "Ministerio de Educación, Cultura y Deporte". AML received a Grant (AP2012/02854) from the "Ministerio de Educación, Cultura y Deporte.” AGB received a Grant FPI 2012 (bes-2012-051888) from the “Ministerio de Economía y Competitividad.”

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

References

1. Abrams SA, Griffin IJ, Hawthorne KM, Chen Z, Gunn SK, Wilde M, Darlington G, Shypailo RJ, Ellis KJ (2005) Vitamin D receptor Fok1 polymorphisms affect calcium absorption, kinetics, and bone mineralization rates during puberty. J Bone Mineral Res 20(6):945–953. https://doi.org/10.1359/jbmr.050114
2. Agostinete RR, Lynch KR, Gobbo LA, Lima MC, Ito IH, Luiz-de-Marco R, Rodrigues-Junior MA, Fernandes RA (2016) Basketball affects bone mineral density accrual in boys more than swimming and other impact sports: 9-mo follow-up. J Clin Densitom 19(3):375–381. https://doi.org/10.1016/j.jocd.2016.04.006
3. Anliker E, Sonderegger A, Toigo M (2013) Side-to-side differences in the lower leg muscle-bone unit in male soccer players. Med Sci Sports Exerc 45(8):1545–1552. https://doi.org/10.1249/MSS.0b013e31828cb712
4. Anonymous (1993) Consensus development conference: diagnosis, prophylaxis, and treatment of osteoporosis. Am J Med 94(6):646–650
5. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA (1999) A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. J Bone Miner Res 14(10):1672–1679. https://doi.org/10.1249/MSS.0b013e31828cb712
6. Bass SL (2000) The prepubertal years: a uniquely opportune stage of growth when the skeleton is most responsive to exercise? Sports Med 30(2):73–78. https://doi.org/10.2165/00007256-200030020-00001
7. Bellew JW, Gehrig L (2006) A comparison of bone mineral density in adolescent female swimmers, soccer players, and weight lifters. Pediatr Phys Ther 18(1):19–22. https://doi.org/10.1097/01.pep.0000200952.63544.16
8. Cooper C, Atkinson EJ, Jacobsen SJ, O'Fallon WM, Melton LJ (1993) Population-based study of survival after osteoporotic fractures. Am J Epidemiol 137(9):1001–1005. https://doi.org/10.1093/oxfordjournals.aje.a116756
9. Crabtree NJ, Arabi A, Bachrach LK, Fewtrell M, El-Hajj Fuleihan G, Kecskemethy HH, Jaworski M, Gordon CM (2014) Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD Pediatric Official Positions. J Clin Densitom 17(2):225–242. https://doi.org/10.1016/j.jocd.2014.01.003
10. Falk B, Braid S, Moore M, Yao M, Sullivan P, Klentrou N (2010) Bone properties in child and adolescent male hockey and soccer players. J Sci Med Sport 13(4):387–391. https://doi.org/10.1016/j.jsams.2009.03.011
11. Ferry B, Duclos M, Burt L, Therre P, Le Gall F, Jaffre C, Courteix D (2011) Bone geometry and strength adaptations to physical constraints inherent in different sports: comparison between elite female soccer players and swimmers. J Bone Miner Metab 29(3):342–351. https://doi.org/10.1007/s00774-010-0226-8
12. Ferry B, Lespessailles E, Rochcongar P, Duclos M, Courteix D (2013) Bone health during late adolescence: effects of an 8-month training program on bone geometry in female athletes. Joint Bone Spine 80(1):57–63. https://doi.org/10.1016/j.jbspin.2012.01.006
13. Hinckson EA, Curtis A (2013) Measuring physical activity in children and youth living with intellectual disabilities: a systematic review. Res Dev Disabil 34(1):72–86. https://doi.org/10.1016/j.ridd.2012.07.022
14. Iuliano-Burns S, Stone J, Hopper JL, Seeman E (2005) Diet and exercise during growth have site-specific skeletal effects: a co-twin control study. Osteoporos Int 16(10):1225–1232. https://doi.org/10.1007/s00198-004-1830-z
15. Julian-Almarcegui C, Gomez-Cabello A, Huybrechts I, Gonzalez-Aguero A, Kaufman JM, Casajus JA, Vicente-Rodriguez G (2015) Combined effects of interaction between physical activity and nutrition on bone health in children and adolescents: a systematic review. Nutr Rev 73(3):127–139. https://doi.org/10.1093/nutrit/nuu065
16. Lanyon LE (1992) Control of bone architecture by functional load bearing. J Bone Miner Res 7(Suppl 2):S369–S375. https://doi.org/10.1002/jbmr.5650071403
17. Madic D, Obradovic B, Smajic M, Obradovic J, Maric D, Boskovic K (2010) Status of bone mineral content and body composition in boys engaged in intensive physical activity. Vojnosanit Pregl 67(5):386–390. https://doi.org/10.2298/VSP1005386M
18. Marshall WA, Tanner JM (1969) Variations in pattern of pubertal changes in girls. Arch Dis Child 44(235):291–303. https://doi.org/10.1136/adc.44.235.291
19. Marshall WA, Tanner JM (1970) Variations in the pattern of pubertal changes in boys. Arch Dis Child 45(239):13–23. https://doi.org/10.1136/adc.45.239.13
20. Mauras N, Rogol AD, Haymond MW, Veldhuis JD (1996) Sex steroids, growth hormone, insulin-like growth factor-1: neuroendocrine and metabolic regulation in puberty. Horm Res 45(1–2):74–80. https://doi.org/10.1159/000184763
21. McCulloch RG, Bailey DA, Whalen RL, Houston CS, Faulkner RA, Craven BR (1992) Bone density and bone mineral content of adolescent soccer athletes and competitive swimmers. Pediatr Exerc Sci 4(4):319–330. https://doi.org/10.1123/pes.4.4.319
22. Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA (2015) Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) 2015 statement. Syst Rev 4(1):1. https://doi.org/10.1186/2046-4053-4-1
23. Mota S, Brito J, Passos E, Marques E, Mota J, Seabra A, Rebelo A (2010) Variation of isokinetic strength and bone mineral density in youth Portuguese soccer players with age. Open Sports Sci J 3(1):49–51. https://doi.org/10.2174/1875399X01003010049
24. Nebigh A, Rebai H, Elloumi M, Bahlous A, Zouch M, Zaouali M, Alexandre C, Sellami S, Tabka Z (2009) Bone mineral density of young boy soccer players at different pubertal stages: relationships with hormonal concentration. Joint Bone Spine 76(1):63–69. https://doi.org/10.1016/j.jbspin.2008.03.002
25. Nichols DL, Sanborn CF, Essery EV (2007) Bone density and young athletic women. An update Sports Med 37(11):1001–1014. https://doi.org/10.2165/00007256-200737110-00006
26. Nichols JF, Rauh MJ, Barrack MT, Barkai HS (2007) Bone mineral density in female high school athletes: interactions of menstrual function and type of mechanical loading. Bone 41(3):371–377. https://doi.org/10.1016/j.bone.2007.05.003
27. Nordstrom P, Pettersson U, Lorentzon R (1998) Type of physical activity, muscle strength, and pubertal stage as determinants of bone mineral density and bone area in adolescent boys. J Bone Miner Res 13(7):1141–1148. https://doi.org/10.1359/jbmr.1998.13.7.1141
28. Pettersson U, Nordstrom P, Alfredson H, Henriksson-Larsen K, Lorentzon R (2000) Effect of high impact activity on bone mass

and size in adolescent females: a comparative study between two different types of sports. Calcif Tissue Int 67(3):207–214. https://doi.org/10.1007/s002230001131

29. Plaza-Carmona M, Ubago-Guisado E, Sánchez-Sánchez J, Felipe JL, Fernández-Luna A, García-Unanue J, Burillo P, Gallardo L (2013) Body composition and physical fitness in prepubertal girls swimmers and soccer players. JSHR 5(3):251–258
30. Plaza-Carmona M, Vicente-Rodriguez G, Gomez-Cabello A, Martin-Garcia M, Sanchez-Sanchez J, Gallardo L, Ara I (2016) Higher bone mass in prepubertal and peripubertal female footballers. Eur J Sport Sci 16(7):877–883. https://doi.org/10.1080/17461391.2016.1144794
31. Plaza-Carmona MP, Vicente-Rodriguez G, Martin-Garcia M, Burillo P, Felipe JL, Mata E, Casajus JA, Gallardo L, Ara I (2014) Influence of hard vs. soft ground surfaces on bone accretion in prepubertal footballers. Int J Sports Med 35(1):55–61. https://doi.org/10.1055/s-0033-1345140
32. Saggese G, Baroncelli GI, Bertelloni S (2002) Puberty and bone development. Best Pract Res Clin Endocrinol Metab 16(1):53–64. https://doi.org/10.1053/beem.2001.0180
33. Sanchis-Moysi J, Dorado C, Olmedillas H, Serrano-Sanchez JA, Calbet JA (2010) Bone mass in prepubertal tennis players. Int J Sports Med 31(6):416–420. https://doi.org/10.1055/s-0030-1248331
34. Seabra A, Marques E, Brito J, Krustrup P, Abreu S, Oliveira J, Rego C, Mota J, Rebelo A (2012) Muscle strength and soccer practice as major determinants of bone mineral density in adolescents. Joint Bone Spine 79(4):403–408. https://doi.org/10.1016/j.jbspin.2011.09.003
35. Silva CC, Goldberg TB, Teixeira AS, Dalmas JC (2011) The impact of different types of physical activity on total and regional bone mineral density in young Brazilian athletes. J Sports Sci 29(3):227–234. https://doi.org/10.1080/02640414.2010.529456
36. Soderman K, Bergstrom E, Lorentzon R, Alfredson H (2000) Bone mass and muscle strength in young female soccer players. Calcif Tissue Int 67(4):297–303. https://doi.org/10.1007/s002230001149
37. Sundgot-Borgen J, Torstveit MK (2007) The female football player, disordered eating, menstrual function and bone health. Br J Sports Med 41(Suppl 1):i68–i72. https://doi.org/10.1136/bjsm.2007.038018
38. Tenforde AS, Fredericson M (2011) Influence of sports participation on bone health in the young athlete: a review of the literature. Pm R 3(9):861–867. https://doi.org/10.1016/j.pmrj.2011.05.019
39. Tooth L, Ware R, Bain C, Purdie DM, Dobson A (2005) Quality of reporting of observational longitudinal research. Am J Epidemiol 161(3):280–288. https://doi.org/10.1093/aje/kwi042
40. Ubago-Guisado E, Garcia-Unanue J, Lopez-Fernandez J, Sanchez-Sanchez J, Gallardo L (2016) Association of different types of playing surfaces with bone mass in growing girls. J Sports Sci 35(15):1484–1492. https://doi.org/10.1080/02640414.2016.1223328
41. Ubago-Guisado E, Gomez-Cabello A, Sanchez-Sanchez J, Garcia-Unanue J, Gallardo L (2015) Influence of different sports on bone mass in growing girls. J Sports Sci 33(16):1–9. https://doi.org/10.1080/02640414.2015.1004639
42. Vicente-Rodriguez G (2006) How does exercise affect bone development during growth? Sports Med 36(7):561–569. https://doi.org/10.2165/00007256-200636070-00002
43. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA (2004) High femoral bone mineral density accretion in prepubertal soccer players. Med Sci Sports Exerc 36(10):1789–1795. https://doi.org/10.1249/01.MSS.0000142311.75866.D7
44. Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I, Serrano-Sanchez JA, Dorado C, Calbet JA (2003) Enhanced bone mass and physical fitness in prepubescent footballers. Bone 33(5):853–859. https://doi.org/10.1016/j.bone.2003.08.003
45. Villareal DT, Fontana L, Weiss EP, Racette SB, Steger-May K, Schechtman KB, Klein S, Holloszy JO (2006) Bone mineral density response to caloric restriction-induced weight loss or exercise-induced weight loss: a randomized controlled trial. Arch Intern Med 166(22):2502–2510. https://doi.org/10.1001/archinte.166.22.2502
46. Vlachopoulos D, Barker AR, Williams CA, Arngrimsson SA, Knapp KM, Metcalf BS, Fatouros IG, Moreno LA, Gracia-Marco L (2017) The impact of sport participation on bone mass and geometry in adolescent males. Med Sci Sports Exerc 49(2):317–326. https://doi.org/10.1249/mss.0000000000001091
47. Zouch M, Jaffre C, Thomas T, Frere D, Courteix D, Vico L, Alexandre C (2008) Long-term soccer practice increases bone mineral content gain in prepubescent boys. Joint Bone Spine 75(1):41–49. https://doi.org/10.1016/j.jbspin.2006.12.008
48. Zouch M, Vico L, Frere D, Tabka Z, Alexandre C (2013) Young male soccer players exhibit additional bone mineral acquisition during the peripubertal period: 1-year longitudinal study. Eur J Pediatr 173(1):53–61. https://doi.org/10.1007/s00431-013-2115-3
49. Zouch M, Zribi A, Alexandre C, Chaari H, Frere D, Tabka Z, Vico L (2015) Soccer increases bone mass in prepubescent boys during growth: a 3-yr longitudinal study. J Clin Densitom 18(2):179–186. https://doi.org/10.1016/j.jocd.2014.10.004

Is playing football more osteogenic for females before the pubertal spurt?

Abstract

The aims of this study were to assess bone mass in children and adolescent football players and to evaluate the influence of both genders and pubertal status on bone mass. A total of 110 football players (75 males/35 females; 12.73±0.65/12.76±0.59 years) participated in this cross-sectional study. They were divided into two groups according to their pubertal status. Bone and lean masses were measured with Dual-energy X-ray Absorptiometry. An independent *t*-test and an adjusted by subtotal lean and number of years of football training multivariate analysis of covariance were used to analyse the differences in bone mass values between genders and maturity status. Female football players presented higher bone mass values than their male counterparts in most of the measured weight-bearing sites. Moreover, when stratifying by pubertal status, peripubertal and postpubertal females had higher subtotal body and lumbar spine bone mass than males. Comparing between pubertal status groups before adjustment, both male and female postpubertal players showed higher bone mass than their pubertal counterparts. After adjusting, these differences disappeared and, in fact results were inverted as bone mass at the femoral neck was higher in both male and female peripubertal football players than in postpubertal players. Bone mass seems to be more intensely stimulated by playing football in female than male players, particularly in the lumbar spine. The results of peripubertal players showing higher bone mass at the femoral neck after adjusting suggest that playing football during the peripubertal stage could be an effective activity to achieve optimal bone mass values.

Key words: Soccer, sports, bone density, adolescent.

Introduction

Osteoporosis is a disease characterised by low bone mineral density (BMD) and microarchitectural deterioration. According to the World Health Organization (WHO), this disease affects approximately 75 million people in the United States, Europe, and Japan (WHO, 2004). Moreover, the National Osteoporosis Foundation (NOF) reported that one in two women and one in four men over 50 years old will suffer a bone fracture due to osteoporosis. The interest in assessing bone mass during adolescence has increased as this period is an essential stage to reach appropriate bone development (Wallace & Ballard, 2002) and almost 90% of bone mass in adults is obtained during this period in life. Furthermore, genetics, nutrition, hormones, and mechanical factors (Cousins et al., 2010; Rizzoli, Bianchi, Garabedian, McKay, & Moreno, 2010) help to attain adequate values of bone mass at this stage and consequently, to prevent osteoporotic fractures during one's elderly years. In addition, bone mass can also be altered by playing sport (Vicente-Rodriguez et al., 2003), but not all sports provoke the same osteogenic effect. Therefore, classifications according to the influence of sports participation on bone health have been proposed: low-impact sports, such as swimming and cycling; odd-impact sports, such as football, basketball, and racquet games; or high-impact sports, such as volleyball and karate (Tenforde & Fredericson, 2011).

Focusing on football, this odd-impact sport has been defined by a combination of high-intensity actions such as running, changes of direction, starts, stops, jumps, and kicks, that have a positive effect on bone mass (Bangsbo, 1994). Moreover, it is most likely one of the most practised sports by children and adolescents worldwide. This fact has prompted research to focus studies on the effects of football on bones, reporting bone mass improvements after playing football in different periods of life, such as childhood (Vicente-Rodriguez et al., 2004), adolescence (Ferry et al., 2011; Author-citation, 2018), and adulthood (Calbet, Dorado, Diaz-Herrera, & Rodriguez-Rodriguez, 2001). Nevertheless, neither Soderman et al. (2000) (females) nor Zouch et al. (2008) (males) found bone mineral content (BMC) and BMD differences between football players and a control group. On the other hand, longitudinal studies found that whole body, total hip, and lower limbs BMD values were higher in football players than controls after one year of playing football (Zouch et al., 2008). Therefore, the effects of football on bone mass are still fully unknown.

The period of life in which football is practised also seems important to bone mass acquisition, as stronger influences on bone mass were demonstrated in pubertal male (Nebigh et al., 2009; Zouch, Vico, Frere, Tabka, & Alexandre, 2014) and female (Soderman et al., 2000; Ubago-Guisado, Gomez-Cabello, Sanchez-Sanchez, Garcia-Unanue, & Gallardo, 2015) football players than in their prepubertal counterparts when these players were compared with controls. However, only Zouch et al. (2014) directly evaluated differences between prepubertal and pubertal football players. On the other hand, only McCulloch et al. (1992) analysed differences between genders, showing no differences in BMC and BMD between male and female football players.

Overall, it has been shown that playing football may improve bone health in young males and females, although the effects of football according to pubertal status or gender still remain unclear. Therefore, the aims of this study are as follows: 1) to assess bone mass in a group of adolescent football players, and 2) to evaluate the influence of both gender and pubertal status on BMC and BMD. We hypothesized that female football players would exhibit higher bone mass than their male counterparts either in the peripubertal or postpubertal periods because females accumulate bone earlier than males.

Methods

Participants

Eight football clubs (all of them competed at provincial level for their age category) of XXXXXX (XXXX) were invited to participate in this study. A total of 121 football players (81 males and 40 females) agreed to participate in the study. However, 11 players (6 males and 5 females) were not included because they did not assist to the measurement citation. Consequently, the final sample for the present study consisted of 110 football players (75 males and 35 females; mean age 12.73 ± 0.65 and 12.76 ± 0.59 years respectively). Twenty female football players (10 peripubertal and 10 postpubertal; mean age of 11.45 ± 1.19 years old) had achieved the menarche (at the mean age of 11.45 ± 1.19 years old) before the beginning of the present study.

The number of years of football training ranged from 1 to 10 years in peripubertal males, from 2 to 9 years in postpubertal males, from 1 to 8 years in peripubertal females, and from 1 to 9 years in postpubertal females. Although the ranges of training years were wide, no number of years of football training differences were found between peripubertal and postpubertal football players either in males ($\chi^2(10)=12.48$, $p = 0.254$) or females ($\chi^2\ (7)=6.95$, $p = 0.435$). On the other hand, despite not performing the same football exercises, trainings of all teams included in this study (both genders) lasted approximately 90 min, including 5-min warm-up consisting of low-intensity running; 5-10 min of low-intensity games; 60 min of technical football exercises (e.g. passing, kicking, running, dribbling); and finally, 5-10 minutes of cold down performing stretching exercises. All teams that participated in the present study played one match per week and trained two days per week, except one male team that trained 3 days per week (this team had 15 peripubertal football players and 3 postpubertal football players).

The participants, their parents, and clubs were informed about the protocol of this study, its benefits, and risks. Written informed consent from parents and verbal assent from the participants were obtained. This study followed the declaration of Helsinki 1961 (revision of Fortaleza 2013).

Measures

Anthropometric measurements

Height was measured with a stadiometer to the nearest 0.1 cm (SECA 225, SECA, Hamburg, Germany) and weight was measured using a scale to the nearest 0.1 kg (SECA, Hamburg, Germany) without shoes and with minimum clothes. Body mass index (BMI) was calculated according to the equation BMI ($kg \cdot m^{-2}$) = Weight/Height^2.

Pubertal development

Pubertal status was self-determined according to the pubertal stages proposed by Tanner and Whitehouse (1976). Adolescents' self-assessment of sexual maturation according to Tanner's standard photographs has been found as a valid and reliable method (Duke, Litt, & Gross, 1980).

Participants were classified into two groups: peripubertal (Tanner II and III) and postpubertal football players (Tanner IV and V) to compare bone mass by sexual maturation.

Bone and lean measurements by Dual X-ray Absorptiometry (DXA)

Bone and lean masses were evaluated with DXA QDR-Explorer (paediatric version of the software QDR-Explorer, Hologic Corp. Software version 12.4, Bedford, Massachusetts, USA). DXA equipment was calibrated daily following the manufacturer guidelines. Whole body, non-dominant hip, and lumbar spine scans were performed in supine position by the same technician who was fully trained to perform the scans. BMC (g) and lean mass (g) were obtained from the total and regional analyses of the whole body. The subregions evaluated in this study were subtotal body and mean legs from the whole-body test; hip and femoral neck from hip test; and total lumbar spine from lumbar spine test. The coefficients of variation of the DXA in our laboratory are published elsewhere (Author-citation, 2012).

Procedures

The protocol of this study was approved by the Ethics Committee of XXXXXXXXXX. The research was registered in the public database Clinicaltrials.gov [XXXXXXXXX]. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement was used as a guideline for reporting observational studies (von Elm et al., 2007).

All participants were measured between November and December of 2013 in the Laboratory of XXXXXXXXX. These participants had to be Caucasian, with at least one year of football practice, between 11 and 14 years old, and free of medication that could affect bone mass.

Statistical analysis

The sample size was calculated for whole body BMD by bilateral Student t-test for two independent samples to obtain a power of 95% and to observe differences in comparison to a null hypothesis H_0:$\mu1=\mu2$. Taking into account that the confidence level is 95% and assuming that the means of male and female football players are 0.942 and 0.980 respectively and the standard deviation of both groups is 0.037, 52 football players (26 males and 26 females) were needed. Sample size calculations were developed with G*Power 3.1 (Düsseldorf, Germany)

Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used for the statistical analysis. All variables demonstrated normal distribution with the Kolmogorov-Smirnov test. Results were presented as a mean ± standard deviation (SD).

Two independent *t*-test were performed in order to compare subject characteristics and bone mass variables between groups. A multivariate analysis of covariance (MANCOVA) was used to analyse differences in BMC and BMD variables between pubertal status and genders, using subtotal body lean mass, due to its influence on bone mass (Vicente-Rodriguez et al., 2008), and the number of years of playing football as covariates. Effect size statistics using Cohen´s d and partial eta square (n^2_p) were calculated. The effect size for Cohen´s *d* can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8); and the effect size n^2_p can be small (0.01 – 0.06), medium (0.06 – 0.14) or large (>0.14). Statistical significance was set at $p<0.05$.

Results

The characteristics of the participants by gender and pubertal status are showed in Table 1. Male peripubertal football players were lighter, smaller, trained more hours, and had lower BMI and subtotal lean mass than male postpubertal players ($p<0.05$, Cohen´s *d* ranged from 0.5 to 1.5). Female peripubertal football players presented lower subtotal lean mass than their postpubertal counterparts ($p<0.05$, Cohen´s *d* 1.0). When male and female football players within the same pubertal group were compared, differences were only found at the peripubertal stage as males were lighter, had lower BMI, and had been playing football for more years than females ($p<0.05$, Cohen´s *d* ranged from 0.5 to 1.0).

insert Table 1 here

Adjusted differences between genders

Comparisons of BMC and BMD for male and female football players without dividing by pubertal status are presented in Figure 1. Females demonstrated higher subtotal body and lumbar spine BMC and higher subtotal body, mean legs, lumbar spine, and femoral neck BMD than males ($p<0.05$; n^2_p ranged from 0.04 to 0.26; Figure 1).

insert Figure 1 here

Unadjusted bone mass differences between genders by pubertal groups

Higher lumbar spine BMC and BMD were found in female peripubertal and postpubertal football players compared to their male counterparts ($p<0.05$; Cohen´s *d* ranged from 0.88 to 1.65; Table 2). Female peripubertal participants also presented significantly higher subtotal body BMC and subtotal body, mean legs and femoral neck BMD values compared to their male counterparts ($p<0.05$; Cohen´s *d* ranged from 0.46 to 0.70; Table 2).

Unadjusted bone mass differences between pubertal groups by gender

In females, postpubertal players showed higher subtotal body and lumbar spine BMC and lumbar spine BMD values when compared to peripubertal players ($p<0.05$; Cohen´s *d* ranged from 0.81 to 1.22; Table 2). On the other hand, male postpubertal players showed higher BMC and BMD values at all sites except for the femoral neck BMD when compared to peripubertal football players ($p<0.05$; Cohen´s *d* ranged from 0.51 to 1.21; Table 2).

insert Table 2 here

Adjusted bone mass differences between genders by pubertal groups

Female peripubertal and postpubertal football players had significantly higher BMC and BMD values at subtotal body and lumbar spine than their male counterparts ($p<0.05$; n^2_p ranged from 0.09 to 0.60; Table 3). Moreover, female peripubertal football players showed higher mean legs BMD compared to males ($p<0.05$; n^2_p 0.09; Table 3).

Adjusted bone mass differences between pubertal groups by gender

Adjusted BMC and BMD at the femoral neck were higher in peripubertal than postpubertal female football players ($p<0.05$, n^2_p were 0.15 and 0.20; Table 3). In males, peripubertal football players demonstrated higher femoral neck BMD than postpubertal male players ($p<0.05$, n^2_p 0.057).

insert Table 3 here

Discussion

The main findings of the present study were that subtotal body and lumbar spine BMC and BMD were significantly higher in female than in male adolescent football players, even considering the pubertal status of the participants. When bone comparisons between groups were not adjusted, both male and female postpubertal football players showed greater BMC and BMD at several sites than their peripubertal counterparts. After adjusting by subtotal body lean mass and the number of years of football training, these BMC and BMD differences between pubertal groups disappeared and, in fact, both peripubertal male and female football players showed higher femoral neck BMD than their postpubertal peers. Femoral neck BMC was also higher in peripubertal females than in postpubertal females after adjusting by the same covariates.

Previous studies in female (Ferry et al., 2011; Ferry, Lespessailles, Rochcongar, Duclos, & Courteix, 2013; Plaza-Carmona et al., 2013; Soderman et al., 2000) and male football players (Nebigh et al., 2009; Silva, Goldberg, Teixeira, & Dalmas, 2011; Vicente-Rodriguez et al., 2004; Vicente-Rodriguez et al., 2003; Zouch et al., 2015) observed higher BMC and BMD values at most weight-bearing sites when compared to other athletes or controls; however, these differences were more important in females. Although these studies showed the positive influence of playing football in both genders up to now, the only study that directly compared bone mass between male and female football players reported no BMC and BMD differences between genders (McCulloch et al., 1992). In contrast, the current study established that females presented higher bone mass values at most weight-bearing sites when compared to males, even though peripubertal females had been playing football for fewer years than their male counterparts. Nevertheless, McCulloch et al. (1992) included participants who were 15.3 years old and in the present study, the mean age of participants was 12.7 years old. It has been demonstrated that females accumulate BMC earlier than males: 26% of adult BMC is accumulated around the age of 12 in females (Theintz et al., 1992) and 14 in males (Bailey, McKay, Mirwald, Crocker, & Faulkner, 1999). Thus, these differences between studies could be justified by the fact that our males were younger and might not have attained their age of peak bone mass accumulation yet.

To our knowledge, the only study that has compared bone mass between different pubertal status in male football players was performed by Zouch et al. (2014). They reported that football had a higher influence on bone mass in male pubertal than prepubertal players. Moreover, Nebigh et al. (2009) reinforced these results and suggested that these improvements on bone mass at weight-bearing sites were more marked during puberty than prepuberty in male football players. On the other hand, in females, Soderman et al. (2000), Ubago-Guisado et al. (2015) and Plaza-Carmona et al. (2016) divided football players into pubertal groups and compared them separately with other athletes and controls of the same pubertal status. These authors reported that bone mass differences between female football players, other athletes, and controls were higher and more evident in athletes with higher pubertal status. The findings of the present study before adjustment, also reported higher BMC and BMD at most weight-bearing sites in postpubertal than peripubertal male and female football players (see Table 2). However, when the data of the current study was adjusted by subtotal lean mass and the number of years of football training, these differences were in fact inverted, with higher femoral neck BMC and BMD appearing in peripubertal football players than their postpubertal peers (see Table 3). This suggests that peripubertal football players had strong bones in relation to their age and muscles. Bone adapts to external loads being the highest loads of bone caused for muscles (Frost, 2003). Therefore, an adequate muscle tissue in peripubertal stage could be an important factor to attain high BMC and BMD in these athletes. But, these differences between peripubertal and postpubertal might be influenced by the fact that peripubertal football players trained more hours per week than postpubertal ones.

Some limitations should be recognised. The present study did not have a control group; therefore, further studies evaluating the influence of gender and pubertal status between football players and controls could provide more information to better understand the effects of football during growth. After calculating the sample size, 52 football players (26 males and 26 females) were needed to obtain a power of 95%. However, when the sample of 110 football players was divided into four groups by gender and pubertal development, the number of subjects in some groups was lower than 26 participants, with the female postpubertal group presenting the lowest sample (n = 10). Therefore, the present findings of postpubertal females should be cautiously interpreted. Finally, the cross-sectional design of the current study (instead of longitudinal) does not allow one to obtain strong conclusions and to study bone development.

Conclusions

The current study provides evidence that female football players presented higher BMC and BMD at most of the weight-bearing sites than their male peers, being lumbar spine the site with the larger gender differences. Additionally, both male and female postpubertal football players showed higher BMC and BMD than peripubertal players. Nonetheless, these results were inverted after adjusting by subtotal body lean mass and the number of years of football training which suggests that playing football during peripuberty may be an interesting tool to reduce future osteoporotic problems in adulthood and elderly years.

References

Author-citation. 2012

Author-citation. 2018

Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. *J Bone Miner Res,* 1999; 59: 1672-1679

Bangsbo J. The physiology of soccer with special reference to intense intermittent exercise. *Acta Physiol Scand Suppl*, 1994; 619: 1-155

Calbet JA, Dorado C, Diaz-Herrera P, Rodriguez-Rodriguez LP. High femoral bone mineral content and density in male football (soccer) players. *Med Sci Sports Exerc*, 2001; 33: 1682-1687

Cousins JM, Petit MA, Paudel ML, Taylor BC, Hughes JM, Cauley JA, Zmuda JM, Cawthon PM, Ensrud KE, Osteoporotic Fractures in Men Study Group. Muscle power and physical activity are associated with bone strength in older men: The osteoporotic fractures in men study. *Bone*, 2010; 47, 205-211

Duke PM, Litt IF, Gross RT. Adolescents' self-assessment of sexual maturation. *Pediatrics*, 1980; 66: 918-920

Ferry B, Duclos M, Burt L, Therre P, Le Gall F, Jaffre C, Courteix D. Bone geometry and strength adaptations to physical constraints inherent in different sports: comparison between elite female soccer players and swimmers. *J Bone Miner Metab*, 2011; 29: 342-351

Ferry B, Lespessailles E, Rochcongar P, Duclos M, Courteix D. Bone health during late adolescence: effects of an 8-month training program on bone geometry in female athletes. *Joint Bone Spine*, 2013; 80, 57-63

Frost HM. Bone's mechanostat: a 2003 update. *Anat Rec A Discov Mol Cell Evol Biol*, 2003; 275: 1081-1101

McCulloch RG, Bailey DA, Whalen RL, Houston CS, Faulkner RA, Craven BR. Bone Density and Bone Mineral Content of Adolescent Soccer Athletes and Competitive Swimmers. *Pediatr Exerc Sci*, 1992; 4: 319-330

Nebigh A, Rebai H, Elloumi M, Bahlous A, Zouch M, Zaouali M, Alexandre C, Sellami S, Tabka Z. Bone mineral density of young boy soccer players at different pubertal stages: relationships with hormonal concentration. *Joint Bone Spine*, 2009; 76: 63-69

National Osteoporosis Foundation. What is Osteoporosis and What Causes it? Available at: https://www.nof.org/patients/what-is-osteoporosis/ ; accessed on 12.11.2017

Plaza-Carmona M, Ubago-Guisado E, Sánchez-Sánchez J, Felipe JL, Fernández-Luna A, García-Unanue J, Burillo P, Gallardo, L. Body composition and physical fitness in prepubertal girls swimmers and soccer players. *JSHR*, 2013; 5: 251-258

Plaza-Carmona M, Vicente-Rodriguez G, Gomez-Cabello A, Martin-Garcia M, Sanchez-Sanchez J, Gallardo L, Ara I. Higher bone mass in prepubertal and peripubertal female footballers. *Eur J Sport Sci*, 2016; 16: 877-883

Rizzoli R, Bianchi ML, Garabedian M, McKay HA, Moreno LA. Maximizing bone mineral mass gain during growth for the prevention of fractures in the adolescents and the elderly. *Bone*, 2010; 46: 294-305

Silva CC, Goldberg TB, Teixeira AS, Dalmas JC. The impact of different types of physical activity on total and regional bone mineral density in young Brazilian athletes. *J Sports Sci*, 2011; 29: 227-234

Soderman K, Bergstrom E, Lorentzon R, Alfredson H. Bone mass and muscle strength in young female soccer players. *Calcif Tissue Int*, 2000; 67: 297-303

Tanner JM, Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. *Arch Dis Child*, 1976; 51: 170-179

Tenforde AS, Fredericson M. Influence of sports participation on bone health in the young athlete: a review of the literature. *Pm R*, 2011; 3: 861-867

Theintz G, Buchs B, Rizzoli R, Slosman D, Clavien H, Sizonenko PC, Bonjour JP. Longitudinal monitoring of bone mass accumulation in healthy adolescents: evidence for a marked reduction after 16 years of age at the levels of lumbar spine and femoral neck in female subjects. *J Clin Endocrinol Metab*, 1992; 75: 1060-1065

Ubago-Guisado E, Gomez-Cabello A, Sanchez-Sanchez J, Garcia-Unanue J, Gallardo L. Influence of different sports on bone mass in growing girls. *J Sports Sci*, 2015; 33: 1710-1718

Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA. High femoral bone mineral density accretion in prepubertal soccer players. *Med Sci Sports Exerc*, 2004; 36: 1789-1795

Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I, Serrano-Sanchez JA, Dorado C, Calbet, JA. Enhanced bone mass and physical fitness in prepubescent footballers. *Bone*, 2003; 33: 853-859

Vicente-Rodriguez G, Urzanqui A, Mesana MI, Ortega FB, Ruiz JR, Ezquerra J, Casajus JA, Blay G, Blay VA, Gonzalez-Gross M, Moreno LA, AVENA Zaragoza Study Group. Physical fitness effect on bone mass is mediated by the independent association between lean mass and bone mass through adolescence: a cross-sectional study. *J Bone Miner Metab*, 2008; 26: 288-294 von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP, Strobe Initiative. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *PLoS Med*, 2007; 4: e296

Wallace LS, Ballard JE. Lifetime physical activity and calcium intake related to bone density in young women. *J Womens Health Gend Based Med*, 2002; 11: 389-398

World Health Organization. WHO Scientific group on the asssessment of osteoporosis at primary health care level. Summary Metting Report, 2004. Available at: http://www.who.int/chp/topics/Osteoporosis.pdf ; accessed on 10.11.2017

Zouch M, Jaffre C, Thomas T, Frere D, Courteix D, Vico L, Alexandre C. Long-term soccer practice increases bone mineral content gain in prepubescent boys. *Joint Bone Spine*, 2008; 75: 41-49

Zouch M, Vico L, Frere D, Tabka Z, Alexandre C. Young male soccer players exhibit additional bone mineral acquisition during the peripubertal period: 1-year longitudinal study. *Eur J Pediatr*, 2014; 173: 53-61

Zouch M, Zribi A, Alexandre C, Chaari H, Frere D, Tabka Z, Vico L. Soccer increases bone mass in prepubescent boys during growth: a 3-yr longitudinal study. *J Clin Densitom*, 2015; 18: 179-186

Table 1

Subject characteristics of peripubertal and postpubertal male and female football players.

	Peripubertal (Tanner II and III)		Postpubertal (Tanner IV and V)	
	Males (n = 53)	Females (n = 25)	Males (n = 22)	Females (n = 10)
Age (year)	12.66 (0.68)	12.67 (0.58)	12.87 (0.57)	12.90 (0.61)
Weight (kg)	42.74 (7.79)*†	47.63 (7.49)	53.59 (11.06)	53.70 (9.11)
Height (cm)	151.59 (7.61)†	154.32 (6.45)	161.31 (7.01)	158.79 (7.40)
BMI ($kg \cdot m^{-2}$)	18.53 (2.69)*†	19.98 (2.75)	20.49 (3.45)	21.16 (2.11)
Years training	5.32 (2.23)*	2.72 (2.30)	4.82 (1.79)	3.45 (3.08)
Training duration (h/week)	4.17 (1.59)†	3.58 (1.66)	3.50 (1.06)	3.05 (0.69)
Subtotal lean mass (kg)	29.30 (4.81)†	30.59 (4.01)†	37.55 (6.09)	35.41 (5.81)
Tanner status‡	(18/35)	(12/13)	(18/4)	(8/2)

Data are means (±standard deviation). ‡ For peripubertal number of participants in Tanner 2 and 3, for postpubertal number of participants in Tanner 4 and 5; BMI: body mass index

** $p<0.05$ between genders; † $p<0.05$ between pubertal status*

Table 2

Unadjusted BMC and BMD at different regions in peripubertal and postpubertal male and female football players.

		Peripubertal (Tanner II and III)		Postpubertal (Tanner IV and V)	
		Males (n = 53)	Females (n = 25)	Males (n = 22)	Females (n = 10)
BMC (g)	Subtotal body	1091.847 (190.016)*†	1214.832 (222.324)*	1354.562 (257.965)	1422.628 (288.962)
	Mean legs	296.645 (53.691)*	318.851 (57.287)	370.917 (71.498)	357.023 (70.785)
	Lumbar spine	32.444 (5.739)*†	39.076 (8.938)*	40.724 (7.822)†	49.962 (8.855)
	Hip	25.860 (4.368)*	25.874 (4.600)	31.239 (6.226)	29.104 (5.478)
	Femoral neck	3.676 (0.470)*	3.746 (0.658)	4.052 (0.645)	4.030 (0.668)
BMD ($g\cdot cm^{-2}$)	Subtotal body	0.813 (0.069)*†	0.856 (0.068)	0.881 (0.072)	0.899 (0.075)
	Mean legs	0.989 (0.097)*†	1.056 (0.096)	1.094 (0.109)	1.077 (0.102)
	Lumbar spine	0.707 (0.076)*†	0.818 (0.112)*	0.781 (0.093)†	0.947 (0.108)
	Hip	0.888 (0.091)*	0.921 (0.113)	0.939 (0.111)	0.950 (0.111)
	Femoral neck	0.814 (0.088)†	0.862 (0.120)	0.844 (0.090)	0.856 (0.113)

Data are means (±standard deviation). BMC: bone mineral content; BMD: bone mineral density

** p<0.05 between pubertal status; † p<0.05 between genders*

Table 3

Adjusted BMC and BMD at different regions in peripubertal and postpubertal male and female football players.

		Peripubertal (Tanner II and III)		Postpubertal (Tanner IV and V)	
		Males (n = 53)	Females (n = 25)	Males (n = 22)	Females (n = 10)
BMC (g)	Subtotal body	1181.782 (92.945)†	1280.420 (106.065)	1137.898 (102.415)†	1258.660 (111.698)
	Mean legs	321.126 (30.052)	335.482 (28.420)	311.939 (33.114)	315.445 (29.928)
	Lumbar spine	34.712 (4.310)†	40.855 (6.955)	35.259 (4.751)†	45.514 (7.324)
	Hip	27.507 (3.640)	27.161 (2.655)	27.272 (4.010)	25.887 (2.795)
	Femoral neck	3.844 (0.415)	3.926 (0.365)*	3.648 (0.460)	3.581 (0.383)
BMD ($g \cdot cm^{-2}$)	Subtotal body	0.838 (0.044)†	0.873 (0.045)	0.820 (0.052)†	0.857 (0.047)
	Mean legs	1.025 (0.073)†	1.077 (0.075)	1.005 (0.075)	1.026 (0.079)
	Lumbar spine	0.730 (0.073)†	0.836 (0.095)	0.727 (0.080)†	0.902 (0.101)
	Hip	0.912 (0.087)	0.946 (0.080)	0.880 (0.098)	0.888 (0.085)
	Femoral neck	0.837 (0.080)*	0.888 (0.085)*	0.789 (0.089)	0.790 (0.092)

Data are means (±standard deviation). BMC: bone mineral content; BMD: bone mineral density. Data adjusted by subtotal lean mass and the number of years training football.

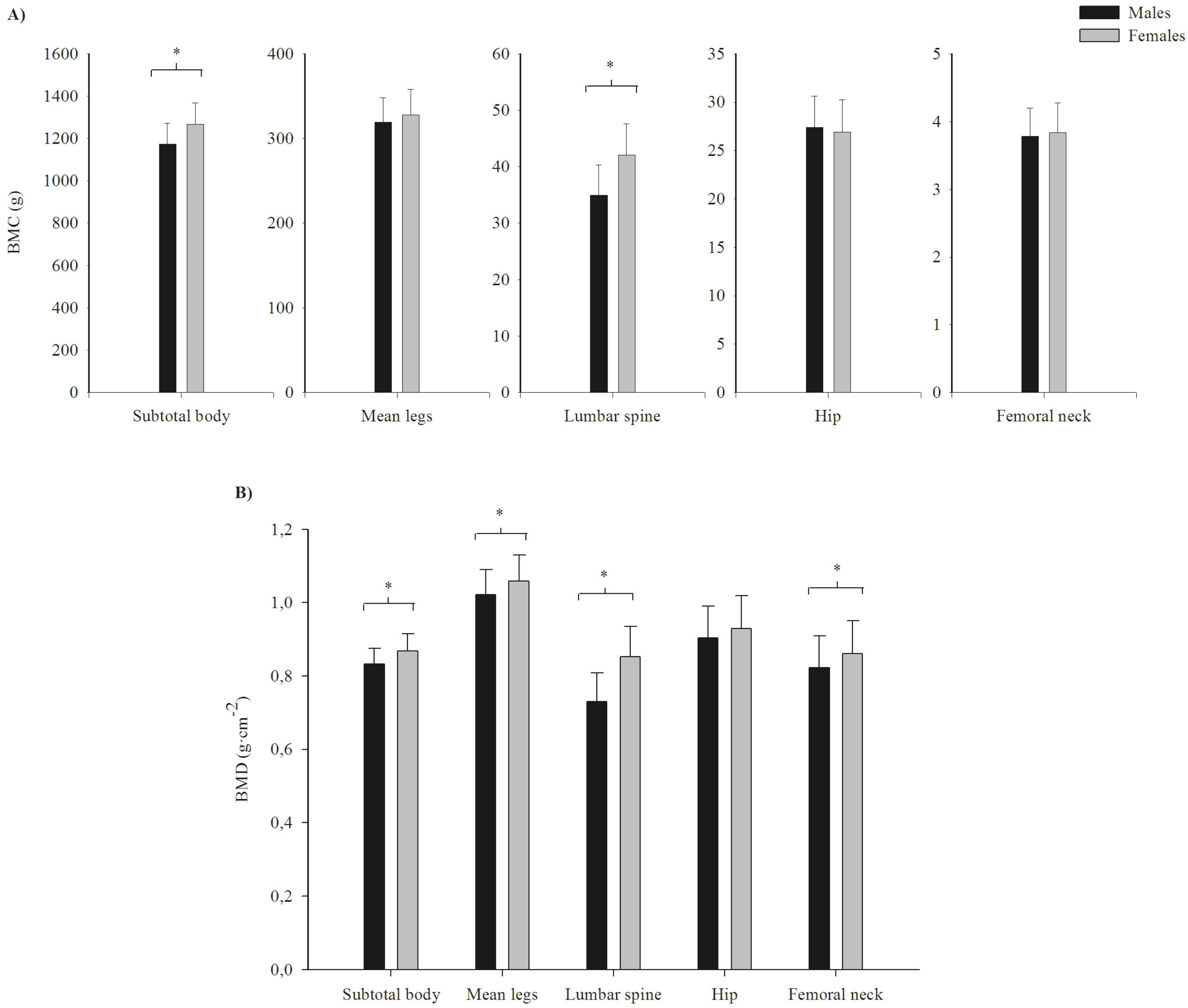
** $p<0.05$ between genders pubertal status; † $p<0.05$ between genders.*

351

14

Figure 1

Adjusted bone mass values by DXA in adolescent football players without stratifying by pubertal status.



*(**A**) Bone mineral content (BMC) and (**B**) bone mineral density (BMD) differences between genders without taking into account the pubertal status. Data adjusted by subtotal lean mass and the number of years training football.*

** p<0.05 between genders.*

Archives of Osteoporosis (2018) 13:57
https://doi.org/10.1007/s11657-018-0472-2

ORIGINAL ARTICLE

Bone geometry in young male and female football players: a peripheral quantitative computed tomography (pQCT) study

Gabriel Lozano-Berges [1,2,3] • Ángel Matute-Llorente [1,2,3,4] • Alejandro Gómez-Bruton [1,3,4,5] • Alex González-Agüero [1,2,3,4] • Germán Vicente-Rodríguez [1,2,3,4] • José A. Casajús [1,3,4,6]

Received: 28 July 2017 / Accepted: 26 April 2018

Abstract

Summary The present study shows that football practice during growth may improve bone geometry in male and female football players. However, only females had better bone strength in comparison with controls.

