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

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classified into two groups according to the surface they trained 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. For both football players and controls, bone variables measured at subtotal body, lumbar spine, legs and tibia ($p<0.05$) significantly increased. Based on the time spent practicing football, the increase in aBMD for the legs ($p<0.05$) was 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 with the lower shock absorption seems to have produced the highest 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 surfaces on bone mass accretion in male adolescent football players: a one-season study

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Abstract

There are different surfaces on which football is played, but their influence on bone mass accretion still remains unknown. The aims of this study were to compare bone mass accretion between football players and controls and evaluate the influence of two different playing 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 two groups according to the surface they trained 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. For both football players and controls, bone variables measured at subtotal body, lumbar spine, legs and tibia ($p<0.05$) significantly increased. Based on the time spent practicing football, the increase in aBMD for the legs ($p<0.05$) was 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 with the lower shock absorption seems to have produced the highest 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, body composition, bone density, bone mass, third-generation artificial turf

Introduction

Childhood and adolescence are crucial periods for bone building and children should 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, the review did not include the effects of individual sports. A study by Mautalen[4] highlighted the positive effects of football practice on bone mass during adolescent growth. These positive effects on bone mass are mainly explained by the fact that football is a weight-bearing sport which is characterized by high-impact actions, such as accelerations, decelerations, changes of direction, jumps and kicks.[5] Furthermore, this sport has great importance for young people because football is one of the most, if not the most, practiced sport worldwide.[6]

The positive benefits of football practice on bone tissue have been amply demonstrated;[7] 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.[8-10] More importantly, the positive effects generated by football have been shown to remain after 1- and 3-year follow-ups.[8, 11-15] 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 explaining up to 60% of the variance in bone strength, it cannot directly measure bone geometry variables.[16] For this reason, some studies have used other techniques, such as hip structural analysis (HSA)[14] and peripheral quantitative computed tomography (pQCT)[17-19] for measuring bone geometry in football players. HSA is derived from hip scan images acquired by DXA. According to the 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.[20] 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 like DXA, measures trabecular and cortical bone, allowing for evaluation of the tibia, which is directly affected by football. Up to now, only one study has compared young male football players and the CG, showing higher bone geometry in football players than the CG.[19] On the other hand, to the authors' knowledge, there are no studies which have evaluated the effects of playing football compared to a population not engaged in any sport on bone geometry and strength measured by pQCT during growth.

Ground reaction forces could be described as one of the main contributing factors influencing bone accretion. However, properties of playing surfaces change over time, which may affect this relationship. The number of natural grass football fields is decreasing, whereas the number of artificial turf pitches is increasing.[21] To replicate the playing properties of natural grass football fields, new developments in construction methods of artificial turf fields include the use of materials such as rubber and sand infill.[21] At the same time, different infill materials create different mechanical characteristics.[22] Thus, the inclusion or lack of an elastic layer in the installation process generates differences in shock absorption and vertical deformation forces.[22] Due to these mechanical properties, different types of surfaces may evoke different loads to the bone. To the authors' knowledge, only Plaza-Carmona et al.[23] compared the influence of third-generation artificial turf fields and soil football fields on bone mass accrual in male children football players, finding no differences for BMC and aBMD. However, the influence of recent third-generation artificial turfs with an elastic layer (3G-EL) and without an elastic layer (3G-NEL) on bone tissue in young football players is yet unknown. During adolescent growth, the short-term effects on bone mass while playing football versus not playing a sport should be studied more deeply, especially bone geometry and strength. 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 the 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.

The authors hypothesized that all adolescents will improve bone mass and strength values throughout the season, but football players will have increased bone mass, geometry and strength compared to the CG. Also, those football players who play on 3G-NEL during this period will exhibit additional bone mass gain in comparison with players on the 3G-EL due to the fact that the 3G-NEL surface will have lower shock absorption than the 3G-EL. Therefore, the football players will receive increased loads.