Purpose The aim of this study was to compare bone geometry in adolescent football players and controls.

Methods A total of 107 football players (71 males/36 females; mean age 12.7 ± 0.6/12.7 ± 0.6 years) and 42 controls (20 males/22 females; mean age 13.1 ± 1.4/12.7 ± 1.3 years) participated in this study. Total and trabecular volumetric bone mineral content (Tt.BMC/Tb.BMC), cross-sectional area (Tt.Ar/Tb.Ar), and bone strength index (BSI) were measured at 4% site of the non-dominant tibia by peripheral quantitative computed tomography (pQCT). Moreover, Tt.BMC, cortical BMC (Ct.BMC), Tt.Ar, cortical Ar (Ct.Ar), cortical thickness (Ct.Th), periosteal circumference (PC), endosteal circumference (EC), fracture load in *X*-axis, and polar strength strain index (SSIp) were measured at 38% site of the tibia. Multivariate analyses of covariance were used to compare bone pQCT variables between football players and controls using the tibia length and maturity offset as covariates.

Results Female football players demonstrated 13.8–16.4% higher BSI, Ct.Th, fracture load in *X*-axis, and SSIp than controls ($p < .0036$). Males showed no significant differences in bone strength when compared to controls ($p > .0036$). In relation to bone mineral content and area, male football players showed 8.8% higher Tt.Ar and Tb.Ar at the 4% site of the tibia when compared to controls; whereas 13.8–15.8% higher Tt.BMC, Ct.BMC, and Ct.Ar at the 38% site of the tibia were found in female football players than controls ($p < .0036$).

Conclusions In this study, female adolescent football players presented better bone geometry and strength values than controls. In contrast, only bone geometry was higher in male football players than controls.

Keywords Soccer · Body composition · Bone health · Youth

Introduction

Several studies have described the importance of environmental and genetic factors in the determination of bone mass. Genetic or hereditary factors are the major contributors (up to 80%) to the variability in peak bone mass but they are non-modifiable [1]. Environmental factors play an important role because bones adapt to the specific mechanical load [2]. Exercising is an effective strategy to attain optimal bone mass and strength during growth [3], such is it so several studies

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s11657-018-0472-2) contains supplementary material, which is available to authorized users.

✉ José A. Casajús
joseant@unizar.es

1 GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza, Zaragoza, Spain

2 Faculty of Health and Sport Science (FCSD), Department of Physiatry and Nursing, Universidad de Zaragoza, Huesca, Spain

3 Instituto Agroalimentario de Aragón-IA2-(Universidad de Zaragoza -CITA), Zaragoza, Spain

4 Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn), Madrid, Spain

5 Universidad Isabel I, Burgos, Spain

6 Faculty of Health Sciences, Department of Physiatry and Nursing, Universidad de Zaragoza, Zaragoza, Spain

Published online: 08 May 2018

have shown that high-impact sports such as football, volleyball, or racquet games have positive effects on bone mass [4–7]. Regular football training causes site-specific skeletal responses mainly because of the type of specific actions executed while playing and the biomechanical properties of the surface in which football players practice their sport [8, 9].

The majority of studies performed with children and adolescent football players evaluated bone mineral content and density via dual X-ray absorptiometry (DXA) finding positive effects on those parameters, in different moments of maturation [9–11], being more marked in pubertal than prepubertal stages [12]. Nevertheless, BMD can explain up to 60% of the variance in bone strength, but due to its intrinsic two-dimensional character, DXA cannot determine whether bone changes are due to differences in volumetric bone mineral content (BMC) or in bone geometrical parameters [13]. In addition, it is also known that physical exercise performed during growth mainly improves bone geometry rather than bone mass [14]. Further studies have measured bone geometry with peripheral quantitative computed tomography (pQCT) [15, 16] or hip structural analysis (HSA) [8, 17, 18] in young male and female football players. When compared to swimmers, cyclists, and controls, higher cross-sectional area, moment of inertia, and stiffness index were found in male football players [17]. Also, female football players demonstrated higher strength and structure values when compared to swimmers [8, 18].

Vlachopoulos et al. [17] and Ferry et al. [8, 18] used HSA for comparing bone geometry between football players and controls; nevertheless, this technique has limitations. HSA is a calculation derived from hip scans performed by DXA, and consequently, final geometric results could be altered by the two-dimensional image obtained from DXA which is highly influenced by femur rotation, as demonstrated by Beck [19]. Furthermore, the hip is not the preferred skeletal site to measure bone mass in young populations because of the high variability of bone development during growth [20]. The use of pQCT can, at least partially, mitigate these limitations. It is a three-dimensional technique to assess bone geometry variables without the influence of bone size. Until now, only Anliker et al. [15] and Varley et al. [16] have used pQCT for measuring bone geometry within male adolescent football players; however, neither performed sex-specific bone geometry comparison between football players and controls. While no previous study has used pQCT to compare bone outcomes between adolescent football players and controls, several studies have used pQCT to compare bone outcomes between young adult football players and controls [21–23]. These authors showed that football players had better bone geometry (i.e., cortical area (Ct.Ar), periosteal circumference (PC), volumetric bone mineral density) than controls in both genders.

Therefore, the main aim of this study was to examine and compare bone mass variables—at the 4 and 38% sites of the tibia length—and geometric variables—at the 38% site of the tibia length—between adolescent football players and controls separated by gender. We hypothesized that football players will exhibit higher bone variables than controls in both genders due to the fact that loads produced by specific football actions will provoke an extra skeletal response.

Methods

Participants

Eight football clubs (all of them competed at provincial level for their age category) and two high schools of Aragon (Spain) were invited to participate in the present study. All football players agreed to participate in this study (100% of players); however, in the control group, only 45 of 114 students voluntarily decided to collaborate. An initial sample of 121 football players (81 males and 40 females) and 45 controls (23 males and 22 females) agreed to participate in the study. Nonetheless, 14 football players and 3 controls were not included because of the following reasons: 11 football players did not assist to the measurement citation; and data of 3 football players and 3 controls had blurred pQCT images; Fig. 1). Consequently, the final sample for the present study consisted of 107 football players (71 males and 36 females; mean age 12.7 ± 0.6 and 12.7 ± 0.6 years, respectively) and 42 controls (20 males and 22 females; mean age 13.1 ± 1.4 and 12.7 ± 1.3 years, respectively). Twenty female football players (mean age of 12.9 ± 0.6 years) and 9 female controls (mean age of 13.8 ± 0.2 years) experienced menarche (at the mean age of 11.4 ± 1.2 and 11.9 ± 0.8 years, respectively; Online Resource 1) before the beginning of the study. Moreover, no proportion differences between football players and controls in pre- and post-menarcheal groups were found ($\chi^2(1) = 1.172$, $p = .279$). Although controls were physically active, they were not engaged in any regular sport. Measurements took place between November and December 2013 in Zaragoza, Spain.

Despite not performing the same football exercises, trainings of all teams included in the present study (both males and females) lasted approximately 90 min, including 5-min warm-up consisting of low-intensity running; 5–10 min of low-intensity games; 60 min of technical football exercises (e.g., passing, kicking, running, dribbling); and finally, 5–10 min of cold down performing stretching exercises.

The protocol of the study, its benefits, and risks were explained to the participants, parents, and the club managers. Participants completed the written assent and their parents completed the written informed consent. This study followed the Declaration of Helsinki 1961 (revision of Fortaleza 2013) and was approved by the Ethics Committee of Clinical Research from the Government of Aragon (CEICA, Spain) prior the commencement of it [C.I. PI13/0091]. This cross-

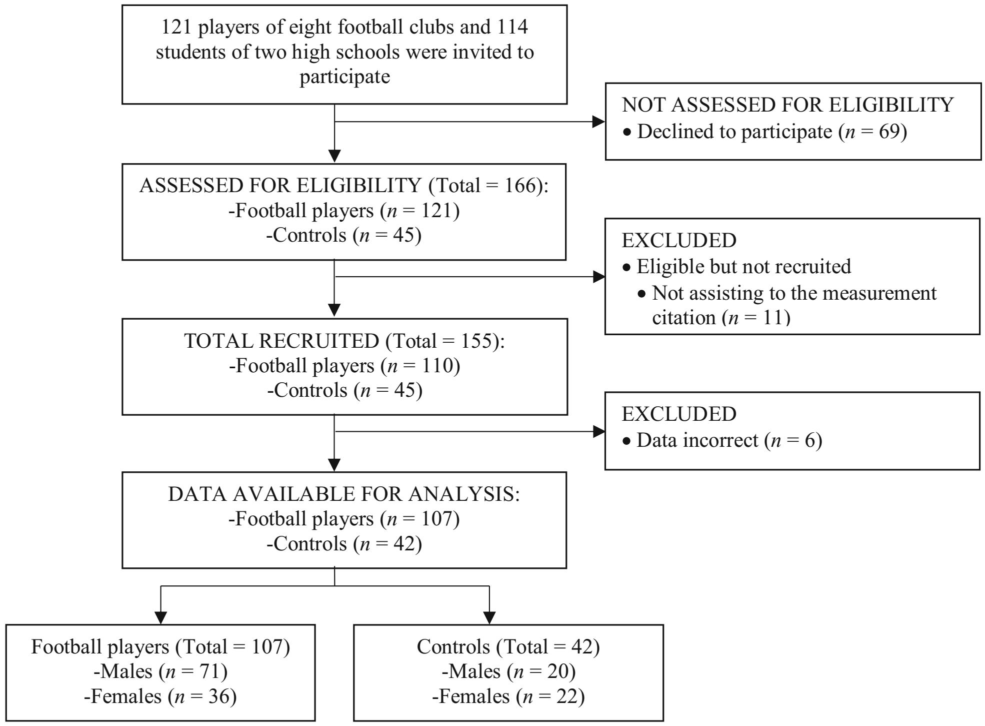


Fig. 1 Flow diagram of football players and controls who participated in this study

sectional study is part of a larger randomized controlled trial that evaluated the effect of football surfaces and boot model on bone during growth. Football players and controls were measured three times during two football seasons. The first measurement was performed at the beginning of the first season (November–December 2013). The second measurement was performed at the end of the first season (May–July 2014) to evaluate the effect of football surfaces and boot model on bone. Finally, the third measurement took place at the end of the second season (May–July 2015) to assess the perdurability of the previously mentioned effects. Furthermore, the research project was registered in a public database Clinicaltrials.gov [NCT02399553]. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement was used as a guideline for reporting observational data [24].

Inclusion criteria

Participants must be Caucasian, with at least 1 year of football practice (football players) or should not be engaged in any regular sport (control group), age between 11 and 14 years old, and free of medication that could affect bone mass or development.

Anthropometric measurements

Height (stadiometer SECA 225, SECA, Hamburg, Germany;) was measured without shoes and the minimum clothes to the nearest 0.1 cm and weight to the nearest 0.1 kg (SECA 861, SECA, Hamburg, Germany). Body mass index (BMI) was calculated as weight (kilograms) divided by height (square meters).

Maturity offset

Age and height were used to estimate maturity offset in males and females using the following sex-specific equations [25]:

$$\text{Males} : \text{Maturity } offset = -7.999994 + (0.0036124 \times (\text{age} \times \text{height}))$$

$$\text{Females} : \text{Maturity } offset = -7.709133 + (0.0042232 \times (\text{age} \times \text{height}))$$

Moreover, the age of peak height velocity was calculated as the subtraction of the age from maturity offset.

Calcium intake

A validated calcium food frequency questionnaire was used to calculate milligrams of daily calcium intake [26, 27].

Bone assessment by pQCT

Bone strength indexes, bone morphometry, BMC, and bone area were measured at the non-dominant tibia using a Stratec XCT-2000 L pQCT scanner (Stratec Medizintechnik, Pforzheim, Germany). The device is a translate-rotate, small bore computed tomography scanner that acquires a trans-axial image. The pQCT was calibrated daily based on a quality control phantom provided by the manufacturer (Stratec Medizintechnik, Pforzheim, Germany). The coefficients of variation of the pQCT in our laboratory for each variable have been already published [28].

Dominance was determined by asking which leg would be used to kick a ball [29]. Although there is no consensus about the measurement of dominant or non-dominant leg in pQCT studies [30], Anliker et al. [15] reported higher bone strength values in non-dominant than dominant leg in young male football players. Thus, based on their findings and protocol study, non-dominant leg was selected in the present study. Participants were seated on a chair adjustable to the body proportions of each participant. Tibia length was measured from the medial knee joint cleft to the medial malleolus of the tibia using a wooden ruler and was always measured by the same researcher. The scanner was positioned on the distal tibia, and a scout view was performed to manually set the reference line on the midpoint of the distal tibia endplate. Then, the measurements were performed at 4 and 38% sites of the tibia length to assess trabecular and cortical bone. Following the International Society for Clinical Densitometry (ISCD) recommendations [30], the measured variables at the 4% site of the tibia were total BMC (Tt.BMC, g), trabecular BMC (Tb.BMC, g), total area (Tt.Ar, mm^2), trabecular area (Tb.Ar, mm^2), and bone strength index (BSI was calculated as Tt.Ar multiplied by squared total density; mg/mm). Moreover, the parameters examined at the 38% site of the tibia were total BMC (Tt.BMC, g), cortical BMC (Ct.BMC, g), total area (Tt.Ar, mm^2), Ct.Ar (mm^2), cortical thickness (Ct.Th, mm), PC (mm), endosteal circumference (EC, mm), fracture load in *X*-axis (N), and polar strength strain index (SSIp, mm^3). Muscle and fat cross-sectional areas (mm^2) were measured at the 66% site of the length of the tibia.

Images were analyzed with version 6.20 of the manufacturer's software. Contour mode 1 with a threshold of 180 mg/cm^3 for the 4% site of the tibia and 280 mg/cm^3 for the 38% site of the tibia was used to determine the periosteal surface of the bone. At 4% site of the tibia, trabecular bone was determined from a central area covering 45% of the total bone cross-sectional area. At 38% site of the tibia, cortical bone was obtained using cortical mode 1 with a threshold of 710 mg/cm^3. Additionally, cortical mode 1 with a threshold of 280 mg/cm^3 was used to obtain bone strength variables (SSIp and fracture load in *X*-axis). After that, bone mineralization of 1200 mg/cm^3 was assumed.

Statistical analyses

As no previous studies had measured bone geometry and strength by pQCT in young football players and controls, HSA data from the Vlachopoulos et al. [17] and Ferry et al. [8, 18] studies evaluating cross-sectional area at the femoral shaft section in football players and controls (males 140.9 ± 20.4 vs 109.8 ± 21.0 mm^2; females 4.66 ± 0.54 vs 3.97 ± 0.27 cm^2, respectively) were used to calculate sample size.

The sample size for MANCOVA analysis was calculated for the cross-sectional area at the femoral shaft to get a power of 95% at the 5% alpha power and to observe differences in comparison to a null hypothesis H_0:$\mu 1 = \mu 2$. In males, assuming that the means of football players and controls are 140.9 and 109.8 mm^2, respectively and the standard deviation (SD) of both groups is 20.7 mm^2, at least 32 participants (a minimum of 16 participants per group) would be needed. In females, assuming that the means of football players and controls are 4.66 and 3.97 cm^2, respectively and the SD of both groups is 0.40 cm^2, at least 24 participants (a minimum of 12 participants per group) would be needed.

The Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Continuous data were presented as mean ± SD. All variables showed normal distribution by the Kolmogorov-Smirnov test.

Two-way analysis of variance (ANOVA) was used to test for an interaction of football practice and gender on participant characteristics. A multivariate analysis of covariance (MANCOVA) was performed to analyze differences at bone pQCT variables within football players and controls, using the length of the tibia and maturity offset as covariates (model 1). After that, these analyses were repeated adding other two covariates as follows: Model 1 + weight (model 2); and model 1 + muscle area (model 3). Bonferroni corrections were applied to control the overall type I error rate of multiple comparison, and therefore, the p value of .05 was divided by 14 (the number of comparisons conducted). Effect sizes calculated by SPSS were reported as omega squared (ω^2) for ANOVAs and partial eta squared (η^2_p) for MANCOVAs. The effect size for ω^2 and η^2_p can be small (0.01–0.06), medium (0.06–0.14), or large (> 0.14).

Results

Table 1 presents descriptive characteristics of the football players and controls by sex. There were significant interaction effects between the practice of football and gender on weight, BMI, and muscle cross-sectional area, ($p < .05$, ω^2 ranged from 0.03 to 0.04). Muscle cross-sectional area was higher in female football players than the control group (mean difference was 14.3%; $p < .05$; Cohen's d 0.73). Male football players demonstrated lower fat area than controls (mean difference was − 18.3%; $p < .05$; Cohen's d 0.56).

There was a significant effect of football practice (in both males and females separately) on bone geometry and strength,

Table 1 Descriptive values of football players and controls

	Males			Females			Interaction gender group*	
	Football players ($n = 71$)	Controls ($n = 20$)	d	Football players ($n = 36$)	Controls ($n = 22$)	d	p	ω^2
Age (year)	12.7 ± 0.6	13.1 ± 1.4	0.39	12.7 ± 0.6	12.7 ± 1.3	0.05	0.150	0.007
Weight (kg)	45.4 ± 10.1	49.9 ± 10.8	0.42	49.3 ± 8.2	44.9 ± 11.0	045	0.017‡	0.038
Height (cm)	154.5 ± 8.8	156.7 ± 10.9	0.22	155.4 ± 7.0	153.0 ± 9.1	0.29	0.164	0.006
BMI (kg m^{-2})	18.9 ± 2.9	20.1 ± 2.8	0.44	20.4 ± 2.6	19.0 ± 3.2	0.48	0.013‡	0.035
Tibia length (mm)	350 ± 24	357 ± 29	0.25	347 ± 21	345 ± 23	0.12	0.300	0.001
Muscle CSA (mm^2)	5300 ± 1037	5575 ± 1106	0.26	5449 ± 922*	4767 ± 952	0.73	0.011‡	0.036
Fat CSA (mm^2)	1984 ± 785*	2430 ± 803	0.56	2373 ± 689	2380 ± 765	0.01	0.123	0.010
Daily calcium intake (mg)	862.4 ± 401.1	785.5 ± 288.7	0.22	765.7 ± 486.4	759.4 ± 294.3	0.02	0.633	0.005
Maturity offset (year)	− 0.9 ± 0.6	− 0.5 ± 1.3	0.40	0.6 ± 0.7	0.5 ± 1.2	0.10	0.107	0.011
Age PHV (year)	13.6 ± 0.4	13.7 ± 0.4	0.25	12.1 ± 0.3	12.2 ± 0.4	0.28	0.793	0.006
Training years (year)	5 ± 2	–	–	3 ± 3	–	–	–	–
Training hours (h/week)	3.2 ± 1.3	–	–	2.9 ± 0.6	–	–	–	–

Values are mean ± SD. Cohen's d can be small (0.2–0.5), medium (0.5–0.8), or large (> 0.8). $\omega^2{}_p$ can be small (0.01–0.06), medium (0.06–0.14), or large (> 0.14)

BMI body mass index, *CSA* cross-sectional area, *PHV* peak height velocity

*Significant differences between football players and controls

‡ Significant interaction

Wilk's $\Lambda = 0.71$, $F(13/75) = 2.39$, $p = .010$, $\eta^2{}_p = 0.29$ (males); and Wilk's $\Lambda = 0.52$, $F(13/42) = 2.97$, $p = .004$, $\eta^2{}_p = 0.48$ (females).

Data of BMC and bone area at the 4% and the 38% sites of the length of the tibia are shown in Table 2. Male football players demonstrated higher Tt.Ar and Tb.Ar at the 4% site of the tibia in comparison to male controls (both mean differences were 8.8%; both $p = .001$; both $\eta^2{}_p$ 0.11; Table 2). Female football players showed higher Tt.BMC at the distal tibia and also Tt.BMC, Ct.BMC, and Ct.Ar at diaphyseal tibia than controls (mean differences ranged from 14.9 to 15.8%; $p < .001$; $\eta^2{}_p$ ranged from 0.23 to 0.28; Table 2).

Geometric variables measured at the 38% diaphyseal tibia and strength indexes at the 4% and the 38% sites of the tibia are also summarized in Table 2. Only female football players exhibited higher BSI, Ct.Th, fracture load in *X*-axis, and SSIp than controls (mean differences ranged from 13.8 to 26.8%; $p < .001$; $\eta^2{}_p$ ranged from 0.18 to 0.26; Table 2). Similar results were obtained when weight (model 2) or muscle area (model 3) were added as covariates (Online Resource 2).

Discussion

The main finding of the present study was that female adolescent football players showed better bone geometry and higher bone strength indexes than controls. When comparing male groups, football players exhibited better bone geometry at 4% site of the tibia than controls; nevertheless, no bone strength differences were found between these groups.

The lack of differences between male groups could be explained by the fact that cortical bone parameters and bone strength values (all of these variables measured at 38% site of the tibia) abruptly increase after 14 years old in males [31] and participants included in this study were younger. Moreover, trabecular bone is more sensitive and has more remodeling activity than cortical bone due to trabecular bone having a higher surface-to-volume ratio in comparison with cortical one [32]. Thus, bone increments caused by football practice before maturation may be more marked on trabecular than on cortical bone.

Previous studies have reported higher bone mineral content and bone mineral density at most weight-bearing sites in young male and female football players than controls [6, 9, 11], these differences being more marked in pubertal than prepubertal players. The previously commented studies used DXA for evaluating bone mass; which is known to explain 60% of the variance of bone strength [13]; bone geometry (via pQCT) explains the remaining percentage. Physical exercise during growth improves more bone geometry than bone mass parameters [14]. The present study found better bone geometry (Tt.BMC, Ct.BMC, and Ct.Ar) and higher bone strength (except PC and EC) in female football players compared to controls. In males, football players demonstrated better bone geometry at 4% site of the tibia (Tt.Ar and Tb.Ar) compared to controls. The effects of football actions and their inherent loads cause microdamages in bone and an increase of bone

Table 2 Adjusted pQCT values of football players and controls

	Males				Females			
	Football players ($n = 71$)	Controls ($n = 20$)	MD (95% CI)	Test statistic	Football players ($n = 36$)	Controls ($n = 22$)	MD (95% CI)	Test statistic
4% site								
Tt.BMC (g)	3.88 ± 0.62	3.53 ± 0.62	0.35 (0.04, 0.66)	$F(1,87) = 4.98$, $p = .028$, $\eta^2_p = 0.05$	3.11 ± 0.38	2.69 ± 0.38	0.42 (0.21, 0.62)*	$F(1,54) = 16.30$, $p < .001$, $\eta^2_p = 0.23$
Tb.BMC (g)	1.62 ± 0.31	1.41 ± 0.32	0.21 (0.04, 0.37)	$F(1,87) = 6.43$, $p = .013$, $\eta^2_p = 0.07$	1.19 ± 0.19	1.05 ± 0.19	0.15 (0.04, 0.25)	$F(1,54) = 7.75$, $p = .007$, $\eta^2_p = 0.13$
Tt.Ar (mm^2)	1192 ± 114	1095 ± 116	97 (39, 155)*	$F(1,87) = 10.87$, $p = .001$, $\eta^2_p = 0.11$	1001 ± 90	956 ± 90	45 (− 4, 94)	$F(1,54) = 3.42$, $p = .070$, $\eta^2_p = 0.06$
Tb.Ar (mm^2)	536 ± 51	493 ± 52	44 (17, 70)*	$F(1,87) = 10.85$, $p = .001$, $\eta^2_p = 0.11$	450 ± 40	430 ± 40	20 (− 2, 42)	$F(1,54) = 3.42$, $p = .070$, $\eta^2_p = 0.06$
BSI (mg/mm)	127.9 ± 32.0	116.1 ± 32.3	11.8 (− 4.6, 28.2)	$F(1,87) = 2.06$, $p = .155$, $\eta^2_p = 0.02$	97.4 ± 19.9	76.8 ± 19.9	20.6 (9.7, 31.4)*	$F(1,54) = 14.50$, $p < .001$, $\eta^2_p = 0.21$
38% site								
Tt.BMC (g)	2.96 ± 0.32	2.92 ± 0.32	0.04 (− 0.12, 0.20)	$F(1,87) = 0.23$, $p = .634$, $\eta^2_p < 0.01$	2.91 ± 0.29	2.56 ± 0.30	0.35 (0.19, 0.51)*	$F(1,54) = 19.65$, $p < .001$, $\eta^2_p = 0.27$
Ct.BMC (g)	2.68 ± 0.30	2.62 ± 0.31	0.07 (− 0.09, 0.23)	$F(1,87) = 0.74$, $p = .391$, $\eta^2_p = 0.01$	2.65 ± 0.29	2.31 ± 0.29	0.34 (0.18, 0.50)*	$F(1,54) = 18.83$, $p < .001$, $\eta^2_p = 0.26$
Tt.Ar (mm^2)	378 ± 43	369 ± 43	9 (− 14, 30)	$F(1,87) = 0.59$, $p = .445$, $\eta^2_p = 0.01$	348 ± 34	322 ± 34	27 (8, 45)	$F(1,54) = 8.52$, $p = .005$, $\eta^2_p = 0.14$
Ct.Ar (mm^2)	255 ± 29	246 ± 30	9 (− 6, 24)	$F(1,87) = 1.39$, $p = .242$, $\eta^2_p = 0.02$	243 ± 27	209 ± 27	33 (19, 48)*	$F(1,54) = 21.11$, $p < .001$, $\eta^2_p = 0.28$
Ct.Th (mm)	4.73 ± 0.44	4.59 ± 0.45	0.13 (− 0.09, 0.36)	$F(1,87) = 1.37$, $p = .245$, $\eta^2_p = 0.02$	4.74 ± 0.49	4.16 ± 0.49	0.58 (0.31, 0.84)*	$F(1,54) = 19.07$, $p < .001$, $\eta^2_p = 0.26$
PC (mm)	68.7 ± 3.9	67.8 ± 4.0	0.9 (− 1.1, 2.9)	$F(1,87) = 0.78$, $p = .379$, $\eta^2_p = 0.01$	66.0 ± 3.3	63.4 ± 3.3	2.6 (0.9, 4.4)	$F(1,54) = 8.86$, $p = .004$, $\eta^2_p = 0.14$
EC (mm)	39.0 ± 3.9	39.0 ± 3.9	0.1 (− 1.9, 2.0)	$F(1,87) = 0.00$, $p = .952$, $\eta^2_p < 0.01$	36.3 ± 3.8	37.3 ± 3.8	− 1.0 (− 3.1, 1.1)	$F(1,54) = 0.94$, $p = .338$, $\eta^2_p = 0.02$
Frc.LdX (N)	2964.3 ± 516.8	2927.8 ± 523.0	36.5 (− 227.9, 300.9)	$F(1,87) = 0.08$, $p = .784$, $\eta^2_p < 0.01$	2811.8 ± 417.4	2415.9 ± 417.7	395.9 (169.1, 622.8)*	$F(1,54) = 12.24$, $p = .001$, $\eta^2_p = 0.19$
SSIp (mm^3)	1323.2 ± 228.8	1233.9 ± 231.5	89.3 (− 27.7, 206.3)	$F(1,87) = 2.30$, $p = .133$, $\eta^2_p = 0.03$	1202.7 ± 159.4	1056.5 ± 159.5	146.3 (59.6, 232.9)*	$F(1,54) = 11.46$, $p = .001$, $\eta^2_p = 0.18$

Values are mean ± SD. pQCT variables adjusted by tibia length and maturity offset

pQCT peripheral quantitative computed tomography, *MD* mean difference, *CI* confidence interval, *Tt.BMC* total volumetric bone mineral content, *Tb.BMC* trabecular volumetric bone mineral content, *Tt.Ar* total cross-sectional area, *Tb.Ar* trabecular cross-sectional area, *BSI* bone strength index, *Ct.BMC* cortical volumetric bone mineral content, *Ct.Ar* cortical cross-sectional area, *Ct.Th* cortical thickness, *PC* periosteal circumference, *EC* endosteal circumference, *Frc.LdX* fracture load in axe X, *SSIp* strength strain index in polar, η^2_p partial eta squared

Bonferroni correction $^*p < .0036$ differences between football players and controls remodeling activity [33]. Due to this bone adaptation, football players could attain wider and stronger bones during adolescence, and more importantly, they could reduce future bone diseases in adulthood. Thus, football practice could be a good choice to improve bone health in those children and adolescent who have weak bones.

It has been demonstrated that bones adapt to the loads modifying their shape, size, architecture, and mass [34]. To the best of our knowledge, this is the first study to evaluate tibia with pQCT in female adolescent football players and controls. A cross-sectional study by Ferry et al. [18] assessed bone mass and geometry measured by DXA and HSA in late adolescent female football players and swimmers. These authors reported better bone geometry values in football players than swimmers. Another longitudinal study [8] with the same participants reported improvements on cross-sectional area and subperiosteal width after 8 months of football training in female players. According to the present study, female football players demonstrated higher BSI, Ct.Th, fracture load in *X*-axis, and SSIp than controls. These results could be justified as periosteal expansion is the main response of the bones to exercise loading during prepubertal stage [35, 36], increasing, at the same time, cortical thickness and the resistance of the tibia to bending and torsional forces [37].

Although no differences in pQCT variables at the 38% site of the tibia were found in male football players, they exhibited higher BMC and cross-sectional area at the 4% site of the length of the tibia. Up to now, only Vlachopoulos et al. [17] compared bone mass and geometry measured by DXA and HSA between male football players, swimmers, cyclist, and controls. They reported better bone geometry and higher stiffness index and BMD in football players than the other groups. These bone geometry differences between studies could be explained by different techniques used (pQCT vs. HSA) and the different bone sites measured (tibia vs. proximal femur). Moreover, HSA could be more imprecise in measuring geometric variables because it uses a two-dimensional image obtained from DXA, and the rotation of femur may fundamentally affect bone geometry [19]. Thus, future longitudinal studies using pQCT are in need to clarify if football practice causes an adaptation in bone geometry and strength also in males.

As it is known that peak bone mineral accretion rate occurs approximately 2 years earlier in girls (12.5 years old) than boys (14.1 years old) [38]. Male players in this study were 12.7 ± 0.6 years old, and females were 12.7 ± 0.6 years old; therefore, it is most likely that the peak bone accretion rate was reached by a higher percentage of females than males. Almost half of females included in this study had experienced menarche, suggesting a higher biological development than their male counterparts. Therefore, due to such reasons, only female football players showed higher geometric variables and strength indexes at 38% site of the tibia than controls, and not males. On the other hand, taking into account the effects of high-impact sports on bone geometry during growth, the principal response during prepubertal years in males and females is periosteal apposition. Nevertheless, during pubertal years is periosteal apposition in males and is endocortical apposition in females [36]. Following this statement, either male or female football players should have better bone geometry and higher bone strength than controls; nevertheless, males only demonstrated higher but not significant bone values. As explained above, male football players in the present study were all under 14 years old, which is determined as the point of higher increase of cortical bone [31].

The main limitation of this study is that due to the cross-sectional design, causal conclusions cannot be attained. Bailey et al. [38] demonstrated that age of peak bone mineral accretion was different between genders (14.1 years old in males and 12.5 years old in females). Thus, males and females of this study who had similar chronological ages (12.7 and 12.7 years old respectively) might have presented different bone maturation age. On the other hand, the main strength is that this is the first study comparing bone geometry between young football players and controls with pQCT. Moreover, the analyses have been divided by genders in order to clarify if differences in bone parameters in males and females were separately present. Another strength was the sample size of 107 football players (71 males and 36 females) and 42 controls (20 males and 22 females). A large sample size compared to certain studies that evaluated bone geometry during growth (37 or 32 football players vs. 14 or 15 controls [8, 17]).

Conclusions

Overall, football practice during growth could potentially be a useful strategy for improving bone geometry and strength in females, and consequently, for reducing future osteoporotic problems during adulthood and elderly life. On the other hand, despite male football players showed higher bone geometry values in comparison with controls, there were no bone strength differences between them. Therefore, male football players should continue practicing this sport to get improvements in bone geometry as females did.

Acknowledgements The authors want to thank all the children, their parents, and football clubs (Real Zaragoza S.A.D.; Los Molinos U.D.; C.D. Marianistas; C.D. Transportes Alcaine and S.D. Ejea) that participated in the study for their understanding and dedication to the project. The authors also thank Adam Bracey for his work reviewing the English style and grammar.

Funding information This work was supported by the Spanish "Ministerio de Economia y Competitividad" (Project DEP 2012-32724)'. GLB received a grant FPU 2013 (FPU13/02111) from the "Ministerio de Educación, Cultura y Deporte". AML received a grant (AP2012/02854) from the "Ministerio de Educación, Cultura y

Deporte". AGB received a grant FPI 2012 (BES-2012-051888) from the "Ministerio de Economia y Competitividad".

Compliance with ethical standards

Conflicts of interest None.

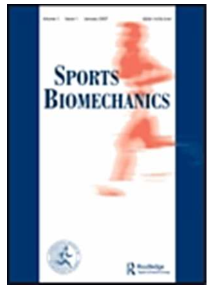
Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Pocock NA, Eisman JA, Hopper JL, Yeates MG, Sambrook PN, Eberl S (1987) Genetic determinants of bone mass in adults. A twin study. J Clin Invest 80:706–710. https://doi.org/10.1172/jci113125
2. Frost HM (1987) Bone "mass" and the "mechanostat": a proposal. Anat Rec 219:1–9. https://doi.org/10.1002/ar.1092190104
3. Nikander R, Sievanen H, Heinonen A, Daly RM, Uusi-Rasi K, Kannus P (2010) Targeted exercise against osteoporosis: a systematic review and meta-analysis for optimising bone strength throughout life. BMC Med 8(47). https://doi.org/10.1186/1741-7015-8-47
4. Falk B, Braid S, Moore M, Yao M, Sullivan P, Klentrou N (2010) Bone properties in child and adolescent male hockey and soccer players. J Sci Med Sport 13:387–391. https://doi.org/10.1016/j.jsams.2009.03.011
5. Pettersson U, Nordstrom P, Alfredson H, Henriksson-Larsen K, Lorentzon R (2000) Effect of high impact activity on bone mass and size in adolescent females: a comparative study between two different types of sports. Calcif Tissue Int 67:207–214. https://doi.org/10.1007/s00223000113
6. Ubago-Guisado E, Gomez-Cabello A, Sanchez-Sanchez J, Garcia-Unanue J, Gallardo L (2015) Influence of different sports on bone mass in growing girls. J Sports Sci 33:1–9. https://doi.org/10.1007/s002230001131
7. Tenforde AS, Fredericson M (2011) Influence of sports participation on bone health in the young athlete: a review of the literature. Pm R 3:861–867. https://doi.org/10.1016/j.pmrj.2011.05.019
8. Ferry B, Lespessailles E, Rochcongar P, Duclos M, Courteix D (2013) Bone health during late adolescence: effects of an 8-month training program on bone geometry in female athletes. Joint Bone Spine 80:57–63. https://doi.org/10.1016/j.jbspin.2012.01.006
9. Zouch M, Zribi A, Alexandre C, Chaari H, Frere D, Tabka Z, Vico L (2015) Soccer increases bone mass in prepubescent boys during growth: a 3-yr longitudinal study. J Clin Densitom 18:179–186. https://doi.org/10.1016/j.jocd.2014.10.004
10. Soderman K, Bergstrom E, Lorentzon R, Alfredson H (2000) Bone mass and muscle strength in young female soccer players. Calcif Tissue Int 67:297–303. https://doi.org/10.1007/s002230001149
11. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA (2004) High femoral bone mineral density accretion in prepubertal soccer players. Med Sci Sports Exerc 36:1789–1795. https://doi.org/10.1249/01.MSS.0000142311.75866.D7
12. Lozano-Berges G, Matute-Llorente Á, González-Agüero A, Gómez-Bruton A, Gómez-Cabello A, Vicente-Rodríguez G, Casajús JA (2017) Soccer helps build strong bones during growth: a systematic review and meta-analysis. Eur J Pediatr 177:295–310. https://doi.org/10.1007/s00431-017-3060-3
13. Sievanen H (2000) A physical model for dual-energy X-ray absorptiometry-derived bone mineral density. Investig Radiol 35:325–330. https://doi.org/10.1097/00004424-200005000-00007
14. Warden SJ, Fuchs RK (2009) Exercise and bone health: optimising bone structure during growth is key, but all is not in vain during ageing. Br J Sports Med 43:885–887. https://doi.org/10.1136/bjsm.2008.054866
15. Anliker E, Sonderegger A, Toigo M (2013) Side-to-side differences in the lower leg muscle-bone unit in male soccer players. Med Sci Sports Exerc 45:1545–1552. https://doi.org/10.1249/MSS.0b013e31828cb712
16. Varley I, Hughes DC, Greeves JP, Fraser WD, Sale C (2017) Increased training volume improves bone density and cortical area in adolescent football players. Int J Sports Med 38:341–346. https://doi.org/10.1055/s-0042-124510
17. Vlachopoulos D, Barker AR, Williams CA, Arngrimsson SA, Knapp KM, Metcalf BS, Fatouros IG, Moreno LA, Gracia-Marco L (2016) The impact of sport participation on bone mass and geometry in adolescent males. Med Sci Sports Exerc 47:317–326. https://doi.org/10.1249/MSS.0000000000001091
18. Ferry B, Duclos M, Burt L, Therre P, Le Gall F, Jaffre C, Courteix D (2011) Bone geometry and strength adaptations to physical constraints inherent in different sports: comparison between elite female soccer players and swimmers. J Bone Miner Metab 29:342–351. https://doi.org/10.1007/s00774-010-0226-8
19. Beck TJ (2007) Extending DXA beyond bone mineral density: understanding hip structure analysis. Curr Osteoporos Rep 5:49–55. https://doi.org/10.1007/s11914-007-0002-4
20. Crabtree NJ, Arabi A, Bachrach LK, Fewtrell M, El-Hajj Fuleihan G, Kecskemethy HH, Jaworski M, Gordon CM (2014) Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD Pediatric Official Positions. J Clin Densitom 17:225–242. https://doi.org/10.1016/j.jocd.2014.01.003
21. Weidauer L, Minett M, Negus C, Binkley T, Vukovich M, Wey H, Specker B (2014) Odd-impact loading results in increased cortical area and moments of inertia in collegiate athletes. Eur J Appl Physiol 114:1429–1438. https://doi.org/10.1007/s00421-014-2870-5
22. Nilsson M, Ohlsson C, Mellstrom D, Lorentzon M (2013) Sport-specific association between exercise loading and the density, geometry, and microstructure of weight-bearing bone in young adult men. Osteoporos Int 24:1613–1622. https://doi.org/10.1007/s00198-012-2142-3
23. Nikander R, Sievanen H, Uusi-Rasi K, Heinonen A, Kannus P (2006) Loading modalities and bone structures at nonweight-bearing upper extremity and weight-bearing lower extremity: a pQCT study of adult female athletes. Bone 39:886–894. https://doi.org/10.1016/j.bone.2006.04.005
24. Vandenbroucke JP, von Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, Poole C, Schlesselman JJ, Egger M, Initiative S (2007) Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med 4:e297. https://doi.org/10.1371/journal.pmed.0040297
25. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, Brasher PM (2015) Enhancing a somatic maturity prediction model. Med Sci Sports Exerc 47:1755–1764. https://doi.org/10.1249/MSS.0000000000000588
26. Julian Almarcegui C, Huybrechts I, Gomez Bruton A, Matute Llorente A, Gonzalez Aguero A, Gomez Cabello A, Moreno LA, Casajus JA, Vicente Rodriguez G (2015) Validity of a food-frequency questionnaire for estimating calcium intake in adolescent swimmers. Nutr Hosp 32:1773–1779. https://doi.org/10.3305/nh.2015.32.4.9490
27. Barr SI (1994) Associations of social and demographic variables with calcium intakes of high school students. J Am Diet Assoc

94(260–266):269; quiz 267-268–269. https://doi.org/10.1016/0002-8223(94)90366-2
28. Gomez-Bruton A, Gonzalez-Aguero A, Casajus JA, Vicente-Rodriguez G (2014) Swimming training repercussion on metabolic and structural bone development; benefits of the incorporation of whole body vibration or pilometric training; the RENACIMIENTO project. Nutr Hosp 30:399–409. https://doi.org/10.3305/nh.2014.30.2.7603
29. Hoffman M, Schrader J, Applegate T, Koceja D (1998) Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. J Athl Train 33:319–322
30. Adams JE, Engelke K, Zemel BS, Ward KA, Densitometry ISC (2014) Quantitative computer tomography in children and adolescents: the 2013 ISCD Pediatric Official Positions. J Clin Densitom 17:258–274. https://doi.org/10.1016/j.jocd.2014.01.006
31. Binkley TL, Specker BL, Wittig TA (2002) Centile curves for bone densitometry measurements in healthy males and females ages 5-22 yr. J Clin Densitom 5:343–353. https://doi.org/10.1385/JCD:5:4:343
32. Ingle BM, Hay SM, Bottjer HM, Eastell R (1999) Changes in bone mass and bone turnover following ankle fracture. Osteoporos Int 10:408–415. https://doi.org/10.1007/s001980050247
33. Schneider DL (2011) The complete book of bone health. Prometheus Books, New York
34. Seeman E (2002) An exercise in geometry. J Bone Miner Res 17:373–380
35. Bass SL, Saxon L, Daly RM, Turner CH, Robling AG, Seeman E, Stuckey S (2002) The effect of mechanical loading on the size and shape of bone in pre-, peri-, and postpubertal girls: a study in tennis players. J Bone Miner Res 17:2274–2280. https://doi.org/10.1359/jbmr.2002.17.12.2274
36. Daly RM (2007) The effect of exercise on bone mass and structural geometry during growth. Med Sport Sci 51:33–49. https://doi.org/10.1159/0000103003
37. Orwoll ES (2003) Toward an expanded understanding of the role of the periosteum in skeletal health. J Bone Miner Res 18:949–954. https://doi.org/10.1359/jbmr.2003.18.6.94
38. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA (1999) A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. J Bone Miner Res 14:1672–1679. https://doi.org/10.1359/jbmr.1999.14.10.1672



Lack of impact moderating movement adaptation when soccer players perform game specific tasks on a third-generation artificial surface without a cushioning underlay.

Journal:	*Sports Biomechanics*
Manuscript ID	RSPB-2018-0084.R1
Manuscript Type:	Original Research
Date Submitted by the Author:	n/a
Complete List of Authors:	Lozano-Berges, Gabriel; GENUD “Growth, Exercise, NUtrition and Development” research group. , Department of Physiatry and Nursing, Universidad de Zaragoza; Faculty of Health and Sport Sciences,, Department of Physiatry and Nursing, Universidad de Zaragoza Clansey, Adam; Spaulding Rehabilitation Hospital, Harvard Medical School Casajus, José ; GENUD “Growth, Exercise, NUtrition and Development” research group, Department of Physiatry and Nursing, Universidad de Zaragoza; Faculty of Health Sciences, Department of Physiatry and Nursing, Universidad de Zaragoza lake, mark J; Research Institute for Sport and Exercise Sciences, Liverpool John Moores University
Keywords:	3G surface, Kinematics < Movement, Kinetics < Movement, Soccer < Sports, Force Measurement < Methods

Abstract

The aim of this study was to investigate how the inclusion of a cushioning underlay in a third-generation artificial turf (3G) affects player biomechanics during soccer-specific tasks. Twelve soccer players (9 males/3 females; age 22.6±2.3 y) participated in this study. Mechanical impact testing of each 3G surface; without (3G-NCU) and with cushioning underlay (3G-CU) were tested. Impact force characteristics, joint kinematics and joint kinetics variables were calculated on each surface condition during the following tasks: a sprint 90º cut (90CUT), a sprint 180º cut (180CUT), a drop jump (DROP) and a sprint with quick deceleration (STOP). For all tasks, greater peak resultant force, maximum knee extensor moment and maximum ankle dorsi-flexion moment were found in 3G-NCU than 3G-CU ($p<0.05$). During 90CUT and STOP, loading rates were higher in 3G-NCU than 3G-CU ($p<0.05$). Additionally, higher hip, knee and ankle ranges of motion were found in the less cushioned surface during 180CUT ($p<0.05$). Overall these findings showed that the inclusion of cushioning underlay in 3G reduces impact loading forces and lower limb joint loading in soccer players across game-specific tasks. On average, participants were not attempting to reduce the higher lower limb impact loading associated with the surface without the cushioning underlay.

Keywords: 3G Surface, force measurements, kinematics, kinetic, soccer.

Introduction

Soccer is typically played on a natural grass surface, although this type of surface is limited by expensive maintenance costs during seasonal climate changes. Artificial turf was introduced to reduce these maintenance concerns and to help keep participation levels high all year round (FIFA, 2015). The evolution of the first-developed artificial turf to the present day, has seen some dramatic advancements with the inclusion of synthetic fibres with rubber particle and/or sand in-fill and sometimes the addition of shock attenuating underlayers that have all helped to emulate natural grass surfaces (Fleming, 2011). Third-generation artificial turfs (3G), introduced in the 1990s were aimed to simulate natural turf characteristics permitting, for instance, the use of studded soccer boots. The 3G systems are composed of monofilament or fibrillated long fibres (approximately a length of 40–65 mm) with a moderately low tuft density. Then surfaces are 'filled' with a sand layer at the base and rubber or elastomeric particles (e.g. recycled tyre) to help with player performance and comfort levels (Fleming, 2011). Moreover, a cushioning underlay may be included if the 3G system do not provide enough shock absorption (Fleming, 2011).

Previous studies have provided evidence that the mechanical characteristics of 3G systems and natural turf can be very closely matched (Livesay, Reda, & Nauman, 2006; Martinez, Dura, Gamez, Zamora, & Alcantara, 2004; Villwock, Meyer, Powell, Fouty, & Haut, 2009), however, factors such as maintenance, its rate of use and its configuration are found to be important in modifying the mechanical characteristics of 3G systems (Burillo, Gallardo, Felipe, & Gallardo, 2012). Importantly, when different types of 3G systems and their constitute components are compared, diverse mechanical characteristics have been found (Burillo et al., 2012; Sánchez-Sánchez, Felipe, Burillo, del Corral, & Gallardo, 2014; Sánchez-Sánchez et al., 2017). For example, one study showed that the inclusion of cushioning underlay in 3G systems increased mechanical shock absorption compared to a no underlay condition (Burillo et al., 2012). Consequently, these 3G systems with cushioning underlay would help to meet the Fédération Internationale de Football Association (FIFA) mechanical requirements (60-70% shock absorption) (FIFA, 2015) and ensure their safety. In another study, Sánchez-Sánchez et al. (2017) also reported that cushioning underlays in 3G systems increased shock absorption. In addition to these mechanical differences between surfaces conditions, biomechanical data is required to fully understand the effects that each surface condition has on the loads experienced by the body during a game of football and to highlight potential for differences in injury risk between surface.

Due to the important implications of 3G surface type and associated mechanical characteristics on injury risk and performance, some investigators have begun to examine the effects of surfaces with different cushioning conditions (i.e. the inclusion of a shock pad or different amount of infill) on biomechanics of players during dynamic game-like activities (Low & Dixon, 2016; McGhie & Ettema, 2013; Meijer, Dethmers, Savelberg, Willems, & Wijers, 2006). For instance, Low and Dixon (2016) investigated the influence of different cushioning underlay densities on heel impact during running and turning movements. Their results showed that low shock-pad densities (more cushioning) reduced forces acting on the heel. In another study by McGhie and Ettema (2013), the 3G system that had the thinnest layer of infill and no shock-pad demonstrated higher peak impact forces and lower time of contact than two different 3G conditions (one with shock-pad and another one without shock-pad and with a thicker layer of infill).

Although, previous findings suggest that the severity of impacts experienced by soccer players are greater on artificial surfaces without a cushioning underlay some studies reported no ground reaction force reductions with softer insoles (Nigg, Cole, & Bruggemann, 1995), higher loading rates in harder surfaces (V. H. Stiles, Guisasola, James, & Dixon, 2011) and, even, no correlations between the stiffness of the surface and peak impact force (Dixon, Batt,

& Collop, 1999; Nigg, 1990). In addition, Dixon et al. (2000) observed kinematic modifications between surfaces of different stiffness during running suggesting that surface characteristics might encourage joint mechanical adaptations of the players. While, Karamanidis et al. (2006) reported that differences in surface condition did not affect joint kinetics. Based on the previous evidence, there still appears to be ambiguity on how the player's lower limb joint kinetics and kinematics adapt during different dynamic, game-like movement tasks. For example, do players modify their movement strategies to keep lower limb loading levels to similar levels despite interacting with a surface with less cushioning properties (i.e. with no cushioning underlay)? Therefore, impact force characteristics and joint kinematic and kinetic adaptations as a whole might provide an greater insight into how the body might adapt biomechanically to reduced surface cushioning. In addition, with the association between greater impact forces and loading rates with overuse injury risk in athletes (Ferber, McClay-Davis, Hamill, Pollard, & McKeown, 2002; Hreljac, Marshall, & Hume, 2000) there is requirement for a further understanding how players adapt to different surfaces during different game-like movement tasks.

The aim of this study was to investigate the influence of a cushioning underlay on soccer player biomechanics (impact force, joint kinetics and movement characteristics) across a range of game-specific tasks. We hypothesised that greater peak resultant force, impulse during impact phase and resultant loading rate will be observed in a 3G surface without cushioning underlay (3G-NCU) than 3G with cushioning underlay (3G-CU) during all tasks. Therefore, players will increase mainly their ankle and knee ranges of motion (ROM) and moments to cope with the higher impact forces and keep them down to a similar manageable level (similar to when the cushioning layer is present).

Methods

Participants

Fifteen injury free soccer players (10 males and 5 females) were recruited for the present study. The inclusion criteria were that they had to be playing soccer for a period of at least a year prior to data collection and did not have any serious or major injuries to their lower limbs within the 6 months prior to testing. Before data collection all participants completed and signed an informed consent form approved by the Liverpool John Moores University Research Ethics Committee. Due to the quality of their data, three participants were excluded from the study. Therefore, a total of 12 players were included (9 males and 3 females; mean age 22.6 ± 2.3 years; height 174.9 ± 0.1 cm; 69.4 ± 13.4 kg) in the study analysis.

3G systems

A 3G system (type: monofilament; material: polypropylene, height: 40 mm, weight: 2 kg·m^{-2}; Direct Artificial Grass, United Kingdom) with styrene-butadiene rubber and quartz sand infill (infill characteristics were installed following the manufacturer guidelines) was used in the present study. Two artificial grass surface conditions were examined with and without the inclusion of a cushioning underlay (type: felt; thickness: 11 mm; weight: 1.42 kg·m^{-2}): 3G-NCU and 3G-CU. The cushioning underlay was placed under the entire 3G system (force platforms and its surroundings). Both 3G-NCU and 3G-CU systems were placed over and around two force platforms (90x60 cm, 9281B, Kistler Holding AG, Winterthur, Switzerland) and in a calibrated volume of a 10-camera opto-electronic motion capture system (Oqus 400, Qualisys AB, Gothenburg, Sweden) (see Figure 1).

Mechanical Properties of the 3G systems

Peak impact acceleration (g) of each 3G surface condition was measured using a standard impact test proposed by the American Society for Testing and Materials (ASTM, 2013). It has been shown that this standard test in a tennis shoe-surface combination supplied an accurate prediction of the impact attenuate ability (Dixon & Stiles, 2003). In brief, this procedure involved 10 pre-conditioning impact trials, followed by 20 impact trials on each surface system. Each trial consisted of dropping a weighted shaft (8 kg) 8 cm onto the 3G surface, with the impacting head of the shaft resembling the area of a human heel. For simulating running impacts, the impact velocity is typically around 1.0 $m \cdot s^{-1}$ (Lafortune & Lake, 1995) but, in order to more closely resemble highly dynamic tasks in soccer, an impact velocity of 1.25 $m \cdot s^{-1}$ was used in the present study. This impact testing showed 28 % greater peak acceleration in the 3G-NCU (17.0 ± 0.5 g) versus the 3G-CU surface condition (13.3 ± 0.3 g). Therefore, from a mechanical perspective the addition of a cushioning underlay reduced impact severity by 28 %.

Protocol

All participants wore standardised soccer shoes (Li-Ning Glory, Hong Kong, China), with a hard-ground stud design (30 studs) suitable for use on artificial surfaces. Data collections on the two types of 3G conditions were conducted on separate days (within a two-week period) in order to reduce to effects of fatigue. Prior to testing all participants performed a warm-up routine that consisted of 3 minutes of ankle, knee and hip articular mobilization, 5 minutes of low intensity cycling (Wattbike cycle ergometer, Wattbike Ltd, Nottingham, United Kingdom) and 5 sub-maximal familiarization trials of each task included in the experimental testing protocol. On each 3G condition, participants performed four different tasks; a sprint 90º cut (90CUT), a sprint 180º cut (180CUT), a drop jump (DROP) and a sprint followed by a quick deceleration (STOP). For each cutting task, participants were instructed to maximally sprint (4.5 m) and change direction when landing on the force platform (see Figure 1). Cutting and the stop tasks were performed after a 4.5 m approach runway. On average, seven acceptable trials of each task per participant-surface condition were used in the present study. Trials were discarded if participants did not land with their foot fully on the force platform or they did not cut to the required cutting angle outlined by gate posts. All participants performed the 90CUT, 180CUT and STOP with their dominant leg. The dominant leg was determined by players preferred kicking leg. For the STOP task participants had to start to decelerate with their dominant leg on the first force platform and they had to complete the stop within the next 2 steps. For the DROP task participants dropped off a 0.3 m box and landed with their feet in the middle of each force platform (mounted side-by-side (Figure 1)) before jumping vertically as high as they could. The initial landing phase of the DROP was analysed for the dominant leg only.

Biomechanical analyses

Forty-three retro-reflective, spherical markers (12 mm diameter) were placed on participant's seventh cervical vertebrae, manubrium, xiphoid process, left and right acromion, left and right posterior superior iliac spine, left and right superior iliac crest, left and right anterior superior iliac spine, lateral and medial femoral knee epicondyles, lateral and medial ankle malleoli, proximal and distal posterior heel, lateral heel and the fifth metatarsal head. Four marker cluster sets were mounted on rigid, lightweight thermoplastic plates and attached on the lateral aspect of participants shanks and thighs. In addition, virtual landmarks were created on the first metatarsal head using a digitised pointer (C-Motion, Inc., Germantown, Maryland, USA). Motion data were collected at 500 Hz using a 10-camera motion capture system. In synchronisation with the motion capture system, two force platforms capturing at 3000 Hz was embedded in the floor and situated in the centre of the calibrated volume (see figure 1).

Data analysis

All kinematic and kinetic data were processed and analysed in Visual 3D (C-Motion, Inc., Germantown, Maryland, USA). A 6-Degrees-of-Freedom eight segment model including feet, upper and lower legs, pelvis and trunk was constructed for each participant. The local segment coordinate systems of the pelvis, thigh, leg and foot were derived from a standing calibration trial. Hip joint centres were defined based on Bell and colleagues equation (Bell, Pedersen, & Brand, 1990). A cardan rotation sequence of x (flexion/extension), y (abduction/adduction), z (axial rotation) was used to calculate joint angles for the hip, knee and ankle (Cole, Nigg, Ronsky, & Yeadon, 1993). Lower limb joint kinematics and kinetics were positive for flexion/dorsi-flexion, abduction/eversion and internal rotation and extension/plantarflexion, adduction/inversion and external rotation were negative. All angles were normalised to an anatomical standing posture with feet comfortably apart, legs fully extended and pelvis and torso in a neutral position. Joint angles were referenced to coordinate systems embedded in the distal segment. Lower extremity 3D joint internal moments were calculated using a Newton–Euler inverse dynamics approach within the Visual 3D software. Internal joint moments at the ankle, knee and hip were calculated and reported in the coordinate system of the leg segment and were normalised to participant's body mass. The segmental data was based on Dempster's data (1955) and using geometrical volumes to represent each segment as cylinders or cones (Hanavan, 1964).

Initial foot contact and toe-off events were detected from the vertical ground reaction force using an ascending and descending threshold of 15 N. Motion data were filtered using a fourth order Butterworth (BW) low-pass filter at 15 Hz, while the force data were filtered at 60 Hz. For lower extremity joint moments we filtered both the force and motion data at the same cut-off frequency of 15 Hz using a fourth-order BW low-pass filter (Kristianslund, Krosshaug, & van den Bogert, 2012).

Instantaneous loading rates were determined from the resultant ground reaction force for each cutting and stop task. The instantaneous loading rate was calculated between 20-80% of initial contact to the first impact peak due to this period being the most linear part of the resultant GRF curve on landing (Milner, Ferber, Pollard, Hamill, & Davis, 2006). Impact peak and impulse of the resultant ground reaction force was also determined. Impulse was calculated (trapezium rule) during the impact phase. Impact phase was determined from the period of initial contact to first initial impact peak. Given that transient impact force characteristics are a measure of landing severity and the association of greater impact forces and loading rates with overuse injury risk in athletes (Ferber et al., 2002; Hreljac et al., 2000; Milner, Ferber, Pollard, Hamill, & Davis, 2006) the above impact force characteristics were deemed appropriate to be studied in the present paper.

Sagittal plane hip, knee and ankle joint ROM was determined from initial contact to maximum flexion during the stance phase. Peak lower extremity joint moments of the hip, knee and ankle were calculated in the sagittal and the frontal planes during the stance phase of each task. In addition, peak joint angular velocities were determined during the stance phase across each task. The reason for including lower extremity joint ROM, joint angular velocities and peak joint moment variables were due to them being important mechanisms for absorbing impact forces during the landing phase of ground contact (Clansey, Hanlon, Wallace, & Lake, 2012; Dufek & Bates, 1991; McNitt-Gray, 1993).

Following the methodology used in McGhie et al. (2013) study, approach velocity during 90CUT and STOP tasks was calculated (the first and the second pairs of photo cells were placed 1.5 and 0.5 m before the force platform, respectively).

Statistical analyses

The Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Data were presented as mean ± standard deviation. Kolmogorov-Smirnov tests were used to test normality in the distribution of the data for all outcome variables.

Paired *t* tests were performed to examine biomechanical differences between surface conditions using the mean result of all tasks performed by each participant. Effect size statistics using Cohen´s *d* were calculated. Taking into account cut-off points established by Hopkins et al. (Hopkins, Marshall, Batterham, & Hanin), the effect size for Cohen´s *d* can be trivial (0.0 – 0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0) or very large (> 2.0). Paired *t* test results and effect sizes of all comparisons are shown in Supplementary Table 1. Statistical significance was set at $p < 0.05$.

Results

Approach velocities, stance times and impact force characteristics

No significant approach velocity differences were found between 3G conditions during 90CUT (3G-NCU: 3.8 m/s vs 3G-CU: 4.0 m/s) and STOP tasks (3G-NCU: 4.6 m/s vs 3G-CU: 4.9 m/s). Stance times during all tasks were greater on 3G-NCU compared to 3G-CU (Table 1; percentage changes ranged from 8.9 to 11.9 %; $p < 0.05$; Cohens´*d* ranged from 0.37 to 0.95). Also, peak resultant impact force was significantly higher on 3G-NCU than 3G-CU during all tasks (Figure 2; percentage changes ranged from 37.4 to 59.8 %; $p < 0.05$; Cohens´*d* ranged from 1.02 to 1.18). Higher impulse during impact phase of stance was found in the 3G-NCU compared to 3G-CU surface condition during 90CUT, DROP and STOP (Figure 2; percentage changes ranged from 30.1 to 58.3 %; $p < 0.05$; Cohens´*d* ranged from 0.87 to 1.26). Instantaneous loading rates during 90CUT and STOP were also greater on 3G-NCU than 3G-CU surface condition (Figure 2; percentage changes were 48.3 to 42.5 %; p <

0.05; Cohens´*d* were 0.91 and 0.86 respectively). Moreover, STOP seems to be the most demanding task in terms of impact force characteristics because it showed the highest absolute magnitude of load and differences between 3G conditions in peak resultant force (1.79 N·kg), impulse during impact phase (0.04 N·s·kg) and resultant loading rate (Supplementary Table 1; 139.77 BW·s). Although the overall finding demonstrated that there were moderate increases in impact force variables on 3G-NCU condition, a large inter-participant variability in response to the different surface conditions was found (Figure 2).

Joint kinematics

During 180CUT task, hip flexion ROM, knee flexion ROM, ankle dorsi-flexion ROM and maximum ankle dorsi-flexion velocity on 3G-NCU were significantly higher than on 3G-CU condition (Table 1; percentage changes ranged from 7.8 to 33.1%; $p < 0.05$; Cohens´*d* ranged from 0.49 to 0.76). There were no significant differences in joint kinematics variables between surface conditions during 90CUT, DROP and STOP (Table 1; $p > 0.05$; Cohens´*d* ranged from 0.03 to 0.76).

Joint kinetics

Maximum knee and ankle extensor moments were significantly higher in all tasks for 3G-NCU compared to 3G-CU turf condition (Table 1; percentage changes ranged from 32.4 to 104.1 %; $p < 0.05$; Cohens´*d* ranged from 0.70 to 1.68). During DROP task, maximum hip extensor and maximum ankle abduction moments were significantly greater for 3G-NCU surface condition compared to the 3G-CU (Table 1; percentage changes were 77.5 to 155.1 %; $p < 0.05$; Cohens´*d* were 1.50 and 0.83, respectively). Additionally, higher maximum knee abduction moment during 90CUT was found on 3G-NCU compared to 3G-CU (Table 1; percentage changes were 119.6 %; $p < 0.05$; Cohens´*d* 0.91).

Discussion and implications

The main finding of the present study is that the inclusion of cushioning underlay increased cushioning of 3G-CU and, consequently, impact force characteristics (mainly peak resultant force and impulse during stance phase), joint kinematics (mainly knee and ankle ROM) and kinetics data (mainly maximum knee and ankle flexion moment) during turning, jumping or stopping were reduced in comparison with those performed in 3G-NCU. Despite these greater impact force values observed in 3G-NCU compared to 3G-CU during all tasks, a large inter-participant variability has been found between different surface conditions. Overall, the general hypothesis that cushioning underlays reduce impact force characteristics and kinetics data is confirmed. On the other hand, the hypothesis that players adapt their movement patterns to cope with higher impact forces is partially supported because of the lack of kinematics differences in DROP and STOP tasks. These greater impact forces found in 3G-NCU compared to 3G-CU could be associated with the incidence of injury. In fact, Woods et al. (2002) compared the number of soccer injuries during preseason and season and found a higher number of injuries during preseason and 70% of these injuries occurred when players played predominantly on a dry and hard surface. Although it has been demonstrated that runners who have experienced a stress fracture show no impact force differences compared to those without stress fractures (Zadpoor & Nikooyan, 2011), a study performed by Herljac et al. (2004) reported that high impact forces may be an important factor to have a greater risk of developing an injury during running. Therefore, based on the previous literature, and our present findings of greater impact forces across all tasks when playing without a cushioning underlay, it maybe that playing soccer on hard surfaces regularly (e.g. without a cushioning underlay), may put players at an increased risk of developing an overuse impact related injury.

Unlike previous published studies that did not show the greatest impact force with the hardest surface (V. H. Stiles & Dixon, 2006; V. H. Stiles et al., 2011), impact force data of this study support the obtained mechanical results (the highest impact forces were found on the surface with less shock absorption). Due to these confusing results obtained by these authors between mechanical data of the surfaces and impact forces received by the players, they suggested the assessment of dynamic stiffness as well as the measures of whole leg and/or joint torsional stiffness in order to understand the mechanical behaviour of the surface (Dixon & Stiles, 2003).

The rate of increase in the impact force is considered a more reliable and better indicator of the impact severity than the peak impact force (V. Stiles & Dixon, 2007). Although resultant loading rates were only higher on 3G-NCU than 3G-CU during 90CUT and STOP, greater but not significant resultant loading rate were found between these 3G conditions during the other tasks. The lack of differences found may be explained by participants increasing their lower limb joint ROM at the hip, knee and ankle in order to cushion the impact during the 180CUT and DROP tasks. Therefore, these adaptations could be considered as an attempt to moderate the impact severity.

The results on player joint kinematics, the present study demonstrated greater hip flexion ROM, knee flexion ROM, ankle dorsi-flexion ROM and maximum ankle dorsi-flexion angular velocity on the less cushioned surface (3G-NCU) during 180CUT. Previous studies showed joint adjustment (e.g. increments of knee flexion ROM) in order to reduce peak impact forces in less cushioned surface (Dixon, Collop, & Batt, 2005; Gerritsen, van den Bogert, & Nigg, 1995). Importantly, knee flexion ROM increased in less cushioned surfaces because of its important role to absorb and dissipate the load (Gerritsen et al., 1995). In fact, this ROM increment in less cushioned surface loads the knee extensors (Damm et al., 2013) and could increase the risk of suffering from patella-femoral pain (Gecha & Torg, 1988). On the other hand, although not significant, the hip, knee and ankle during most of the other soccer tasks showed greater ROM on 3G-NCU compared to 3G-CU. Overall, despite these findings demonstrated that players slightly adapted their lower extremity joint to cushion ground impacts because of the lack of cushioning underlay, percentage changes and effect sizes observed in kinematics variables are lower than those in impact force and kinetics data. Therefore, it seems that there is no conscious attempt to land slightly differently and/or to moderate the impact received.

Turning tasks such as 90CUT and 180CUT are highly influenced by the traction between the footwear and surface. Damm et al. (2013) reported that the higher knee flexion results obtained in the less cushioned surface are mainly explained by the traction instead of the cushioning of the surface. In contrast, this study found greater knee ROM in 3G-NCU compared to 3G-CU with the same level of traction (same footwear in both surfaces conditions). Thus, surface cushioning as well as its traction with the footwear should be considered due to their demonstrated influence in biomechanical parameters and the possible occurrence of musculoskeletal injuries.

In addition to the mentioned impact and kinematic findings, greater maximum knee flexion and maximum ankle dorsi-flexion moments were found in 3G-NCU than 3G-CU during all tasks. It has been demonstrated that high maximum knee extensor moment during vertical drop jump landings was associated with the increase of the risk of anterior cruciate ligament injury (Leppänen et al., 2017). In the current study, knee extensor moment was clearly reduced after the inclusion of the cushioning underlay and, therefore, the risk of anterior cruciate ligament injuries might be reduced. Moreover, greater maximum ankle dorsi-flexion moments were found in less cushioned surface condition during all tasks performed. Thus, soccer practice in hard surfaces increases ankle moments and therefore, the loading of this joint and the lengthening and shortening of triceps surae and Achilles tendon might be also increased. This provokes strain and stress in this tendon and, as Paavola (2001) suggested, if the tendon repeatedly experienced a tension between 4-8% of the maximum tension, Achilles tendon could be damaged. Although the above-mentioned references related joint moments and injury risk, the direct association between greater joint moments and injury risk still remains to be established.

The main limitation of this study is that the measurements were performed in a lab setting as opposed to a more ecological valid scenario (e.g. outside on a soccer pitch). However, the 3G surface was well replicated in the lab and the soccer manoeuvres were performed with no movement restrictions (e.g. large testing area). Moreover, FIFA tests could not be performed to assess mechanical properties of the 3G systems used in the present study and, consequently, no FIFA qualification were obtained. Although a power analysis revealed that the study had adequate statistical power (80%) to detect significant differences ($p<0.05$) between surface cushioning conditions, another limitation of this study is the relatively low sample size (n = 13). On the other hand, the main strength is that the analysis of different biomechanical variables such as impact, joint kinematics and joint kinetics data provide a valid notion about how a cushioning underlay potentially influences impact moderating behaviour in soccer players.

Conclusion

In summary, the results obtained in the present study demonstrated that the inclusion of cushioning underlay in 3G systems modified player and surface interaction across a range of soccer specific tasks. Overall the cushioning underlay reduced resultant impact force characteristics and lower limb joint loading across most of the soccer specific tasks. Importantly, it can be observed that findings of the present study were predominantly explained by the mechanical cushioning of each surface condition instead of any impact moderating behaviour of the player (small ROM adaptations only). Considering the strong association of greater impact forces and joint loading for overuse injury risk, the inclusion of a cushioning underlay within a game scenario may reduce the incidence of impact related injuries in soccer player populations.

Acknowledgements

The authors want to thank all soccer players that participated in the current study for their understanding and dedication to the project. The authors also thank Josh Dorkins and Liam O'Hare from Liverpool John Moores University for their contribution in data collection and analysis.

GLB received a Grant FPU 2013 (FPU13/02111) from the 'Ministerio de Educación, Cultura y Deporte'.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

American Society for Testing and Materials. (2013). *F1976-13, Standard Test Method for Impact Attenuation of Athletic Shoe Cushioning Systems and Materials*. West Conshohocken, PA: ASTM International.

Bell, A. L., Pedersen, D. R., & Brand, R. A. (1990). A comparison of the accuracy of several hip center location prediction methods. *Journal of Biomechanics, 23*(6), 617-621.

Burillo, P., Gallardo, L., Felipe, J. L., & Gallardo, A. M. (2012). Mechanical assessment of artificial turf football pitches: The consequences of no quality certification. *Scientific Research and Essays, 7*(28), 2457-2465.

Clansey, A. C., Hanlon, M., Wallace, E. S., & Lake, M. J. (2012). Effects of fatigue on running mechanics associated with tibial stress fracture risk. *Medicine and Science in Sports and Exercise, 44*(10), 1917-1923.

Cole, G. K., Nigg, B. M., Ronsky, J. L., & Yeadon, M. R. (1993). Application of the joint coordinate system to three-dimensional joint attitude and movement representation: a standardization proposal. *Journal of Biomechanical Engineering, 115*(4A), 344-349.

Damm, L., Low, D., Richardson, A., Clarke, J., Carré, M., & Dixon, S. (2013). The effects of surface traction characteristics on frictional demand and kinematics in tennis. *Sports Biomechanics, 12*(4), 389-402.

Dempster, W. T. (1955). *Space Requirements of the Seated Operator: Geometrical, Kinematic, and Mechanical Aspects of the Body with Special Reference to the Limbs*. Ohio, WA: Wright Air Development Center, Air Research and Development Command, U.S. Air Force.

Dixon, S. J., Batt, M. E., & Collop, A. C. (1999). Artificial playing surfaces research: a review of medical, engineering and biomechanical aspects. *International Journal of Sports Medicine, 20*(4), 209-218.

Dixon, S. J., Collop, A. C., & Batt, M. E. (2000). Surface effects on ground reaction forces and lower extremity kinematics in running. *Medicine and Science in Sports and Exercise, 32*(11), 1919-1926. doi:10.1097/00005768-200011000-00016

Dixon, S. J., Collop, A. C., & Batt, M. E. (2005). Compensatory adjustments in lower extremity kinematics in response to a reduced cushioning of the impact interface in heel–toe running. *Sports Biomechanics, 8*(1), 47-55.

Dixon, S. J., & Stiles, V. H. (2003). Impact absorption of tennis shoe-surface combinations. *Sports Engineering, 6*(1), 1-9.

Dufek, J. S., & Bates, B. T. (1991). Biomechanical factors associated with injury during landing in jump sports. *Sports Medicine, 12*(5), 326-337.

Ferber, R., McClay-Davis, I., Hamill, J., Pollard, C. D., & McKeown, K. A. (2002). Kinetic variables in subjects with previous lower extremity stress fractures. *Medicine and Science in Sports and Exercise, 334*(5), S5.

Fédération Internationale de Football Association. (2015). *FIFA Quality Programme for Football Turf. Handbook of Requirements*. Retrieved from https://football-technology.fifa.com/en/media-tiles/football-turf-handbook-of-requirements-2015/

Fleming, P. (2011). Artificial turf systems for sport surfaces: current knowledge and research needs. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 225*(2), 43-63.

Gecha, S. R., & Torg, E. (1988). Knee injuries in tennis. *Clinics in Sports Medicine, 7*(2), 435-452.

Gerritsen, K. G., van den Bogert, A. J., & Nigg, B. M. (1995). Direct dynamics simulation of the impact phase in heel-toe running. *Journal of Biomechanics, 28*(6), 661-668.

Hanavan, E. P. (1964). *A mathematical model of the human body*. Ohio, WA: Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Exercise in Sports & Exercise, 41*(1), 3-13.

Hreljac, A. (2004). Impact and overuse injuries in runners. *Medicine and Science in Sports and Exercise, 36*(5), 845-849.

Hreljac, A., Marshall, R. N., & Hume, P. A. (2000). Evaluation of lower extremity overuse injury potential in runners. *Medicine and Science in Sports and Exercise, 32*(9), 1635-1641.

Karamanidis, K., Arampatzis, A., & Bruggemann, G. P. (2006). Adaptational phenomena and mechanical responses during running: effect of surface, aging and task experience. *European Journal of Applied Physiology, 98*(3), 284-298.

Kristianslund, E., Krosshaug, T., & van den Bogert, A. J. (2012). Effect of low pass filtering on joint moments from inverse dynamics: implications for injury prevention. *Journal of Biomechanics, 45*(4), 666-671.

Lafortune, M. A., & Lake, M. J. (1995). Human pendulum approach to simulate and quantify locomotor impact loading. *Journal of Biomechanics, 28*(9), 1111-1114.

Leppänen, M., Pasanen, K., Krosshaug, T., Kannus, P., Vasankari, T., Kujala, U. M., . . . Parkkari, J. (2017). Sagittal Plane Hip, Knee, and Ankle Biomechanics and the Risk of Anterior Cruciate Ligament Injury: A Prospective Study. *Orthopaedic Journal of Sports Medicine, 5*(12), 2325967117745487.

Livesay, G. A., Reda, D. R., & Nauman, E. A. (2006). Peak torque and rotational stiffness developed at the shoe-surface interface: the effect of shoe type and playing surface. *American Journal of Sports Medicine, 34*(3), 415-422.

Low, D. C., & Dixon, S. J. (2016). The influence of shock-pad density and footwear cushioning on heel impact and forefoot loading during running and turning movements. *International Journal of Surface Science and Engineering, 10*(1), 86-98.

Martinez, A., Dura, J. V., Gamez, J., Zamora, R. T., & Alcantara, E. (2004). Artificial and natural turf: biomechanical differences between surfaces. Communications to the Fifth World Congress on Science and Football. *Journal of Sports Sciences, 22*, 485-593.

McGhie, D., & Ettema, G. (2013). Biomechanical analysis of surface-athlete impacts on third-generation artificial turf. *American Journal of Sports Medicine, 41*(1), 177-185.

McNitt-Gray, J. L. (1993). Kinetics of the lower extremities during drop landings from three heights. *Journal of Biomechanics, 26*(9), 1037-1046.

Meijer, K., Dethmers, J., Savelberg, H., Willems, P., & Wijers, B. (2006). Biomechanical Analysis of Running on Third Generation Artificial Soccer Turf. In E. Fozzy & S. Haake (Eds.), *The Engineering of Sport 6* (Vol. 1, pp. 29-34). New York, NY: Springer.

Milner, C. E., Ferber, R., Pollard, C. D., Hamill, J., & Davis, I. S. (2006). Biomechanical factors associated with tibial stress fracture in female runners. *Medicine and Science in Sports and Exercise, 38*(2), 323-328.

Nigg, B. M. (1990). The validity and relevance of tests used for the assessment of sports surfaces. *Medicine and Science in Sports and Exercise, 22*(1), 131-139.

Nigg, B. M., Cole, G. K., & Bruggemann, C. P. (1995). Impact Forces during Heel-Toe Running. *Journal of Applied Biomechanics, 11*(4). doi:10.1123/jab.11.4.407

Paavola, M. (2001). *Achilles tendon overuse injuries* (Doctoral dissetation). Retrieved from https://tampub.uta.fi/bitstream/handle/10024/67125/951-44-5122-8.pdf

Stiles, V. H., & Dixon, S. J. (2007). Biomechanical response to systematic changes in impact interface cushioning properties while performing a tennis-specific movement. *Journal of Sports Sciences, 25*(11), 1229-1239.

Stiles, V. H., & Dixon, S. J. (2006). The influence of different playing surfaces on the biomechanics of a tennis running forehand foot plant. *Journal of Applied Biomechanics, 22*(1), 14-24.

Stiles, V. H., Guisasola, I. N., James, I. T., & Dixon, S. J. (2011). Biomechanical response to changes in natural turf during running and turning. *Journal of Applied Biomechanics, 27*(1), 54-63.

Sánchez-Sánchez, J., Felipe, J. L., Burillo, P., del Corral, J., & Gallardo, L. (2014). Effect of the structural components of support on the mechanical behavior and the sport functionality of football fields of artificial turf. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology, 228*(3), 155-164.

Sánchez-Sánchez, J., Haxaire, P., García Unanue, J., Felipe, J. L., M., G. A., & Gallardo, L. (2017). Determination of mechanical properties of artificial turf football pitches according to structural components. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology.* doi:10.1177/1754337117717803

Villwock, M. R., Meyer, E. G., Powell, J. W., Fouty, A. J., & Haut, R. C. (2009). Football playing surface and shoe design affect rotational traction. *American Journal of Sports Medicine, 37*(3), 518-525.

Woods, C., Hawkins, R., Hulse, M., & Hodson, A. (2002). The Football Association Medical Research Programme: an audit of injuries in professional football-analysis of preseason injuries. *British Journal of Sports Medicine, 36*(6), 436-441.

Zadpoor, A. A., & Nikooyan, A. A. (2011). The relationship between lower-extremity stress fractures and the ground reaction force: a systematic review. *Clinical Biomechanics, 26*(1), 23-28. doi:10.1016/j.clinbiomech.2010.08.005

Table 1 Mean (SD) lower limb joint kinematics and kinetics for 90CUT, 180CUT, DROP and STOP across cushioning underlay conditions.

	90CUT		180CUT		DROP		STOP	
	3G-NCU	3G-CU	3G-NCU	3G-CU	3G-NCU	3G-CU	3G-NCU	3G-CU
Stance time (s)	0.34(0.04)*	0.30(0.04)	0.53(0.10)*	0.48(0.06)	0.53(0.10)*	0.49(0.09)	0.25(0.05)*	0.23(0.06)
Joint kinematics								
Hip ROM (deg)	9.6(1.2)	9.7(0.9)	31.0(2.0)*	26.1(1.7)	45.6(3.6)	42.3(3.9)	6.4(0.8)	7.6(0.9)
Knee ROM (deg)	40.4(1.8)	37.8(2.2)	46.8(2.1)*	43.4(1.9)	66.3(3.0)	63.3(4.3)	52.9(3.6)	58.2(4.3)
Ankle ROM (deg)	28.9(1.2)	25.6(2.3)	30.2(2.6)*	22.7(3.0)	44.7(2.3)	43.7(2.8)	30.4(1.8)	28.4(2.1)
Max knee flexion velocity (deg·s)	605.3(53.9)	587.0(48.7)	311.7(54.9)	306.0(54.3)	618.5(26.6)	599.7(29.6)	237.6(32.8)	216.0(26.2)
Max ankle dorsiflexion velocity (deg·s)	312.4(30.2)	345.5(59.4)	445.4(71.1)*	371.8(57.2)	702.8(39.2)	720.1(52.5)	411.7(45.1)	424.3(37.6)
Joint kinetics								
Max hip extensor moment (Nm·kg)	-5.7(0.9)	-4.0(0.3)	-2.9(0.5)	-2.9(0.3)	-3.5(0.4)*	-2.0(0.1)	-8.3(1.8)	-5.2(0.4)
Max knee extensor moment (Nm·kg)	-2.3(0.4)*	-1.6(0.2)	-2.4(0.3)*	-1.2(0.2)	-2.3(0.3)*	-1.5(0.1)	-2.1(0.2)*	-1.3(0.1)
Max ankle plantarflexion moment (Nm·kg)	-3.4(0.3)*	-2.4(0.1)	-2.5(0.2)*	-1.9(0.1)	-2.7(0.4)*	-1.8(0.1)	-3.4(0.4)*	-1.7(0.1)
Max hip abduction moment (Nm·kg)	6.0(1.5)	2.9(0.4)	6.1(1.5)	3.1(0.4)	1.2(0.2)	1.0(0.1)	0.7(0.1)	0.5(0.1)
Max knee abduction moment (Nm·kg)	3.7(0.9)*	1.7(0.2)	4.0(1.0)	1.9(0.3)	0.5(0.1)	0.5(0.1)	0.3(0.1)	0.3(0.1)
Max Ankle abduction moment (Nm·kg)	0.4(0.1)	0.5(0.1)	0.5(0.2)	0.5(0.1)	0.3(0.1)*	0.1(0.0)	0.7(0.1)	0.6(0.1)

Data are means (standard error). 90CUT: sprint 90º cut; 180CUT: sprint 180º cut; DROP: drop jump; STOP: sprint with quick deceleration; 3G-NCU: 3G turf system without cushioning underlay; 3G-NCU: 3G turf system with cushioning underlay; ROM: range of motion; max: maximum.
*Significance: * p<.05 between surface conditions.*

Figure 1 Experimental setup. Two 0.9 x 0.6 m force platforms (white rectangles) are situated in the centre of the three-dimensional recording volume. Dashed line represents a sprint 90º cut (90CUT), solid line represents a sprint 180º cut (180CUT) and dashed-dotted line represents a sprint with quick deceleration (STOP). 90CUT, 180CUT and STOP tasks were performed on force platform 1. For the STOP task participants started to decelerate on force platform 1.

Figure 2 Comparisons of peak resultant force (A), impulse stance during impact phase (B) and resultant loading rate (C) between with and without cushioning underlay conditions in each task separately. Each point represents the mean of each participant in each task and surface condition. 90CUT: a sprint 90º cut; 180CUT: a sprint 180º cut; DROP: a drop jump (DROP); STOP: a sprint with quick deceleration.

*: Significant differences were set at $p < 0.05$.

Figure 1 Experimental setup. Two 0.9 x 0.6 m force platforms (white rectangles) are situated in the centre of the three-dimensional recording volume. Dashed line represents a sprint 90º cut (90CUT), solid line represents a sprint 180º cut (180CUT) and dashed-dotted line represents a sprint with quick deceleration (STOP). 90CUT, 180CUT and STOP tasks were performed on force platform 1. For the STOP task participants started to decelerate on force platform 1.

423x332mm (72 x 72 DPI)

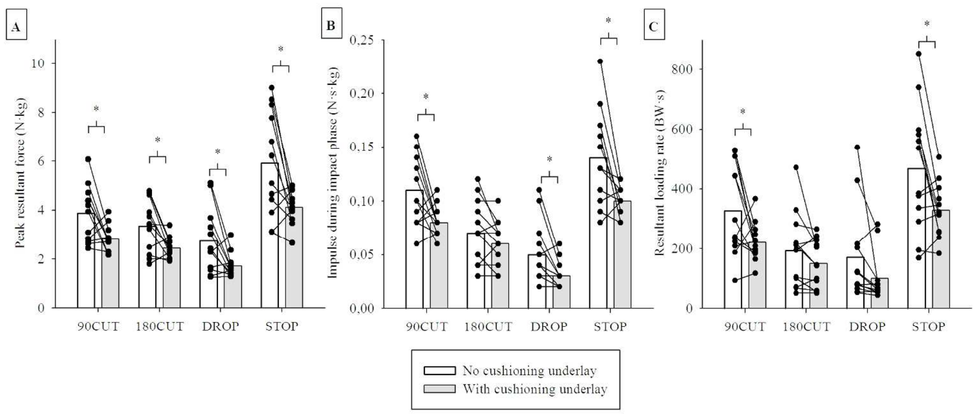


Figure 2 Comparisons of peak resultant force (A), impulse stance during impact phase (B) and resultant loading rate (C) between with and without cushioning underlay conditions in each task separately. Each point represents the mean of each participant in each task and surface condition. 90CUT: a sprint 90º cut; 180CUT: a sprint 180º cut; DROP: a drop jump (DROP); STOP: a sprint with quick deceleration. *: Significant differences were set at $p < 0.05$.

204x90mm (300 x 300 DPI)

Supplementary Table 1 Biomechanical differences between 3G-NEL and 3G-EL, their standard error, their output of paired t test and their effect size (*d*) for 90CUT, 180CUT, DROP and STOP.

		90CUT	180CUT	DROP	STOP
Stance times	MD (SE)	0.04(0.01), %=11.9	0.05(0.02), %=11.4	0.04(0.02), %=8.8	0.02(0.01), %=8.9
	Test statistic	*t*(11)=4.45, p=.001, *d*=0.95	*t*(11)=2.82, p=.017, *d*=0.66	*t*(11)=2.87, p=.015, *d*=0.48	*t*(11)=2.66, p=.022, d=0.37
Impact data					
Peak resultant force (N·kg)	MD (SE)	1.1(0.4), %=37.4	0.9(0,3), %=37.5	1,0(0,4), %=59.8	1.8(0.6), %=43.5
	Test statistic	*t*(11)=2.80, p=.017, *d*=1.18	*t*(11)=3.13, p=.010, *d*=1.12	*t*(11)=2.81, p=.017, *d*=102	*t*(11)=3.06, p=.011, *d*=1.13
Impulse during impact phase (N·s·kg)	MD (SE)	0.0(0.0), %=30.1	0.0(0.0), %=17.8	0.0(0.0), %=58.3	0.0(0.0), %=41.0
	Test statistic	*t*(11)=2.47, p=.031, *d*=1.00	*t*(11)=1.84, p=.092, *d*=0.43	*t*(11)=2.73, p=.020, *d*=0.87	*t*(11)=3.29, p=.007, *d*=1.26
Resultant loading rate (BW·s)	MD (SE)	106.7(46.3), %=48,3	42.8(24.3), %=28.6	70.2(39.3), %=70.2	139.8(52.4), %=42.5
	Test statistic	*t*(11)=2.31, p=.042, *d*=0.91	*t*(11)=1.77, p=.105, *d*=0.41	*t*(11)=1.79, p=.102, *d*=0.56	*t*(11)=2.67, p=.022, *d*=0.86
Joint kinematics data					
Hip ROM (degree)	MD (SE)	-0.1(1.3), %=-1.3	4.8(1.9), %=18.6	3.2(2.9), %=7.6	-1.2(0.7), %=-15.8
	Test statistic	*t*(11)=-0.09, p=.929, *d*=0.03	*t*(11)=2.62, p=.024, *d*=0.76	*t*(11)=1.11, p=.291, *d*=0.25	*t*(11)=-1.70, p=.118, *d*=-0.42
Knee ROM (degree)	MD (SE)	2.6(1.4), %=6.8	3.4(0.9), %=7.8	3.0(3.0), %=4.7	-5.3(2.6), %=-9.2
	Test statistic	*t*(11)=1.88, p=.087, *d*=0.37	*t*(11)=3.65, p=.004, *d*=0.49	*t*(11)=0.99, p=.342, *d*=0.23	*t*(11)=-2.02, p=.069, *d*=-0.39
Ankle ROM (degree)	MD (SE)	3.3(2.6), %=12.8	7.5(1.8), %=33.1	1.0(2.6), %=2.2	2.0(1.7), %=7.0
	Test statistic	*t*(11)=1.26, p=.234, *d*=0.51	*t*(11)=4.20, p=.001, *d*=0.76	*t*(11)=0.37, p=.717, *d*=0.11	*t*(11)=1.20, p=.254, *d*=0.29
Max knee flexion velocity (degree·s)	MD (SE)	18.3(37.9), %=3.1	5.6(22.7), %=1.8	18.8(19.9), %=3.1	21.6(19.3), %=10.0
	Test statistic	*t*(11)=0.48, p=.639, *d*=0.10	*t*(11)=0.25, p=.809, *d*=0.03	*t*(11)=0.95, p=.365, *d*=0.19	*t*(11)=1.12, p=.287, *d*=0.21
Max ankle dorsiflexion angular velocity (degree·s)	MD (SE)	-33.1(55.3), %=-9.6	73.6(28.0), %=19.8	-17.3(41.9), %=-2.4	-12.7(20.1), %=-3.0
	Test statistic	*t*(10)=-0.60, p=.562, *d*=-0.21	*t*(11)=2.63, p=.024, *d*=0.33	*t*(11)=-0.41, p=.687, *d*=-0.11	*t*(10)=-0.63, p=.542, *d*=-0.09
Joint kinetics data					
Hip max flexion moment (Nm·kg)	MD (SE)	-1.7(1.0), %=44.0	0.0(0.4), %=0.0	-1.5(0,4), %=77.5	-3.2(1.8), %=61.4
	Test statistic	*t*(11)=-1.80, p=.100, *d*=-0.75	*t*(11)=0,00, p=.998, *d*=0.00	*t*(11)=-3.69, p=.004, *d*=-1.50	*t*(11)=-1.77, p=.104, *d*=-0.71
Knee max flexion moment (Nm·kg)	MD (SE)	-0.7(0.3), %=44.5	-1.2(0.3), %=104.1	-0.8(0.2), %=55.4	-0.8(0.2), %=58.1
	Test statistic	*t*(11)=-2.40, p=.035, *d*=-0.70	*t*(11)=-4.50, p=.001, *d*=-1.43	*t*(11)=-3.61, p=.004, *d*=-1.18	*t*(11)=-4.45, p=.001, *d*=-1.37
Ankle max dorsiflexion moment (Nm·kg)	MD (SE)	-1.0(0.3), %=39.9	-0.6(0.2), %=32.4	-0.9(0.3), %=52.6	-1.7(0.4), %=100.9
	Test statistic	*t*(11)=-2.98, p=.013, *d*=-1.15	*t*(11)=-3.91, p=.002, *d*=-1.06	*t*(11)=-2.88, p=.015, *d*=-1.07	*t*(11)=-4.31, p=.001, *d*=-1.68
Hip max abduction moment (Nm·kg)	MD (SE)	3.1(1.4), %=106.2	3.1(1.4), %=100.1	0.2(0.2), %=15.9	0.1(0.1), %=19.0
	Test statistic	*t*(11)=2.15, p=.055, *d*=0.80	*t*(11)=2.17, p=.053, *d*=0.79	*t*(11)=0.90, p=.387, *d*=0.26	*t*(11)=0.70, p=.497, *d*=0.29
Knee max abduction moment (Nm·kg)	MD (SE)	2.0(0,9), %=119.6	2.0(0.9), %=105.5	0.0(0.1), %=-8.5	0.1(0.1), %=31.1
	Test statistic	*t*(11)=2.34, p=.039, *d*=0.91	*t*(11)=2.14, p=.055, *d*=0.80	*t*(11)=-0.62, p=.547, *d*=-0.12	*t*(11)=0.95, p=.364, *d*=0.33
Ankle max abduction moment (Nm·kg)	MD (SE)	-0.1(0.2), %=-24.0	0.0(0.2), %=9.5	0.2(0.1), %=155.1	0.1(0.1), %=11.3
	Test statistic	*t*(11)=-0.66, p=.521, *d*=-0.28	*t*(11)=0.22, p=.827, *d*=0.09	*t*(11)=2.30, p=.042, *d*=0.83	*t*(11)=0.49, p=.637, *d*=0.16

90CUT: sprint 90º cut; 180CUT: sprint 180º cut; DROP: drop jump; STOP: sprint with quick deceleration; 3G-NEL: third-generation artificial turf without elastic layer; 3G-NEL: third-generation artificial turf with elastic layer; MD: mean difference; SE: standard error; ROM: range of motion; max: maximum.