Methods

Participants

Two football clubs and two high schools in Aragon (Spain) were invited to participate. Although 35 football players and 23 controls agreed to participate, 16 participants were excluded because of the following reasons: three football players and three controls did not perform the second measurement citation, four football players and two controls did not wear the accelerometer, and one football player and three controls had blurred DXA or pQCT images. Consequently, the final sample of 27 male football players (13.17±0.52 years) and 15 male controls (CG; 12.58±1.11 years) participated in this study (Fig. 1). Football players were split into two groups according to the surface where they trained and played: 3G-EL (n=14; 13.01±0.61 years) and 3G-NEL (n=13; 13.35±0.34 years). Although the CG were physically active, they were not regularly engaged in any sport. Measurements were performed in Zaragoza (Spain) at the beginning of the season (October-December 2013) and end of the season (May-July 2014) with a mean measurement time of 31.5±6.2 weeks, which followed the protocol recommended by the ISCD[20] to evaluate bone changes between DXA scans at a minimum interval of 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 players. Hours of training per week were individually quantified based on the number of training sessions in which the player participated (3G-EL players=2.6±0.2 hours/week; 3G-NEL players=2.3±0.3 hours/week). A sport scientist monitored the type of exercises performed by each team during their training throughout the season. Each training session 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 (passing, kicking, running, dribbling); and 5-10 minutes of cool down stretching exercises. Taking into account training sessions and matches played at home and away grounds, the percentage of time spent on surfaces included in the present study were 80.2% for 3G-EL players and 78.1% for 3G-NEL players (i.e. away games reduced the percentages of per time on the study field).

Participants, parents and coaches of each club were informed about the protocol, and the possible benefits and risks associated with this study. Written informed consent from parents and verbal assent from the participants were obtained. This study was performed in accordance with the Declaration of Helsinki 1961 (revision of Fortaleza

2013). 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]. This longitudinal study is part of a larger randomized controlled trial that evaluated the effect of football surfaces and boot model on bone mass and strength in male and female adolescent football players. However, female football players were not included in the present manuscript because of the low number of participants that could be evaluated in the second assessment (some players stopped playing and others did not perform to the evaluation). The Transparent Reporting of Evaluations with Nonrandomized Designs (TREND) Statement was used as a guideline for reporting non-randomized trials.[24]

Inclusion criteria

The inclusion criteria established for the project included: Caucasian, a minimum of one year of football practice on the playing surface prior to the beginning of the measurements (football players), or not regularly engaged in any sport (controls), between the ages of 11 and 14 and free of any medications affecting bone properties.

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 clothing. Body mass index (BMI) was calculated by dividing the participant's weight (kg) by the squared height (m^2).

Maturity status

Pubertal maturity was determined according to the stages proposed by Tanner and Whitehouse[25] and using a self-assessment method which has been shown to be a valid and reliable technique.[26]

Calcium intake

Milligrams of daily calcium intake were calculated by a validated calcium food frequency questionnaire.[27] Participants were asked how many times per day, week or months they consumed calcium-rich foods.

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 on different body locations, including the right and the left wrists.[28] All participants wore GENEA devices on their non-dominant wrist for seven days, except for football players who had to remove the accelerometer during official matches. Data were recorded at 30 Hz and analysed at 1-s epochs. These data were taken within a duration of seven days towards the end of the season (May-July 2014). Accelerometer data were analysed using the software RStudio (version RStudio Desktop 1.0.153, Boston, MA, United States). Minutes of valid time in light, moderate and vigorous physical activity, as well as sedentary time, were calculated using cut-points proposed by Phillips et al.[28] 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 as follows: 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 (pediatric version of the software QDR-Explorer, Hologic Corp. Software version 12.4, Bedford, MA, USA). DXA equipment was calibrated daily following the manufacturer guidelines. Whole body, non-dominant hip and lumbar spine scans were conducted with participants in supine position by the same technician who had been fully been trained to perform the scans. The positioning of the subjects and analysis of the results were performed according to the manufacturer´s guidelines. The non-dominant limb was determined by asking which leg would be used to kick a ball.[29]