Plantar pressures in male adolescent footballers and its associations with bone geometry and strength

Authors: Gabriel LOZANO-BERGES[1,2,3], Ángel MATUTE-LLORENTE[1,2,3,4], Alejandro GÓMEZ-BRUTON[1,2,3,4], Víctor ALFARO-SANTAFÉ[5], Alex GONZÁLEZ-AGÜERO[1,2,3,4], Germán VICENTE-RODRÍGUEZ[1,2,3,4], José A. CASAJÚS[1,2,3,4]*

Affiliations:
[1]GENUD "Growth, Exercise, NUtrition and Development" research group, Universidad de Zaragoza, Zaragoza, Spain; [2]Faculty of Health and Sport Science (FCSD), Department of Physiatry and Nursing, Universidad de Zaragoza, Huesca, Spain; [3]Instituto Agroalimentario de Aragón-IA2-(Universidad de Zaragoza-CITA), Zaragoza, Spain; [4]Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn), Madrid, Spain; [5]Podoactiva, Huesca, Spain

***Corresponding author:** José A. Casajús, GENUD (Growth, Exercise, NUtrition and Development) Research Group. Faculty of Health Science, Department of Physiatry and Nursing, Universidad de Zaragoza, C/ Pedro Cerbuna Nº 12, 50009, Zaragoza, Spain. E-mail: joseant@unizar.es

ABSTRACT

BACKGROUND: Mechanical loads exerted by football-specific actions increase bone remodeling activity. Nevertheless, little is known about the relationship between plantar pressure and bone structure. Therefore, the aim of this study was to compare bone geometry and strength between football players who exhibited different maximum values of the average pressures (MP) when performing a combination of football-specific tasks.

METHODS: Forty male adolescent football players (mean age 13.2±0.5 y) participated in this study. Biofoot® system was used to measure MP at the non-dominant during a circuit of football-specific tasks. Cluster analysis was performed to classify players into groups of similar MP profiles resulting two different groups as follows: 15 players with high MP (FOOT-HP; mean MP: 392.7±68.2 kPa) and 25 with low MP (FOOT-LP; mean MP: 261.0±49.6 kPa). Total and cortical volumetric bone mineral content (Tt.BMC/Ct.BMC), cross-sectional area (Tt.Ar/Ct.Ar), cortical thickness (Ct.Th), fracture load in *X*-axis, and polar strength index (SSIp) were measured at 38% of the non-dominant tibia by peripheral quantitative computed tomography. Bone geometry and strength comparisons between FOOT-HP and FOOT-LP were performed using analyses of covariance controlling by weight and tibia length.

RESULTS: Greater Tt.BMC and Ct.BMC values were found in FOOT-HP compared to FOOT-LP (Tt.BMC: 3.04 vs 3.21 g, Ct.BMC: 2.76 vs 2.94 g; $p<.05$). Moreover, FOOT-HP showed higher but not significantly different Tt.Ar, Ct.Ar, Ct.Th, fracture load in *X*-axis and SSIp compared to FOOT-LP.

CONCLUSIONS: According to *Frost's mechanostat theory*, developing high MP when training and playing football might be favourable to bone development.

Key words: Adolescent, soccer, foot, bone and bones.

TEXT

Introduction

Osteoporosis has its clinical manifestations mainly through adulthood and old age. Nevertheless, childhood and adolescence are considered critical stages to gain bone mass and fight against this disease.[1] Peak bone accretion occurs at 12.5 years in females and at 14.1 years in males[2] and therefore, the prepubertal and peripubertal years are windows of opportunity for maximizing the response to exercise and osteoporosis prevention.[3]

Although peak bone mass is mainly determined by genetics (60-80% of peak bone mass), there are other parameters such as physical activity, nutrition, and hormones that may influence it.[4] For instance, physical exercise and its inherent impacts and muscle forces cause high mechanical strains to the bone and, at the same time, an increase of bone remodeling activity to reinforce the bone and to protect its structure.[5] Focusing on bone-exercise interactions, it is important to mention that not every sport produces the same effect on bone during growth. In fact, it has been observed that participation in high-impact sports such as football,[6, 7] basketball,[8] racquet games[9] is associated with a gain in bone mass; nevertheless, participation in nonimpact sports such as swimming,[10] cycling[11] do not present this association. Therefore, the effect on bone seems to be sport-dependent and is driven by the specific mechanical loads that sports demand. An option to quantify mechanical loading is measuring plantar pressures when executing different sports actions. This technique has been widely used in football research[12, 13] and provides an insight of the mechanical load intensity that the lower limbs receive during football practice. Although some biomechanical studies have analysed plantar pressures and their association with bone in young football players,[12, 14] these studies were only focused on stress fractures. Since plantar pressure is commonly measured, its association with bone structure could give further information about the effects of playing football on bone health status.

Because football practice is characterized by the repetition of several high-impact movements, the stress in different foot areas such as the 5^{th} metatarsal (one of the most common non-contact injuries in football[15]) increases, which may result in stress fractures. As Shuen et al.[15] reported, the type of surface or shoes and, more importantly, the intensity and the volume of football trainings might be the main factors determining those stress fractures. Thus, in terms of bone, an adequate training volume and intensity in young football players might avoid the above-mentioned fractures and improve bone parameters. To the best of our knowledge, there are no previous studies evaluating bone health of young football players based on their plantar pressures.

Therefore, the aim of the present study was to compare bone geometry and strength between male adolescent football players, taking into account their maximum values of the average pressures (MP) registered during a combination of football-specific tasks. We hypothesized that football players with higher plantar pressures (FOOT-HP) will exhibit better bone geometry and greater bone strength compared to those with lower plantar pressures (FOOT-LP).

Materials and methods

Participants

Forty-four male football players from five different football clubs of Aragon (Spain) agreed to participate in the present study. Four football players were excluded from the analysis as they were not Caucasian. Finally, a total of 40 football players (mean age: 13.2 ± 0.5 y) were included in the study analysis. After performing hierarchical and K-means cluster analyses (see statistical analyses), these players were split into two groups according to their MP, registered in five areas of their non-dominant foot during a combination of game-specific tasks: 15 FOOT-HP (mean age: 13.1 ± 0.4 years, mean MP of the all foot areas: 392.7 ± 68.2 kPa; Table I) and 25 FOOT-LP (mean age: 13.3 ± 0.5 years, mean MP of the all foot areas: 261.0 ± 49.6 kPa; Table I). Moreover, these football players had different foot types (16 players with normal foot, 14 with high arch, and 16 with flat foot). Measurements took place between May and July 2014.

Although the five football teams did not perform exactly the same football exercises, their trainings lasted approximately 90 min, including 5-min warm-up consisting of low-intensity running; 5-10 min of low-intensity games; 60 min of technical football exercises (i.e. passing, kicking, running, dribbling); and finally, 5-10 min of cool down performing stretching exercises. On the other hand, these football clubs competed at provincial level for their age category.

The protocol, and the possible benefits and risks of this study were explained to participants, parents and club managers. Before taking any data, all participants gave verbal assent and parents fulfilled and signed a written informed consent. This study was performed following the guidelines declaration of Helsinki 1961 (revision of Fortaleza 2013) and the protocol was approved by the Ethics Committee of Clinical

Research from the Government of Aragon (CEICA, Spain) [C.I. PI13/0091]. The present study is a part of the FUTBOMAS project, which was registered in the public database Clinicaltrials.gov [NCT02399553]. The STrengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement was used as a guideline for reporting observational data.[16]

Inclusion criteria

Participants had to be Caucasian, playing soccer for a period of at least one year prior to data collection, between 11 and 14 years at the beginning of the FUTBOMAS project, and free of any medication affecting bone.

Anthropometric measurements

Following the procedures defined by the International Society for Advancement in Kinanthropometry (ISAK),[17] height (stadiometer SECA 225. SECA. Hamburg, Germany; to the nearest 0.1 cm) and weight (scale SECA 861. SECA. Hamburg, Germany; to the nearest 0.1 kg) were measured without shoes and with minimal clothes.

Maturity offset

Maturity offset was calculated using the following equation proposed by Moore et al.:[18]

Maturity offset = -7.999994 + (0.0036124 x (age x height))

Additionally, the age of peak height velocity was calculated as the subtraction of the age from maturity offset.

Calcium intake

A validated calcium food frequency questionnaire was used to estimate milligrams per day of calcium intake.[19]

Protocol

Participants wore football shoes (Adidas Nitrocharge 3.0 football shoes, Adidas AG, Herzogenaurach, Germany) with two different stud designs suitable for use on artificial surfaces: 11 football players wore a turf stud design (71 studs) and 29 football players wore a hard-ground stud design (22 studs).

All participants performed a warm-up that consisted of approximately three minutes of lower limb articular mobilization (hip, knee and ankle) and two sub-maximal familiarization trials of the combination of some football-specific tasks. This circuit was composed of three two-footed jumps of 30-cm hurdles, a zigzag run around four poles, a lateral shuffle and two sprints separated by a 90º cut (see Figure 1). Before starting the test, participants were sitting on a chair putting their feet up to avoid plantar pressure interferences. They were instructed to perform two trials at maximum speed resting approximately two min between them. The trial with the highest MP was included in the present study.

Plantar pressure measurements

Biofoot® (IBV, Valencia, Spain) system was used to measure MP of both feet. This system is composed of two insoles that are connected to two amplifiers located on the lateral aspect of participants' shanks. At the same time, these amplifiers are linked with a transmission module that is located on the participant waist (at lower back) and sends the data to the computer by digital telemetry. These thin (0.7 mm thickness), flexible and polyester insoles are size-specific and have 64 piezoelectric sensors distributed along the foot. This system uses kilopascal units (kPa) and the sample frequency was set up at 100 Hz for 15 s.

Plantar pressures of the non-dominant foot were analysed as bone measurements were performed at this side. Following manufacturer's software instructions (version 6.1), plantar pressures were analysed in the following five areas of the foot: lateral foot, medial foot, forefoot, midfoot and rearfoot (Figure 2). The plantar pressure variable selected for each one of the 5 foot areas was MP. Firstly, the software computed for each step the mean of the maximum pressure measured by each sensor of a determined area; afterwards, the final data obtained represents the average maximum value of all steps during the whole circuit.

Bone assessment by peripheral quantitative computed tomography (pQCT)

Volumetric bone mineral content (BMC), bone area and bone strength indexes were assessed at the non-dominant tibia with a Stratec XCT-2000 L pQCT scanner (Stratec Medizintechnik, Pforzheim, Germany). This device is a translate-rotate, small bore computed tomography scanner that acquires a trans-axial image. pQCT equipment was calibrated daily using a quality control phantom and following the manufacturer guidelines (Stratec Medizintechnik, Pforzheim, Germany). Coefficients of variation for each pQCT variable in our laboratory have been already published.[20]

The lower limb dominance was determined by players preferred kicking leg.[21] Although the measurement of non-dominant or dominant lower limb has not been clarified yet in pQCT studies,[22] adolescent football players showed higher bone strength indexes at non-dominant tibia than at dominant tibia.[23] Azevedo et al.[12] also reported greater plantar pressures at the non-dominant foot; accordingly, the non-dominant lower limb was selected for the measurements.

Participants were seated on a chair adjustable to the body proportions of each participant. The tibia length was assessed from the medial knee joint cleft to the medial malleolus of the tibia using a wooden ruler and was always measured by the same researcher (AML). Then, the non-dominant lower limb was centred in the imaging field, and the foot and knee were secured to reduce movement. Once the scanner was positioned on the distal tibia, a scout view was done to manually set the reference line on the midpoint of the distal tibia end plate. Scans were performed at 38% site of the length of the tibia to assess cortical bone and bone strength indexes. Following the International Society of Clinical Densitometry (ISCD) official positions,[22] the measured parameters at the 38% site of the length of the tibia were total BMC (Tt.BMC, g), cortical BMC (Ct.BMC, g), total area (Tt.Ar, mm^2), cortical area (Ct.Ar, mm^2), cortical thickness (Ct.Th, mm), fracture load in *X*-axis (N) and polar strength strain index (SSIp, mm^3). Muscle and fat cross sectional areas (mm^2) were measured at the 66% site of the length of the tibia.

Version 6.20 of the manufacturer's software was used to analyse pQCT images. At 38% site of the tibia, the periosteal surface of the bone was determined using the contour mode 1 with a threshold of 280 mg/cm^3. Cortical bone was obtained using cortical mode 1 with a threshold of 710 mg/cm^3. To obtain bone strength variables (fracture load in *X*-axis and SSIp), cortical mode 1 with a threshold of 280 mg/cm^3 was used. After that, bone mineralization of 1200 mg/cm^3 was assumed.

Statistical analyses

The Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Data were presented as mean ± standard deviation (SD). All variables showed normal distribution tested with the Shapiro-Wilk test.

Cluster analysis was performed to identify groups of football players with similar MP. Following the methodology of clustering applied in Prokasky et al.[24] and Sanson et al.[25] studies, hierarchical clustering and K-means clustering were used. Firstly, to reduce the sensitivity of the Ward's method to outliers, univariate (those that were > 3 SD above or below the mean) and multivariate outliers (those that had high Mahalanobis distance) for MP at each foot area were examined, and no outliers were found. In the first step, hierarchical cluster analysis was performed to determine the number of clusters. After examining the dendrogram obtained from this analysis, the suggested number of clusters were two. In the second step, K-means clustering analysis was applied using as non-random starting points the cluster centres obtained by the previous Ward's hierarchical procedure.

In order to test the stability of these clusters, cluster analysis was repeated in two subsamples randomly obtained from the whole sample of this study. Afterwards, Cohen's Kappa coefficient (κ) was used to measure the agreement between the original cluster obtained from the whole sample with the merger of the new two clusters created by subsamples. This comparison showed an excellent agreement (Cohen's Kappa coefficient was 1).

Independent *t* tests were performed to examine differences between football groups for descriptive characteristics and MP measured at different foot areas (lateral, medial, rearfoot, midfoot and forefoot). Furthermore, analyses of covariance (ANCOVAs) were applied to compare bone geometry and strength variables between the two football groups using weight and the length of the tibia as covariates.

Effect size statistics were reported as Cohen´s *d* for independent *t* tests and partial eta squared (η^2_p) for ANCOVAs. Taking into account cut-off points established by Hopkins et al.,[26] the effect size for Cohen´s *d* can be trivial (0.0 – 0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0) or very large (> 2.0). Additionally, the effect size for η^2_p can be small (0.01 – 0.06), medium (0.06 – 0.14) or large (>0.14). Statistical significance was set at $p < .05$.

Results

Despite the different type of foot and stud design used, no proportion differences between football players with different type of foot ($\chi^2(2) = 0.770$, $p = .681$) and who wore different stud designs ($\chi^2(1) = 0.677$, $p = .411$) were found. Furthermore, no significant MP differences were found in any foot area when football players who had different foot type and those who wore different stud designs were compared (Supplementary Table I and II).

No descriptive differences were found between FOOT-HP and FOOT-LP ($p > .05$; Cohen's *d* ranged from 0.01 to 0.62; Table I). In contrast, FOOT-HP showed higher MP at the lateral foot, medial foot, rearfoot and forefoot compared to FOOT-LP ($p < .05$; Cohen's *d* ranged from 0.86 to 2.56; Table I). Additionally, when MP comparisons between FOOT-HP and FOOT-LP were adjusted by weight, similar results were found (Supplementary Table III).

Table II shows the adjusted pQCT values of FOOT-HP and FOOT-LP, the statistics of the comparisons between these groups and their mean differences (%). Tt.BMC and Ct.BMC were significantly greater in FOOT-HP compared to FOOT-LP (mean differences were -5.4 and -5.9%; $p < .05$; η^2_p were 0.11 and 0.14 respectively; Table II). No significant differences were found in the other pQCT variables ($p > .05$; η^2_p ranged from 0.03 and 0.14; Table II).

Discussion

The present study shows that adolescent footballers with higher plantar pressures present enhanced Tt.BMC and Ct.BMC when compared to those with low pressures. However, bone strength indexes are not different between groups. Thus, the hypothesis that FOOT-HP will exhibit better bone geometry and greater bone strength indexes is partially confirmed.

Although a positive association between high plantar pressures and bone parameters is elucidated, the findings related to bone strength indexes could be slightly mediated by bone growth. Cortical bone and bone strength parameters regularly increase until the age of 14 years in males and, afterward, these parameters abruptly increase.[27] As only three FOOT-LP had just achieved this age, future studies including a sample of football players older than 14 years could help to clarify if these bone differences between football players with different plantar pressures can be observed in later ages.

The main response of bones to physical exercise in both male prepubertal or pubertal athletes is periosteal apposition increasing, at the same time, Tt.Ar, Ct.Ar, Ct.Th and bending and torsional forces.[28] In the present study, higher but not significant differences at Tt.Ar, Ct.Ar, Ct.Th, fracture load in X-axis and SSIp between FOOT-HP and FOOT-LP were found. In addition to this, the lack of differences between football groups could be also explained by the fact that both groups did similar football exercises with a similar amount of impacts, and probably, had comparable enhancements of the bone. Therefore, both groups might have benefited from the effects of football practice on bone.

As Frost explained,[29] high intensity strains (i.e. football actions) increase bone remodeling activity resulting in bone adaptations to loads. Additionally, the intensity of these strains may provoke different bone adaptations.[29] For instance, a study performed with young football players[23] showed higher bone parameters at their non-dominant lower limb compared to their dominant one. In terms of football practice, the non-dominant lower limb supports each action performed by dominant one (skilled lower limb), meaning that mechanical strains received by each lower limb are different (higher in non-dominant lower limb). The present study shows that football players receiving higher mechanical strains have higher bone geometry which is in agreement with the mechanostat theory and previous studies developed in football players.[23, 29]

A stress fracture is defined by Warden et al.[30] as "*the inability of the skeleton to withstand repetitive bouts of mechanical loading, which results in structural fatigue and resultant signs and symptoms of localized pain and tenderness*". This type of fracture is a common overuse injury in athletes[31] and, specifically, in football, the fracture of the fifth metatarsal is one of the most frequent stress fractures[32] being the non-dominant foot the most affected one [33]. These fractures are due to extrinsic (i.e. sport, type of surface, training duration) and intrinsic factors (i.e. body composition, biomechanics).[30]

With regards to football players included in the present study, the absence of stress fractures prior to measurements could be explained by their low exposure time to football practice (FOOT-HP: 5 ± 2 training years and 3.1 ± 1.2 hours per week; FOOT-LP: 6 ± 2 training years and 4.0 ± 1.6 hours per week). As they grow up, it is expected that they will play in upper categories and, probably, they will train more hours and at higher intensity. It has been demonstrated that an increase of football training volume enhances bone density and cortical bone area;[34] nevertheless, the possibility of having a stress fracture might also increase. Thus, the measurement of plantar pressures could provide information about which players have an increased risk of stress fracture and even, in which foot sites these fractures are more probably to occur.

The main limitations of the present study are that football players wore shoes with different stud designs and they had different foot types. Despite this, neither MP nor proportion differences were found between these football players with different foot type and stud designs (Supplementary Table I and II). Although, the total sample size of male football players in the present study (n = 40) was lower compared to those in other pQCT studies (99[34] or 71 male football players[35]), this sample size was higher than those in studies measuring plantar pressures (15[12] or 21[14]). On the other hand, the main strength is that this is the first study comparing bone geometry and strength based on biomechanical parameters such as plantar pressures.

Conclusions

In summary, the present study shows that adolescent football players with higher plantar pressures have better bone geometry than those players with lower plantar pressures. Thus, measurement of plantar pressures might provide a general insight of which is the bone health status of football players. Overall, mechanical loading produced by football-specific actions increases bone development; nevertheless, an excessive repetition of these high-intensity loadings could also increase the risk of stress fracture in lower limbs. Thus, adequate training volume (both training frequency and duration of these trainings) and rest between sessions might prevent from stress fractures without hindering the potential benefit of football practice on bone.

REFERENCES

1. Theintz G, Buchs B, Rizzoli R, Slosman D, Clavien H, Sizonenko PC, et al. Longitudinal monitoring of bone mass accumulation in healthy adolescents: evidence for a marked reduction after 16 years of age at the levels of lumbar spine and femoral neck in female subjects. J Clin Endocrinol Metab 1992;75(4):1060-5.
2. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA. A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. J Bone Miner Res 1999;14(10):1672-9.
3. Going SB, Farr JN. Exercise and Bone Macro-architecture: Is Childhood a Window of Opportunity for Osteoporosis Prevention? Int J Body Compos Res 2010;8:1-9.
4. Davies JH, Evans BA, Gregory JW. Bone mass acquisition in healthy children. Arch Dis Child 2005;90(4):373-8.
5. Parfitt AM. The two faces of growth: benefits and risks to bone integrity. Osteoporos Int 1994;4(6):382-98.
6. Lozano-Berges G, Matute-Llorente Á, González-Agüero A, Gómez-Bruton A, Gómez-Cabello A, Vicente-Rodríguez G, et al. Soccer helps build strong bones during growth: a systematic review and meta-analysis. Eur J Pediatr 2018;177(3):295-310.
7. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA. High femoral bone mineral density accretion in prepubertal soccer players. Med Sci Sports Exerc 2004;36(10):1789-95.
8. Agostinete RR, Lynch KR, Gobbo LA, Lima MC, Ito IH, Luiz-de-Marco R, et al. Basketball Affects Bone Mineral Density Accrual in Boys More Than Swimming and Other Impact Sports: 9-mo Follow-Up. J Clin Densitom 2016;19(3):375-81.
9. Sanchis-Moysi J, Dorado C, Olmedillas H, Serrano-Sanchez JA, Calbet JA. Bone mass in prepubertal tennis players. Int J Sports Med 2010;31(6):416-20.
10. Gomez-Bruton A, Montero-Marin J, Gonzalez-Aguero A, Garcia-Campayo J, Moreno LA, Casajus JA, et al. The Effect of Swimming During Childhood and Adolescence on Bone Mineral Density: A Systematic Review and Meta-Analysis. Sports Med 2016;46(3):365-79.

11. Olmedillas H, Gonzalez-Aguero A, Moreno LA, Casajus JA, Vicente-Rodriguez G. Cycling and bone health: a systematic review. BMC Med 2012;10:168.
12. Azevedo RR, da Rocha ES, Franco PS, Carpes FP. Plantar pressure asymmetry and risk of stress injuries in the foot of young soccer players. Phys Ther Sport 2017;24:39-43.
13. Queen RM, Charnock BL, Garrett WE, Hardaker WM, Sims EL, Moorman CT. A comparison of cleat types during two football-specific tasks on FieldTurf. Br J Sports Med 2008;42(4):278-84; discussion 84.
14. Eils E, Streyl M, Linnenbecker S, Thorwesten L, Volker K, Rosenbaum D. Characteristic plantar pressure distribution patterns during soccer-specific movements. Am J Sports Med 2004;32(1):140-5.
15. Shuen WM, Boulton C, Batt ME, Moran C. Metatarsal fractures and sports. Surgeon 2009;7(2):86-8.
16. Vandenbroucke JP, von Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. PLoS Med 2007;4(10):e297.
17. Marfell-Jones M, Olds T, Stewart A, Carter L. International standards for anthropometric assessment. Potchefstroom, South Africa: International Society for the Advancement of Kinanthropometry; 2006.
18. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, et al. Enhancing a Somatic Maturity Prediction Model. Med Sci Sports Exerc 2015;47(8):1755-64.
19. Julián Almárcegui C, I Huybrechts, A Gómez Bruton, Á Matute Llorente, A González Agüero, A Gómez Cabello, et al. Validity of food-frequency questionnaire for estimating calcium intake in adolescent swimmers. Nutr Hosp 2015;32(4):1773-9.
20. Gomez-Bruton A, Gonzalez-Aguero A, Casajus JA, Vicente-Rodriguez G. Swimming training repercussion on metabolic and structural bone development; benefits of the incorporation of whole body vibration or pilometric training; the RENACIMIENTO project. Nutr Hosp 2014;30(2):399-409.
21. Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. J Athl Train 1998;33(4):319-22.

22. Adams JE, Engelke K, Zemel BS, Ward KA, International Society of Clinical Densitometry. Quantitative computer tomography in children and adolescents: the 2013 ISCD Pediatric Official Positions. J Clin Densitom 2014;17(2):258-74.
23. Anliker E, Sonderegger A, Toigo M. Side-to-side differences in the lower leg muscle-bone unit in male soccer players. Med Sci Sports Exerc 2013;45(8):1545-52.
24. Prokasky A, Rudasill K, Molfese VJ, Putnam S, Gartstein M, Rothbart M. Identifying child temperament types using cluster analysis in three samples. J Res Pers 2017;67:190-201.
25. Sanson A, Letcher P, Smart D, Prior M, Toumbourou J, Oberklaid F. Associations between Early Childhood Temperament Clusters and Later Psychosocial Adjustment. Merrill Palmer Q 2008;55(1):26-54.
26. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 2009;41(1):3-13.
27. Binkley TL, Specker BL, Wittig TA. Centile curves for bone densitometry measurements in healthy males and females ages 5-22 yr. J Clin Densitom 2002;5(4):343-53.
28. Orwoll ES. Toward an expanded understanding of the role of the periosteum in skeletal health. J Bone Miner Res 2003;18(6):949-54.
29. Frost HM. The mechanostat: a proposed pathogenic mechanism of osteoporoses and the bone mass effects of mechanical and nonmechanical agents. Bone Miner 1987;2(2):73-85.
30. Warden SJ, Burr DB, Brukner PD. Stress fractures: pathophysiology, epidemiology, and risk factors. Curr Osteoporos Rep 2006;4(3):103-9.
31. Iwamoto J, Takeda T. Stress fractures in athletes: review of 196 cases. J Orthop Sci 2003;8(3):273-8.
32. Ekstrand J, Torstveit MK. Stress fractures in elite male football players. Scand J Med Sci Sports 2012;22(3):341-6.
33. Fujitaka K, Taniguchi A, Isomoto S, Kumai T, Otuki S, Okubo M, et al. Pathogenesis of Fifth Metatarsal Fractures in College Soccer Players. Orthop J Sports Med 2015;3(9):2325967115603654.

34. Varley I, Hughes DC, Greeves JP, Fraser WD, Sale C. Increased Training Volume Improves Bone Density and Cortical Area in Adolescent Football Players. Int J Sports Med 2017;38(5):341-6.

35. Lozano-Berges G, Matute-Llorente A, Gomez-Bruton A, Gonzalez-Aguero A, Vicente-Rodriguez G, Casajus JA. Bone geometry in young male and female football players: a peripheral quantitative computed tomography (pQCT) study. Arch Osteoporos 2018;13(1):57.

NOTES

Conflicts of interest. The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Funding. This work was supported by the Spanish “Ministerio de Economia y Competitividad” (Project DEP 2012-32724)’. GLB received a Grant FPU 2013 (FPU13/02111) from the “Ministerio de Educación, Cultura y Deporte”.

Authors’ contributions. JAC designed the study. GLB, AML, AGB, VAS and AGA performed experiments. GLB, AML, AGA and JAC analysed the data. GLB, AML, AGB, VAS, AGA, GVR and JAC wrote the paper. All authors approved the manuscript.

Acknowledgements. The authors want to thank all the children, their parents and football clubs (Real Zaragoza S.A.D.; Los Molinos U.D.; C.D. Marianistas and S.D. Ejea) that participated in the study for their understanding and dedication to the project.

Table I. Descriptive characteristics and maximum values of the average pressure of football players with low and high plantar pressures.

	FOOT-LP (n = 25)	FOOT-HP (n = 15)	Cohen's *d*
Descriptive characteristics			
Age (y)	13.3 ± 0.5	13.1 ± 0.4	0.43
Weight (kg)	46.4 ± 11.6	49.0 ± 9.9	0.24
Height (cm)	155.5 ± 8.6	157.9 ± 9.0	0.28
BMI ($kg \cdot m^{-2}$)	19.0 ± 3.1	19.6 ± 3.3	0.19
Tibia length (mm)	351 ± 21	361 ± 22	0.47
Muscle CSA (mm^2)	5370 ± 1100	5692 ± 835	0.33
Fat CSA (mm^2)	1870 ± 721	2123 ± 1057	0.28
Daily calcium intake (mg)	787.9 ± 374.2	731.4 ± 211.5	0.19
Maturity offset (y)	-0.5 ± 0.5	-0.5 ± 0.6	0.01
Age PHV (y)	13.8 ± 0.4	13.6 ± 0.4	0.52
Training years (y)	5 ± 2	6 ± 2	0.57
Training hours (h/week)	3.1 ± 1.2	4.0 ± 1.6	0.62
MP (kPa)			
Lateral	207.6 ± 78.8*	330.6 ± 185.1	0.86
Medial	245.2 ± 55.2*	420.1 ± 79.3	2.56
Rearfoot	427.3 ± 148.9*	612.5 ± 191.5	1.08
Midfoot	187.2 ± 133.2	224.2 ± 203.9	0.22
Forefoot	237.6 ± 70.0*	375.9 ± 83.2	1.80

Values are mean ± SD.

FOOT-LP: football players with low maximum values of the average pressure; FOOT-HP: football players with high maximum values of the average pressure; BMI: body mass index; CSA: cross sectional area; PHV: peak height velocity; MP: maximum value of the average pressure.

* significant differences between groups. Cohen's *d* can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8).

Table II. Adjusted pQCT values of football players with low and high plantar pressures.

	FOOT-LP (n = 25)	FOOT-HP (n = 15)	MD (95% CI)	Test statistic	% Difference
Bone geometry					
Tt.BMC (g)	3.04 ± 0.25	3.21 ± 0.24	0.17 (0.01, 0.34)*	$F(1,36) = 4.6$, $p = .038$, $\eta^2_p = 0.11$	-5.4
Ct.BMC (g)	2.76 ± 0.22	2.94 ± 0.22	0.17 (0.03, 0.32)*	$F(1,36) = 5.7$, $p = .022$, $\eta^2_p = 0.14$	-5.9
Tt.Ar (mm^2)	386 ± 32	397 ± 33	11 (-10, 33)	$F(1,36) = 1.1$, $p = .301$, $\eta^2_p = 0.03$	-2.8
Ct.Ar (mm^2)	265 ± 23	279 ± 24	14 (-2, 29)	$F(1,36) = 3.0$, $p = .090$, $\eta^2_p = 0.08$	-4.9
Bone strength					
Ct.Th (mm)	4.88 ± 0.38	5.10 ± 0.38	0.21 (-0.04, 0.47)	$F(1,36) = 2.9$, $p = .098$, $\eta^2_p = 0.07$	-4.2
Frc.LdX (N)	3017.1 ± 384.8	3223.5 ± 387.4	206.4 (-52.8, 465.6)	$F(1,36) = 2.6$, $p = .115$, $\eta^2_p = 0.07$	-6.4
SSIp (mm^3)	1350.6 ± 153.4	1442.9 ± 154.5	92.3 (-11.1, 195.6)	$F(1,36) = 3.3$, $p = .078$, $\eta^2_p = 0.08$	-6.4

Values are mean ± SD. pQCT variables adjusted by weight and tibia length.

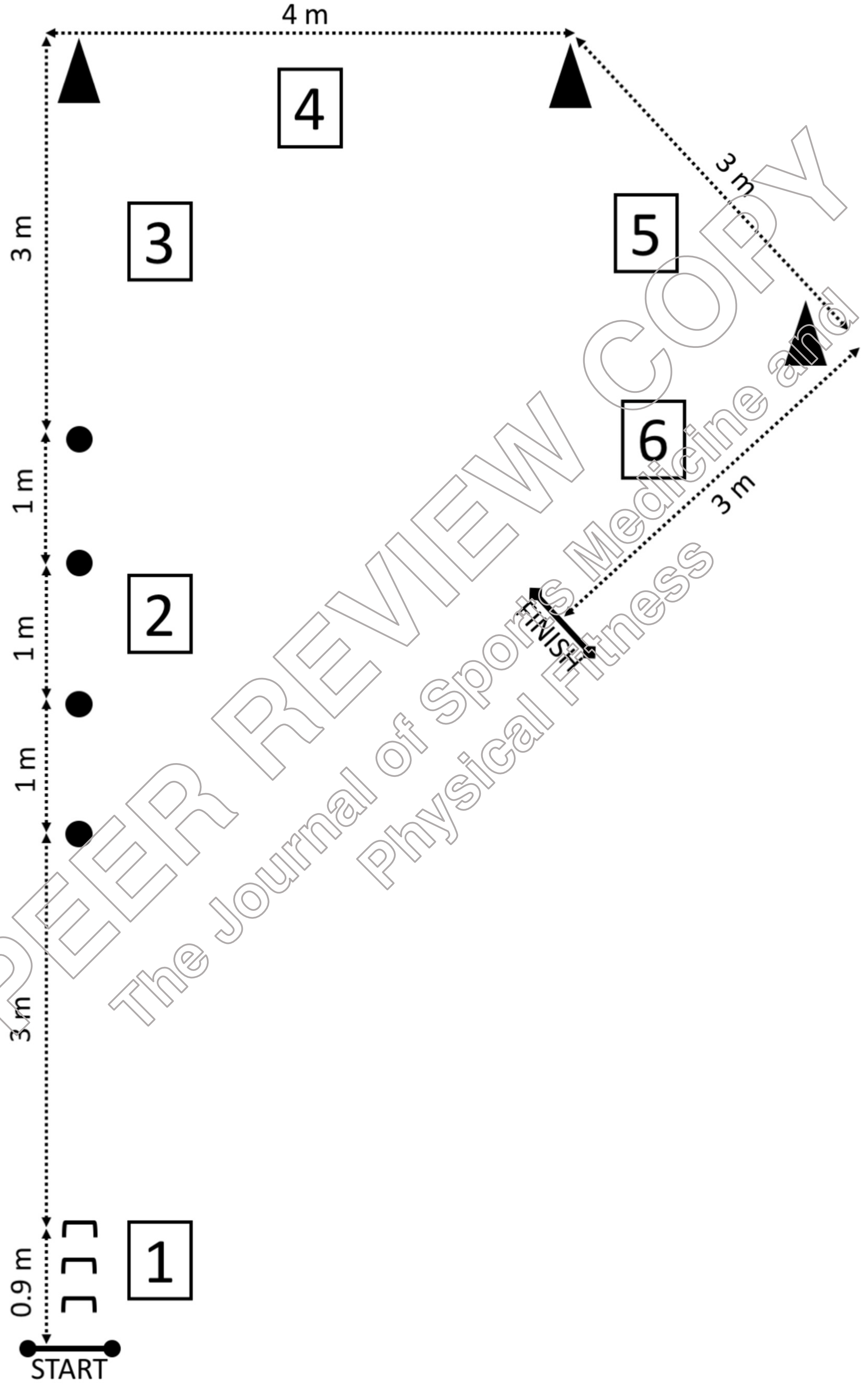
FOOT-LP: football players with low maximum values of the average pressure; FOOT-HP: football players with high maximum values of the average pressure; pQCT: peripheral quantitative computed tomography; MD: mean difference; CI: confidence interval; Tt.BMC: total volumetric bone mineral content; Tt.Ar: total cross sectional area; Ct.BMC: cortical volumetric bone mineral content; Ct.Ar: cortical cross sectional area; Ct.Th: cortical thickness; Frc.LdX: fracture load in axe X; SSIp: strength strain index in polar; η^2_p: partial eta squared.

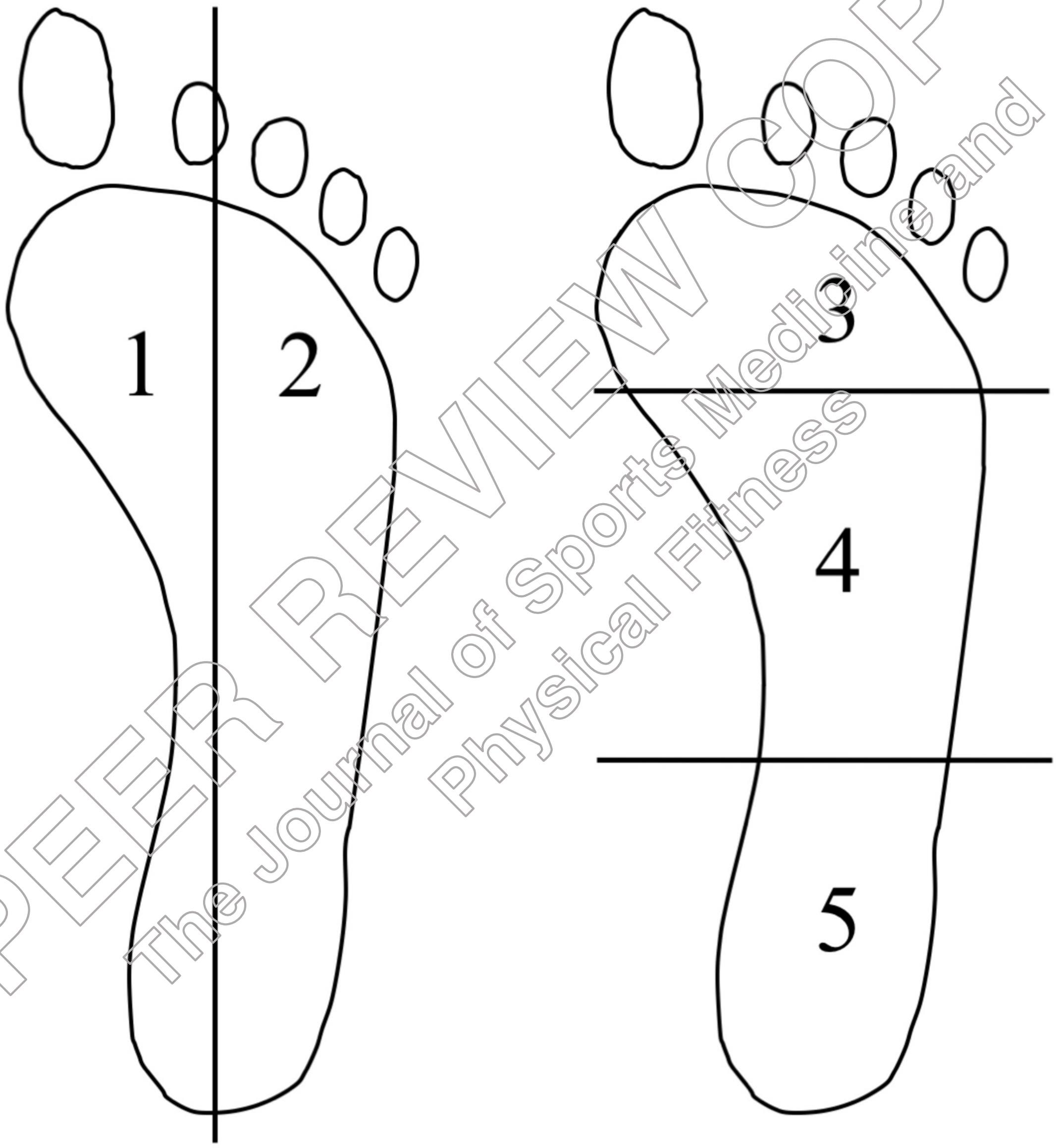
*: $p < .05$ differences between football groups.

TITLES OF FIGURES

Figure 1. Experimental setup. Black circles represent slalom poles and black triangles represent football cones. 1) three two-footed jumps of 30-cm hurdles, 2) a zigzag run around four slalom poles, 3) a three-m sprint, 4) a lateral shuffle, 5-6) two three-m sprints separated by a 90º cut.

Figure 2. Foot areas for plantar pressure analysis. Area 1 represents medial foot, area 2 represents lateral foot, area 3 represents forefoot, area 4 represents midfoot and area 5 represents rearfoot.


4 m
4
3 m
3
5
3 m
6
1 m
2
1 m
1 m
FINISH
3 m
1
0.9 m
START


1
2
3
4
5

Supplementary table I Maximum value of the average pressure of football players wearing turf and hard-ground stud designs.

	Normal foot (n = 16)	High arch foot (n = 14)	Flat foot (n = 10)	η^2_p
MP (kPa)				
Lateral	256.4 ±183.9	280.3 ± 122.4	212.4 ± 67.9	0.04
Medial	324.8 ± 90.2	278.6 ± 129.3	333.4 ± 97.7	0.05
Rearfoot	531.0 ± 179.8	436.7 ± 210.8	526.1 ± 158.9	0.06
Midfoot	197.4 ± 189.6	218.0 ± 137.3	183.2 ± 159.5	0.01
Forefoot	290.7 ± 68.5	294.9 ± 133.9	279.9 ± 99.3	0.00

Values are mean ± SD.

MP: maximum value of the average pressure.

* significant differences between groups. The effect size for η^2_p can be small (0.01 – 0.06), medium (0.06 – 0.14) or large (>0.14)

Supplementary table II Maximum value of the average pressure of football players wearing turf and hard-ground stud designs.

	Turf stud design (n = 11)	Hard-ground stud design (n = 29)	Cohen's *d*
MP (kPa)			
Lateral	249.8 ± 206.0	255.3 ± 111.2	0.03
Medial	292.3 ± 73.8	317.8 ± 117.8	0.26
Rearfoot	517.1 ± 184.2	489.0 ± 191.1	0.15
Midfoot	181.8 ± 121.8	208.4 ± 175.9	0.18
Forefoot	241.4 ± 79.2	307.7 ± 102.8	0.72

Values are mean ± SD.

MP: maximum value of the average pressure.

* significant differences between groups. Cohen's *d* can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8).

Supplementary Table III Adjusted maximum values of the average pressure of football players with low and high plantar pressures.

	FOOT-LP (n = 25)	FOOT-HP (n = 15)	MD (95% CI)	Test statistic
MP (kPa)				
Lateral	205.9 ± 129.2	333.6 ± 129.4	127.7 (41.8, 213.5)*	$F(1,37) = 9.1$, $p = .005$, $\eta^2_p = 0.20$
Medial	244.7 ± 65.9	420.9 ± 66.1	176.3 (132.5, 220.1)*	$F(1,37) = 66.4$, $p < .001$, $\eta^2_p = 0.64$
Rearfoot	429.9 ± 165.9	608.2 ± 166.2	178.2 (68.0, 288.5)*	$F(1,37) = 10.7$, $p = .002$, $\eta^2_p = 0.23$
Midfoot	187.1 ± 165.5	224.3 ± 165.8	37.1 (-72.8, 147.1)	$F(1,37) = 0.5$, $p = .498$, $\eta^2_p = 0.01$
Forefoot	237.1 ± 76.1	376.7 ± 76.2	139.6 (89.1, 190.2)*	$F(1,37) = 31.3$, $p < .001$, $\eta^2_p = 0.46$

Values are mean ± SD. Plantar pressure data adjusted by weight.

FOOT-LP: football players with low maximum values of the average pressure; FOOT-HP: football players with high maximum values of the average pressure; MP: maximum value of the average pressure.

* significant differences between groups. The effect size for η^2_p can be small (0.01 – 0.06), medium (0.06 – 0.14) or large (>0.14).

Influence of different playing surface on bone mass accretion in male adolescent football players: a one-season longitudinal study.

Journal:	*Part P: Journal of Sports Engineering and Technology*
Manuscript ID	Draft
Manuscript Type:	Original Article
Date Submitted by the Author:	n/a

Complete List of Authors:	Lozano-Berges, Gabriel; GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza; Faculty of Health and Sport Sciences, Department of Physiatry and Nursing Matute-Llorente, Ángel; GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza; Faculty of Health and Sport Sciences, Department of Physiatry and Nursing Gómez-Bruton, Alejandro; GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza; Faculty of Health and Sport Science, Department of Physiatry and Nursing Gonzalez-Aguero, Alex; GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza; Faculty of Health and Sport Sciences, Department of Physiatry and Nursing Vicente-Rodríguez, Germán; GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza; Faculty of Health and Sport Sciences, Department of Physiatry and Nursing Casajús, José; GENUD (Growth, Exercise, NUtrition and Development) Research Group, Universidad de Zaragoza; Faculty of Health Sciences, Department of Physiatry and Nursing

Keywords:	Soccer, Sports, Body composition, Bone density, Bone and bones

Abstract:	There are different types of football surfaces but their influence on bone still remain unknown. The aims of this study were to compare bone mass accrual between football players and controls and to evaluate the influence of two different surfaces on bone accretion. Twenty-seven male football players (13.2±0.5 y) and 15 controls (12.6±1.1 y) participated in this study. Football players were classified into 2 different groups according to the surface they trained and played on: 14 on third-generation artificial turf with elastic layer (3G-EL) and 13 on third-generation artificial turf without elastic layer (3G-NEL). Bone mineral content (BMC) and areal bone mineral density (aBMD) were measured with dual-energy X-ray absorptiometry. Bone mineral apparent density (BMAD) variables were calculated. Bone geometry and strength of the non-dominant tibia were assessed with peripheral quantitative computed tomography. Both, football players and controls, significantly increased bone variables measured at subtotal body, lumbar spine, legs and tibia (p<0.05). Group by time interaction was found for aBMD at legs (p<0.05) being the aBMD increment higher in football players than controls. Moreover, lumbar spine BMAD increased more in 3G-NEL players in comparison with 3G-EL players (p<0.05). Playing football on 3G-EL and 3G-NEL seems to positively affect bone mass during growth. After playing for one season on these playing

		surfaces, football practice on 3G-NEL, surface with lower shock absorption than 3G-EL, seems to positively affect the increment in aBMD at lumbar spine. Thus, football practice on surfaces with lower shock absorption could provide an extra benefit on bone health.