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 was obtained from lumbar spine scans (L1-L4). Femoral neck values used to calculate BMAD were obtained from hip scans. Coefficients of variation for BMC and aBMD at whole body in the laboratory in this study were 2.3% and 1.3%, respectively. However, subtotal body BMC and lumbar spine BMAD were the preferred bone sites for evaluating bone changes during growth.[20] 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 BMAD is less sensitive to size changes than aBMD, Carter et al.[31] and Katzman et al.[32] developed new mathematical models to calculate BMAD. In this study, Eqs. (1) – (3) have been used:

$$\text{Whole body BMAD} = \text{BMC (whole body)} / [Ap^2 / h] \qquad (1)$$

where Ap is the projected area (whole body) from DXA and h is the height of the participant.[32]

$$\text{Lumbar spine BMAD} = \text{BMC (L1-L4)} / Ap^{3/2} \qquad (2)$$

where Ap is the projected area (L1-L4) from DXA[31]

$$\text{Femoral neck BMAD} = \text{BMC (femoral neck)} / Ap^2 \qquad (3)$$

where Ap is the projected area (femoral neck) from DXA[31]

pQCT

Bone mass, geometry and strength were measured at the 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 performed daily using a quality control phantom. Coefficients of variation for each pQCT variable used in the present study were as follows: 0.71% for total volumetric bone mineral density (Tt.vBMD), 0.93% for trabecular vBMD (Tb.vBMD), 0.25% for total BMC (Tt.BMC), 0.25% for cortical vBMD (Ct.vBMD), 0.73% for cortical cross sectional area (Ct.Ar), 1.12% for cortical thickness (Ct.Th), 2.51% for fracture load in X-axis (Frc.LdX); and 2.08% for polar strength strain index (SSIp).

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 using a wooden ruler (to the nearest 1 mm). Then, the 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[34] recommendations for evaluating bone geometry and strength with pQCT, Tt.vBMD (mg/cm^3) and Tb.vBMD (mg/cm^3) at the 4% site of the tibia were analysed. Moreover, the parameters measured at 38% of the length of the tibia were total Tt.BMC (g), Ct.vBMD (mg/cm^3), Ct.Ar (mm^2), Ct.Th (mm), Frc.LdX (N) and SSIp (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 (Frc.LdX and SSIp). 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) and the Handbook of Test Methods for Football Turf.[35] 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. Although maintenance of these football fields could vary, 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. The other mechanical characteristics were measured with the equipment proposed by the Handbook of Test Methods for Football Turf.[35]

All tests were performed at stable meteorological conditions at temperatures 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 to evaluate meteorological conditions. These measurements were performed in April (3G-NEL) and May (3G-EL).

Statistical analyses

Sample size calculation

To the authors knowledge, there have been no studies that have calculated whole body or lumbar spine BMAD. Therefore, data from a Zouch et al.[13] study evaluating aBMD at whole body in football players and the CG (1.098 ± 0.093 and 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 80% at the 5% alpha level and to reject the null hypothesis H_0:µ1=µ2. 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, a total sample size of 32 (16 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. ANOVA for repeated measures were applied to check differences within all football players and the CG, as well as within 3G-EL and 3G-NEL between pre- and post-season 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). MVPA was selected as a covariate to analyse the possible effect of these high intensity activities on bone mass. In addition, lean mass was used as a covariate due to its influence on bone mass.[36] Moreover, weight was not used as covariate to avoid multicollinearity in the analysis due to its high correlation with lean mass (Pearson correlation coefficient = 0.922; $p < 0.001$). 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 squared (η^2_p) can be small (0.01 – 0.06), medium (0.06 – 0.14) or large (>0.14). Statistical significance was set at $p < 0.05$.

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; $p > 0.05$). Between different surfaces (3G-EL and 3G-NEL), no differences were found either (Cohen´s *d* ranged from 0.06 to 0.70; $p > 0.05$).

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 in all groups (η^2_p ranged from <0.001 to 0.943; $p < 0.05$). Moreover, football players who trained on 3G-NEL demonstrated lower percentage of body fat at post- than pre-season (η^2_p was 0.357; $p < 0.05$).

No significant differences were found in MVPA between football players and the CG (93.29±19.93 vs 95.50±33.46 minutes per day; 95% CI, -17.54 to -21.95; Cohen´s *d* was 0.08; $p > 0.05$) and between football players who trained in 3G-EL and 3G-NEL (100.25±21.69 vs 85.80±15.29 minutes per day; 95% CI, -29.29 to 0.40; Cohen´s *d* was 0.77; $p > 0.05$).