Influence of different playing surface on bone mass accretion in male adolescent football players: a one-season longitudinal study.

Gabriel Lozano-Berges, Ángel Matute-Llorente, Alejandro Gómez-Bruton, Alex González-Agüero, Germán Vicente-Rodríguez, José A. Casajús.

Abstract

There are different types of football surfaces but their influence on bone still remain unknown. The aims of this study were to compare bone mass accrual between football players and controls and to evaluate the influence of two different surfaces on bone accretion. Twenty-seven male football players (13.2±0.5 y) and 15 controls (12.6±1.1 y) participated in this study. Football players were classified into 2 different groups according to the surface they trained and played on: 14 on third-generation artificial turf with elastic layer (3G-EL) and 13 on third-generation artificial turf without elastic layer (3G-NEL). Bone mineral content (BMC) and areal bone mineral density (aBMD) were measured with dual-energy X-ray absorptiometry. Bone mineral apparent density (BMAD) variables were calculated. Bone geometry and strength of the non-dominant tibia were assessed with peripheral quantitative computed tomography. Both, football players and controls, significantly increased bone variables measured at subtotal body, lumbar spine, legs and tibia ($p<0.05$). Group by time interaction was found for aBMD at legs ($p<0.05$) being the aBMD increment higher in football players than controls. Moreover, lumbar spine BMAD increased more in 3G-NEL players in comparison with 3G-EL players ($p<0.05$). Playing football on 3G-EL and 3G-NEL seems to positively affect bone mass during growth. After playing for one season on these playing surfaces, football practice on 3G-NEL, surface with lower shock absorption than 3G-EL, seems to positively affect the increment in aBMD at lumbar spine. Thus, football practice on surfaces with lower shock absorption could provide an extra benefit on bone health.

Keywords

Soccer, Sports, Body composition, Bone density, Bone and Bones.

Introduction

Childhood and adolescence are crucial periods for bone building and thus, to reduce the risk of having low bone mass[1] by means of physical exercise and sports participation.[2] In fact, a recent review by Weaver et al. [3] graded the positive effects of physical activity on bone mass with a grade A (maximum level of evidence); however, they did not specify about the effects of each sport separately. This review was complemented by Mautalen study[4] which highlighted the positive effects of football practice on bone mass during growth. The latter has great importance for young people because football, in which high-impact actions such as starts, stops, changes of direction, jumps and kicks occur,[5] is probably one of the most, if not the most, practiced sports worldwide.

The positive benefits of football practice on bone tissue have been amply demonstrated;[6] higher levels of bone mineral content (BMC) or areal bone mineral density (aBMD) levels when compared to a control group (CG) have been reported in youth football players.[7-9] More importantly, the positive effects generated by football have been shown to remain after 1- and 3-year follow-ups.[7, 10-14] To assess bone mass, most of studies performed on youth football teams have used dual-energy X-ray absorptiometry (DXA). Although DXA is capable of explain up to 60% of the variance in bone strength, it cannot directly measure bone geometry variables.[15] For this reason, some studies have used other techniques such as hip structural analysis (HSA)[13] and peripheral quantitative computed tomography (pQCT)[16-18] for measuring bone geometry in football players. HSA derives from hip scan images acquired by DXA. According to International Society for Clinical Densitometry (ISCD), the hip is not the recommended site for evaluating BMC and aBMD in children and adolescents due to its high variability during bone development.[19] Thus, bone geometry measured with HSA in young populations could be biased as described above. In contrast, pQCT, which is not influenced by bone size as DXA, measures trabecular and cortical bone and it permits to evaluate the tibia, which is directly affected by football. Up to now, only a study has compared young male football players and CG showing higher bone geometry in football players than CG.[18]

Ground reaction forces could be described as one of the main contributing factors influencing bone accretion; however, there is a constant evolution on the playing surfaces that may affect this relationship. Natural grass football fields are tending to disappear, whereas artificial turf pitches are considerably increasing in number.[20] Nowadays, new developments in construction methods are promoting the inclusion or the use of materials such as rubber and sand infill.[20] At the same time, different components mean different mechanical characteristics,[21] concretely, the inclusion or not of an elastic layer in the installation process generates differences on shock absorption and vertical deformation forces.[21] Due to these mechanical properties, different types of surfaces may evoke different loads to the bone. As far as we know, only Plaza-Carmona et al.[22] compared the influence of a soft surface against a hard surface on bone mass accrual in male children football players, finding no differences for BMC and aBMD. However, the influence of playing surfaces of the latest generation such as third-generation artificial turf with (3G-EL) and without elastic layer (3G-NEL) on bone tissue in young football players is yet unknown. Therefore, the aims of this study were: 1) to compare BMC, aBMD, bone mineral apparent density (BMAD), bone geometry and bone strength between young male football players and CG; and 2) to evaluate the influence of training and playing football on two playing surfaces, 3G-EL or 3G-NEL, on previous bone values.

We hypothesized that all adolescents will improve bone mass and strength values throughout the season but football players will improve more their bone mass, geometry and strength compared to CG. Also, those football players who play on 3G-NEL during this period will exhibit an extra bone mass gain in comparison with 3G-EL due to the fact that 3G-NEL surface could be harder than the other one and will, therefore, increase the loads that football players receive.

Methods

Participants

Two football clubs and two high school of Aragon (Spain) were invited to participate. Although 35 football players and 23 controls agreed to participate, a final sample of 27 male football players (13.17±0.52 years) and 15 age and sex matched controls (CG; 12.58±1.11 years) participated in this study (Figure 1). Football players were split into two different groups according to the surface where they trained and played on: 3G-EL (n=14; 13.01±0.61 years) and 3G-NEL (n=13; 13.35±0.34 years). Although CG were physically active, they were not engaged in any sport. Measurements were performed at the beginning (October-December 2013) and at the end of the season (May-July 2014) in Zaragoza (Spain). It followed the protocol recommended by the ISCD[19] to evaluate bone changes between DXA scans the minimum interval is six months.

The years of exposure to football practice prior to the beginning of this study were 5±2 years in 3G-EL players and 5±1 years in 3G-NEL. Hours of training per week were individually quantified based on the number of trainings in which the player had assisted (3G-EL players=2.6±0.2 hours/week; 3G-NEL players=2.3±0.3 hours/week). Besides, a sport scientist monitored the type of exercises performed by each team during their trainings throughout the season. Trainings lasted approximately 90 min, including 5-min warm-up consisting in low-intensity running; 5-10 min of low-intensity games; 60 min of technical football exercises (passing, kicking, running, dribbling); and finally, 5-10 minutes of cool down stretching exercises.

Participants, parents and coaches of each club were informed about the protocol, and the possible benefits and risks derived from this study. Written informed consent from parents and verbal assent from the participants were obtained. This study was performed following the declaration of Helsinki 1961 (revision of Fortaleza 2013) and the protocol was approved by the Ethics Committee of Clinical Research from the Government of Aragon (CEICA, Spain) [C.I. PI13/0091]. The research was registered in a public database Clinicaltrials.gov [NCT02399553]. The Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) Statement was used as a guideline for reporting non-randomized trials.[23]

Inclusion criteria

Caucasian, at least one year of football practice on the playing surface prior to the beginning of the measurements, to be aged between 11 and 14 years, and to be free of any medication affecting bone were the inclusion criteria established for this project.

Anthropometric measurements

Height (stadiometer SECA 225, SECA, Hamburg, Germany; to the nearest 0.1 cm) and weight (scale SECA 861, SECA, Hamburg, Germany; to the nearest 0.1 kg) were measured without shoes and with minimum clothes. Body mass index (BMI) was calculated as the division between weight (kg) and squared height (m^2).

Maturity status

Pubertal maturity was determined according to the stages proposed by Tanner and Whitehouse[24] and using a self-assessment method which has been shown to be a valid and reliable technique.[25]

Calcium intake

Milligrams of daily calcium intake were calculated by a validated calcium food frequency questionnaire.[26]

Physical activity measurements

Physical activity was assessed with triaxial accelerometers (GENEActiv developed by Unilever Discover, Colworth, UK; and distributed by ActivInsights Ltd., Kimbolton, Cambridge, UK). These accelerometers have been calibrated and validated for measuring physical activity in children and adolescents in different locations including the right and the left wrists.[27] Participants wore GENEA devices in their non-dominant wrist during 7 days; although, football players had to remove the accelerometer during official matches. Data were recorded at 30 Hz and analysed at 1-s epochs. Accelerometer data were analysed in the software Rstudio (version RStudio Desktop 1.0.153, Boston, United States). Minutes of valid time in light, moderate and vigorous physical activity intensities and sedentary time were calculated using cut-points proposed by Phillips et al.[27] for right wrist as follows: light, 2.4 – 7.9 g·s; moderate, 8.0 – 21.0 g·s; vigorous >21.1g·s; sedentary, <2.3 g·s; and for left wrist were light, 2.7 – 7.1 g·s; moderate, 7.2 – 22.5 g·s; vigorous >22.6 g·s; sedentary, <2.6 g·s.

Bone measurements

DXA

Bone and lean masses were measured with DXA QDR-Explorer (paediatric version of the software QDR-Explorer, Hologic Corp. Software version 12.4, Bedford, Massachusetts, USA). DXA equipment was calibrated daily following the manufacturer guidelines. Whole body, non-dominant hip and lumbar spine scans were measured with participants in supine position by the same technician who had fully been trained to perform the scans, the positioning of the subjects and the analysis of the results according to the manufacturer´s guidelines. The non-dominant limb was determined by asking which leg would be used to kick a ball.[28]

Subtotal (total body less head) body BMC (g), legs (calculated as a mean of both legs) aBMD (g/cm^2), subtotal lean mass (g) and subtotal percentage of body fat (%) were obtained from whole body scans; and lumbar spine BMC from lumbar spine scans (L1-L4). Femoral neck values to calculate BMAD were obtained from hip scans. The coefficients of variation of the DXA in our laboratory are published elsewhere.[29] Although, subtotal body BMC and lumbar spine BMAD were the preferred bone sites for evaluating bone changes during growth;[19] legs aBMD and femoral neck BMAD have also been included in the present study because they could be skeletal sites directly influenced by football actions.

Due to the fact that DXA results are highly influenced by skeletal dimensions and also that BMAD is less sensitive to size changes than aBMD, Carter et al.[30] and Katzman et al.[31] developed new mathematical models to calculate BMAD. In this study, the following equations has been used:

-Whole body BMAD = BMC (whole body) / [Ap^2 / h], where Ap is the projected area (whole body) from DXA and h is the height of the participant.[31]

-Lumbar spine BMAD = BMC (L1-L4) / $Ap^{3/2}$, where Ap is the projected area (L1-L4) from DXA.[30]

-Femoral neck BMAD = BMC (femoral neck) / Ap^2, where Ap is the projected area (femoral neck) from DXA.[30]

pQCT

Bone mass, geometry and strength were measured at non-dominant tibia using a Stratec XCT-2000 L pQCT scanner (Stratec Medizintechnik, Pforzheim, Germany). This device is a rotate-translate scanner that obtains a trans-axial image. Following the guidelines provided by the manufacturer, the pQCT calibration was daily performed using a quality control phantom. Coefficients of variation for each pQCT variable used in the present study have been already published.[32]

Tibia length was determined as the inner border of the medial condyle to the farthest point of the medial malleolus of the tibia and it was always measured by the same technician by using a wooden ruler (to the nearest 1 mm). Then, non-dominant leg was centred in the imaging field and the foot and knee were secured to reduce movement. The scanner was positioned on the distal tibia, and a scout view was performed to manually set the reference line on the midpoint of the distal tibia end plate. Bone parameters were assessed at 4% (distal tibia) and 38% (diaphyseal tibia) of the length of the tibia with a voxel dimension of 0.5 mm and a slice thickness of 1 mm. Following ISCD[33] recommendations for evaluating bone geometry and strength with pQCT, total (vBMD4) and trabecular volumetric bone mineral density (vBMD; mg/cm^3) at the 4% site of the tibia were analysed. Moreover, the parameters measured at the 38% of the length of the tibia were total BMC (BMC38; g), cortical vBMD (mg/cm^3), cortical cross sectional area (CSA; mm^2), cortical thickness (mm), fracture load in X-axis (FRC_LDX; N) and polar strength strain index (SSI_POL; mm^3).

All pQCT images were analysed with version 6.20 of the manufacturer's software. Contour mode 1 with a threshold of 180 mg/cm^3 for the 4% site of the tibia and 280 mg/cm^3 for the 38% site of the tibia was used to determine the periosteal surface of the bone. At 4% site of the tibia, trabecular bone was determined from a central area covering 45% of the total bone cross-sectional area. At 38% site of the tibia, cortical bone was obtained using cortical mode 1 with a threshold of 710 mg/cm^3. Additionally, cortical mode 1 with a threshold of 280 mg/cm^3 was used to obtain bone strength variables (SSI_POL and FRC_LDX). After that, bone mineralization of 1200 mg/cm^3 was assumed.

Mechanical properties of the pitches

Two different surfaces were included in the present study: 3G-EL and 3G-NEL. By the time the study was performed, no more than six years had passed since they were installed. Both pitches presented similar infill characteristics and were constructed by the same manufacturer.

Assessments of mechanical characteristics of the football fields used in the present study were performed according to the quality standards proposed by the European Committee for Standardisation (EN 15530-1:2007). This standard is applied for amateur, educational and recreational sport and evaluates the performance and durability of outdoor sport surfaces. Thus, test requirements used for evaluating mechanical properties of the football pitches are as follows: ball rebound has to be between 0.608 and 1.012 m; ball roll between 4 and 10 m; shock absorption between 55 and 70%; vertical deformation between 4 and 10 mm; and rotational resistance between 25 and 50 N·m. Both 3G-EL (ball rebound: 0.825 m; ball roll: 10 m; shock absorption: 62%; vertical deformation: 7 mm; and rotational resistance: 50 N·m) and 3G-NEL (ball rebound: 0.944 m; ball roll: 10 m; shock absorption: 56%; vertical deformation: 6 mm; and rotational resistance: 41 N·m) were within these parameters.

These mechanical characteristics were measured in five-field positions following the quality standards guidelines. Each test was performed three or five times (according to the required attempts) in all field positions. An advanced artificial athlete was used for measuring shock absorption and vertical deformation variables.

All tests were performed at stable meteorological conditions, with temperature between 10 and 22ºC, wind speed between 0 and 1.2 m/s and humidity between 45 and 60%. Pocket Weather Tracker 4000 (Kestrelmeters, Birmingham, UK) was used in order to evaluate meteorological conditions.

Statistical analyses

Sample size calculation

There was no longitudinal study that had calculated whole body or lumbar spine BMAD; therefore, data from a Zouch et al.[12] study evaluating aBMD at whole body in football players and CG (1.098 ± 0.093; 1.010 ± 0.087 g/cm^2 respectively) was used to calculate sample size. Due to the fact that the main analysis of the present study was the repeated measures, the sample size calculation was performed for these analyses. The sample size for repeated measures was calculated in whole body aBMD to get a power of 70% at the 5% alpha level and to reject the null hypothesis H_0:$\mu1$=$\mu2$. Thus, assuming a small to medium effect size (f = 0.20) and a correlation among repeated measures of 0.7 at pre- and post-season moments, a total sample size of 26 (13 per group) would be needed.

Outcome measures treatment

Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. All variables showed normal distribution tested with the Kolmogorov-Smirnov test.

Chi-square test was performed to evaluate differences between pubertal stages. Independent t-tests were applied to examine differences among groups for descriptive characteristics and bone parameters at pre- and post-season moments. ANOVA for repeated measures were applied to check differences within all football players and CG; and within 3G-EL and 3G-NEL between pre- and post-season moments without adjusting by covariates (Model 1). After that, these analyses were repeated including two covariates as follow: Model 1 + minutes per day of moderate-vigorous physical activity (MVPA; Model 2); and Model 2 + total lean mass less head for DXA parameters or tibia muscle area for pQCT parameters (Model 3). Group by time interactions for changes in bone values were also performed by repeated measures analyses.

Effect size statistics using Cohen´s *d* was calculated for independent t-test; and partial eta squared (η^2_p) for repeated measures analyses. The effect size for Cohen´s d can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8) and partial eta square (η^2_p) can be small (0.01 – 0.06), medium (0.06 – 0.14) or large (>0.14). Statistical significance was set at $p < .05$.

Results

Descriptive data

The physical characteristics of the participants are shown in Table 1. No differences were found in any descriptive data between football players and controls (Cohen´s *d* ranged from 0.05 to 0.69; $p > .05$). Between different surfaces (3G-EL and 3G-NEL), no differences were found either (Cohen´s *d* ranged from 0.06 to 0.70; $p > .05$).

As expected, there were significant differences for the age, weight, height, BMI, subtotal lean mass, tibia length and tibia muscle area between pre- and post-season moments in all groups (η^2_p ranged from <0.001 to 0.943; $p < .05$). Moreover, football players who trained on 3G-NEL demonstrated lower percentage of body fat at post- than pre-season moments (η^2_p was 0.357; $p < .05$).

No significant differences were found in MVPA between football players and CG (93.29±19.93 vs 95.50±33.46; 95% CI, -17.54 to -21.95; Cohen´s *d* was 0.08; $p > .05$) and between football players who trained in 3G-EL and 3G-NEL (100.25±21.69 vs 85.80±15.29; 95% CI, -29.29 to 0.40; Cohen´s *d* was 0.77; $p > .05$).

BMC, aBMD and BMAD

Comparisons between all football players and CG

Table 2 summarizes BMC and aBMD measured at pre- and post-season moments. Higher legs aBMD was found in all football players than CG at post-season moment (CI 95%=-0.02 -0.19; Cohen´s *d* was 0.72; $p < .05$). Football players and CG significantly increased subtotal body BMC, lumbar spine BMC, legs aBMD and lumbar spine BMAD (η^2_p ranged from 0.192 to 0.713; $p < .05$). Furthermore, a significant group by time interaction was found for legs aBMD (η^2_p was 0.097; $p < .05$). This interaction showed that the increase in the legs aBMD was significantly greater in football players in comparison with CG. The same result was obtained when MVPA were included as covariate; but it became non-significant when subtotal lean mass was introduced as covariate (η^2_p was 0.063; $p > .05$; Figure 2). Therefore, a lean mass correction could under-estimate the effects of this high-impact sport on bone mass.

Comparison between 3G-EL and 3G-NEL

3G-EL showed higher lumbar spine and femoral neck BMAD at pre- and post-season moments than 3G-NEL (Cohen´s *d* ranged from 0.80 to 1.45; $p < .05$). Both football groups improved subtotal body BMC, lumbar spine BMC, legs aBMD and lumbar spine BMAD from pre- to post-season moments (η^2_p ranged from 0.203 to 0.674; $p < .05$).

Moreover, 3G-NEL also increased femoral neck BMAD (η^2_p was 0.096; $p < .05$). There was a group by time interaction for lumbar spine BMAD (η^2_p was 0.169; $p < .05$). This interaction demonstrated that during one year of football practice, BMAD at lumbar spine increased more in football players who trained on 3G-NEL than in those who trained on 3G-EL. On the other hand, no group by time interaction was found for lumbar spine BMAD when MVPA was included as covariate (η^2_p was 0.109; $p > .05$; Figure 3).

Bone geometry and strength

Comparisons between all football players and CG

Bone geometry and strength measured at the 4% and 38% sites of the tibia are shown in Table 2. Higher cortical CSA at pre-season moment and SSI_POL at pre- and post-season moments were found in football players than CG (Cohen´s d ranged from 0.46 to 0.80; $p < .05$). Both groups improved BMC38, cortical CSA, cortical thickness, FRC_LDX and SSI_POL (η^2_p ranged from 0.106 to 0.635; $p < .05$). Furthermore, CG decreased vBMD4 and trabecular vBMD at distal tibia (η^2_p were 0.102 and 0.128; $p < .05$). No group by time interactions were found in bone geometry and strength values (η^2_p ranged from <0.001 to 0.053; $p < .05$); however, when tibia muscle area was added as covariate, there was a group by time interaction for BMC38 (η^2_p was 0.105; $p < .05$; Figure 2). This interaction demonstrated that BMC38 increased more in CG than football players. As we found in DXA parameters, a tibia muscle area correction could modify the differences between groups and, consequently, under-estimate the effects of this high-impact sport on bone mass.

Comparison between 3G-EL and 3G-NEL

At pre- and post-season moments, 3G-EL players showed higher vBMD4 and trabecular vBMD than 3G-NEL (Cohen´s *d* ranged from 1.01 to 1.31; $p < .05$). 3G-EL and 3G-NEL players improved BMC38, cortical CSA, cortical thickness, FRC_LDX and SSI_POL (η^2_p ranged from 0.199 to 0.683; $p < .05$). There were no group by time interactions between both 3G-EL and 3G-NEL players even when MVPA and tibia muscle area were used as covariates (η^2_p ranged from <0.001 to 0.086; $p < .05$).

Discussion

The main finding of the present study is that one season of football practice, independently of the playing surface, may positively affect bone accretion in the lower limbs of young players. As stated previously, subtotal body BMC and lumbar spine BMAD are the variables that ISCD recommends to compare densitometry results in children and adolescents;[19] however, the analysis of legs could be also interesting because of legs are the closest site of the body to the floor and could support much impact than the others bone sites. On the other hand, football players playing on 3G-EL and 3G-NEL demonstrated similar bone mass, geometry and strength increases in most variables studied except for lumbar spine BMAD that increased more in football players who played on 3G-NEL than those who played on 3G-EL.

The present study has demonstrated that legs aBMD improved more in football players than CG. Adolescence is an important period to gain adequate levels of bone mass [1]; therefore, these football players will probably have better bone health than CG also later in life. In addition, football players showed greater, despite not reaching significance, BMC, aBMD and BMAD values in most skeletal sites at both pre- and post-season moments, being legs aBMD at post-season moment the only variable that was significantly higher in football players than CG. Although most of the differences are higher but not significant between these groups, these high bone values in football players could be crucial to achieve a high peak bone mass and to reduce the risk of having osteoporosis later in life. To the best of our knowledge, six studies have analysed longitudinally the effects of football practice on DXA parameters in young football players and CG.[7, 10-14] In line with our results, most of them demonstrated that football practice seems to be a good strategy for increasing BMC and aBMD during growth, being these improvements higher than those obtained by CG. Moreover, they also reported higher BMC and aBMD at lower limbs in football players than CG. Most of them also demonstrated differences in lumbar spine, a preferred site to assess densitometry variables during growth.[19] Nonetheless, none of them included subtotal body site and BMAD parameters in their study, therefore their results could be slightly influenced by bone mass of the skull (site not responsive to physical activity and their loads[34]) and bone size of their participants.[30] In contrast, the present study included subtotal body BMC and lumbar spine BMAD and higher but not significant subtotal BMC and lumbar spine BMAD were found between football players and CG. These results could be explained by the fact that the number of hours per week of football training could not be sufficient to have significant bone differences between groups. In summary, football practice during childhood and adolescence might be a good alternative to attain a higher peak of bone mass and, consequently, to reduce the risk of suffering osteoporosis during adulthood.

In terms of bone geometry and strength parameters, the present study showed that bone strength was higher in football players than CG being more marked in SSI_POL values. Up to now, there are only a cross-sectional study[18] and a 1-year follow-up longitudinal study[13] that have compared bone geometry and strength values between male football players and CG using pQCT and HSA respectively. Despite the use of different techniques, all of them found greater but not significant bone geometry and strength in football players than CG. This lack of differences between these groups could be explained by the fact that cortical bone parameters increase sharply after 14 years old[35] and the age of participants of the present study was lower. Thus, future longitudinal studies evaluating bone geometry and strength acquisition before and after 14 years will help to clarify the effects of football practice on these bone variables during growth.

To date, only a cross-sectional study performed by Plaza-Carmona et al. [22] analysed bone mass in football players who trained in different playing surfaces (artificial and soil fields). In line with our results, these authors showed that neither BMC nor aBMD were different between football players according to playing surface. The present study also included bone geometry measure with pQCT and strength variables showing that lumbar spine BMAD, femoral neck BMAD, vBMD4 and trabecular vBMD were higher in 3G-EL than 3G-NEL players at both pre- and post-season moments. These bone geometry differences could be due to by the fact that 3G-EL players trained a few more minutes per week than 3G-NEL players and, as demonstrated Varley et al.[17], an increase of training volume improved bone geometry and strength parameters.

Artificial fields aim to emulate physical and mechanical characteristics of the natural one, in fact, since rubber and sand were added in artificial turf, differences in mechanical variables and the number of injuries between both surfaces were reduced.[20, 36] Afterwards, the inclusion of the elastic layer behind the artificial turf systems increased shock absorption,[21] and consequently, reduced the amount of load received by football players. Although shock absorption characteristics measured in the present study in 3G-EL (62%) and 3G-NEL (56%) were slightly different, the effects of each surface on bone mass, geometry and strength seem to be similar between fields with the exception of lumbar spine BMAD. The closest bone sites to the ground receive the highest loads produced by football and progressively, as they move away from the ground to other bone sites, these loads are dissipating. Loads produced in both 3G-EL and 3G-NEL at tibia and femoral neck sites are high and cause similar bone adaptations; however, only loads produced by football actions in 3G-NEL are capable of cause an extra lumbar spine BMAD compared to those produced in 3G-EL. On the other hand, the fact that both football groups included in this study trained less than 3 hours per week could be limiting the differences between football players. To reinforced this idea, Zouch et al.[10] and Varley et al.[17] demonstrated that higher training volume improved both DXA and pQCT parameters.

The main limitation of the present study was the limited sample size, mainly when football players were split into two different groups according to the playing surface. Moreover, the type of the football exercises performed by each team was similar but not equal, and therefore, the effect of these football training exercises on bone mass could be slightly different. Another limitation was that the hours per week of both teams are lower than those in other longitudinal studies performed with football players (approximately 2.4 vs 10.0[13] and 11.9[17] hours per week). On the other hand, the main strength was that this is the first study that evaluated the influence of two third-generation artificial turf surfaces (3G-EL and 3G-NEL) on bone mass, geometry and strength in male adolescent football players. Moreover, this is also the first longitudinal study that compares bone geometry and strength between football players and CG.

Conclusions

Although no significant differences were found in most of sites included between football groups and CG, the present study provides robust evidence that football practice in artificial surfaces with or without elastic layer seems to be effective to increase bone mass at lower limbs during growth. After one-season follow-up, football practice in 3G-NEL, surface with lower shock absorption, seems to be an adequate alternative to improve BMAD at lumbar spine. Thus, soccer practice on surfaces with lower shock absorption could provoke an extra benefit on bone health.

Acknowledgements

The authors want to thank all the children, their parents and football clubs (C.D. Marianistas and S.D. Ejea) that participated in the study for their understanding and dedication to the project.

Funding

This work was supported by the Spanish “Ministerio de Economia y Competitividad” (Project DEP 2012-32724)’. GLB received a Grant FPU 2013 (FPU13/02111) from the “Ministerio de Educación, Cultura y Deporte”.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

References

1. Rizzoli R, Bianchi ML, Garabedian M, et al. Maximizing bone mineral mass gain during growth for the prevention of fractures in the adolescents and the elderly. *Bone* 2010; 46: 294-305.
2. Tenforde AS and Fredericson M. Influence of sports participation on bone health in the young athlete: a review of the literature. *Pm R* 2011; 3: 861-867.
3. Weaver CM, Gordon CM, Janz KF, et al. The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations. *Osteoporos Int* 2016; 27: 1281-1386.
4. Mautalen CA. Soccer and bone development. *Osteoporos Int* 2016; 27: 3133-3134.
5. Bangsbo J. The physiology of soccer with special reference to intense intermittent exercise. *Acta physiologica Scandinavica Supplementum* 1994; 619: 1-155.
6. Lozano-Berges G, Matute-Llorente Á, González-Agüero A, et al. Soccer helps build strong bones during growth: a systematic review and meta-analysis. *Eur J Pediatr* 2018; 177: 295-310.
7. Vicente-Rodriguez G, Ara I, Perez-Gomez J, et al. High femoral bone mineral density accretion in prepubertal soccer players. *Med Sci Sports Exerc* 2004; 36: 1789-1795.
8. Nebigh A, Rebai H, Elloumi M, et al. Bone mineral density of young boy soccer players at different pubertal stages: relationships with hormonal concentration. *Joint Bone Spine* 2009; 76: 63-69.
9. Seabra A, Marques E, Brito J, et al. Muscle strength and soccer practice as major determinants of bone mineral density in adolescents. *Joint Bone Spine* 2012; 79: 403-408.
10. Zouch M, Jaffre C, Thomas T, et al. Long-term soccer practice increases bone mineral content gain in prepubescent boys. *Joint Bone Spine* 2008; 75: 41-49.
11. Zouch M, Vico L, Frere D, et al. Young male soccer players exhibit additional bone mineral acquisition during the peripubertal period: 1-year longitudinal study. *Eur J Pediatr* 2013; 173: 53-61.
12. Zouch M, Zribi A, Alexandre C, et al. Soccer Increases Bone Mass in Prepubescent Boys During Growth: A 3-Yr Longitudinal Study. *J Clin Densitom* 2015; 18: 179-186.
13. Vlachopoulos D, Barker AR, Ubago-Guisado E, et al. Longitudinal Adaptations of Bone Mass, Geometry, and Metabolism in Adolescent Male Athletes: The PRO-BONE Study. *J Bone Miner Res* 2017; 32: 2269-2277.
14. Vlachopoulos D, Barker AR, Ubago-Guisado E, et al. The effect of 12-month participation in osteogenic and non-osteogenic sports on bone development in adolescent male athletes. The PRO-BONE study. *J Sci Med Sport* 2018; 21: 404-409.
15. Sievanen H. A physical model for dual-energy X-ray absorptiometry--derived bone mineral density. *Invest Radiol* 2000; 35: 325-330.
16. Anliker E, Sonderegger A and Toigo M. Side-to-side differences in the lower leg muscle-bone unit in male soccer players. *Med Sci Sports Exerc* 2013; 45: 1545-1552.
17. Varley I, Hughes DC, Greeves JP, et al. Increased Training Volume Improves Bone Density and Cortical Area in Adolescent Football Players. *Int J Sports Med* 2017; 38: 341-346.

18. Lozano-Berges G, Matute-Llorente A, Gomez-Bruton A, et al. Bone geometry in young male and female football players: a peripheral quantitative computed tomography (pQCT) study. *Arch Osteoporos* 2018; 13: 57.
19. Crabtree NJ, Arabi A, Bachrach LK, et al. Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD Pediatric Official Positions. *J Clin Densitom* 2014; 17: 225-242.
20. McNitt AS. Synthetic turf in the USA - Trends and issues. *ITSRJ* 2005; 10: 27-33.
21. Burillo P, Gallardo L, Felipe JL, et al. Mechanical assessment of artificial turf football pitches: The consequences of no quality certification. *Sci Res Essays* 2012; 7: 2457-2465.
22. Plaza-Carmona MP, Vicente-Rodriguez G, Martin-Garcia M, et al. Influence of hard vs. soft ground surfaces on bone accretion in prepubertal footballers. *Int J Sports Med* 2014; 35: 55-61.
23. Des Jarlais DC, Lyles C, Crepaz N, et al. Improving the reporting quality of nonrandomized evaluations of behavioral and public health interventions: the TREND statement. *Am J Public Health* 2004; 94: 361-366.
24. Tanner JM and Whitehouse RH. Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. *Arch Dis Child* 1976; 51: 170-179.
25. Duke PM, Litt IF and Gross RT. Adolescents' self-assessment of sexual maturation. *Pediatrics* 1980; 66: 918-920.
26. Julián Almárcegui C, Huybrechts I, Gómez Bruton A, et al. Validity of food-frequency questionnaire for estimating calcium intake in adolescent swimmers. *Nutr Hosp* 2015; 32: 1773-1779.
27. Phillips LR, Parfitt G and Rowlands AV. Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. *J Sci Med Sport* 2013; 16: 124-128. 2012/07/10.
28. Hoffman M, Schrader J, Applegate T, et al. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *J Athl Train* 1998; 33: 319-322.
29. Gracia-Marco L, Ortega FB, Jimenez-Pavon D, et al. Adiposity and bone health in Spanish adolescents. The HELENA study. *Osteoporos Int* 2012; 23: 937-947.
30. Carter DR, Bouxsein ML and Marcus R. New approaches for interpreting projected bone densitometry data. *J Bone Miner Res* 1992; 7: 137-145.
31. Katzman DK, Bachrach LK, Carter DR, et al. Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. *J Clin Endocrinol Metab* 1991; 73: 1332-1339.
32. Gomez-Bruton A, Gonzalez-Aguero A, Casajus JA, et al. Swimming training repercussion on metabolic and structural bone development; benefits of the incorporation of whole body vibration or pilometric training; the RENACIMIENTO project. *Nutr Hosp* 2014; 30: 399-409.
33. Adams JE, Engelke K, Zemel BS, et al. Quantitative computer tomography in children and adolescents: the 2013 ISCD Pediatric Official Positions. *J Clin Densitom* 2014; 17: 258-274.
34. Taylor A, Konrad PT, Norman ME, et al. Total body bone mineral density in young children: influence of head bone mineral density. *J Bone Miner Res* 1997; 12: 652-655.
35. Binkley TL, Specker BL and Wittig TA. Centile curves for bone densitometry measurements in healthy males and females ages 5-22 yr. *J Clin Densitom* 2002; 5: 343-353.

36. Dragoo JL and Braun HJ. The effect of playing surface on injury rate: a review of the current literature. *Sports Med* 2010; 40: 981-990.

Table 1. Subject characteristics of football players who played in different surfaces and controls.

	Pre-season moment		Post-season moment		Pre-season moment		Post-season moment	
	All players (n = 27)	CG (n = 15)	All players (n = 27)	CG (n = 15)	3G-EL (n = 14)	3G-NEL (n = 13)	3G-EL (n = 14)	3G-NEL (n = 13)
Age (year)	13.17±0.52	12.58±1.11	13.75±0.51*	13.37±1.15*	13.01±0.61	13.35±0.34	13.61±0.61*	13.90±0.34*
Weight (kg)	50.57±11.19	46.26±8.94	54.07±12.09*	50.32±9.77*	50.89±12.01	50.23±10.72	54.41±12.57*	53.69±12.05*
Height (cm)	158.32±8.77	153.37±8.82	162.97±9.11*	158.62±9.15*	157.26±10.09	159.47±7.31	161.96±10.62*	164.05±7.42*
BMI ($kg \cdot m^{-2}$)	19.99±3.06	19.54±2.51	20.18±3.27*	19.86±2.61*	20.35±3.24	19.60±2.93	20.54±3.32*	19.80±3.30*
Daily calcium intake (mg)	819.88±210.85	793.18±309.33	855.09±329.62	1001.54±505.92	812.27±213.77	828.08±216.06	879.42±432.92	828.88±175.88
Subtotal lean mass (g)	34269.71±6804.01	30965.97±5982.53	37438.26±7871.54*	34295.15±7183.19*	34677.22±7597.57	33830.86±6113.04	37979.51±8586.61*	36855.38±7325.65*
Percentage of body fat (%)	23.98±6.86	24.35±6.76	22.50±6.59*	23.92±6.61	23.57±7.53	24.42±6.34	22.00±7.69	23.04±5.43*
Tibia Length (mm)	359±23	349±26	366±24*	363±32*	357±25	362±21	364±26*	369±21*
Tibia Muscle Area (mm^2)	5637.13±972.37	5185.67±985.63	5958.94±1085.76*	5538.15±1335.06*	5823.79±1066.85	5436.12±855.09	6108.96±1168.91*	5797.37±1009.69*
Tanner (I/II/III/IV/V)	0/6/11/9/1	0/4/4/7/0	0/3/8/14/2	0/2/6/6/1	0/3/7/3/1	0/3/4/6/0	0/2/5/6/1	0/1/3/8/1

Data presented as mean ± standard deviation. 3G-EL: football players who trained in third-generation artificial turf with elastic layer; 3G-NEL: football players who trained in third-generation artificial turf without elastic layer; CG: control group; BMI: body mass index. * significant differences between values obtained at the beginning and end of the season.

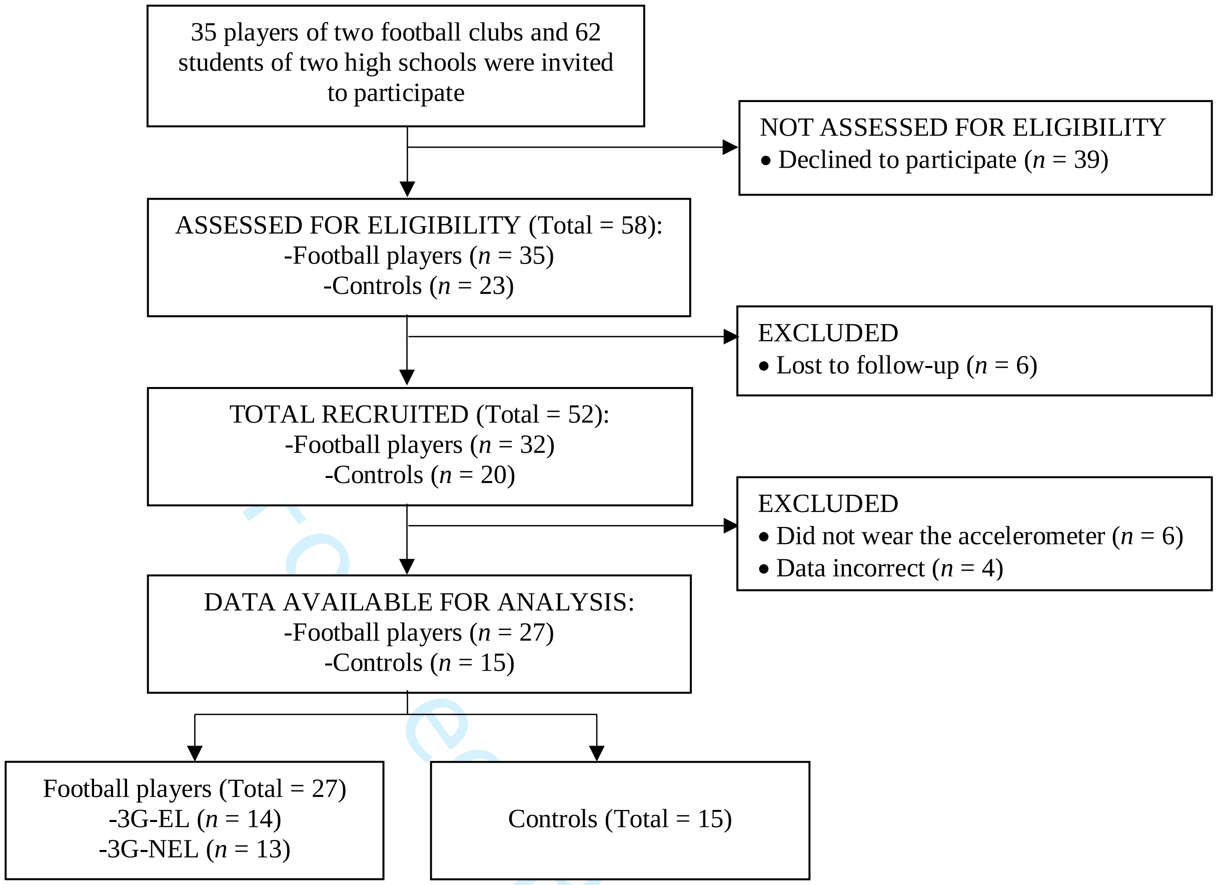
Table 2. Bone mineral content, density, strength and structure in football players and controls.

		All players	CG	Repeated Measures: Within Group, All players	Within Group, CG	Group by time	3G-EL	3G-NEL	Repeated Measures: Within Group, 3G-EL	Within Group, 3G-NEL	Group by time
		N=27	N=15	η^2_p	η^2_p	η^2_p	N=14	N=13	η^2_p	η^2_p	η^2_p
DXA											
BMC (g)											
Subtotal body	T0	1289.290±263.534	1130.329±267.328				1334.216±305.267	1240.909±211.261			
	T1	1467.438±330.159	1288.363±322.811	0.713‡	0.521‡	0.011	1517.670±375.491	1413.341±278.067	0.674‡	0.629‡	0.004
Lumbar Spine	T0	38.44±8.10	35.24±8.13				38.72±9.76	38.14±6.22			
	T1	43.96±10.14	40.68±10.56	0.642‡	0.492‡	<0.001	44.21±12.12	43.70±7.98	0.602‡	0.591‡	<0.001
aBMD (g/cm²)											
Legs	T0	1.089±0.111	1.025±0.127				1.125±0.127	1.050±0.079			
	T1	1.165±0.131	1.066±0.144#	0.592‡	0.192‡	0.097*	1.198±0.150	1.130±0.100	0.549‡	0.572‡	0.005
BMAD (g/cm³)											
Whole body	T0	0.093±0.005	0.094±0.006				0.093±0.004	0.094±0.006			
	T1	0.094±0.005	0.094±0.005	0.074	0.006	0.051	0.094±0.004	0.095±0.007	0.057	0.090	0.003
Lumbar Spine	T0	0.108±0.012	0.107±0.014				0.114±0.010	0.102±0.011§			
	T1	0.112±0.011	0.110±0.016	0.440‡	0.213‡	0.013	0.116±0.011	0.108±0.010§	0.203‡	0.553‡	0.169*
Femoral Neck	T0	0.184±0.019	0.178±0.025				0.195±0.018	0.173±0.012§			
	T1	0.186±0.019	0.180±0.031	0.017	0.015	<0.001	0.195±0.021	0.177±0.013§	0.002	0.096‡	0.064
pQCT											
4% site											
vBMD (mg/cm³)	T0	323.239±36.539	322.503±48.332				340.621±37.567	304.520±25.136§			
	T1	318.962±30.043	315.847±48.179	0.078	0.102‡	0.009	334.884±28.814	301.816±21.023§	0.109	0.025	0.016
Trabecular vBMD (mg/cm³)	T0	298.757±43.691	287.146±51.027				317.911±44.056	278.130±33.827§			
	T1	291.867±37.550	275.365±54.061	0.083	0.128‡	0.016	309.011±34.253	273.404±32.739§	0.112	0.032	0.013
38% site											
BMC (g)	T0	3.072±0.339	2.841±0.511				3.135±0.369	3.004±0.302			
	T1	3.254±0.398	3.061±0.598	0.635‡	0.586‡	0.026	3.349±0.441	3.153±0.334	0.683‡	0.494‡	0.086
Cortical vBMD (mg/cm³)	T0	1057.859±30.134	1055.431±30.778				1053.591±29.836	1062.454±30.967			
	T1	1055.337±28.683	1061.363±32.942	0.014	0.041	0.053	1051.289±32.829	1059.696±23.984	0.017	0.023	<0.001
Cortical CSA (mm²)	T0	391.991±43.761	357.433±63.992#				398.911±46.288	384.539±41.377			
	T1	412.398±51.080	382.033±79.129	0.500‡	0.346‡	<0.001	423.714±56.310	400.212±43.680	0.606‡	0.462‡	0.036
Cortical thickness (mm)	T0	4.832±0.422	4.605±0.512				4.941±0.501	4.716±0.295			
	T1	5.017±0.418	4.779±0.603	0.192‡	0.106‡	<0.001	5.122±0.476	4.903±0.326	0.383‡	0.384‡	<0.001
FRC_LDX (N)	T0	3142.342±497.580	2822.855±763.484				3210.438±553.960	3069.009±439.040			
	T1	3317.777±510.716	3050.249±783.238	0.280‡	0.266‡	0.012	3428.474±535.839	3198.564±473.699	0.432‡	0.199‡	0.057
SSI_POL (mm³)	T0	1410.744±228.345	1190.714±314.927#				1455.894±245.232	1362.122±207.083			
	T1	1502.870±221.134	1296.479±320.088#	0.259‡	0.204‡	0.003	1544.487±224.998	1458.052±216.588	0.379‡	0.399‡	0.002

Data presented as mean ± standard deviation. T0: pre-season moment; T1: post-season moment; 3G-EL: football players who trained in third-generation artificial turf with elastic layer; 3G-NEL: football players who trained in third-generation artificial turf without elastic layer; CG: control group; DXA: dual-energy X-ray absorptiometry; BMC: bone mineral content; aBMD: areal bone mineral density; BMAD: bone mineral apparent density; pQCT: peripheral quantitative computed tomography; CSA: cross sectional area; FRC_LDX: fracture load (axe X); SSI_POL: polar strain index; η^2_p: partial eta square.

#Significant differences when compared to all players; §Significant differences when compared to 3G-EL; ‡significant differences within groups between the beginning and the final of the season; *significant group by time interaction.

can be small (0.01 – 0.06). medium (0.06 – 0.14) or large (>0.14).