BMC, aBMD and BMAD

Comparisons between football players and the CG

Table 2 summarizes BMC and aBMD measured at pre- and post-season in football players and CG. Higher legs aBMD was found in football players than the CG at post-season (95% CI =-0.02 -0.19; Cohen´s *d* was 0.72; $p < 0.05$). Football players and the 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; $p < 0.05$). Furthermore, a significant group by time interaction was found for legs aBMD (percentage changes of football players and CG were 7.0% and 4.0%, respectively; η^2_p was 0.097; $p < 0.05$). This interaction showed that the increase in the legs aBMD was significantly greater in football players in comparison with the CG. The same result was obtained when MVPA were included as covariate (percentage changes of football players and the CG were 7.0% and 4.1%, respectively; η^2_p was 0.099; $p < 0.05$), but it became non-significant when subtotal lean mass was introduced as covariate (percentage changes of football players and the CG were 6.9% and 4.5%, respectively; η^2_p was 0.063; $p > 0.05$; Fig. 2). Therefore, a lean mass correction could underestimate the effects of this high-impact sport on bone mass.

Comparison between 3G-EL and 3G-NEL football players

Table 3 summarizes BMC and aBMD measured at pre- and post-season in 3G-EL and 3G-NEL football players. 3G-EL showed higher lumbar spine and femoral neck BMAD at pre- and post-season than 3G-NEL (Cohen´s *d* ranged from 0.80 to 1.45; $p < 0.05$). Both football groups increased subtotal body BMC, lumbar spine BMC, legs aBMD and lumbar spine BMAD from pre- to post-season (η^2_p ranged from 0.203 to 0.674; $p < 0.05$). Moreover, 3G-NEL also increased femoral neck BMAD (η^2_p was 0.096; $p < 0.05$). There was a group by time interaction for lumbar spine BMAD (percentage changes of 3G-EL and 3G-NEL players were 1.8% and 5.9%, respectively; η^2_p was 0.169; $p < 0.05$). 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 (percentage changes of 3G-EL and 3G-NEL players were 2.6% and 5.9%, respectively; η^2_p was 0.109; $p > 0.05$; Fig. 3).

Bone geometry and strength

Comparisons between football players and the CG

Bone geometry and strength measured at the 4% and 38% sites of the tibia in football players and the CG are shown in Table 2. Higher Ct.Ar at pre-season and SSIp at pre- and post-season were found in football players than the CG (Cohen´s d ranged from 0.63 to 0.80; $p < 0.05$). Both groups improved Tt.BMC, Ct.Ar, Ct.Th, Frc.LdX and SSIp (η^2_p ranged from 0.106 to 0.635; $p < 0.05$). Furthermore, the CG decreased Tt.vBMD and Tb.vBMD at distal tibia (η^2_p were 0.102 and 0.128; $p < 0.05$). No group by time interactions were found in bone geometry and strength values (η^2_p ranged from <0.001 to 0.053; $p < 0.05$); however, when tibia muscle area was added as covariate, there was a group by time interaction for Tt.BMC (percentage changes of football players and the CG were 5.7% and 8.1%, respectively; η^2_p was 0.105; $p < 0.05$; Figure 2). This interaction demonstrated that Tt.BMC increased more in the CG than football players. As determined 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 football players

Bone geometry and strength measured at the 4% and 38% sites of the tibia in 3G-EL and 3G-NEL football players are shown in Table 3. At pre- and post-season, 3G-EL players showed higher Tt.vBMD and Tb.vBMD than 3G-NEL (Cohen´s *d* ranged from 1.01 to 1.31; $p < 0.05$). 3G-EL and 3G-NEL players improved Tt.BMC, Ct.Ar, Ct.Th, Frc.LdX and SSIp (η^2_p ranged from 0.199 to 0.683; $p < 0.05$). 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; $p < 0.05$).

Discussion

The main finding of the present study is that one season of football practice, independent of the playing surface, positively affect bone accretion in the lower limbs of young players. Subtotal body BMC and lumbar spine BMAD are the variables that ISCD recommends to compare densitometry results in children and adolescents.[20] However, the analysis of legs would help to explain how football practice affects bone mass because legs are the closest site of the body to the floor and support more impact than the other 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 the CG. To the best of the authors' knowledge, six studies have analysed the effects of football practice on DXA parameters in young football players and the CG.[8, 11-15] Most of them demonstrated that football practice seems to be a good strategy for increasing BMC and aBMD during growth. These results were higher for football players than those obtained by the CG. Moreover, they also reported higher BMC and aBMD at lower limbs in football players than the CG. Most of them also demonstrated differences in lumbar spine, a preferred site to assess densitometry variables during growth.[20] 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[37]) and bone size of their participants.[31] In the present study, although subtotal body BMC and lumbar spine BMAD were included, no significant differences in these variables were found between football players and the 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 help 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 the CG, with larger SSIp values. Up to now, there are only a cross-sectional study[19] and a 1-year follow-up study[14] that have compared bone geometry and strength values between male football players and the 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 the CG. The lack of differences between these groups could be explained by the fact that cortical bone parameters increase sharply after the age of 14[38] and the age of participants of the present study was lower. Thus, future studies evaluating bone geometry and strength acquisition before and after 14 years of age 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. [23] analysed bone mass in football players who trained on different playing surfaces (artificial and soil fields). These authors showed that neither BMC nor aBMD were different between football players according to playing surface. The present study demonstrated that lumbar spine BMAD, femoral neck BMAD, Tt.vBMD and Tb.vBMD were higher in 3G-EL than 3G-NEL players at both pre- and post-season. Although no significant differences in hours of trainings per week were found between football groups (3G-EL players=2.6±0.2 hours/week; 3G-NEL players=2.3±0.3 hours/week), the extra 15-20 minutes per week of training performed by players who trained in 3G-EL might explain the observed bone differences between both football groups. In addition to this, as demonstrated Varley et al.[18], an increase of training volume improved bone geometry and strength parameters.

Artificial fields aim to emulate physical and mechanical characteristics of natural surfaces. 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.[21, 39] Afterwards, the inclusion of the elastic layer behind the artificial turf systems increased shock absorption,[22] 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 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 impacts produced by football and progressively, as they move away from the ground to other bone sites, these impacts dissipate. Impacts 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 causing 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 three hours per week could be limiting the differences between football players. To reinforced this idea, Zouch et al.[11] and Varley et al.[18] demonstrated that higher training volume improved both DXA and pQCT parameters.

Prior to the beginning of this study, sample sizes of each group were higher than that obtained in the sample size calculation. Nevertheless, some participants were excluded because of the above-mentioned reasons (see Methods section). Consequently, the main limitation of the present study was that sample sizes of 3G-EL (n = 14), 3G-NEL (n = 13) and the CG (n = 15) were lower than the predicted number obtained in the sample size calculation (16 participants per group). Therefore, bone comparisons between groups may have been affected by type II error. Moreover, the type of football exercises performed by each team was similar but not equal. Therefore, the variation in football training exercises could cause slight differences in bone mass. Participants' calcium intake data may be somewhat unreliable due to the fact that questionnaires were undertaken by the youth participants with supervision by the researchers, as opposed to their parents or guardians. Another limitation was that the number of practice hours per week for both teams was lower than those in other studies performed with football players (approximately 2.4 vs 10.0 and 11.9 hours per week).[14, 18] Moreover, football players could not use accelerometers during matches and accelerations registered could not accurately represent the accelerations of lower limbs as they had to be placed on the wrist. 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 study that compares bone geometry and strength between football players and the CG.

Conclusions

The present study demonstrates that football practice on artificial surfaces with or without an elastic layer seems to increase bone mass in lower limbs during growth compared to not playing football. Moreover, after one-season follow-up, football practice on a 3G-NEL surface with lower shock absorption seems to be an adequate alternative to improve BMAD in the lumbar spine. Thus, soccer practice on surfaces with lower shock absorption could provide an extra benefit to bone health.

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Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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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·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.