35 players of two football clubs and 62 students of two high schools were invited to participate
NOT ASSESSED FOR ELIGIBILITY
• Declined to participate (n = 39)
ASSESSED FOR ELIGIBILITY (Total = 58):
-Football players (n = 35)
-Controls (n = 23)
EXCLUDED
• Lost to follow-up (n = 6)
TOTAL RECRUITED (Total = 52):
-Football players (n = 32)
-Controls (n = 20)
EXCLUDED
• Did not wear the accelerometer (n = 6)
• Data incorrect (n = 4)
DATA AVAILABLE FOR ANALYSIS:
-Football players (n = 27)
-Controls (n = 15)
Football players (Total = 27)
-3G-EL (n = 14)
-3G-NEL (n = 13)
Controls (Total = 15)

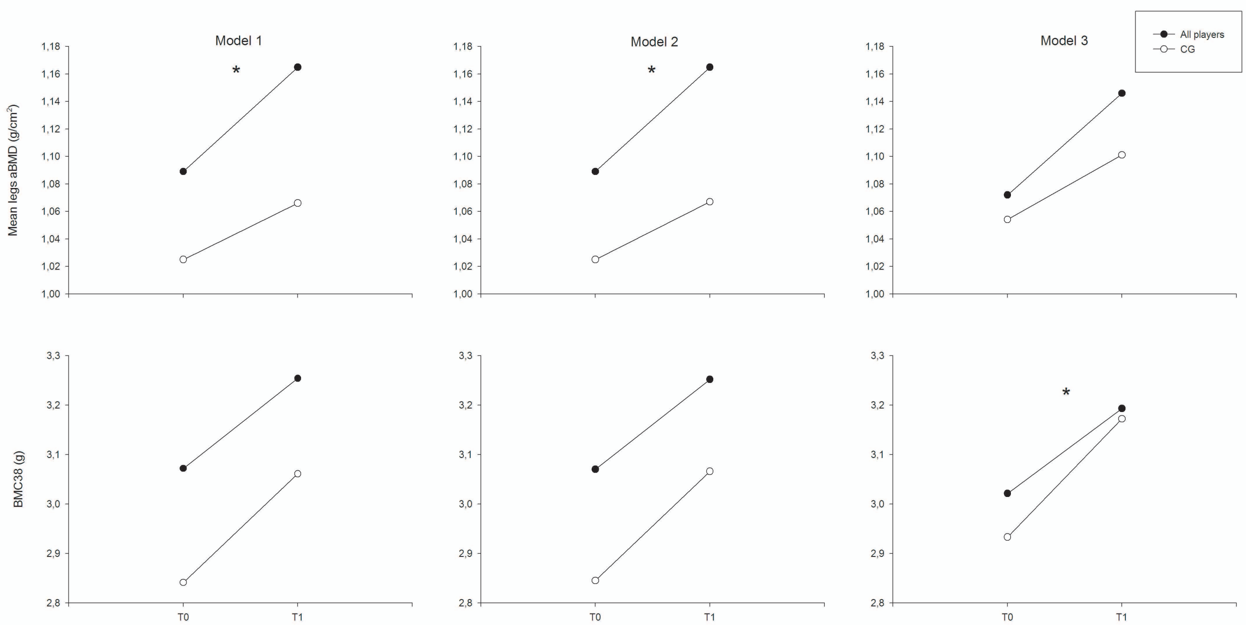


Figure 2 Legs aBMD and BMC38 interactions in football players and CG.
aBMD: areal bone mineral density; BMC38: total bone mineral content at the 38% of the length of the tibia; CG: control group; T0: pre-season moment; T1: post-season moment; Model 1: unadjusted data; Model 2: adjusted data by MVPA; Model 3: adjusted data by MVPA and subtotal lean mass (legs aBMD)/tibia muscle area (BMC38). *: Significant interactions were set at p < .05.

95x48mm (300 x 300 DPI)

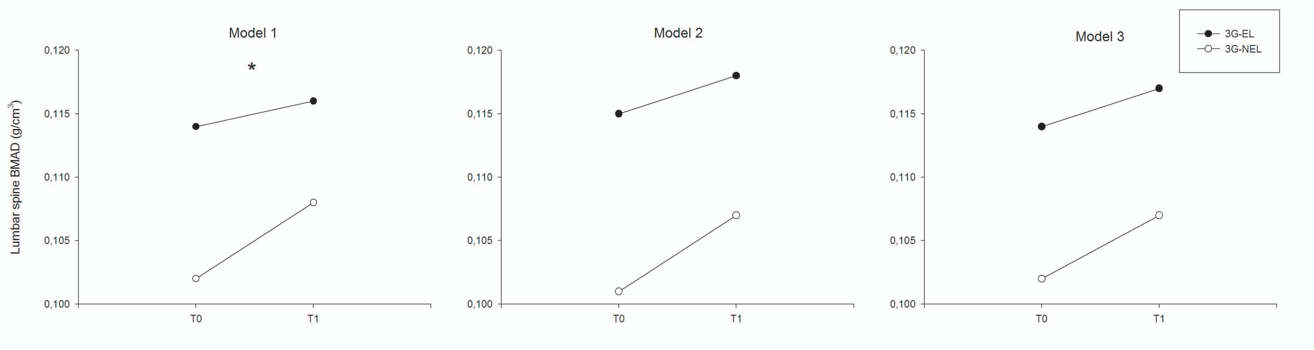


Figure 3 Lumbar spine BMAD interactions in football players.
BMAD: bone mineral apparent density; 3G-EL: football players who trained in third-generation artificial turf with elastic layer; 3G-NEL: football players who trained in third-generation artificial turf without elastic layer; T0: pre-season moment; T1: post-season moment; Model 1: unadjusted data; Model 2: adjusted data by MVPA; Model 3: adjusted data by MVPA and subtotal lean mass. *: Significant interactions were set at $p < .05$.

50x13mm (300 x 300 DPI)

Nutr Hosp. 2017; 34(5):1119-1124 ISSN 0212-1611 - CODEN NUHOEQ S.V.R. 318

ARÁN

Nutrición Hospitalaria

Trabajo Original

Valoración nutricional

Body fat percentage comparisons between four methods in young football players: are they comparable?

Comparación del porcentaje de grasa corporal medido con cuatro métodos diferentes en jóvenes futbolistas: ¿son comparables?

Gabriel Lozano Berges[1,2,3,4], Ángel Matute Llorente[1,2,3,4], Alejandro Gómez Bruton[1,2,3,4], Alejandro González Agüero[1,2,3,4], German Vicente Rodríguez[1,2,3,4] and José Antonio Casajús[1,2,3,4]

[1]Growth, Exercise, Nutrition and Development (GENUD) Research Group. Universidad de Zaragoza. Zaragoza, Spain. [2]Faculty of Health and Sport Science (FCSD). Department of Physiatry and Nursing. Universidad de Zaragoza. Zaragoza, Spain. [3]Instituto Agroalimentario de Aragón-IA2. Universidad de Zaragoza-CITA. Zaragoza, Spain. [4]Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y Nutrición (CIBERObn)

Abstract

Introduction: Dual X-ray absorptiometry (DXA), air displacement plethysmography (ADP), bioelectrical impedance analysis (BIA) and anthropometry are four body composition methods that have been frequently used for the assessment of body fat percentage (%BF) in athletes. However, the agreement between these methods has not been studied yet in adolescent football players.

Objectives: The aim of this study was to compare %BF calculated by DXA, ADP, BIA and anthropometry in 92 participants.

Methods: Sixty-four males (13.4 ± 0.6 years of age) and 28 females (13.4 ± 0.6 years) participated in this study. %BF was measured with four methods: DXA, ADP, BIA, and anthropometry. ADP %BF was calculated by using Siri's equation. The equation proposed by Slaughter et al. was used to calculate %BF by anthropometry. Paired t-test was used to compare %BF means. The heteroscedasticity was calculated by Bland-Altman analyses.

Results and conclusions: Both in males and females, DXA, ADP, BIA and Slaughter et al. equation demonstrated significant %BF differences when compared to each other ($p < 0.05$); 95% limits of agreements ranged from 5.13 to 15.09% points. Only BIA showed heteroscedasticity compared to the other methods in both genders ($p < 0.05$). Although DXA, ADP, BIA, and anthropometry have been used in the scientific literature in order to assess %BF in adolescent football players, these results demonstrate that these body composition methods are not interchangeable in this population.

Key words:

Soccer. Body composition. Absorptiometry. Photon. Skinfold thickness.

Resumen

Introducción: los métodos absorciometría fotónica dual de rayos X (DXA), pletismografía por desplazamiento de aire (ADP), análisis de la impedancia bioeléctrica (BIA) y antropometría han sido utilizados para el cálculo del porcentaje de grasa corporal (%CG) en atletas. Sin embargo, la concordancia entre estos métodos no ha sido estudiada en futbolistas adolescentes.

Objetivos: el objetivo de este estudio fue comparar el %GC calculado mediante DXA, ADP, BIA y antropometría en 92 participantes.

Métodos: sesenta y cuatro chicos (13,4 ± 0,6 años) y 28 chicas (13,4 ± 0,6 años) participaron en este estudio. El %GC fue medido mediante cuatro métodos diferentes: DXA, ADP, BIA, y antropometría. ADP %GC fue calculado a partir de la ecuación de Siri. La ecuación propuesta por Slaughter y cols. fue utilizada para calcular el %CG mediante antropometría y se emplearon las pruebas t de Student para muestras relacionadas para comparar las medias de %CG. La heterocedasticidad fue calculada por análisis de Bland-Altman.

Resultados y conclusiones: tanto en chicos como en chicas, DXA, ADP, BIA y la ecuación de Slaughter y cols. demostraron diferencias significativas en el %GC al ser comparados ($p < 0,05$). Los límites de concordancia al 95% oscilaron entre 5,13 y 15,09%. El BIA fue el único método que mostró heterocedasticidad con los otros métodos ($p < 0.05$). Aunque los métodos DXA, ADP, BIA y la antropometría han sido usados en la literatura científica para calcular el %GC en futbolistas adolescentes, estos resultados demuestran que estos métodos de valoración de la composición corporal no son intercambiables en la población de estudio.

Palabras clave:

Fútbol. Composición corporal. Absorciometría fotónica dual de rayos X. Pliegues cutáneos.

Received: 22/11/2016
Accepted: 14/02/2017

Funding: This work was supported by the Spanish Ministry of Economy and Competitiveness (Project DEP 2012-32724). GLB received a grant FPU 2013 (AP13-2111) from the Spanish Ministry of Education, Culture and Sports. AML received a grant AP12-2854 from the Spanish Ministry of Education, Culture and Sports. AGB received a grant FPI 2012 (BES-2012-051888) from the Spanish Ministry of Economy and Competitiveness.

Clinical trials: The research study was registered in the public database Clinicaltrials.gov (NCT02399553).

Lozano Berges G, Matute Llorente A, Gómez Bruton A, González Agüero A, Vicente Rodríguez G, Casajús JA. Body fat percentage comparisons between four methods in young football players: are they comparable? Nutr Hosp 2017;34:1119-1124

DOI: http://dx.doi.org/10.20960/nh.760

Correspondence:

José Antonio Casajús. Growth, Exercise, Nutrition and Development (GENUD) Research Group. Faculty of Health and Sport Science. University of Zaragoza. C/ Pedro Cerbuna, 12. 50009 Zaragoza, Spain
e-mail: joseant@unizar.es

INTRODUCTION

The components of human body can be quantified at five-levels of body composition according to their complexity from atomic to anatomic levels (1). Methods for analysis of body composition can divide body mass into components on the basis of differing physical properties. At a molecular level, a four-component model (4C) of body composition divides body mass into fat, water, mineral and protein; a three-component model (3C), into fat, mineral and lean soft tissue; and a two-component model (2C), into fat and fat-free mass (1). The 4C model is considered as the gold standard to assess body composition in pediatric populations (2). Nevertheless, the use of a 4C model is not available for most researches due to its high economic cost and time involvement (2). For example, dual energy X-ray absorptiometry (DXA), as a body composition analysis device, derives a 3C model, or air displacement plethysmography (ADP) uses a 2C model, therefore these two are not the most recommended methods to be used in children and adolescents (2). Nevertheless, several studies have monitored the percentage of body fat (%BF) with DXA as well as ADP in these populations (3,4).

In fact, despite DXA is the criterion method for measuring bone mass, it also calculates fat and lean masses, and several studies have used DXA as a reference method for measuring body composition, concretely %BF (5,2). Toombs et al. (6) pointed out that DXA may be a convenient method to be used in the assessment of body composition because of its high precision, safety and time efficiency. ADP is considered as the reference method for evaluating %BF in adults (7), but it can over- or underestimate it in children and adolescents assuming the adult constant values for lean tissue hydration (8). Lohman (9) and Wells et al. (10) adapted Siri's equation and developed age- and gender-specific equations for pediatric populations.

At a whole-body level, bioelectrical impedance analysis (BIA) and anthropometry are simple and low cost techniques that have also been used for the estimation of %BF in young athletes (11,12).

Body composition has been related to physical performance through childhood and adolescence (13). An elevated %BF has a negative effect on the performance of athletes such as football players (14). Thus, assessments of %BF during the season might be a useful variable for coaches in order to plan specific training.

Some studies have demonstrated that DXA, ADP and BIA are not interchangeable for the evaluation of %BF in different populations such as moderately active adolescents (15), overweight children (7) and obese adolescents (16). However, to our knowledge, no studies have determined the agreement between body composition methods such as DXA, ADP, BIA, and anthropometry in young football players. Therefore, the aim of the present study was to compare %BF calculated by DXA, ADP, BIA and anthropometry (Slaughter et al. [17]) in adolescent football players.

MATERIAL AND METHODS

PARTICIPANTS

Eight clubs of Aragón (Spain) participated in this cross-sectional study. A total of 121 football players (81 males and 40 females) signed the written consent. Twenty-nine football players were not included because they did not meet the inclusion criteria or could not do the assessment. Finally, 92 adolescent football players (64 males, 13.4 ± 0.6 years; 28 females, 13.4 ± 0.6 years) participated in this study.

Participants, their parents and their corresponding clubs were informed about the protocol of this study. Their parents or guardians completed and signed each written informed consent to participate in the study prior to taking any measurement. This study was performed in accordance with the Declaration of Helsinki of 1964 (revised in Fortaleza, 2013) and was reviewed and approved by the Research Ethics Committee of the Government of Aragon (CEICA, Spain) (C.I. PI13/0091).

INCLUSION CRITERIA

Age between eleven and 14 years and at least one year of football practice were the inclusion criteria of the present study.

DUAL ENERGY X-RAY ABSORPTIOMETRY MEASUREMENTS

Whole body %BF was calculated by DXA QDR-Explorer (pediatric version of the software QDR-Explorer, Hologic Corp., software version 12.4, Bedford, Massachusetts, USA). DXA equipment was calibrated daily with a spine phantom following the manufacturer guidelines. Football players were measured in supine position and all DXA scans were performed and analyzed by the same technician who was fully trained to perform them.

AIR DISPLACEMENT PLETHYSMOGRAPHY MEASUREMENTS

Total body density was calculated via ADP (BODPOD®, Body Composition System, Life Measurement Instruments, Concord, CA). The same technician performed all exams and ADP was calibrated following the guidelines established by the manufacturer. The software of the BODPOD® estimated pulmonary capacity. Total body density was inserted in Siri equation (18) to calculate %BF.

BIOELECTRICAL IMPEDANCE ANALYSES MEASUREMENTS

Each participant was also measured using BIA (TANITA BC-418, Tanita, Tokyo, Japan) to obtain %BF. Sex, age, and height were inserted into BIA prior to the impedance measure. The same trained technician following the device guidelines also performed these measurements.

ANTHROPOMETRIC MEASUREMENTS

Height with a stadiometer (SECA 225, SECA, Hamburg, Germany) to the nearest 0.1 cm and weight with a scale (SECA, Hamburg, Germany) to the nearest 0.1 kg were measured with participants in underwear and barefoot. Body mass index (BMI) was calculated as weight (in kilograms) divided by squared height (in meters).

Triceps and subscapular skinfolds were measured following the recommendations of the International Society for the Advancement of Kinanthropometry (ISAK), with a skinfold calliper (Holtain Ltd. Crymmych, UK) to the nearest 0.2 mm, by the same trained technician (level 2 ISAK anthropometrist) (19). BF% was directly estimated via the Slaughter et al. (17) equation.

STATISTICAL ANALYSES

Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analyses. The studied variables showed a normal distribution according to the Kolmogorov-Smirnov test. Data were presented as mean and standard deviation (SD).

Differences between %BF obtained via DXA, ADP, BIA and anthropometry were analyzed by two-paired samples t-test. The 95% limits of agreement (inter-methods difference ± 1.96 SD) of each equation were also calculated. The agreement between DXA, ADP, BIA and Slaughter et al. (17) equation was evaluated according to Bland-Altman plots (20), in both genders separately. Inter-method differences were plotted against the mean of both methods. In addition, heteroscedasticity was examined by linear regression to determine whether the absolute inter-methods difference was associated with the magnitude of the measurement. Effect size statistics using Cohen's d were calculated. The effect size for Cohen's d can be small (0.2-0.5), medium (0.5-0.8) or large (> 0.8). Statistical significance was set at $p < 0.05$.

RESULTS

Table I shows the characteristics of the participants. No differences were found in age, height and Tanner between males and females (all $p > 0.05$). Male football players were heavier and showed higher BMI than their female counterparts ($p < 0.05$; Cohen's d were 0.5 and 0.7).

Comparisons of %BF for DXA, ADP, BIA and the Slaughter et al. (17) equation are shown in table II. In both genders, these methods demonstrated %BF differences when compared to each other ($p < 0.05$; Cohen's d ranged from 0.4 to 1.6).

Inter-methods differences, 95% limits of agreement and heteroscedasticity are summarized in table III. ADP, BIA, and Slaughter et al. (17) equation underestimated %BF between -1.24 and -10.52% points compared to DXA ($p < 0.05$; Cohen's d ranged from 0.5 to 1.6). Moreover, all methods showed a random error between 5.13 and 12.99, being the Slaughter et al. (17) equation the highest one in females. As compared with ADP, significant %BF differences were found with BIA and the Slaughter et al. (17) equation in both genders ($p < 0.05$; Cohen's d ranged from 0.4 to 0.9). BIA and the Slaughter et al. (17) equation showed a random error between 7.13 and 15.09, being also the Slaughter et al. (17) equation the highest one in female football players. On the other hand, the Slaughter et al. (17) equation underestimated %BF by 0.96 and 9.47% points in males and females, respectively.

Bland-Altman plots for the differences between DXA, ADP, BIA and anthropometry are shown in figure 1. In males, ADP, BIA and Slaughter et al. (17) equation showed heteroscedasticity when compared to DXA ($p < 0.05$). Moreover, BIA showed heteroscedasticity when compared with ADP and Slaughter et al. (17) equation both in males and females ($p < 0.05$).

Table I. Subject characteristics (mean ± standard deviation)

	All (n = 92)	Males (n = 64)	Females (n = 28)
Age (years)	13.4 ± 0.6	13.4 ± 0.6	13.4 ± 0.6
Weight (kg)	49.8 ± 10.7	48.3 ± 10.9*	53.1 ± 9.6
Height (cm)	159.8 ± 8.5	159.8 ± 9.1	159.8 ± 7.1
BMI (kg/m^2)	19.3 ± 2.9	18.7 ± 2.7*	20.7 ± 2.9
Tanner (I/II/III/IV/V)	1/11/34/36/10	0/7/28/22/7	1/4/6/14/3

*BMI: Body mass index. *p < 0.05 between genders.*

Table II. Percentage of body fat calculated by DXA, ADP, BIA and the Slaughter et al. equation in young football players

Model	Males (n = 64)		Females (n = 28)	
	%BF	SD	%BF	SD
DXA	19.93	4.75	26.38	4.72
ADP	18.48*	5.65	22.38*	5.69
BIA	16.92*,#	3.92	25.14*,#	4.01
Slaughter et al. (17)	15.95*,#,$	6.29	15.47*,#,$	6.14

*DXA: Dual energy X-ray absorptiometry; ADP: Air displacement plethysmography; BIA: Bioelectrical impedance analysis; %BF: Percentage of body fat; SD: Standard deviation. *%BF differences with DXA; #%BF differences with ADP; $%BF differences with BIA. Statistical significance was set at p < 0.05.*

DISCUSSION

The main finding of the present study is that significant differences in determining %BF exist between different body compo-

Table III. Percentage of body fat differences between methods (DXA, ADP, BIA and Slaughter et al. equation), limits of agreement 95%, confidence interval, correlation coefficient (R) and heteroscedasticity

Model	Differences between methods	95% limits of agreement	Confidence interval	R	Heteroscedasticity (p)
Compared to DXA					
Males (n = 64)					
DXA	-	-	-	-	-
ADP	1.45	5.13	(-3.69-6.58)	0.355	0.004*
BIA	3.02	5.17	(-2.15-8.18)	0.330	0.008*
Slaughter et al. (17)	3.98	6.41	(-2.43-10.39)	0.490	< 0.001*
Females (n = 28)					
DXA	-	-	-		
ADP	4.00	7.60	(-3.61-11.60)	0.269	0.166
BIA	1.24	5.21	(-3.97-6.45)	0.281	0.148
Slaughter et al. (17)	10.52	12.99	(-2.47-23.51)	0.346	0.078
Compared to ADP					
Males (n = 64)					
ADP	-	-	-	-	-
BIA	1.57	7.13	(-5.56-8.70)	0.506	< 0.001*
Slaughter et al. (17)	2.53	6.09	(-3.56-8.62)	0.214	0.089
Females (n = 28)					
ADP	-	-	-		
BIA	-2.76	8.57	(-11.33-5.82)	0.424	0.025*
Slaughter et al. (17)	6.94	15.09	(-8.16-22.03)	0.057	0.778
Compared to BIA					
Males (n = 64)					
BIA	-	-	-	-	-
Slaughter et al. (17)	0.96	7.20	(-6.23-8.16)	0.674	< 0.001*
Females (n = 28)					
BIA	-	-	-	-	-
Slaughter et al. (17)	9.47	12.95	(-3.48-22.43)	0.423	0.028*

*DXA: Dual energy X-ray absorptiometry; ADP: Air displacement plethysmography; BIA: Bioelectrical impedance analysis. *p < 0.05.*

sition analysis methods in young football players, and they are therefore non comparable. In addition, these methods demonstrated high random errors when compared to each other.

The different model that the ADP and DXA use (2C *vs* 3C) could explain the differences in %BF between these two methods. Fat-free mass assumptions of the 2C model is its major disadvantage (21). The 2C model used by ADP was developed from adult body dissection and its application in children might be inadequate (9). Even when age- and sex-specific equations for children and adolescents (Lohman [9] and Wells et al. [10] equations) were used, significant differences for %BF were found between methods (personal observations). In addition, these differences between DXA and ADP, using the Lohman (9) and Wells et al. (10) equations, were even higher in comparison with the differences found between DXA and ADP, and using the Siri equation (personal observations).

In the present study, BIA also underestimated %BF compared with DXA. BIA was created to calculate total body water by the resistance offered to an alternate current. Fat mass has lower hydration than fat-free mass (22) and BIA assumes that total body water is the 73.2% of fat-free mass; however, Wells et al. (10) demonstrated that the hydration of fat-free mass was higher than 75% during growth. These assumptions and hydration differences between participants could explain the differences between DXA and BIA in the present study. Moreover, the amount of water could be modified during the day depending on physical activity performed or water

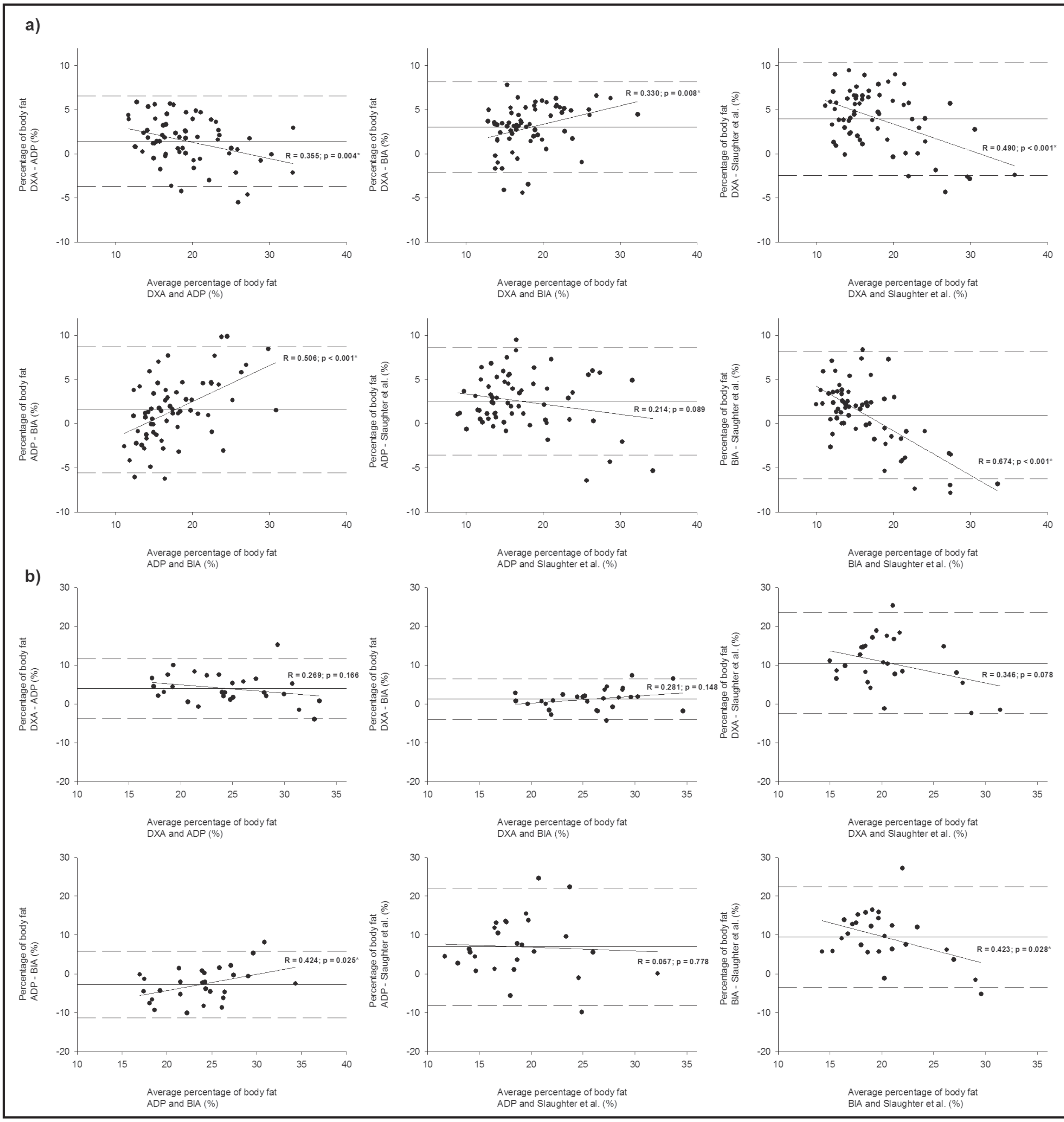


Figure 1.

Comparison of percentage of body fat between DXA, ADP, BIA and Slaughter et al. equation by Bland-Altman plots. Caption: comparison of predicted percentage of body fat between DXA, ADP, BIA and Slaughter et al. (17) equation a) in males; b) in females. Each point describes individual differences values between methods. Central line represents standard error and dash lines represent the 95% limits of agreement (standard error ± 1.96 x SD). The solid line in each plot represents the linear regression between the average of both field methods and differences between these methods (%BF: percentage of body fat; DXA: dual X-ray absorptiometry; ADP: air displacement plethysmography; BIA: bioelectrical impedance analysis. *p < 0.05).

drunk before the measurement; nevertheless, DXA and other measurement methods are not affected by these external variables.

The use of the Slaughter's (17) equation has been recommended for estimating %BF in adolescents because it has been developed with a 4C model (2). A study comparing different methods for measuring %BF in adolescents reported that DXA showed better agreement with the Slaughter et al. (17) equation than with ADP or BIA (15). In contrast, our results showed that %BF by the

Slaughter et al. (17) equation was not interchangeable with DXA and ADP neither in male nor female football players. The highest %BF difference was found between DXA and the Slaughter et al. (17) equation, and heteroscedasticity was found. This equation was created with a 4C model that uses underwater weighing to measure volume and estimate fat mass. Underwater weighing and DXA use different techniques and processes to measure fat mass and this could explain the differences found.

The main limitation of the present study is the use of DXA, ADP, BIA and anthropometry, instead of a 4C model as recommended in pediatric populations. However, the main objective of the present study was not to evaluate %BF in these athletes, but to compare the different methods to ascertain whether or not those are comparable. On the other hand, the main strengths of this study are sample size, which is bigger than any previous comparable study (84 moderately active adolescents [15] or 69 overweight and obese children [7]). Also, all measurements were made in the same session by the same technician, which means that intra-variability changes in the participants were avoided.

Overall, this study demonstrates that %BFs assessed by DXA, ADP, BIA and anthropometry in adolescents football players are not comparable. Compared with DXA, all methods underestimated %BF in a higher or smaller way. Future studies should evaluate agreement between these methods in comparison to %BF estimated by using a 4C model (it combines different methods such as DXA, ADP and deuterium dilution).

ACKNOWLEDGEMENTS

The authors want to thank all the children, their parents and football clubs (Real Zaragoza S.A.D., Los Molinos U.D., C.D. Marianistas, C.D. Transportes Alcaine and S.D. Ejea) that participated in the study for their understanding and dedication to the project.

REFERENCES

1. Wang ZM, Heshka S, Pierson RN Jr, Heymsfield SB. Systematic organization of body-composition methodology: An overview with emphasis on component-based methods. Am J Clin Nutr 1995;61:457-65.
2. Silva AM, Fields DA, Sardinha LB. A PRISMA-driven systematic review of predictive equations for assessing fat and fat-free mass in healthy children and adolescents using multicomponent molecular models as the reference method. J Obes 2013;2013:148696.
3. El Hage R. Fat mass index and hip bone mineral density in a group of Lebanese adolescents and young adults. J Med Liban 2014;62:137-42.
4. Fields DA, Allison DB. Air-displacement plethysmography pediatric option in 2-6 years old using the four-compartment model as a criterion method. Obesity 2012;20:1732-7.
5. Silva DR, Ribeiro AS, Pavao FH, Ronque ER, Avelar A, Silva AM, et al. Validity of the methods to assess body fat in children and adolescents using multi-compartment models as the reference method: A systematic review. Rev Assoc Med Bras 2013;59:475-86.
6. Toombs RJ, Ducher G, Shepherd JA, De Souza MJ. The impact of recent technological advances on the trueness and precision of DXA to assess body composition. Obesity 2012;20:30-9.
7. Radley D, Gately PJ, Cooke CB, Carroll S, Oldroyd B, Truscott JG. Estimates of percentage body fat in young adolescents: A comparison of dual-energy X-ray absorptiometry and air displacement plethysmography. Eur J Clin Nutr 2003;57:1402-10.
8. Schoeller DA. Human body composition. In: Heymsfield MD, Lohman TG, Wang Z, Going SB, eds. Human Body Composition. United States: Human Kinetics; 1996.
9. Lohman TG. Applicability of body composition techniques and constants for children and youths. Exerc Sport Sci Rev 1986;14:325-57.
10. Wells JC, Williams JE, Chomtho S, Darch T, Grijalva-Eternod C, Kennedy K, et al. Pediatric reference data for lean tissue properties: Density and hydration from age 5 to 20 y. Am J Clin Nutr 2010;91:610-8.
11. Yamada Y, Masuo Y, Nakamura E, Oda S. Inter-sport variability of muscle volume distribution identified by segmental bioelectrical impedance analysis in four ball sports. Open Access J Sports Med 2013;4:97-108.
12. Portal S, Rabinowitz J, Adler-Portal D, Burstein RP, Lahav Y, Meckel Y, et al. Body fat measurements in elite adolescent volleyball players: Correlation between skinfold thickness, bioelectrical impedance analysis, air-displacement plethysmography, and body mass index percentiles. J Pediatr Endocrinol Metab 2010;23:395-400.
13. Artero EG, Espana-Romero V, Ortega FB, Jiménez-Pavón D, Ruiz JR, Vicente-Rodríguez G, et al. Health-related fitness in adolescents: Underweight, and not only overweight, as an influencing factor. The AVENA study. Scand J Med Sci Sports 2010;20:418-27.
14. Nikolaidis PT. Physical fitness is inversely related with body mass index and body fat percentage in soccer players aged 16-18 years. Med Pregl 2012;65:470-5.
15. Vicente-Rodríguez G, Rey-López JP, Mesana MI, Poortvliet E, Ortega FB, Polito A, et al. Reliability and intermethod agreement for body fat assessment among two field and two laboratory methods in adolescents. Obesity 2012;20:221-8.
16. Lazzer S, Bedogni G, Agosti F, De Col A, Mornati D, Sartorio A. Comparison of dual-energy X-ray absorptiometry, air displacement plethysmography and bioelectrical impedance analysis for the assessment of body composition in severely obese Caucasian children and adolescents. Br J Nutr 2008;100:918-24.
17. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, et al. Skinfold equations for estimation of body fatness in children and youth. Hum Biol 1988;60:709-23.
18. Siri WE. Body composition from fluid spaces and density: Analysis of methods. 1961. Nutrition 1993;9:480-91.
19. Marfell-Jones MJ, Olds T, Stewart AD, Carter L. International Standards for Anthropometric Assessment. Adelaida: International Society for the Advancement of Kinanthropometry; 2006.
20. Krouwer JS. Why bland-altman plots should use X, not (Y+X)/2 when X is a reference method. Stat Med 2008;27:778-80.
21. Lohman TG. Research progress in validation of laboratory methods of assessing body composition. Med Sci Sports Exerc 1984;16:596-605.
22. Hewitt MJ, Going SB, Williams DP, Lohman TG. Hydration of the fat-free body mass in children and adults: Implications for body composition assessment. Am J Physiol 1993;265:E88-95.

International Journal of Sport Nutrition and Exercise Metabolism

Accurate Prediction Equation to Assess Body Fat in Male and Female Adolescent Football Players.

Journal:	*International Journal of Sport Nutrition & Exercise Metabolism*
Manuscript ID	IJSNEM.2018-0099.R1
Manuscript Type:	Original Research
Keywords:	Soccer, body composition, anthropometry

Accurate Prediction Equation to Assess Body Fat in Male and Female Adolescent Football Players.

Abstract

The aims of this study were (a) to determine which of the most used anthropometric equations was the most accurate to estimate percentage of body fat (%BF), (b) to develop a new specific anthropometric equation, and (c) to validate this football-specific equation. A total of 126 (13.3±0.6 y) football players (86 males) participated in the present study. Participants were divided into two groups: 98 players were included in the assessment of existing equations and in the development of the new prediction equation; and 28 were used to validate it. %BF was measured with dual-energy X-ray absorptiometry (DXA) and also estimated with six different %BF anthropometric equations: Johnston, Slaughter, Carter, Faulkner, Deurenberg and Santi-Maria. Paired *t*-tests were used to analyze differences between methods. A football-specific equation was developed by a stepwise linear-regression. The existing anthropometric equations showed significant bias for %BF when compared to DXA (p<.001; constant error [CE] ranged from -4.57 to 9.24%; standard error of estimate [SEE] ranged from 2.46 to 4.20). On the other hand, the developed football-specific equation was %BF = 11.115 + 0.775(triceps skinfold) + 0.193(iliac-crest skinfold) – 1.606(sex). The developed equation demonstrated neither %BF differences (p=.121; CE=0.57%; SEE=0.36) when compared to DXA, presenting a high cross-validation prediction power (R^2=0.85). Published anthropometric equations were not accurate to estimate %BF in adolescent football players. Due to the fact that the developed football-specific equation showed neither differences nor heteroscedasticity when compared to DXA, this equation is recommended to assess %BF in adolescent football players.

Keywords: Soccer; Body composition; Anthropometry.

Introduction

The assessment of percentage of body fat (%BF) is often performed in sport clubs to monitor body composition changes in the athletes during the season due to its relationship with physical fitness and performance (Avlonitou, Georgiou, Douskas, & Louizi, 1997).

Anthropometry, bioelectrical impedance analysis, dual x-ray absorptiometry (DXA), air displacement plethysmography (ADP) and hydrostatic weighing are some of the available methods to assess %BF (Silva, Fields, & Sardinha, 2013). ADP, which uses the two-component model (2C, fat mass (FM) and fat free mass (FFM)) and DXA, which uses the three-component model (3C, fat, mineral and lean soft tissue), have been widely used to calculate %BF (Horner, Byrne, Cleghorn, & King, 2015; Zhang et al., 2017). However, these methods are not recommended in pediatric population (A. M. Silva et al., 2013). The four-component model (4C), which divides the body into fat, water, mineral and protein, is considered the most adequate model for assessing body composition in children and adolescents (A. M. Silva et al., 2013). Nevertheless, the use of the 4C model is impractical for most researchers as a consequence of its high costs and time involvement.

The accuracy of DXA (3C model) to assess %BF in children and adolescents has been analyzed respect to reference methods such as 4C (Fields & Goran, 2000) or five-component model (5C) (Silva, Minderico, Teixeira, Pietrobelli, & Sardinha, 2006). Despite some inter-methods differences observed in these studies, these authors demonstrated a strong association between DXA and the above-mentioned reference methods (4C and 5C). Furthermore, DXA has been used in several studies to evaluate %BF or as a criterion method to develop anthropometric equations in children and adolescents (A. M. Silva et al., 2013; D. R. Silva et al., 2013). However, DXA is not an available method for coaches due to the high economic cost. Thus, the use of a simple, practical and accessible method such as anthropometry to estimate %BF or FFM could be a useful tool for non-professional football teams (Valente-dos-Santos et al., 2012).

Anthropometry has been used to evaluate body composition in different athletes from different sports (Dellagrana et al., 2015; Falk et al., 2010). However, specific anthropometric equations should be used for each population in order to reduce the error of estimation of this method. Many studies have evaluated anthropometric equations for children (Eisenmann, Heelan, & Welk, 2004) and adolescents (Rodriguez et al., 2005) to find the one that best fits with their morphology. It has been known that only Reilly et al. (2009) and Santi-Maria et al. (2015) created specific equations for adult and adolescent male football players respectively. However, cross-validations using a comparable sample have not been performed yet. In addition, the recent and growing increment on female participation requires especial attention and specific equation. Therefore, due to the importance of monitoring %BF in sports, the aims of this study were (a) to determine the accuracy of the most used anthropometric equation in male and female adolescent football players, (b) to develop a specific equation for male and female football players, and (c) to cross-validate this new equation with another sample of the same population.

Methods

Participants

Ten clubs of Aragon (Spain) participated in the present study. A total of 149 Caucasian football players from these clubs agreed to participate; 23 players were not included because they did not meet the inclusion criteria or could not do the assessment. Finally, 126 adolescent football players participated in this study. They were randomly divided into two groups: 98 (65 males, 13.4 ± 0.6 years old; 33 females, 13.4 ± 0.6 years old, Table 1) participated in the assessment of previous anthropometric equations and the development of a new specific equation, and 28 (21 males, 13.1 ± 0.5 years old; 7 females, 13.3 ± 0.4 years old, Table 1) included in the validation of the new equation.

All participants, their parents and their corresponding clubs were informed about the risk and benefits associated to this study. We obtained written informed consent from parents or legal guardians and written assent from all participants. This study was performed according to the declaration of Helsinki 1961 (revision of Fortaleza 2013) and the protocol was approved by the Ethics Committee of Clinical Research from the Government of Aragon (CEICA, Spain) [C.I. PI13/0091]. The present study is part of the FUTBOMAS project, which is registered in the public database Clinicaltrials.gov [NCT02399553].

Inclusion Criteria

Ages between 11 and 14 years old, at least two football trainings per week during the last year, and free of any medication affecting body composition were the inclusion criteria established for the present study.

Body Fat Measurement with DXA

Whole body %BF was obtained via DXA using the QDR-Explorer (pediatric version of the software QDR-Explorer, Hologic Corp. Software version 12.4, Bedford, Massachusetts, USA). The age-, gender- and ethnicity-specific reference data provided by the National Health and Nutrition Examination Survey (NHANES) were used. Calibration tests with a spine phantom were daily performed before taking any measurements. The participants had not eaten anything at least 2-hours before testing and also, had not trained. They were measured with minimum clothes and without jewelry and placed in a supine position in the center of the scanning area. Velcro straps were used to hold their feet in place with their toes pointed upwards. Their hands were placed flat on the table next to the hips. Both arms and hands were separated to the torso and hips respectively. All DXA scans were done during the afternoon and the evening (between 17:00-19:00 hours) and were conducted and analyzed by the same technician who had been fully trained in the operation of the scanner, the positioning of participants and the analysis of results according to the manufacturer´s guidelines.

Anthropometric Measurements

Height (stadiometer to the nearest 0.1 cm, SECA 225, SECA, Hamburg, Germany) and weight (scale to the nearest 0.1 kg, SECA, Hamburg, Germany) were measured without shoes and the minimum clothes. Body mass index (BMI) was calculated as weight (in kilograms) divided by squared height (in meters).

Biceps, triceps, subscapular, iliac-crest, supraspinale, abdominal, front thigh and medial calf skinfolds were registered following the recommendations of the International Society of the Advancement of Kinanthropometry (ISAK) (Marfell-Jones, Olds, Stewart, & Carter, 2006), with a skinfold caliper (to the nearest 0.2 mm, constant pressure of 10 $g \cdot mm^{-2}$ Holtain Ltd. Crymmych, UK) by a level 2 ISAK anthropometrist. Pubertal maturity was self-determined according to the stages proposed by Tanner and Whitehouse (1976).

Total body density was calculated via Johnston et al. (1988). Then, the Siri (1961) equation was used to estimate %BF. In addition, %BF was directly estimated using the equations proposed by Slaughter et al. (1988), Carter (1982), Faulkner (1968), Deurenberg et al. (1991) and Santi-Maria et al. (2015) (Table 2). Most of these equations were included based on the selection performed in Rodriguez et al. study (2005). On the other hand, the Santi-Maria et al. (2015) equation was included because it was developed with male football players, and the Carter (1982) equation because it was developed with athletes. From all equations included in this study, only Santi-Maria et al. (2015) equation followed the procedures of ISAK.

Experimental Design

The present study was divided into three experiments in order to achieve the three main aims.

Assessment of previous anthropometric equations (98 football players): %BF calculated by published anthropometric equations were compared to %BF via DXA to determine its accuracy in adolescent football players.

Development of a new anthropometric equation (98 football players): A specific anthropometric equation was created for male and female football players.

Validation study (28 football players): %BF calculated by the new anthropometric equation was compared to DXA %BF in order to determine its accuracy.

Statistical Analyses

Statistical Package for the Social Sciences (SPSS) version 22.0 for Mac OS X (SPSS Inc., Chicago, IL, USA) was used to perform all statistical analysis. Data are presented as means and standard deviation (SD). All variables showed normal distribution by the Kolmogorov-Smirnov test. Tanner status differences between genders were assessed using the Chi square test.

Paired *t*-tests were performed to analyze differences in %BF between equations and DXA. The potential inflation of multiple comparisons was controlled by Bonferroni correction, and consequently, the *p* value of .05 was divided by 6 (number of comparisons that were conducted) when the accuracy of previous anthropometric equations was evaluated. The constant error (CE) was calculated as the mean difference between %BF by DXA and by each anthropometric equation. The 95% limits of agreement (CE ± 1.96 SD) were also calculated for each equation. Regression analyses between the %BF measured by DXA and anthropometric equations were applied to determine the Pearson correlation coefficient (r) and the Standard Error of Estimation (SEE). Besides, correlation analyses were performed to calculate the trend between the %BF differences of both methods and their means.

A new football-specific anthropometric equation was developed using step-wise linear regression models. Sex, height, weight and skinfold thickness were the independent variables and %BF from DXA the dependent one. The predictive power of the new equation was calculated with the Stein equation (Field, 2005). Additionally, root mean squared errors (RMSE) of the model were calculated using leave-one-out (LOOCV) and 10-fold cross-validations to determine the ability of the proposed anthropometric equation to predict %BF in young football players. Stata v.13 (StataCorp, College Station, Texas, USA) was used to perform these analyses. Moreover, to carry out an external validation, a new sample of football players were recruited.

Effect size statistics using Cohen´s *d* (G*Power version 3.1.9.2 for Mac OS X) were calculated for differences between methods. Taking into account the cut-off established by Hopkins et al. (2009), the threshold for Pearson correlation coefficient can be trivial (0.0 – 0.1), small (0.1 – 0.3), moderate (0.30 – 0.49), large (0.50 – 0.69), very large (0.70 – 0.89) or nearly perfect (0.90 – 1.00); and for differences between methods trivial (0.0 – 0.2), small (0.2 – 0.6), moderate (0.6 – 1.2), large (1.2 – 2.0) or very large (>2.0). Statistical significance was set at p < .05.

Results

Descriptive results are shown in Table 1. Age, height, weight and Tanner stages were not significantly different between genders (all $p > .05$). BMI was higher in female football players than in males ($p < .05$). The anthropometric equations used in this study are summarized in Table 2. Anthropometrist's TEM for each skinfold thickness is shown in Table 3.