					Repeated Measures		
					Within Group		Group by time
		All players	CG		All players	CG	
		N=27	N=15	*d*	η^2_p	η^2_p	η^2_p
DXA							
BMC (g)							
Subtotal body	T0	1289.290±263.534	1130.329±267.328	0.60			
	T1	1467.438±330.159	1288.363±322.811	0.55	0.713‡	0.521‡	0.011
Lumbar Spine	T0	38.44±8.10	35.24±8.13	0.39			
	T1	43.96±10.14	40.68±10.56	0.32	0.642‡	0.492‡	<0.001
aBMD (g/cm²)							
Legs	T0	1.089±0.111	1.025±0.127	0.54			
	T1	1.165±0.131	1.066±0.144#	0.72	0.592‡	0.192‡	0.097*
BMAD (g/cm³)							
Whole body	T0	0.093±0.005	0.094±0.006	0.20			
	T1	0.094±0.005	0.094±0.005	0.07	0.074	0.006	0.051
Lumbar Spine	T0	0.108±0.012	0.107±0.014	0.08			
	T1	0.112±0.011	0.110±0.016	0.14	0.440‡	0.213‡	0.013
Femoral Neck	T0	0.184±0.019	0.178±0.025	0.29			
	T1	0.186±0.019	0.180±0.031	0.23	0.017	0.015	<0.001
pQCT							
4% site							
Tt.vBMD (mg/cm³)	T0	323.239±36.539	322.503±48.332	0.02			
	T1	318.962±30.043	315.847±48.179	0.08	0.078	0.102‡	0.009
Tb.vBMD (mg/cm³)	T0	298.757±43.691	287.146±51.027	0.71			
	T1	291.867±37.550	275.365±54.061	0.91	0.083	0.128‡	0.016
38% site							
Tt.BMC (g)	T0	3.072±0.339	2.841±0.511	0.53			
	T1	3.254±0.398	3.061±0.598	0.38	0.635‡	0.586‡	0.026
Ct.vBMD (mg/cm³)	T0	1057.859±30.134	1055.431±30.778	0.22			
	T1	1055.337±28.683	1061.363±32.942	0.28	0.014	0.041	0.053
Ct.Ar (mm²)	T0	391.991±43.761	357.433±63.992#	0.63			
	T1	412.398±51.080	382.033±79.129	0.46	0.500‡	0.346‡	<0.001
Ct.Th (mm)	T0	4.832±0.422	4.605±0.512	0.48			
	T1	5.017±0.418	4.779±0.603	0.46	0.192‡	0.106‡	<0.001
Frc.LdX (N)	T0	3142.342±497.580	2822.855±763.484	0.50			
	T1	3317.777±510.716	3050.249±783.238	0.41	0.280‡	0.266‡	0.012
SSIp (mm³)	T0	1410.744±228.345	1190.714±314.927#	0.80			
	T1	1502.870±221.134	1296.479±320.088#	0.75	0.259‡	0.204‡	0.003

Data presented as mean ± standard deviation. T0: pre-season moment; T1: post-season moment; 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; Tt.vBMD: total volumetric bone mineral density; Tb.vBMD: trabecular volumetric bone mineral density; Tt.BMC: total bone mineral content; Ct.vBMD: cortical volumetric bone mineral density; Ct.Ar: cortical cross sectional area; Frc.LdX: fracture load (axe X); SSIp: polar strain index; *d*: Cohen`s *d*; η^2_p: partial eta square.

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

Cohen´s *d* can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8) and η^2_p can be small (0.01 – 0.06). medium (0.06 – 0.14) or large (>0.14).

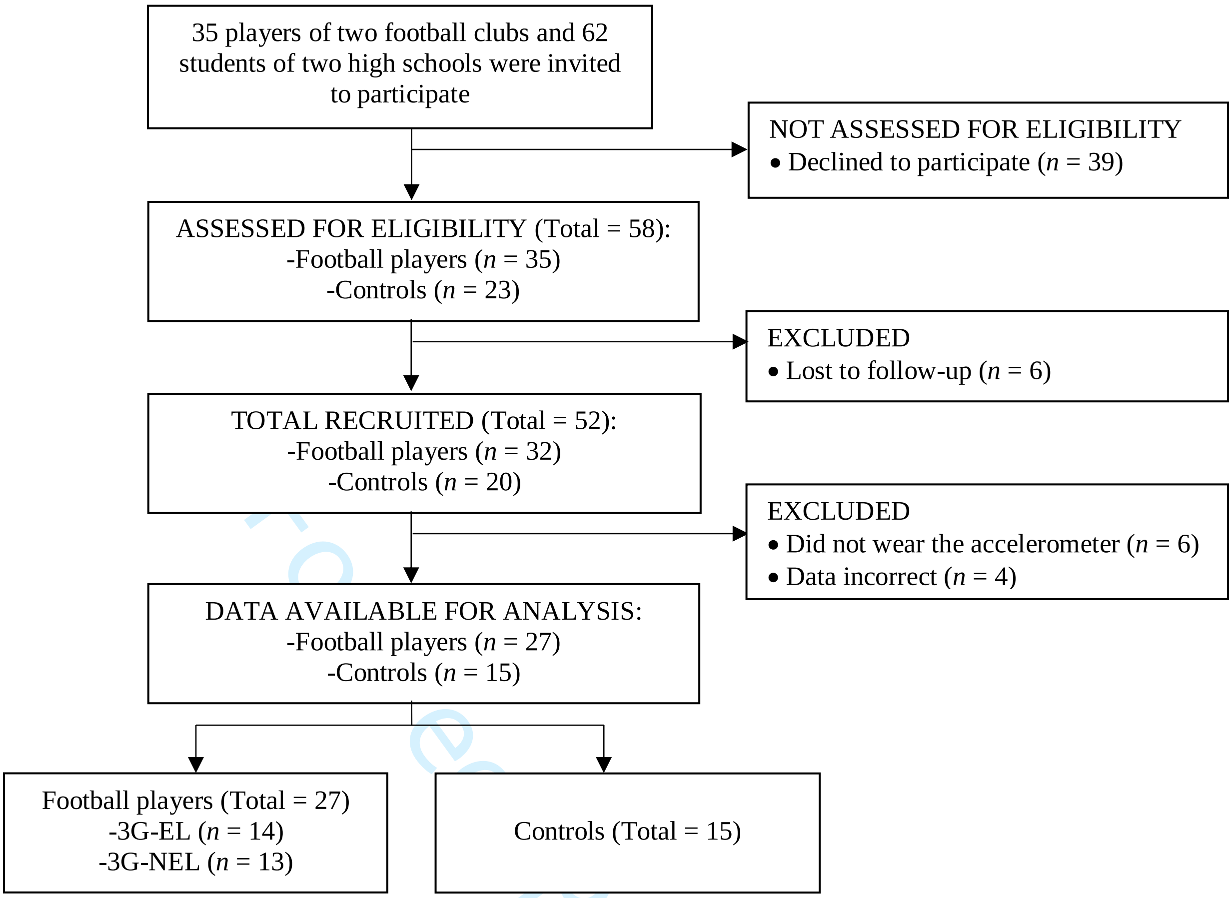
Table 3. Bone mineral content, density, strength and structure in football players who played in third-generation artificial turf with and without elastic layer.

					Repeated Measures		
					Within Group		Group by time
		3G-EL	3G-NEL		3G-EL	3G-NEL	
		N=14	N=13	*d*	η^2_p	η^2_p	η^2_p
DXA							
BMC (g)							
Subtotal body	T0	1334.216±305.267	1240.909±211.261	0.36			
	T1	1517.670±375.491	1413.341±278.067	0.32	0.674‡	0.629‡	0.004
Lumbar Spine	T0	38.72±9.76	38.14±6.22	0.07			
	T1	44.21±12.12	43.70±7.98	0.05	0.602‡	0.591‡	<0.001
aBMD (g/cm^2)							
Legs	T0	1.125±0.127	1.050±0.079	0.70			
	T1	1.198±0.150	1.130±0.100	0.53	0.549‡	0.572‡	0.005
BMAD (g/cm^3)							
Whole body	T0	0.093±0.004	0.094±0.006	0.20			
	T1	0.094±0.004	0.095±0.007	0.25	0.057	0.090	0.003
Lumbar Spine	T0	0.114±0.010	0.102±0.011§	1.12			
	T1	0.116±0.011	0.108±0.010§	0.80	0.203‡	0.553‡	0.169*
Femoral Neck	T0	0.195±0.018	0.173±0.012§	1.45			
	T1	0.195±0.021	0.177±0.013§	1.01	0.002	0.096‡	0.064
pQCT							
4% site							
Tt.vBMD (mg/cm^3)	T0	340.621±37.567	304.520±25.136§	1.13			
	T1	334.884±28.814	301.816±21.023§	1.31	0.109	0.025	0.016
Tb.vBMD (mg/cm^3)	T0	317.911±44.056	278.130±33.827§	1.01			
	T1	309.011±34.253	273.404±32.739§	1.06	0.112	0.032	0.013
38% site							
Tt.BMC (g)	T0	3.135±0.369	3.004±0.302	0.39			
	T1	3.349±0.441	3.153±0.334	0.50	0.683‡	0.494‡	0.086
Ct.vBMD (mg/cm^3)	T0	1053.591±29.836	1062.454±30.967	0.29			
	T1	1051.289±32.829	1059.696±23.984	0.29	0.017	0.023	<0.001
Ct.Ar (mm^2)	T0	398.911±46.288	384.539±41.377	0.33			
	T1	423.714±56.310	400.212±43.680	0.47	0.606‡	0.462‡	0.036
Ct.Th (mm)	T0	4.941±0.501	4.716±0.295	0.55			
	T1	5.122±0.476	4.903±0.326	0.54	0.383‡	0.384‡	<0.001
Frc.LdX (N)	T0	3210.438±553.960	3069.009±439.040	0.28			
	T1	3428.474±535.839	3198.564±473.699	0.46	0.432‡	0.199‡	0.057
SSIp (mm^3)	T0	1455.894±245.232	1362.122±207.083	0.41			
	T1	1544.487±224.998	1458.052±216.588	0.39	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; 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; Tt.vBMD: total volumetric bone mineral density; Tb.vBMD: trabecular volumetric bone mineral density; Tt.BMC: total bone mineral content; Ct.vBMD: cortical volumetric bone mineral density; Ct.Ar: cortical cross sectional area; Frc.LdX: fracture load (axe X); SSIp: polar strain index; *d*: Cohen`s *d*; η^2_p: partial eta square.