Accuracy of Previous Anthropometric Equations

Predicted %BF with different anthropometric equations, Pearson correlation coefficient, SEE, CE, 95% limits of agreement and trend of each equation against DXA are represented in Table 4. All of the equations showed significant differences with DXA (CE ranged from -4.57

to 9.24% points; all p < .008, Cohen´s *d* ranged from 0.71 to 3.15), being the Johnston et al. (1988) equation the one that demonstrated the lowest CE (2.31) and 95% limits of agreement (-2.94 to 7.56). Large, very large and nearly perfect correlation coefficients between %BF measured by all previous equations and DXA were found (*r* ranged from 0.69 to 0.91, Table 4). Moreover, Slaughter et al. (1988), Deurenberg et al. (1991) and Santi-Maria et al. (2015) showed significant trend regression lines (*r* were -0.47, 0.20 and -0.51 respectively; $p < .05$; Table 4).

Development of a New Anthropometric Equation

The combination of sex (male = 1; female = 0), triceps and iliac-crest skinfold thickness explained 85.6% of variability in %BF. Moreover, the values of R, adjusted R^2, R^2 calculated by the equation of Stein and RMSE were 0.925, 0.851, 0.85 and 2.22 respectively (Table 5). On the other hand, either LOOCV or 10-fold cross-validations showed very similar RMSE compared to that obtained by the proposed equation (RMSE: 2.28 and 2.19 vs. 2.22 respectively; Table 5). The new specific equation was:

$$\%BF = 11.115 + 0.775\text{ (triceps skinfold)} + 0.193\text{ (iliac-crest skinfold)} - 1.606\text{ (sex)}$$

Validation of the New Football-specific Equation

The new equation developed in the present study showed no significant %BF differences in comparison with DXA (CE = 0.57 %; $p = .112$, Cohen´s *d* 0.30; Table 4). Moreover, nearly perfect Pearson correlation coefficient ($r = 0.93$) and no significant trend regression line ($r = 0.36$; $p > .05$; Table 4) were found between this new equation and DXA.

Discussion

The main findings of the present study were previously published anthropometric equations did not accurately estimate %BF, and a new valid and accurate football-specific equation for assessing %BF presenting no differences and no trend regression line when compared to

DXA and being therefore, recommended for assessing %BF in male and female adolescents football players.

According to the review performed by Silva et al. (2013), the Slaughter et al. (1988) equation was the recommended equation to estimate %BF in children and adolescents; however, in this study, the Slaughter et al. (1988) equation presented significant %BF differences when compared to DXA %BF. These differences between %BF obtained by anthropometric equations and the reference method suggest that participants in different sports, even during adolescence, may present different morphologic characteristics, which are probably caused by the practice itself. Therefore, the development and use of a specific equation for each population is recommended.

Only 2 skinfolds are needed for making the calculation in the new developed equation (triceps and iliac crest), compared with 4 in Johnston's (1988) and Santi-Maria's (2015) equations. Furthermore, Reilly et al. (2009) developed and validated an equation for adult football players using also 4 skinfolds. Thus, the specific equation performed herein could be applied spending less time in performing the anthropometric measurements. Moreover, the new equation for male and females football players accounted for 86% variance in DXA %BF, being higher than the amount explained by Johnston et al. (1988), Santi-Maria et al. (2015) and Reilly et al. (2009) equations (49.2, 75.0 and 78.4% of variability compared to DXA, respectively).

One important issue is that Faulkner et al. (1968), Johnston et al.(1988) and Slaughter et al. (1988) equations and the developed equation of this study only included upper-body skinfold sites. The equation designed by Santi-Maria et al. (2015) also included lower-body skinfolds in their equation; even though, it does not improve the explained variability. Other differences between the Santi-Maria et al. (2015) equation and ours could be due to differences in age and ethnicity of the included participants in the studies. On the other hand, Reilly et al. (2009) developed and validated an equation which also employed lower-body sites, but they included adult participants; thus, the differences between both equations might be explained by the age and the type of training of the participants. The type and the amount of hours per week of training are different between amateur and professional football players; therefore, the football-specific adaptations in lower limbs and their influence on fat deposition through the body reported by Reilly et al. (2009) could be more evident in professional football players than in those football players in formation.

This study is not exempt of limitations: the use of DXA (3C model) instead of a 4C one was the main (A. M. Silva et al., 2013). However, several studies have used DXA as a reference method to develop anthropometric equations (A. M. Silva et al., 2013; D. R. Silva et al., 2013). Although the total sample size was considerably important (n = 126), the female sample size was not as large as we would have expected (n = 40). We tried to include as many female football players as possible throughout the recruitment process; nevertheless, there were few football clubs including female players in the range of 11-14 years old. The small sample size in this group is a limitation to be considered. On the other hand, due to participants included in the present study went to high-school during the morning, all measurements were performed during the afternoon and the evening. Despite that the best biological situation to perform DXA scans is during the morning with overnight fasting and without fluid intake (Nana, Slater, Stewart, & Burke, 2015). Another limitation was the use of different calipers among studies. Previous authors used the Harpenden caliper (Carter, 1982; Deurenberg et al., 1991; Faulkner, 1968; Johnston et al., 1988; T. Santi-Maria et al., 2015; Slaughter et al., 1988) while we used the Holtain one. Although, Holtain and Harpenden calipers exerted a constant pressure of 10 $g \cdot mm^{-2}$, Lohman et al. (1984) reported different values in the measure of skinfolds by using both calipers (Harpenden or Holtain). However, they demonstrated that the differences between investigators and standard errors of measurement were lower using Harpenden or Holtain calipers than for Lange or Adipometer calipers. They also concluded that the use of Harpenden or Holtain caliper in addition to the use of triceps and subscapular skinfolds, and a valid equation for young basketball players could be an adequate and reliable combination to monitor weight loss based on anthropometry. For all the above reasons, comparisons between these calipers should be made cautiously.

The main strength of this study was the sample size (n = 126), being much bigger in comparison to that used in published studies (45 adult football players (Reilly et al., 2009) or 26 moderately active adolescents (De Lorenzo et al., 1998)). Moreover, this equation took into account the sex of the participants. Reilly et al. (2009) and Santi-Maria et al. (2015) developed anthropometric equations for male football players; however, the present study is the first one that have created and validated a specific equation for both male and female football players.

In conclusion, the football-specific anthropometric equation for estimating %BF in male and female adolescents (ranged from 12 to 14.5 years old) developed in this study demonstrated to be valid and accurate. Moreover, this equation reported a high average of cross-validation predictive power and a low RMSE. It is therefore recommended to estimate %BF in young football players when no other method than anthropometry is available. On the other hand, no validation study of this specific equation to track changes across the season has been done. Therefore, future studies validating this equation aiming to track body composition changes across the season are recommended.

Acknowledgements

The authors want to thank all the children, their parents and football clubs (Real Zaragoza S.A.D.; Los Molinos U.D.; C.D. Marianistas, C.D. Transportes Alcaine and S.D. Ejea) that participated in the study for their understanding and dedication to the project. This work was supported by the Spanish "Ministerio de Economia y Competitividad" (Project DEP 2012-32724)'. GLB received a Grant FPU 2013 (FPU13/02111) from the "Ministerio de Educación, Cultura y Deporte". The study was designed by JAC; data were collected and analyzed by GLB, AML, AGB, AGA and JAC; data interpretation and manuscript preparation were undertaken by GLB, AML, AGB, AGA, GVR and JAC. All authors approved the manuscript. The authors reported no potential conflict of interest.

Practical application statement

The present study has developed an accurate prediction equation to assess %BF in male and female adolescent football players. Although it is true that football coaches could estimate %BF with previous anthropometric equations, the present study can guide coaches towards which anthropometric equation might be used in young male and female football players.

References

Avlonitou, E., Georgiou, E., Douskas, G., & Louizi, A. (1997). Estimation of body composition in competitive swimmers by means of three different techniques. *International Journal of Sports Medicine, 18(5)*, 363-368. doi:10.1055/s-2007-972647

Carter, J. (1982). Body composition of Montreal Olympic athletes. In J. E. L. Carter (Ed.), *Physical structure of Olympic athletes* (pp. 81–106). Basel, Switzerland: Karger.

De Lorenzo, A., Bertini, I., Candeloro, N., Iacopino, L., Andreoli, A., & Van Loan, M. D. (1998). Comparison of different techniques to measure body composition in moderately active adolescents. *British Journal of Sports Medicine, 32(3)*, 215-219.

Dellagrana, R. A., Guglielmo, L. G., Santos, B. V., Hernandez, S. G., da Silva, S. G., & de Campos, W. (2015). Physiological, anthropometric, strength, and muscle power characteristics correlates with running performance in young runners. *Journal of Strength and Conditioning Research, 29(6)*, 1584-1591. doi:10.1519/jsc.0000000000000784

Deurenberg, P., Weststrate, J. A., & Seidell, J. C. (1991). Body mass index as a measure of body fatness: Age- and sex-specific prediction formulas. *British Journal of Nutrition, 65(2)*, 105-114.

Eisenmann, J. C., Heelan, K. A., & Welk, G. J. (2004). Assessing body composition among 3- to 8-year-old children: Anthropometry, BIA, and DXA. *Obesity Research, 12(10)*, 1633-1640. doi:10.1038/oby.2004.203

Falk, B., Braid, S., Moore, M., Yao, M., Sullivan, P., & Klentrou, N. (2010). Bone properties in child and adolescent male hockey and soccer players. *Journal of Science and Medicine in Sport, 13(4)*, 387-391. doi:10.1016/j.jsams.2009.03.011

Faulkner, J. A. (1968). Physiology of swimming and diving. In H. Falls (Ed.), Exercise physiology (pp. 415–446). Baltimore, MD: Academic Press.

Field, A. (2005). *Discovering Statistics Using SPSS*. London: SAGE Publications.

Fields, D. A., & Goran, M. I. (2000). Body composition techniques and the four-compartment model in children. *Journal of Applied Physiology, 89(2)*, 613-620. doi:10.1152/jappl.2000.89.2.613

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Exercise in Sports & Exercise, 41(1)*, 3-13. doi:10.1249/MSS.0b013e31818cb278

Horner, K. M., Byrne, N. M., Cleghorn, G. J., & King, N. A. (2015). Influence of habitual physical activity on gastric emptying in healthy males and relationships with body composition and energy expenditure. *British Journal of Nutrition, 114(3)*, 489-496. doi:10.1017/s0007114515002044

Johnston, J. L., Leong, M. S., Checkland, E. G., Zuberbuhler, P. C., Conger, P. R., & Quinney, H. A. (1988). Body fat assessed from body density and estimated from skinfold thickness in normal children and children with cystic fibrosis. *American Journal of Clinical Nutrition, 48(6)*, 1362-1366.

Lohman, T. G., Pollock, M. L., Slaughter, M. H., Brandon, L. J., & Boileau, R. A. (1984). Methodological factors and the prediction of body fat in female athletes. *Medicine and Science in Sports and Exercise, 16(1)*, 92-96.

Marfell-Jones, M. J., Olds, T., Stewart, A. D., & Carter, L. (2006). *International Standards for Anthropometric Assessment*. Adelaida: International Society for the Advancement of Kinanthropometry.

Nana, A., Slater, G. J., Stewart, A. D., & Burke, L. M. (2015). Methodology review: using dual-energy X-ray absorptiometry (DXA) for the assessment of body composition in athletes and active people. *International Journal of Sport Nutrition and Exercise Metabolism, 25(2)*, 198-215. doi:10.1123/ijsnem.2013-0228

Reilly, T., George, K., Marfell-Jones, M., Scott, M., Sutton, L., & Wallace, J. A. (2009). How well do skinfold equations predict percent body fat in elite soccer players? *International Journal of Sports Medicine, 30(8)*, 607-613. doi:10.1055/s-0029-1202353

Rodriguez, G., Moreno, L. A., Blay, M. G., Blay, V. A., Fleta, J., Sarria, A., & Bueno, M. (2005). Body fat measurement in adolescents: comparison of skinfold thickness equations with dual-energy X-ray absorptiometry. *European Journal of Clinical Nutrition, 59*(10), 1158-1166. doi:10.1038/sj.ejcn.1602226

Santi-Maria, T., Gómez Campos, R., Andruske, C. L., Gamero, D. H., Rocha, C. L., de Arruda, M., . . . Cossio-Bolaños, M. (2015). Percentage of Body Fat of Young Soccer Players: Comparison of Proposed Regression Frequencies between Goalkeepers and Soccer Camp Players. *Journal of Exercise Physiology Online, 18(6)*, 70-80.

Silva, A. M., Fields, D. A., & Sardinha, L. B. (2013). A PRISMA-driven systematic review of predictive equations for assessing fat and fat-free mass in healthy children and adolescents using multicomponent molecular models as the reference method. *Journal of Obesity, 2013*, 148696. doi:10.1155/2013/148696

Silva, A. M., Minderico, C. S., Teixeira, P. J., Pietrobelli, A., & Sardinha, L. B. (2006). Body fat measurement in adolescent athletes: multicompartment molecular model comparison. *European Journal of Clinical Nutrition, 60(8)*, 955-964. doi:10.1038/sj.ejcn.1602405

Silva, D. R., Ribeiro, A. S., Pavao, F. H., Ronque, E. R., Avelar, A., Silva, A. M., & Cyrino, E. S. (2013). Validity of the methods to assess body fat in children and adolescents using multi-compartment models as the reference method: a systematic review. *Revista da Associacao Medica Brasileira, 59(5)*, 475-486. doi:10.1016/j.ramb.2013.03.006

Siri, W. E. (1961). Body composition from fluid spaces and density: Analysis of methods. In J. Brozek and A. Henschel (Ed.), Techniques for measuring body composition (pp. 223–234). Washington, DC: National Academy of Sciences.

Slaughter, M. H., Lohman, T. G., Boileau, R. A., Horswill, C. A., Stillman, R. J., Van Loan, M. D., & Bemben, D. A. (1988). Skinfold equations for estimation of body fatness in children and youth. *Human Biology, 60(5)*, 709-723.

Tanner, J. M., & Whitehouse, R. H. (1976). Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. *Archives of Disease in Childhood, 51(3)*, 170-179.

Valente-dos-Santos, J., Coelho-e-Silva, M. J., Duarte, J., Figueiredo, A. J., Liparotti, J. R., Sherar, L. B., . . . Malina, R. M. (2012). Longitudinal predictors of aerobic performance in adolescent soccer players. *Medicina, 48(8)*, 410-416.

Zhang, H., Tong, T. K., Qiu, W., Zhang, X., Zhou, S., Liu, Y., & He, Y. (2017). Comparable Effects of High-Intensity Interval Training and Prolonged Continuous Exercise Training on Abdominal Visceral Fat Reduction in Obese Young Women. *J Diabetes Res, 2017*, 5071740. doi:10.1155/2017/5071740

Table 1 Participants Characteristics.

	Experiment 1			Experiment 2		
	All (n=98)	Males (n=65)	Females (n=33)	All (n=28)	Males (n=21)	Females (n=7)
Age (y)	13.4 ± 0.6	13.4 ± 0.6	13.4 ± 0.6	13.2 ± 0.5	13.1 ± 0.5	13.3 ± 0.4
Weight (kg)	49.4 ± 10.3	48.1 ± 10.8	52.0 ± 8.8	48.6 ± 7.39	47.4 ± 6.0	51.9 ± 10.5
Height (cm)	159.2 ± 8.3	159.4 ± 9.1	158.8 ± 6.3	157.4 ± 6.8	157.2 ± 6.2	158.0 ± 8.8
BMI (kg/m^2)	19.3 ± 2.8	18.7 ± 2.7*	20.6 ± 2.7	19.5 ± 1.8	19.1 ± 1.5	20.6 ± 2.3
Tanner (I/II/III/IV/V)	1/12/37/38/10	0/8/28/23/6	1/4/9/15/4	0/6/13/9/0	0/5/9/7/0	0/1/4/2/0

Note. BMI = body mass index; Experiment 1= Assessment of existing equations and development of a new equation; Experiment 2 = Validation of the new equation.

Values are mean ± standard deviation

*: sex differences; $p < .05$

Table 2 Anthropometric Equations Used to Estimate Body Density and Percentage of Body Fat.

Authors	R^2	Population	Equations
Johnston et al. (1988)	0.45	8-14	F: $D = 1.144 – 0.06 (\log_{10} (^{A}\Sigma 4_{SKF}))$
	0.49		M: $D = 1.166 – 0.07 (\log_{10} (^{A}\Sigma 4_{SKF}))$
Slaughter et al. (1988)	NA	Pubertal F:	All F: %BF = 1.33 (tric + subsc) – 0.013 $(\text{tric + subsc})^2$ – 2.5
		11.4 ± 1.9	Pubertal M: %BF = 1.21 (tric + subsc) – 0.008 $(\text{tric + subsc})^2$ – 3.4
		Pubertal M:	All F when (tric + subsc) > 35mm: %BF = 0.546 (tric + subsc) + 9.7
		12.2 ± 1.4	All M when (tric + susc) > 35mm: %BF = 0.783 (tric + subsc) + 1.6
Carter (1982)	NA	General	F: %BF = 0.1548 ($\Sigma 6_{SKF}$) + 3.58
			M: %BF = 0.1051 ($\Sigma 6_{SKF}$) + 2.58
Faulkner (1968)	NA	8 – 16	F: %BF = 0.213 ($^{B}\Sigma 4_{SKF}$) + 7.9
			M: %BF = 0.153 ($^{B}\Sigma 4_{SKF}$) + 5.783
Deurenberg et al. (1991)	0.38	0 – 15	All (0 – 15): %BF = 1.51 (BMI) – 0.7 (age) – 3.6 (sex) + 1.4
Santi-Maria et al. (2015)	0.94	11 – 18.9	GK: %BF = 20.38 – 0.695 (age) + 0.298 (iliac) + 0.344 (ab) + 0.595 (calf)
	0.75		SCP: %BF = 22.46 – 0.866 (age) + 0.642 (iliac) – 0.055 (ab) + 0.464 (thigh)
Siri (1961)	NA	Adults	All: %BF = 100 (4.95/BD - 4.5)

Note. M = male; F = female; NA = Not available; BD = total body density; %BF = percentage of body fat; $^{A}\Sigma 4_{SKF}$ = sum of biceps, triceps, subscapular and iliac-crest skinfolds); $^{B}\Sigma 4_{SKF}$ = sum of triceps, subscapular, supraspinale and abdominal; $\Sigma 6_{SKF}$ = sum of triceps, subscapular, supraspinale, abdominal, anterior thigh and medial calf; tric = triceps skinfold; subsc = subscapular skinfold; iliac = iliac-crest skinfold; ab = abdominal skinfold; thigh = front thigh skinfold; calf = medial calf skinfold; BMI = body mass index; GK = goalkeeper; SCP = football camp players.

The R^2 reported by each study. Sex: male = 1; female = 0.

382

383

Table 3 Technical error of measurement (mm and %) for skinfolds thickness.

	TEM	%
Triceps	0.29	3.32
Subscapular	0.21	3.10
Biceps	0.19	4.61
Iliac-crest	0.41	4.97
Supraspinale	0.27	4.15
Abdominal	0.25	2.71
Front thigh	0.28	2.26
Medial calf	0.28	3.05

TEM = technical error of measurement

Table 4 Body Fat Percentage (%BF) differences between methods (DXA and anthropometry).

Anthropometric equation	%BF (Mean ± SD)	p-value	Cohen's *d*	r	SEE	CE ± 1.96 SD	95% LoA Upper	95% LoA Lower	Trend
DXA	21.93 ± 5.77	---	---	---	---	---	---	---	---
Johnston et al. (1988)	19.63 ± 6.27	<.001	0.86	0.90	2.48	2.31 ± 5.25	-2.94	7.56	-0.19
Slaughter et al. (1988)	18.60 ± 7.22	<.001	1.06	0.91	2.46	3.33 ± 6.18	-2.85	9.51	-0.47*
Carter (1982)	12.69 ± 5.91	<.001	3.15	0.87	2.82	9.24 ± 5.75	3.49	14.99	-0.05
Faulkner (1968)	15.13 ± 5.88	<.001	2.24	0.86	2.92	6.80 ± 5.96	0.84	12.76	-0.04
Deurenberg et al. (1991)	18.86 ± 4.97	<.001	0.71	0.69	4.20	3.07 ± 8.42	-5.35	11.48	0.20*
Santi-Maria et al. (2015)[a]	24.25 ± 6.59	<.001	1.35	0.87	2.49	-4.57 ± 6.64	-11.22	2.08	-0.51*
DXA	22.79 ± 5.17	---	---	---	---	---	---	---	---
New specific-football equation	22.21 ± 4.49	.121	0.30	0.93	0.36	0.57 ± 3.72	-3.14	4.29	0.36

Note. %BF = percentage of body-fat; SD: standard deviation; DXA = dual energy X-ray Absorptiometry; r: Pearson correlation coefficient; SEE: standard error of estimation; CE: constant error; LoA: limits of agreement. [a]Santi-Maria et al. (2015) equation is only performed with males (n = 65). %BF for males (n = 65) was 19.68 ± 4.93. If the p-value is below .008, statistically significant are presented between %BF measured with DXA and estimated with the previous anthropometric equations; and if it is below .05, between %BF measured with DXA and estimated with the new specific-football equation. Trend represents the correlation between %BF mean of the methods and their difference with DXA. *: significant trend (p < .05).

Table 5 Lineal regression analyses, LOOCV, 10-fold cross-validation and the coefficient of determination by Stein of each proposed anthropometric equation in adolescent football players.

Model	R	R^2	R^2 adjusted	R^2 Stein	Root Mean Squared Errors		
					Observed	LOOCV	10-fold
1	0.907	0.824	0.822	0.82	2.44	2.46	2.41
2	0.918	0.843	0.839	0.83	2.31	2.37	2.28
3	0.925	0.856	0.851	0.85	2.22	2.28	2.19

LOOCV: leave-one-out cross-sectional variation. Dependent variable: whole body percentage of body fat; independent variable: sex, height, weight, biceps, triceps, subscapular, iliac-crest, supraspinale, front thigh and medial calf skinfolds.

Model 1: (constant), triceps skinfold thickness

Model 2: (constant), triceps, iliac-crest skinfold thickness

Model 3: (constant), triceps, iliac-crest skinfold thickness, sex

6. Conclusiones

- **Artículo I.** La práctica del fútbol tiene un efecto positivo en la adquisición de masa ósea durante el crecimiento en ambos sexos; sin embargo, estos efectos parecen ser más marcados en los futbolistas post-puberales que pre-puberales.
- **Artículo II.** Las chicas futbolistas tienen mayores valores de CMO y DMO comparado con los chicos futbolistas, siendo la columna lumbar la zona con mayores diferencias. Tanto las chicas como los chicos futbolistas post-puberales presentan mayores valores de CMO y DMO en comparación con los futbolistas peri-puberales.
- **Artículo III.** Las chicas futbolistas presentan mejor geometría ósea y mayor fortaleza ósea en comparación con las chicas controles. Los chicos futbolistas tienen mejor geometría ósea que los chicos controles, aunque no parece que esto se traduzca en una mayor fortaleza ósea a estas edades.
- **Artículo IV.** La inclusión de sub-base elástica en el césped artificial de tercera generación reduce las fuerzas de impacto y la carga recibida por el deportista durante tareas específicas del fútbol.
- **Artículo V.** Los chicos futbolistas que muestran mayores presiones plantares durante una combinación de acciones específicas del fútbol tienen mejor geometría ósea y mayor fuerza ósea en comparación con los que muestran presiones plantares más bajas.
- **Artículo VI.** Los chicos futbolistas presentan un aumento mayor de la DMO en las extremidades inferiores en comparación con los controles. Además, la práctica del fútbol en césped artificial de tercera generación sin sub-base elástica provoca un

aumento de la DMO aparente en la columna lumbar en comparación con la práctica del fútbol en césped artificial de tercera generación con sub-base elástica.

- **Artículo VII.** El porcentaje de grasa corporal medido con el DXA, ADP, BIA y antropometría es diferente entre métodos.
- **Artículo VIII.** Se recomienda la ecuación antropométrica desarrollada en la presente Tesis Doctoral para estimar el porcentaje de grasa corporal en chicos y chicas futbolistas.

6. Conclusions

- **Manuscript I.** Football practice has a positive effect on bone mass during growth in both sexes; nevertheless, these effects seem to be more marked in postpubertal compared to prepubertal football players.
- **Manuscript II.** Female football players have higher BMC and aBMD compared to male ones, being the lumbar spine the site with higher sex differences. Both male and female postpubertal football players present higher BMC and aBMD compared to their prepubertal counterparts.
- **Manuscript III.** Female football players have better bone geometry and higher bone strength compared to female controls. Male football players only present better bone geometry compared to controls, without bone strength differences between them.
- **Manuscript IV.** The inclusion of cushioning underlay in third-generation artificial turf reduces impact force variables and lower limb loading across football-specific tasks.
- **Manuscript V.** Male football players who present high plantar pressures across a combination of football-specific tasks have an enhanced bone geometry and higher bone strength in comparison with those players with low plantar pressures.
- **Manuscript VI.** Male football players present gain more aBMD at the lower limbs compared to controls. Additionally, football practice in third-generation artificial turf without elastic layer induces an increase of BMD apparent at the lumbar spine compared to football practice in third-generation artificial turf with elastic layer.
- **Manuscript VII.** Body fat percentage measured by DXA, ADP, BIA and anthropometry (Slaughter equation) is different between methods.

- **Manuscript VIII.** The anthropometric equation developed in this Thesis is recommended to estimate body fat percentage in male and female adolescent football players.

7. Aportaciones principales de la Tesis Doctoral

- Con la revisión sistemática y meta-análisis se se puso en evidencia que la práctica del fútbol puede mejorar la masa ósea durante el crecimiento en ambos sexos, siendo estos incrementos más marcados durante la pubertad.
- Con los estudios transversales, se determinó que los chicos y chicas futbolistas post-puberales (Tanner IV y V) tenían mayor masa ósea comparado con los peri-puberales (Tanner II y III). Además, las chicas futbolistas demostraron mayores valores de masa ósea que los chicos futbolistas. Cuando se comparó la geometría y la fuerza ósea entre futbolistas y controles, las chicas futbolistas mostraron mejores valores que los controles; sin embargo, los chicos futbolistas sólo mostraron mejores valores de geometría ósea que los controles. En relación con los datos de biomecánica, la inclusión de la sub-base elástica en el césped artificial de tercera generación redujo el impacto y la carga recibida por el futbolista. Asimismo, los futbolistas con presiones plantares elevadas tenían mayores valores de geometría ósea que aquellos con presiones plantares bajas. Por otra parte, se encontraron diferencias significativas en el porcentaje de grasa entre los métodos de DXA, ADP, BIA y antropometría (ecuación de Slaughter). Para la estimación del porcentaje de grasa en jóvenes futbolistas, se recomienda la ecuación antropométrica desarrollada en la presente Tesis Doctoral.
- Mediante el articulo longitudinal se identificó que los chicos futbolistas incrementaron la DMO en las extremidades inferiores en comparación con los controles después de una temporada de seguimiento. Al mismo tiempo, los futbolistas que jugaban en césped artificial de tercera generación sin sub-base elástica (superficie de juego con menor absorción de impacto) aumentaron

significativamente la DMO aparente en la columna lumbar en comparación con aquellos que jugaban en una superficie más blanda (césped artificial de tercera generación con sub-base elástica).

7. Main contributions of the Thesis

- From the systematic review and meta-analysis, it was observed that football practice may improve bone mass during growth in both sexes, being these increases more marked during puberty.
- From cross-sectional studies, it was observed that male and female postpubertal football players (Tanner IV and V) had higher bone mass compared to peripubertal ones (Tanner II and III). Higher bone mass was found in female football players when compared to their male counterparts. When bone geometry and strength was compared between football players and controls in each sex separately, female football players showed better bone geometry and higher bone strength compared to controls. Nonetheless, male players only demonstrated better bone geometry than controls. In terms of biomechanical data, the inclusion of an elastic layer in third-generation artificial turf reduced force impact variables and the loading received by the player. Additionally, football players who experienced high plantar pressures presented higher bone strength values than those players with low plantar pressures. On the other hand, DXA, ADP, BIA and anthropometry (Slaughter equation) presented significant body fat percentage differences when they were compared to each other. The anthropometric equation developed in this Thesis is recommended to estimate body fat percentage in male and female young football players.
- The main findings of the longitudinal study were that after one-season follow-up, football players increased more aBMD at lower limbs than controls. Furthermore, football players who trained in third-generation artificial turf without elastic layer (surface with low shock absorption) significantly increased BMD apparent at

lumbar spine than players who trained in a more cushioning surface (third-generation artificial turf with elastic layer).

8. Referencias

1. FIFA History of Football - The Origins. http://www.fifa.com/about-fifa/who-we-are/the-game/index.html. Accessed 05/04/2018
2. Consejo Superior de Deporte. Gobierno de España. Ministerio de Educación CyD (2016) Federaciones Deportivas y Agrupaciones de Clubes. Histórico de licencias [Athletic federations and clubs. Licenses history]. http://www.csd.gob.es/csd/estaticos/asoc-fed/historico-de-licencias.pdf. Accessed 17/05/2018
3. Murray B (1996) The Worl's Game: A History of Soccer. University of Illinois, Champaign
4. FIFA (2015) FIFA Quality Programme for Football Turf. Handbook of Requirements. https://football-technology.fifa.com/media/1239/fqp-handbook-of-requirements-v25.pdf. Accessed 26/05/2018
5. Burillo P, Felipe JL, Gallardo A, Gallardo L, Sanchís M, Gude R, Pérez V, Rosa D (2010) El césped artificial. La revolución del pavimento en el fútbol. Trisorgar, S.L., Tarancón
6. ESTO (2012) Synthetic Turf Study in Europe. European Synthetic Turf Organisation, Brussels
7. Fleming P (2011) Artificial turf systems for sport surfaces: current knowledge and research needs. Proc Inst Mech Eng Part P-J Sport Eng Technol 225:43-63. https://doi.org/10.1177/1754337111401688
8. Sánchez-Sánchez J (2014) Efectos de los componentes estructurales de soporte sobre el comportamiento mecánico y el rendimiento deportivo en los campos de fútbol de césped artificial. Departamento de Actividad Física y Ciencias del Deporte. Universidad de Castilla-La Mancha, Toledo
9. Correal J (2008) Situación actual y perspectivas del césped artificial como superficie deportiva. II Curso de Experto Universitario en Gestión del Césped Deportivo Natural y Artificial. Fundación RFEF y UCLM, Las Rozas
10. Burillo P, Gallardo L, Felipe JL, Gallardo AM (2012) Mechanical assessment of artificial turf football pitches: The consequences of no quality certification. SRE 7:2457-2465. https://doi.org/10.5897/sre11.1454

11. FIFA (2012) FIFA Quality Concept for Football Turf. Handbook of Test Methods. https://footballtechnology.fifa.com/media/1015/football_turf_handbook_of_test_methods_2012.pdf. Accessed 26/05/2018
12. Rosa D, Sanchís M, Alcántara E, Zamora T (2008) Contribuciones de la Biomecánica al estudio de los terrenos de juego de hierba artificial. In Izquierdo M (ed) Biomecánica y Bases Neuromusculares de la Actividad Física y el Deporte. Editorial Médica Panamericana, Madrid
13. Applegate EJ (2011) The Anatomy and Physiology Learning System. Saunders/Elsevier, St. Louis, Mo
14. Anonymous (1993) Consensus development conference: diagnosis, prophylaxis, and treatment of osteoporosis. Am J Med 94:646-650
15. Crabtree NJ, Arabi A, Bachrach LK, Fewtrell M, El-Hajj Fuleihan G, Kecskemethy HH, Jaworski M, Gordon CM (2014) Dual-energy X-ray absorptiometry interpretation and reporting in children and adolescents: the revised 2013 ISCD Pediatric Official Positions. J Clin Densitom 17:225-242. https://doi.org/10.1016/j.jocd.2014.01.003
16. Anonymous (1994) Assessment of fracture risk and its application to screening for postmenopausal osteoporosis. Report of a WHO Study Group. World Health Organ Tech Rep Ser 843:1-129
17. WHO (2004) World Health Organisation Scientific group on the asssessment of osteoporosis at primary health care level. Summary Metting Report. http://www.who.int/chp/topics/Osteoporosis.pdf. Accessed 28/05/2018
18. Seeman E, Delmas PD (2006) Bone quality--the material and structural basis of bone strength and fragility. N Engl J Med 354:2250-2261. https://doi.org/10.1056/NEJMra053077
19. Currey JD (2002) Bones: structure and mechanics. Princeton University Press, Princeton, N.J.
20. Weaver CM, Gordon CM, Janz KF, Kalkwarf HJ, Lappe JM, Lewis R, O'Karma M, Wallace TC, Zemel BS (2016) The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations. Osteoporos Int 27:1281-1386. https://doi.org/10.1007/s00198-015-3440-3

21. Carter DR, Bouxsein ML, Marcus R (1992) New approaches for interpreting projected bone densitometry data. J Bone Miner Res 7:137-145. https://doi.org/10.1002/jbmr.5650070204
22. Katzman DK, Bachrach LK, Carter DR, Marcus R (1991) Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. J Clin Endocrinol Metab 73:1332-1339. https://doi.org/10.1210/jcem-73-6-1332
23. Adams JE, Engelke K, Zemel BS, Ward KA, Densitometry ISoC (2014) Quantitative computer tomography in children and adolescents: the 2013 ISCD Pediatric Official Positions. J Clin Densitom 17:258-274. https://doi.org/10.1016/j.jocd.2014.01.006
24. Ingle BM, Hay SM, Bottjer HM, Eastell R (1999) Changes in bone mass and bone turnover following ankle fracture. Osteoporos Int 10:408-415. https://doi.org/10.1007/s001980050247
25. Heaney RP, Abrams S, Dawson-Hughes B, Looker A, Marcus R, Matkovic V, Weaver C (2000) Peak bone mass. Osteoporos Int 11:985-1009. https://doi.org/10.1007/s001980070020
26. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA (1999) A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the university of Saskatchewan bone mineral accrual study. J Bone Miner Res 14:1672-1679. https://doi.org/10.1359/jbmr.1999.14.10.1672
27. Baxter-Jones AD, Faulkner RA, Forwood MR, Mirwald RL, Bailey DA (2011) Bone mineral accrual from 8 to 30 years of age: an estimation of peak bone mass. J Bone Miner Res 26:1729-1739. https://doi.org/10.1002/jbmr.412
28. Berger C, Goltzman D, Langsetmo L, et al. (2010) Peak bone mass from longitudinal data: implications for the prevalence, pathophysiology, and diagnosis of osteoporosis. J Bone Miner Res 25:1948-1957. https://doi.org/10.1002/jbmr.95
29. Seeman E (2003) Periosteal bone formation--a neglected determinant of bone strength. N Engl J Med 349:320-323. https://doi.org/ 10.1056/NEJMp038101
30. Seeman E (2008) Bone quality: the material and structural basis of bone strength. J Bone Miner Metab 26:1-8. https://doi.org/10.1007/s00774-007-0793-5
31. Caspersen CJ, Powell KE, Christenson GM (1985) Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 100:126-131
32. American College of Sports MedicineMedicine (2017) ACSM's Guidelines for testing and prescription. Wolters Kluwer, London

33. Turner CH, Robling AG (2003) Designing exercise regimens to increase bone strength. Exerc Sport Sci Rev 31:45-50. https://doi.org/10.1097/00003677-200301000-00009
34. Frost HM (1987) The mechanostat: a proposed pathogenic mechanism of osteoporoses and the bone mass effects of mechanical and nonmechanical agents. Bone Miner 2:73-85
35. Al Nazer R, Lanovaz J, Kawalilak C, Johnston JD, Kontulainen S (2012) Direct in vivo strain measurements in human bone-a systematic literature review. J Biomech 45:27-40. https://doi.org/10.1016/j.jbiomech.2011.08.004
36. McCulloch RG, Bailey DA, Whalen RL, Houston CS, Faulkner RA, Craven BR (1992) Bone Density and Bone Mineral Content of Adolescent Soccer Athletes and Competitive Swimmers. Pediatr Exerc Sci 4:319-330
37. Vicente-Rodriguez G, Ara I, Perez-Gomez J, Serrano-Sanchez JA, Dorado C, Calbet JA (2004) High femoral bone mineral density accretion in prepubertal soccer players. Med Sci Sports Exerc 36:1789-1795. https://doi.org/10.1249/01.MSS.0000142311.75866.D7
38. Vicente-Rodriguez G, Jimenez-Ramirez J, Ara I, Serrano-Sanchez JA, Dorado C, Calbet JA (2003) Enhanced bone mass and physical fitness in prepubescent footballers. Bone 33:853-859. https://doi.org/10.1016/j.bone.2003.08.003
39. Zouch M, Zribi A, Alexandre C, Chaari H, Frere D, Tabka Z, Vico L (2015) Soccer increases bone mass in prepubescent boys during growth: a 3-yr longitudinal study. J Clin Densitom 18:179-186. https://doi.org/10.1016/j.jocd.2014.10.004
40. Zouch M, Vico L, Frere D, Tabka Z, Alexandre C (2014) Young male soccer players exhibit additional bone mineral acquisition during the peripubertal period: 1-year longitudinal study. Eur J Pediatr 173:53-61. https://doi.org/10.1007/s00431-013-2115-3
41. Zouch M, Jaffre C, Thomas T, Frere D, Courteix D, Vico L, Alexandre C (2008) Long-term soccer practice increases bone mineral content gain in prepubescent boys. Joint Bone Spine 75:41-49. https://doi.org/10.1016/j.jbspin.2006.12.008
42. Plaza-Carmona MP, Vicente-Rodriguez G, Martin-Garcia M, Burillo P, Felipe JL, Mata E, Casajus JA, Gallardo L, Ara I (2014) Influence of hard vs. soft ground surfaces on bone accretion in prepubertal footballers. Int J Sports Med 35:55-61. https://doi.org/10.1055/s-0033-1345140

43. Falk B, Braid S, Moore M, Yao M, Sullivan P, Klentrou N (2010) Bone properties in child and adolescent male hockey and soccer players. J Sci Med Sport 13:387-391. https://doi.org/10.1016/j.jsams.2009.03.011
44. Madic D, Obradovic B, Smajic M, Obradovic J, Maric D, Boskovic K (2010) Status of bone mineral content and body composition in boys engaged in intensive physical activity. Vojnosanit Pregl 67:386-390. https://doi.org/10.2298/VSP1005386M
45. Sanchis-Moysi J, Dorado C, Olmedillas H, Serrano-Sanchez JA, Calbet JA (2010) Bone mass in prepubertal tennis players. Int J Sports Med 31:416-420. https://doi.org/10.1055/s-0030-1248331
46. Vlachopoulos D, Barker AR, Williams CA, Arngrimsson SA, Knapp KM, Metcalf BS, Fatouros IG, Moreno LA, Gracia-Marco L (2017) The Impact of Sport Participation on Bone Mass and Geometry in Adolescent Males. Med Sci Sports Exerc 49:317-326. https://doi.org/10.1249/mss.0000000000001091
47. Agostinete RR, Lynch KR, Gobbo LA, Lima MC, Ito IH, Luiz-de-Marco R, Rodrigues-Junior MA, Fernandes RA (2016) Basketball Affects Bone Mineral Density Accrual in Boys More Than Swimming and Other Impact Sports: 9-mo Follow-Up. J Clin Densitom 19:375-381. https://doi.org/10.1016/j.jocd.2016.04.006
48. Mota S, Brito J, Passos E, Marques E, Mota J, Seabra A, Rebelo A (2010) Variation of Isokinetic Strength and Bone Mineral Density in Youth Portuguese Soccer Players with Age. Open Sports Sci J 3:49-51
49. Anliker E, Sonderegger A, Toigo M (2013) Side-to-side differences in the lower leg muscle-bone unit in male soccer players. Med Sci Sports Exerc 45:1545-1552. https://doi.org/10.1249/MSS.0b013e31828cb712
50. Seabra A, Marques E, Brito J, Krustrup P, Abreu S, Oliveira J, Rego C, Mota J, Rebelo A (2012) Muscle strength and soccer practice as major determinants of bone mineral density in adolescents. Joint Bone Spine 79:403-408. https://doi.org/10.1016/j.jbspin.2011.09.003
51. Nebigh A, Rebai H, Elloumi M, Bahlous A, Zouch M, Zaouali M, Alexandre C, Sellami S, Tabka Z (2009) Bone mineral density of young boy soccer players at different pubertal stages: relationships with hormonal concentration. Joint Bone Spine 76:63-69. https://doi.org/10.1016/j.jbspin.2008.03.002
52. Silva CC, Goldberg TB, Teixeira AS, Dalmas JC (2011) The impact of different types of physical activity on total and regional bone mineral density in young Brazilian athletes. J Sports Sci 29:227-234. https://doi.org/10.1080/02640414.2010.529456

53. Soderman K, Bergstrom E, Lorentzon R, Alfredson H (2000) Bone mass and muscle strength in young female soccer players. Calcif Tissue Int 67:297-303. https://doi.org/10.1007/s002230001149
54. Plaza-Carmona M, Vicente-Rodriguez G, Gomez-Cabello A, Martin-Garcia M, Sanchez-Sanchez J, Gallardo L, Ara I (2016) Higher bone mass in prepubertal and peripubertal female footballers. Eur J Sport Sci 16:877-883. https://doi.org/10.1080/17461391.2016.1144794
55. Plaza-Carmona M, Ubago-Guisado E, Sánchez-Sánchez J, Felipe JL, Fernández-Luna A, García-Unanue J, Burillo P, Gallardo L (2013) Body composition and physical fitness in prepubertal girls swimmers and soccer players. JSHR 5:251-258
56. Ubago-Guisado E, Gomez-Cabello A, Sanchez-Sanchez J, Garcia-Unanue J, Gallardo L (2015) Influence of different sports on bone mass in growing girls. J Sports Sci 33:1-9. https://doi.org/10.1080/02640414.2015.1004639
57. Ferry B, Duclos M, Burt L, Therre P, Le Gall F, Jaffre C, Courteix D (2011) Bone geometry and strength adaptations to physical constraints inherent in different sports: comparison between elite female soccer players and swimmers. J Bone Miner Metab 29:342-351. https://doi.org/10.1007/s00774-010-0226-8
58. Bellew JW, Gehrig L (2006) A comparison of bone mineral density in adolescent female swimmers, soccer players, and weight lifters. Pediatr Phys Ther 18:19-22. https://doi.org/10.1097/01.pep.0000200952.63544.16
59. Pettersson U, Nordstrom P, Alfredson H, Henriksson-Larsen K, Lorentzon R (2000) Effect of high impact activity on bone mass and size in adolescent females: A comparative study between two different types of sports. Calcif Tissue Int 67:207-214. https://doi.org/10.1007/s002230001131
60. Ferry B, Lespessailles E, Rochcongar P, Duclos M, Courteix D (2013) Bone health during late adolescence: effects of an 8-month training program on bone geometry in female athletes. Joint Bone Spine 80:57-63. https://doi.org/10.1016/j.jbspin.2012.01.006
61. Ubago-Guisado E, Garcia-Unanue J, Lopez-Fernandez J, Sanchez-Sanchez J, Gallardo L (2016) Association of different types of playing surfaces with bone mass in growing girls. J Sports Sci 35:1484-1492. https://doi.org/10.1080/02640414.2016.1223328

62. Nichols JF, Rauh MJ, Barrack MT, Barkai HS (2007) Bone mineral density in female high school athletes: interactions of menstrual function and type of mechanical loading. Bone 41:371-377. https://doi.org/10.1016/j.bone.2007.05.003
63. Gracia-Marco L, Ortega FB, Jiménez-Pavón D, Rodríguez G, Castillo MJ, Vicente-Rodríguez G, Moreno LA (2012) Adiposity and bone health in Spanish adolescents. The HELENA study. Osteoporos Int 23:937-947. https://doi.org/10.1007/s00198-011-1649-3
64. Hoffman M, Schrader J, Applegate T, Koceja D (1998) Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. J Athl Train 33:319-322
65. Gomez-Bruton A, Gonzalez-Aguero A, Casajus JA, Vicente-Rodriguez G (2014) Swimming training repercussion on metabolic and structural bone development; benefits of the incorporation of whole body vibration or pilometric training; the RENACIMIENTO project. Nutr Hosp 30:399-409. https://doi.org/10.3305/nh.2014.30.2.7603
66. Siri WE (1961) Body composition from fluid spaces and density: analysis of methods. In Brozek J, Henschel A (eds) Techniques for Measuring Body Composition. National Academy of Sciences, Washington, DC
67. Marfell-Jones MJ, Olds T, Stewart AD, Carter L (2006) International Standards for Anthropometric Assessment. International Society for the Advancement of Kinanthropometry, Adelaida
68. Catón J (2018) Campos de césped artificial: Diseño, tipos, construcción, normativa y mantenimiento. In Real Federación Gallega de Fútbol (ed) I Jornada de conocimiento y gestión de campos de fútbol de césped artificial y natural. Santiago de Compostela
69. Tanner JM, Whitehouse RH (1976) Clinical longitudinal standards for height, weight, height velocity, weight velocity, and stages of puberty. Arch Dis Child 51:170-179
70. Moore SA, McKay HA, Macdonald H, Nettlefold L, Baxter-Jones AD, Cameron N, Brasher PM (2015) Enhancing a Somatic Maturity Prediction Model. Med Sci Sports Exerc 47:1755-1764. https://doi.org/10.1249/MSS.0000000000000588
71. Julian Almarcegui C, Huybrechts I, Gomez Bruton A, Matute Llorente A, Gonzalez Aguero A, Gomez Cabello A, Moreno LA, Casajus JA, Vicente Rodriguez G (2015) Validity of a Food-Frequency Questionnaire for Estimating Calcium Intake in Adolescent Swimmers. Nutr Hosp 32:1773-1779. https://doi.org/10.3305/nh.2015.32.4.9490

72. Barr SI (1994) Associations of social and demographic variables with calcium intakes of high school students. J Am Diet Assoc 94:260-266. https://doi.org/10.1016/0002-8223(94)90366-2
73. Phillips LR, Parfitt G, Rowlands AV (2013) Calibration of the GENEA accelerometer for assessment of physical activity intensity in children. J Sci Med Sport 16:124-128. https://doi.org/10.1016/j.jsams.2012.05.013
74. Hopkins WG, Marshall SW, Batterham AM, Hanin J (2009) Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41:3-13. https://doi.org/10.1249/MSS.0b013e31818cb273

Apéndice ***[Appendix]***

Factor de impacto y ranking de cada revista en "*ISI Web of Knowledge – Journal Citation Reports*" dentro de sus áreas correspondientes.