§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.

Cohen´s *d* can be small (0.2 – 0.5), medium (0.5 – 0.8) or large (>0.8) and η^2_p 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)

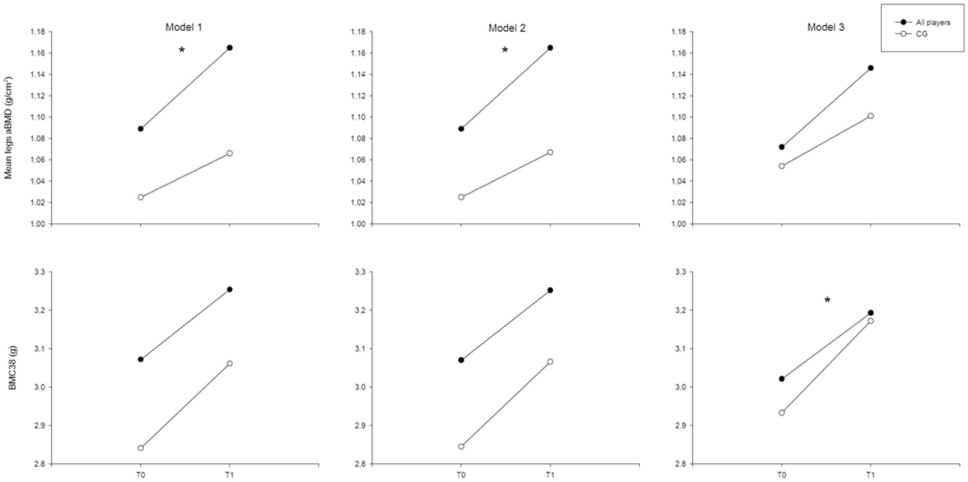


Figure 2 Legs aBMD and BMC38 interactions in football players and CG.
aBMD: areal bone mineral density; BMC38: total bone mineral content at the 38% of the length of the tibia; CG: control group; T0: pre-season moment; T1: post-season moment; Model 1: unadjusted data; Model 2: adjusted data by MVPA; 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)

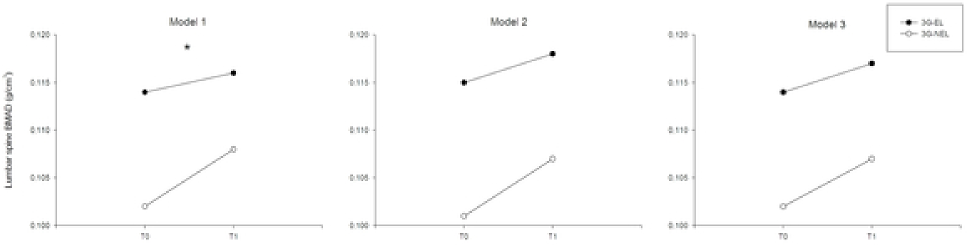


Figure 3 Lumbar spine BMAD interactions in football players.
BMAD: bone mineral apparent density; 3G-EL: football players who trained in third-generation artificial turf with elastic layer; 3G-NEL: football players who trained in third-generation artificial turf without elastic layer; T0: pre-season 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)