[*Impact factor and ranking of each journal in "ISI Web of Knowledge – Journal Citation Reports" within their subject categories.*]

Artículos publicados o aceptados [*Published or accepted manuscripts*]:

Artículo *[Manuscript]*	***Revista*** *[Journal]*	***Factor de impacto*** *[Impact factor]*
I.	**European Journal of Pediatrics** *Ranking in 2017 ISI – JCR: 42/124 (Pediatrics) – Q2*	**2.242**
III.	**Archives of Osteoporosis** *Ranking in 2017 ISI – JCR: 24/77 (Orthopedics) – Q2*	**2.382**
VII.[a]	**Nutrición Hospitalaria**	**-**
VIII.[b]	**International journal of sport nutrition and exercise metabolism** *Ranking in 2017 ISI – JCR: 24/81 (Sport Sciences) – Q2*	**2.489**

[a]: Esta revista estaba indexada en el año 2016 en "ISI Web of Knowledge – Journal Citation Reports" con un factor de impacto 0,747 (68/81 del área *Nutrition and Dietetics*; Q4).
[During 2016, this journal was indexed in ISI Web of Knowledge – Journal Citation Reports with an impact factor of 0,747 (68/81 *Nutrition and Dietetics* area; Q4)]
[b]: Anexo VIII. Carta de aceptación [Acceptance letter].

Artículos sometidos [*Submitted manuscripts*]:

Artículo *[Manuscript]*	***Revista*** *[Journal]*	***Factor de impacto*** *[Impact factor]*
II.	**Journal of Human Kinetics** *Ranking in 2017 ISI – JCR: 61/81 (Sport Sciences) – Q3*	**1.174**
IV.	**The Journal of Sports Medicine and Physical Fitness** *Ranking in 2017 ISI – JCR: 65/81 (Sport Sciences) – Q4*	**1.120**
V.	**Sports Biomechanics** *Ranking in 2017 ISI – JCR: 64/81 (Sport Sciences) – Q4*	**1.141**
VI.	**Proceedings of the Institution of Mechanical Engineers. Part P, Journal of sports engineering and technology.** *Ranking in 2017 ISI – JCR: 93/128 (Mechanical Engineering) – Q3*	**1.070**

Contribución del doctorado en cada uno de los trabajos

En el artículo I que se trata de una revisión sistemática y meta-análisis, el doctorando realizó la búsqueda sistemática de los artículos en las diferentes bases de datos, evaluó y seleccionó los artículos que cumplían con los criterios de inclusión, y escribió el documento.

En los artículos II – VIII, el doctorando participó en la toma de datos, en la realización de las evaluaciones y en la supervisión de los entrenamientos de fútbol. Además, exportó los datos de cada uno de los equipos utilizados, creó la base de datos con la que realizó los análisis estadísticos y escribió los artículos.

Contribution of the PhD candidate to the included manuscript

In manuscript number I which is a systematic review and meta-analysis, the PhD candidate performed the literature search in different electronic databases, evaluated and selected the articles that met the inclusion criteria, and wrote the document.

In manuscripts number II – VIII, the PhD candidate was involved in the data acquisition, in the participant evaluation and in the supervision of football trainings. Additionally, he exported the data from equipment used, created the database, performed the statistical analyses, and wrote the manuscripts.

Agradecimientos ***[Acknowledgements]***

La vida no es un camino de rosas, pero vale la pena vivirla a pesar de las espinas. Esta misma sensación he tenido con la realización de esta Tesis doctoral. Cuando me planteé realizarla, yo sabía que no sería tarea fácil, pero no era consciente de lo difícil y duro que ha sido todo este camino. Más allá de publicar artículos científicos en revistas con factor de impacto o de presentar una comunicación oral en un congreso internacional, la forma de gestionar la montaña rusa de emociones y estados de ánimo que se generan durante este proceso es incluso más importante. Por todo ello considero que no habría podido realizar esta Tesis sin el apoyo, la fuerza y los ánimos recibidos de todas y cada una de las personas que he tenido a mi alrededor.

Durante mi niñez y adolescencia ya era un apasionado del deporte, razón más que suficiente para tomar una de las primeras decisiones más importantes en mi vida, estudiar el grado de Ciencias de la Actividad Física y del Deporte. Fueron cuatro años de aprendizaje, formación y diversión que nunca caerán en el olvido y que, sobre todo, no habrían sido lo mismo sin vosotros, **compañeros y amigos de la promoción 2009-2013**. Muchas gracias a todos.

Una vez finalizados los estudios de grado, inicié la etapa más importante de mi vida, donde he cambiado tanto a nivel profesional como personal. Todo comenzó cuando **José Antonio Casajús** me dio la posibilidad de realizar la presente Tesis doctoral y de solicitar con él una beca de investigación que me ayudaría en la realización de la misma. Sólo puedo agradecerte todo lo que has hecho por mí, todo lo que me has apoyado y todo lo que has confiado en mí incluso cuando yo difícilmente lo hacía. Te admiro y te admiraré, eres un referente para mí tanto en lo personal como en lo profesional y si tuviera que

empezar de nuevo esta etapa, tengo claro que me gustaría que fuera contigo como director. Nunca podré agradecerte todo lo que has hecho por mí José Antonio. Gracias de corazón.

También me gustaría agradecer a **Germán Vicente** todo el apoyo y todas las facilidades que me has dado para que esta Tesis saliera adelante. Desde el primer momento, me has demostrado toda la confianza que tenías en mí y en el trabajo que estábamos realizando. Para mí ha sido un placer poder tenerte como mi director. Muchas gracias Germán.

Alejandro González de Agüero, no sabes lo que me habría gustado que tú también hubieras sido uno de mis directores. Aunque no pudiste serlo oficialmente, quiero darte las gracias por comportarte conmigo como si lo hubieras sido. Además de un gran profesional y ejemplo a seguir, a mi has demostrado que eres una persona que está siempre cerca cuando se le necesita y que ayuda siempre por muy complicada que sea la situación. Gracias por haberme tratado y cuidado así de bien durante todo este tiempo. Me sentido muy querido por tu parte "*Agüerín*" y espero haberte hecho sentir lo mismo. No cambies nunca.

"*Gracias por orientarme cuando estaba perdido, por avisarme cuando me iba a caer; y por levantarme cuando me había caído*". **Ángel Matute**, *gracias, gracias y gracias*. No se me ocurre una palabra mejor para intentar expresar todo lo que has hecho por mí durante todo este tiempo. Si algo tengo claro es que, sin tu apoyo, realizar esta Tesis doctoral habría sido mucho más complicado. Para mí has sido un pilar fundamental durante estos cuatro años en los que siempre has intentado conseguir lo mejor para mí y que no cometiese los errores que habías cometido tú en el pasado. Por esto y por otras tantas cosas que has hecho por mí, me siento un privilegiado de haber coincidido contigo en este camino. Gracias por convertirte en una tan persona importante para mí.

Alejandro Gómez, desde el primer día que nos conocimos sabía que ibas a ser muy especial y muy importante durante todo este proceso y así ha sido, no me equivoqué. Gracias por allanarme el camino, por ayudarme siempre con una sonrisa y por hacerme sentir como si te conociera de toda la vida. Thanks a lot "*Brutoncín*".

Dentro de este grupo de investigación hay muchas personas que, sea de una manera o de otra, han contribuido mucho en esta Tesis doctoral. **Alba Gómez**, gracias por escucharme cuando lo necesitaba y demostrarme que todo iba a salir bien. **Nuria Garatachea**, tu confianza en mi trabajo y en mi forma de hacer las cosas me ha ayudado mucho a seguir adelante, gracias. **Jorge Marín**, ya realizamos una etapa juntos y a los dos nos fue de maravilla. Por eso, sé que esta segunda etapa va a acabar genial para los dos. Muchas gracias por todo el apoyo que he recibido de tu parte diariamente y mucho ánimo para lo que te queda. Todo esfuerzo tiene su recompensa. **Borja Muñiz**, en muy poco tiempo te has convertido en una persona muy importante para mí. Juntos nos hemos reído de nuestras caídas, nos hemos levantado y hemos celebrado nuestros éxitos. Estoy seguro de que todo va a salir como tú quieres que salga ya sea aquí, en Escocia o en Kenia. Muchas gracias por ser conmigo como eres "*Muñiz-Pardos*". **José Luis Pérez**, **Adrián Hernández**, **David Navarrete** y **Ana Moradel**, prácticamente acabáis de empezar y por ello me gustaría trasmitiros lo que yo he sentido. Para no mentir, la Tesis es un camino complicado que tiene muchos obstáculos. Sin embargo, tengo claro que en el lugar en el que estáis y el grupo de personas que os rodean son las mejores condiciones posibles para sacar vuestra Tesis adelante.

También me gustaría agradecer a **Luis A. Moreno** y a **mis compañeras del grupo de investigación GENUD** todo su apoyo durante estos años. **Marcus Vinicius**, ha sido un

placer conocerte y haber compartido tantos momentos contigo. Sé que nos volveremos a ver, muchas gracias Marcus.

Me he sentido un privilegiado de haberos conocido, haber trabajado con todos vosotros, haber tenido la oportunidad de aprender a vuestro lado, y de poder tener una relación que va más allá de lo meramente profesional. *Muchas gracias GENUD*.

I would like to give special thanks **Mark J. Lake** and **Craig Sale** for your confidence in me and the opportunity to work with you. I would also like to thank **Adam C. Clansey** and **Charlotte Apps** for your personal and scientific support during my temporary stays at Liverpool John Moores University and Nottingham Trent University.

Muchas gracias a mis amigos de Ejea de los Caballeros, Zaragoza, Nottingham y Liverpool. Habéis sido personas muy importantes para mí durante esta etapa y estoy seguro de que lo seguiréis siendo en el futuro. En especial, me gustaría dar las gracias a todos y cada uno de mis amigos de *La Samba* por hacerme sentir muy querido, por entenderme y respetarme siempre y por acompañarme en los buenos y en los malos momentos. Se dice que los amigos son la familia que se elige; si es así, estoy seguro de que he elegido a la mejor. Gracias por ser tan importantes en mi vida.

Agradecer a toda mi familia el apoyo incondicional durante todo este tiempo. En especial me gustaría dar las gracias a mis tíos, **Oli** y **Alfonso**, por conseguir que desde el primer día de esta etapa estuviera como en mi casa; **Sole** y **Ernesto**, por hacerme la vida tan fácil y conseguir que cada viaje empiece y acabe con una sonrisa; y **Sefa** y **Manolo**, por todo el apoyo que me habéis dado siempre. Tío Manolo, aunque ya no estés, no tengo duda de que me estás apoyando desde la distancia. A mis primos, **Eduardo**, **Borja**, **Sonia**, **María** y **Santi** muchas gracias por estar a mi lado cuando lo he necesitado y por demostrarme que puedo contar con vosotros siempre. No me quiero olvidar de los más pequeños de la familia, **Daniel** y **Lucía**, sois especiales para mí campeones. Gracias a todos de corazón, os quiero.

Pili y **José**, Mamá y Papá, no existe la palabra que pueda definir y agradecer todo lo que habéis hecho por mí. Me habéis trasmitido todos valores necesarios para que haya podido llegar hasta aquí, me habéis cuidado y apoyado siempre sin esperar nada a cambio y me habéis demostrado que en esta vida cualquier problema con vuestra ayuda y cariño es más fácil de solucionar. Me siento orgulloso de tener unos padres como vosotros, sois unos padres increíbles, os quiero mucho.

Nuria, mi hermana, mi "*tata*". Tengo claro que no se puede tener una hermana mejor, que suerte tengo de tenerte. Me has enseñado lo difícil que es la vida y me has ayudado a afrontar y superar todos los problemas y situaciones complicadas a los que estamos expuestos. Sabiendo que siempre vas a estar cerca, todo en la vida se vuelve más fácil. También me gustaría agradecer a **Fernando** todo el cariño y apoyo que me has dado desde el primer momento. Eres el cuñado perfecto Fer. Muchas gracias por ser como sois conmigo y por todo lo que hacéis por mí, os quiero mucho.

Me siento muy afortunado de estar rodeado de tantas personas, tan buenas y que me hacen tan feliz. Muchas gracias a todos de corazón.

*Anexos **[Annexes]***

GOBIERNO DE ARAGON
Departamento de Sanidad, Bienestar Social y Familia

Informe Dictamen Favorable
Proyecto Investigación Biomédica
C.P. - C.I. PI13/0091
19 de junio de 2013

Dña. María González Hinjos, Secretaria del CEIC Aragón (CEICA)

CERTIFICA

1º. Que el CEIC Aragón (CEICA) en su reunión del día 19/06/2013, Acta Nº CP12/2013 ha evaluado la propuesta del investigador referida al estudio:

Título: Efecto de la interacción ente el tipo de césped artificial y modelo de botas en la salud ósea de niños y niñas futbolistas.
Investigador Principal: José Antonio Casajús Mallén. Universidad de Zaragoza.
Versión Protocolo: 20/01/2012
Versión hoja de información para los padres: Versión 1.1 17-06-2013
Versión hoja de información para adolescentes: Versión 1.1 17-06-2013

1º. Considera que

- El proyecto se plantea siguiendo los requisitos de la Ley 14/2007, de 3 de julio, de Investigación Biomédica y su realización es pertinente.
- Se cumplen los requisitos necesarios de idoneidad del protocolo en relación con los objetivos del estudio y están justificados los riesgos y molestias previsibles para el sujeto.
- Son adecuados tanto el procedimiento para obtener el consentimiento informado como la compensación prevista para los sujetos por daños que pudieran derivarse de su participación en el estudio.
- El alcance de las compensaciones económicas previstas no interfiere con el respeto a los postulados éticos.
- La capacidad de los Investigadores y los medios disponibles son apropiados para llevar a cabo el estudio.

2º. Por lo que este CEIC emite un **DICTAMEN FAVORABLE.**

Lo que firmo en Zaragoza, a 19 de junio de 2013

Fdo:

GOBIERNO DE ARAGON
DEPARTAMENTO DE SANIDAD, BIENESTAR SOCIAL Y FAMILIA
COMITÉ ÉTICO DE INVESTIGACIÓN CLÍNICA

Dña. María González Hinjos
Secretaria del CEIC Aragón (CEICA)

Tel. 976 71 48 57 Fax. 976 71 55 54 Correo electrónico mgonzalezh.ceic@aragon.es

ClinicalTrials.gov PRS
Protocol Registration and Results System

ClinicalTrials.gov Protocol Registration and Results System (PRS) Receipt
Release Date: 05/11/2016

ClinicalTrials.gov ID: NCT02399553

Study Identification

Unique Protocol ID: DEP 2103-32724

Brief Title: Effect of the Interaction Between the Type of Artificial Turf and Boots Model of Bone Health in Children Soccer Players (FUTBOMAS)

Official Title: Effect of the Interaction Between the Type of Artificial Turf and Boots Model of Bone Health in Children Soccer Players

Secondary IDs:

Study Status

Record Verification: May 2016

Overall Status: Completed

Study Start: September 2013

Primary Completion: January 2016 [Actual]

Study Completion: January 2016 [Actual]

Sponsor/Collaborators

Sponsor: Universidad de Zaragoza

Responsible Party: Principal Investigator
Investigator: José A. Casajús [jcasajus]
Official Title: Proffesor
Affiliation: Universidad de Zaragoza

Collaborators:

Oversight

FDA Regulated?: No

IND/IDE Protocol?: No

Review Board: Approval Status: Approved
Approval Number: CP12/2013
Board Name: Ethics Committe of Clinical Research of Aragon
Board Affiliation: Ethics Committe of Clinical Research of Aragon (CEICA)
Phone: 976 71 65 84
Email: ceica@aragon.es

Data Monitoring?:

Plan to Share Data?:

Oversight Authorities: SPAIN: CEICA Government of Aragon

Study Description

Brief Summary: The number of turf fields has experienced an important increase in public and private facilities during the last years. This artificial surface will be predominant in any soccer field in the next years. Among turf fields there are many different types depending on their construction characteristics (with and without asphalted base, elastic base, rubber filling, etc.). Officially all types of artificial turfs should have similar stability and impact absorption characteristics. On the other hand there is a great variety of soccer-boots, especially for youth soccer players, similar to the football stars.

Many evidences support the fact that when a person exercises many different type of impacts-stimulus are necessary in order to stimulate bone and skeletal muscle systems. However, it is not known yet whether this effect can be extended or shortened depending on the type of artificial surface and soccer-boots used, or even more whether it could be more or less dangerous and/or provoke injuries/disagreement among the users. Little information is available in youth soccer player pointing in the same direction but still controversial. Furthermore, bone strength do not only depends on bone mass but on bone structure and microarchitecture. The cross sectional area, cortex thickness or trabecular density are important aspects of bone health. There are few studies on the effect of interaction between turf field and soccer boots on bone architecture of youth soccer players. This information is relevant for present and future health of adolescents practicing football and for all the organizations promoting this sport.

Due to the fact that turf fields are preferentially used by youth populations, it is important to know the real effects of the interaction between of different type of artificial surfaces and soccer boots on children bone mass development. Nowadays, there are no data and/or defined guidelines that can answer those unresolved questions, thus the main aim of the present project is to identify which turf field and soccer boots are the most adequate to optimize the acquisitions of bone mass in children soccer players.

Detailed Description:

Conditions

Conditions: Soccer
Bone Density
Physical Fitness

Keywords:

Study Design

Study Type: Interventional

Primary Purpose: Prevention

Study Phase: N/A

Intervention Model: Parallel Assignment

Number of Arms: 5

Masking: Open Label

Allocation: Randomized

Endpoint Classification:

Enrollment: 129 [Actual]

Arms and Interventions

Arms	Assigned Interventions
Experimental: Soccer 2G Soccer players who trained in second generation artificial turf	Soccer boot intervention
Experimental: Soccer 3G Soccer players who trained in third generation artificial turf	Soccer boot intervention
Experimental: Soccer NG Soccer players who trained in natural grass	Soccer boot intervention
Experimental: Soccer NON-NG Soccer players who trained in non-natural grass	Soccer boot intervention
No Intervention: Control group	

Outcome Measures

Primary Outcome Measure:

1. Change in body composition during 2 years evaluated by Dual energy X-ray absorptiometry
   [Time Frame: Change from baseline in body composition at 2 years] [Safety Issue: Yes]

Eligibility

Minimum Age: 11 Years

Maximum Age: 13 Years

Gender: Both

Accepts Healthy Volunteers?: Yes

Criteria: Inclusion Criteria:

- Both: Aged from 11-13 years.
- Both: Parental/guardian permission (informed consent) and if appropriate, child verbal assent.
- Specific for the control group: Subjects that do not perform more than 3 hours of physical activity per week.

Exclusion Criteria:

- Taking medication affecting bone.
- Non-Caucasian.

Contacts/Locations

Study Officials:

Locations: Spain
José Antonio Casajús Mallén
Zaragoza, Zaragoza, Spain, 50009

References

Citations:

Links:

Study Data/Documents:

HOJA DE INFORMACIÓN PARA PADRES

Proyecto: EFECTO DE LA INTERACCIÓN ENTRE EL TIPO DE CÉSPED ARTIFICIAL Y MODELO DE BOTAS EN LA SALUD ÓSEA DE NIÑOS Y NIÑAS FUTBOLISTAS (ACRÓNIMO: FUTBOMAS).

Financiado por el Ministerio de Ciencia e Innovación (DEP2012-32724)

Información sobre el estudio

En los últimos años, la instalación de campos de césped artificial ha experimentado un aumento considerable tanto en instalaciones públicas como en privadas. Dentro de los campos de césped artificial existen diferentes tipos de construcción (con o sin sub-base asfáltica, con base elástica, tipo de relleno de caucho, etc.). Por otro lado la utilización de botas de fútbol en estas superficies es heterogénea, especialmente en los niños, donde los ídolos marcan tendencias poco justificadas desde el punto de vista científico- técnico y de la salud.

Por todo ello, queremos conocer cómo afecta a los huesos la práctica del fútbol en función de la superficie y el modelo de botas utilizados. La información recogida en FUTBOMAS nos ayudará a entender el desarrollo óseo en niños y niñas futbolistas en función del modelo de bota empleado y el tipo de campo en el que se práctica. Os pediremos que vuestros hijos, rellenen unos cuestionarios y lleven a cabo una serie de pruebas y tests médico-físicos sencillos.
Si queréis y estáis de acuerdo en formar parte del estudio, os podremos informar de cualquier tipo de problema de salud que se detecte durante el examen médico.

Pruebas que se llevaran a cabo

Desde Septiembre de 2013 hasta Junio de 2014 se llevarán a cabo las siguientes valoraciones:

- Si su hijo/a forma parte del estudio realizará dos controles: septiembre de 2013 y Junio de 2014. Estos controles incluyen las siguientes pruebas:
- Determinación de la composición corporal (masa ósea, magra, y grasa) total, del tronco y de las extremidades superiores e inferiores de todos los participantes mediante absorciometría fotónica dual de rayos X (DXA).
- Determinación de la estructura y microarquitectura del hueso a nivel de extremidades inferiores y superiores mediante tomografía axial computerizada periférica.
- Se analizaran las presiones plantares en función de los diferentes modelos de botas de fútbol y superficies de juego.
- Se obtendrán muestras de sangre y orina para la determinación de los marcadores de metabolismo óseo.
- Un equipo de investigadores cualificados valorará las características antropométricas (peso, talla, pliegues cutáneos y circunferencias).
- Se realizarán también pruebas de valoración de la condición física, se estudiará la ingesta dietética mediante un cuestionario electrónico y se valorará el desarrollo puberal. (Posteriormente se explican las pruebas con más detalle)

- Transcurridos 12 meses desde la segunda evaluación se realizará una tercera evaluación en los meses de Mayo y Junio de 2015 para investigar la evolución de las variables estudiadas.

Las pruebas que se van a realizar estarán divididas en ***dos días diferentes.***

1º Día: vuestro hijo/a acudirá al Edificio Cervantes (Corona de Aragón nº 42) de la Universidad de Zaragoza para realizar las pruebas de composición corporal y fuerza. Para la realización de las mismas, deberá permanecer en ropa interior deportiva para la primera parte y en ropa deportiva para la segunda. *La duración total de estas pruebas es de 2 horas aproximadamente.*

2º Día: el grupo de investigadores se desplazará a los lugares de entrenamiento de los equipos para realizar las extracciones de sangre, a continuación se les dará de desayunar y posteriormente se realizarán las pruebas de condición física. *La duración total de estas pruebas es de unas 3 horas aproximadamente.*

Confidencialidad

Toda la información recogida en este estudio será estrictamente confidencial. Si se detectará algún resultado fuera de lo normal durante la realización de las pruebas a vuestros hijos/as, se os comunicarían siempre y cuando tengáis la voluntad de conocer los mismos. Además, toda la información relativa a su hijo/a y su participación en este proyecto será exclusivamente utilizada con fines científicos, respetándose la legislación Nacional vigente (Ley Orgánica 15/99 de Protección de Datos de Carácter Personal y Ley 41/02 de Autonomía del paciente). Dicha información permanecerá de forma anónima mediante codificación de cuestionarios tanto en formato electrónico como en papel. Únicamente los miembros del equipo de investigación tendrán acceso a la información obtenida. Ni su nombre ni el de su hijo/a serán utilizados en ningún artículo o informe. Los datos personales se guardarán de forma separada a la información obtenida y estarán convenientemente guardados bajo llave.

Voluntariedad

Su participación y la de su hijo/a en esta investigación son totalmente voluntarias. Tanto usted como su hijo/a son libres de retirarse de la investigación en cualquier momento sin tener que dar ninguna explicación al respecto. La no participación o la retirada de la investigación durante su desarrollo no tendrán consecuencia alguna.

Detalles de contacto

Para cualquier información adicional que pueda necesitar, puede dirigirse a cualquiera de los investigadores responsables a través del teléfono o del correo electrónico.
José A Casajús: 876553755 o joseant@unizar.es.
Ángel Matute Llorente: 661953480 o amatute@unizar.es

EXPLICACIÓN DE LAS PRUEBAS A REALIZAR

Valoración de la composición corporal y de la masa ósea

La masa ósea, magra y grasa se determinará mediante absorciometría fotónica dual de rayos X (DXA) utilizando el software y los valores de referencia pediátricos (Hologic Explorer, Hologic Corp., Software versión 12.4, Waltham, MA).

Análisis de la arquitectura, sección transversal y expansión cortical del hueso

Se valorará la sección transversal y expansión cortical determinada a nivel de extremidades inferiores y superiores, lo que proporcionará información sobre posibles diferencias en regiones específicas. Los análisis se realizarán con tomografía cuantitativa computerizada periférica (XCT 2000 Peripheral QCT Scanner, Ortometrix, INC.).

Estas técnicas conllevan una dosis de radiación total de entre 5 y 10 mrem. Equivalente a una dosis *20 veces más baja que la de una radiografía de tórax* y similar a la radiación solar que se absorbe en *un día de playa*.

Analíticas

Marcadores de metabolismo óseo

Se tomará una muestra de orina y una de sangre (punción cubital) a primera hora de la mañana tras una noche de ayuno. La extracción será realizada por personal cualificado del ámbito sanitario.

Valoración de la condición física

Test de potencia aeróbica

El consumo máximo de oxigeno (VO_{2max}) se estima utilizando un test de ida y vuelta de 20-m tal y como fue diseñado por Luc Leger (Leger, 1988). Los sujetos tienen que correr 20 metros ida y vuelta al ritmo de una señal sonora. La frecuencia de las señales sonoras se incrementa de tal modo que comenzando a una velocidad de 8.5 $km \cdot h^{-1}$ se van incrementando 0.5 $km \cdot h^{-1}$ cada minuto. Se trata de un test que se suele realizar en los colegios.

Test de velocidad de carrera

El tiempo invertido en correr 30 m (T30) se medirá utilizando células fotoeléctricas (Byomedics, Barcelona).

La fuerza isométrica máxima (FIM)

De pierna

Test de máxima contracción voluntaria isométrica (MCVI)

Mediante una galga extensiométrica (MuscleLab) anclada firmemente de una determinada manera y conectada a un interface específico, se registrará la fuerza de los cuádriceps ejercida por el sujeto durante 10 segundos.

De brazo

La dinamometría manual se realizará con un dinamómetro Takei-Grip dinamometer de 5 a 100 kg ajustando la empuñadura a la medida óptima para desarrollar la mayor fuerza según se ha descrito para población adolescente. Se efectúan 2 intentos en cada mano, alternando una mano con otra y anotando, a efectos estadísticos el valor más elevado.

Fuerza dinámica de las piernas.

Las fuerzas generadas durante el salto vertical se medirán mediante el cálculo de la altura de vuelo durante el salto con una plataforma de infrarrojos ERGO JUMP Plus – BOSCO SYSTEM (Byomedic, S.C.P., Barcelona, Spain). Cada sujeto realiza dos tipos diferentes de saltos verticales máximos.

Valoración de las presiones plantares

El objetivo de dicha evaluación será cuantificar la presión que soporta cada participante en la planta del pie en función del modelo de bota utilizado y teniendo en cuenta el tipo de superficie de juego. Se utilizaran unas plantillas específicas con sensores de presión distribuidos estratégicamente que permitirán evaluar las presiones en diferentes zonas del pie y establecer presiones medias. La empresa Podoactiva® colaborará en esta tarea.

Determinación del estado de desarrollo puberal

El estado de desarrollo puberal se determinará mediante autoevaluación siguiendo el método Tanner, que es un método de reconocida validez y reproductibilidad.

Valoración de la dieta

La dieta se valorará a partir de tres recuerdos de 24 h no consecutivos y en días distintos de la semana, realizados con el software informático YANA-C.

HOJA DE INFORMACIÓN PARA ADOLESCENTES

Proyecto: EFECTO DE LA INTERACCIÓN ENTRE EL TIPO DE CÉSPED ARTIFICIAL Y MODELO DE BOTAS EN LA SALUD ÓSEA DE NIÑOS Y NIÑAS FUTBOLISTAS (ACRÓNIMO: FUTBOMAS).

Financiado por el Ministerio de Ciencia e Innovación (DEP2012-32724)

Información sobre el estudio para los adolescentes

En los últimos años, la instalación de campos de césped artificial ha experimentado un aumento considerable. Dentro de los campos de césped artificial existen diferentes tipos de construcción (con o sin sub-base asfáltica, con base elástica, tipo de relleno de caucho, etc.). Por otro lado, es limitado el conocimiento existente sobre qué modelo de tacos es el mejor en función de la superficie en la que se va a desarrollar el partido.
Por todo ello queremos conocer cómo afecta a los huesos la práctica del fútbol en función de la superficie y el modelo de botas utilizados. El proyecto en el que podéis formar parte si lo deseáis se llama FUTBOMAS.
Para poder lograr este objetivo, esperamos que gente joven como tú, formen parte de este proyecto de investigación.

ESTE ESTUDIO ES PARTICULAMENTE RELEVANTE PARA LA FUTURA SALUD ÓSEA DE LOS FUTBOLISTAS. Vuestra participación en este proyecto es muy importante, y será de gran utilidad para mejorar el conocimiento actual sobre la salud ósea de los jóvenes que practican un deporte tan popular como es el fútbol.

Formar parte de FUTBOMAS

Es tu elección el formar parte o no del estudio. No habrá ningún tipo de desventaja para ti o tu familia si no queréis participar. Al ser un estudio de libre participación, podrás abandonar si así lo deseas en cualquier momento del estudio, incluso después de haber entregado el consentimiento firmado, o incluso con alguna prueba ya realizada. Además de tener tu consentimiento, también necesitaremos la aceptación de tus padres en la participación de este proyecto. A pesar de que tus padres puedan estar de acuerdo, tú eres libre de participar o no.

¿Qué pruebas te vamos a hacer?

Como parte del estudio, te pediremos que participes en las siguientes pruebas:

- Unas pruebas médicas básicas, que incluirán medidas sencillas como la altura o el peso y pliegues cutáneos.
- Estudiaremos la composición corporal (masa ósea, magra, y grasa) total que tenéis, mediante absorciometría fotónica dual de rayos X (DXA). La prueba consiste en estar tumbado en una camilla unos 10 minutos aproximadamente.
- También estudiaremos los huesos del brazo y la pierna mediante tomografía axial computerizada periférica. Es un aparato que determina como de fuertes están los huesos y lo único que hay que hacer es estar sentado en una silla sin moverse durante 5 minutos.
- Analizaremos mediante la colocación de una plantilla, las presiones plantares en función de los diferentes modelos de botas de fútbol y superficies de juego.
- Se obtendrán muestras de sangre y orina para la determinación de los marcadores de metabolismo óseo, solo si tú estás de acuerdo.
- Participar en pruebas de valoración de la condición física similares a las que hacéis en los institutos (Course-Navette, salto a pies juntos etc.).

- Responder sencillas preguntas de cuestionarios que sirven para estudiar la ingesta dietética.
- Llevar un acelerómetro (un dispositivo del tamaño de una caja de cerillas colocado en un cinturón a la altura de la cintura) durante unos días que nos ayudará a registrar la actividad física que realizáis.

El número de evaluaciones que realizaremos serán 3. La primera en Septiembre de 2013, la segunda en Junio de 2014 y la tercera en Junio de 2015. En cada evaluación las pruebas que se van a realizar estarán divididas en *dos días diferentes.*

1º Día: deberéis acudir al Edificio Cervantes (Corona de Aragón nº 42) de la Universidad de Zaragoza para realizar las pruebas de composición corporal y fuerza. Para la realización de las mismas, deberéis llevar ropa interior deportiva para la primera parte y en ropa deportiva para la segunda. *La duración total de estas pruebas es de 2 horas aproximadamente.*

2º Día: el grupo de investigadores nos desplazaremos a vuestros lugares de entrenamiento de los equipos para realizar las extracciones de sangre, y a continuación daros de desayunar y realizar las pruebas de condición física. *La duración total de estas pruebas es de unas 3 horas aproximadamente.*

Tu información será confidencialidad

Los resultados obtenidos son para uso exclusivo de la investigación. Las pruebas físicas, como por ejemplo las medidas corporales (peso o talla) o las muestras de sangre, podrían informarnos de tu estado de salud. Si tú y tus padres estáis de acuerdo, se os informará de cualquier contratiempo que detectemos. Las respuestas que des a las preguntas de los cuestionarios son totalmente privadas.

Si tienes cualquier duda o consulta acerca del estudio o sobre lo que tendrás que hacer, por favor comunícanoslo y te informaremos de la mejor manera posible.
Nuestros datos de contacto son:

Edif. Cervantes, C/Corona de Aragón, nº 42, 2ª planta, 50009, Zaragoza.
Tfno.: 876553755 Email: joseant@unizar.es

Muchas gracias por considerar nuestra propuesta.

José Antonio Casajús

CONSENTIMIENTO INFORMADO PARA PADRES

Nos gustaría invitarte a firmar este consentimiento informado para poder formar parte del estudio "*Efecto de la interacción entre el tipo de césped artificial y modelo de botas en la salud ósea de niños y niñas futbolistas*". Con la firma de este documento, el participante:

1. Es advertido sobre la posibilidad de utilizar los resultados del diagnóstico en un proceso de investigación, que en ningún caso podrá comportar riesgo adicional para su salud y que no tendrá carácter comercial.
2. Es advertido de que su participación y la de su hijo/a en esta investigación son totalmente voluntarias. Tanto usted como su hijo/a son libres de retirarse de la investigación en cualquier momento sin tener que dar ninguna explicación al respecto
3. Es advertido de su derecho a que se le dé una copia del documento firmado.
4. Contará con la cobertura de un seguro para la realización de las pruebas.
5. Puede obtener la información complementaria del investigador principal del proyecto, cuya dirección figura en este escrito.
6. Puede solicitar por escrito dirigido al investigador principal del proyecto los resultados concretos obtenidos en su muestra donada.

☐ Acepto la participación en el estudio y manifiesto que he recibido información suficiente y en términos comprensibles para tomar la decisión de acuerdo con su propia y libre voluntad y presto mi consentimiento y autorización a la práctica de la intervención reseñada en el proyecto: "*Efecto de la interacción entre el tipo de césped artificial y modelo de botas en la salud ósea de niños y niñas futbolistas*" (acrónimo: FUTBOMAS), financiado por el Ministerio de Economía y Competitividad, en el que participa el Departamento de Fisiatría y Enfermería de la Universidad de Zaragoza, y del que es investigador principal el profesor Dr. José Antonio Casajús Mallén, Catedrático de la Universidad de Zaragoza (Departamento de Fisiatría y Enfermería C/ Domingo Miral s/n 50008 Zaragoza, teléfono 974238422 (ext 853258), e-mail: joseant@unizar.es).

Datos personales:

Nombre y apellidos del padre*: ……………………………………………………………………..

Nombre y apellidos de la madre*: …………………………………………………………………..

Nombre y apellidos del adolescente/niño/a que participa en el estudio: ……………….……….

Nombre y apellidos del 2º adolescente/niño/a (si es aplicable): ………………………………….

Datos de contacto:

Domicilio de la familia: ………………………………………………………………………………

Calle/número/piso: ………………………………………………………………………………….

Código postal: ………………………… Ciudad: ………………………………………………….

Teléfono (fijo y móvil): ………………………………………. Correo electrónico: ……………..

Estamos de acuerdo en que guardéis nuestra dirección: sí ☐ no ☐

Deseo ser informado sobre los resultados del estudio: sí ☐ no ☐

Acepto que las muestras derivadas de este estudio puedan ser utilizadas en futuras investigaciones, incluyendo análisis genéticos: sí ☐ no ☐

Firmas: Padre* Madre*

....

Fecha: ………………………….. Fecha: ………………………………………………………

Científico responsable de la investigación: José Antonio Casajús Mallén

Fecha: ……………………

---

*Por padre o madre, se entiende los tutores legales, no necesariamente los padres biológicos. Si eres el único tutor legal o padre/madre, por favor, ignora las casillas relativas al otro padre/madre.

CONSENTIMIENTO INFORMADO PARA ADOLESCENTES

Nos gustaría invitarte a firmar este consentimiento informado para poder formar parte del estudio "*Efecto de la interacción entre el tipo de césped artificial y modelo de botas en la salud ósea de niños y niñas futbolistas*".

Con la firma de este documento, acepto la participación en el estudio arriba descrito

Yo,

…………………………………………………………………….... (Nombre y apellidos del participante)

Dirección: ……………………………………………………………………………………………….

Teléfonos de contacto: ……………………………………………………………………………..

He leído la hoja de información que se me ha entregado.

He podido hacer preguntas sobre el estudio y he recibido suficiente información sobre el mismo.

He hablado con: Dr. José A. Casajús (teléfono de contacto 876553755)

Comprendo que la participación es voluntaria.

Comprendo que podemos retirarnos cuando queramos, sin tener que dar explicaciones y sin que esto repercuta en mis cuidados médicos

Deseo ser informado sobre los resultados del estudio: $\boxed{\text{sí}}$ $\boxed{\text{no}}$ (marque lo que proceda)

Acepto que las muestras derivadas de este estudio puedan ser utilizadas en futuras investigaciones (relacionadas con ésta), excluyendo análisis genéticos: sí no (marque lo que proceda)

Doy mi asentimiento para que mis datos clínicos sean revisados por personal ajeno al centro, para los fines del estudio, y soy consciente de que este consentimiento es revocable.

He recibido una copia firmada de este Consentimiento Informado.

Firma del participante: ______________________________

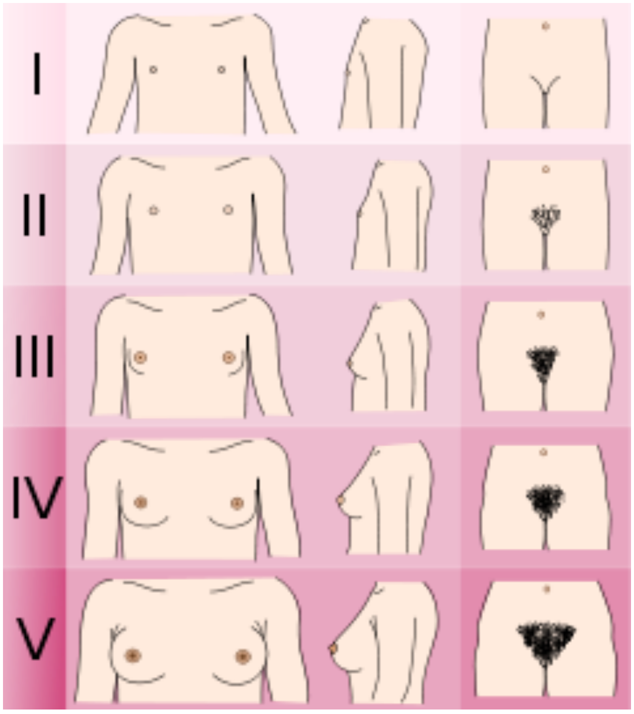
Fecha: ______________________________

He explicado la naturaleza y el propósito del estudio al padre/madre/tutor y participante mencionado

Firma del Investigador: ______________________________

Fecha:

ESTADIO DE TANNER



Considerando las siguientes imágenes, marca la casilla que consideres que más se parece a tu propio cuerpo.

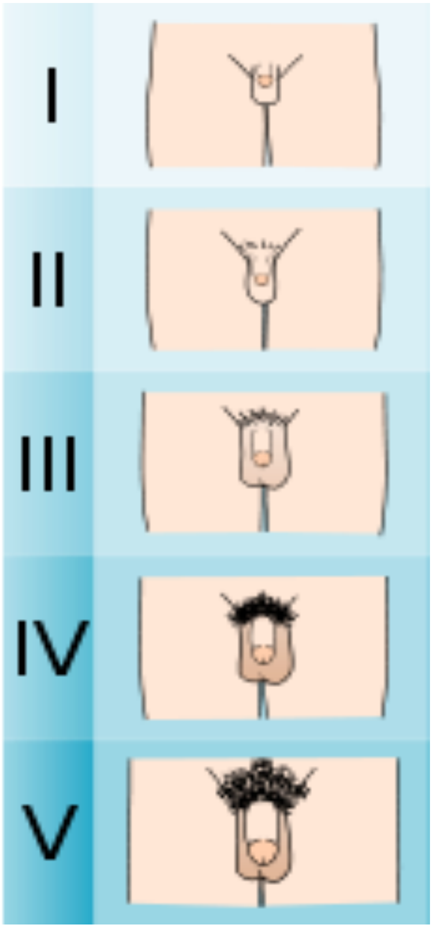
I	II	III	IV	V

1. ¿A qué edad tuviste tu primera menstruación?________________________
   (*Si aun no la has tenido deja de responder*)

2. ¿Tus menstruaciones se producen de manera regular? SI ☐ NO ☐

3. ¿Cuántos periodos tienes a lo largo de un año? Más de 8 ☐ Menos de 8 ☐
   Específicamente tengo ______ periodos al año

ESTADIO DE TANNER



Considerando las siguientes imágenes, marca la casilla que consideres que más se parece a tu propio cuerpo.

I	II	III	IV	V

NOMBRE: **CÓDIGO:**

FECHA:

	NÚMERO DE VECES QUE COMO			
	DÍA	SEMANA	MES	NUNCA
Pan (**una rebanada pan de molde, un trozo pequeño**)				
Blanco	______	______	______	______
Integral	______	______	______	______
Pizza **(1/4 pizza Tarradellas)**	______	______	______	______
Hamburguesa **con queso**	______	______	______	______
Queso **(1 loncha)**	______	______	______	______
Brócoli 70g (1 plato)	______	______	______	______
Col 70g (1 plato)	______	______	______	______
Helado **(1 bola)**	______	______	______	______
Yogurt helado (1 bola)	______	______	______	______
Batido comercial (1 brick individual)	______	______	______	______
Requesón 255ml (1 taza)	______	______	______	______
Yogurt (1 unidad)	______	______	______	______
Sardinas, anchoas o salmón **(1 lata o 1 trozo)**	______	______	______	______
Refresco (1 lata)	______	______	______	______
Refresco light (1 lata)	______	______	______	______
Café o té (1 taza)	______	______	______	______
Zumo de naranja (1 vaso, 200ml)	______	______	______	______
Leche,cualquier tipo (1 taza)	______	______	______	______
Macarrones con queso (1 plato)	______	______	______	______

Anexo VII

NOMBRE DEL PARTICIPANTE/NÚMERO DE IDENTIFICACIÓN DEL ACELERÓMETRO							
	Lunes	Martes	Miércoles	Jueves	Viernes	Sábado	Domingo
Hora, duración Y motivo							

NOMBRE DEL PARTICIPANTE/NÚMERO DE IDENTIFICACIÓN DEL ACELERÓMETRO							
	Lunes	Martes	Miércoles	Jueves	Viernes	Sábado	Domingo
Hora, duración Y motivo							

Anexo VIII

International Journal of Sport Nutrition & Exercise Metabolism

Decision Letter (IJSNEM.2018-0099.R1)

Subject: International Journal of Sport Nutrition & Exercise Metabolism - Decision on Manuscript ID IJSNEM.2018-0099.R1

Body: 4/7-18

Dear Professor Casajus:

It is a pleasure to accept your manuscript entitled "Accurate Prediction Equation to Assess Body Fat in Male and Female Adolescent Football Players." in its current form for publication in the International Journal of Sport Nutrition & Exercise Metabolism. The comments of the reviewer(s) who reviewed your manuscript are included at the foot of this letter.

Thank you for your fine contribution. On behalf of the Editors of the International Journal of Sport Nutrition & Exercise Metabolism, we look forward to your continued contributions to the journal.

Sincerely,
Dr Ina Garthe
Associate Editor, International Journal of Sport Nutrition & Exercise Metabolism

Reviewer(s)' Comments to Author:
Reviewer: 1

Recommendation: Accept

Comments:
I recommend acceptance.

Additional Questions:
How relevant is the topic of the article to the field?: 5

How clear is the research question?: 5

How original is the research question?: 5

To what degree is the article based on sound theory?: 5

How appropriate is the methodology?: 5

How thorough is the data analysis?: 5

How informative is the interpretation of results?: 5

To what extent does the discussion yield new insights?: 5

How clear is the writing?: 5

Are the results of the research original?: Yes

Reviewer: 2

Recommendation: Accept

Comments:
(There are no comments.)

Additional Questions:
How relevant is the topic of the article to the field?: 4

How clear is the research question?: 3

How original is the research question?: 3

To what degree is the article based on sound theory?: 3

How appropriate is the methodology?: 2

How thorough is the data analysis?: 4

How informative is the interpretation of results?: 4

To what extent does the discussion yield new insights?: 4

How clear is the writing?: 3

Are the results of the research original?: Yes

Date Sent: 04-Jul-2018