

Relationship between knee alignment in asymptomatic subjects and flexibility of the main muscles that are functionally related to the knee

Journal of International Medical Research

2018, Vol. 46(8) 3065–3077

© The Author(s) 2018

Article reuse guidelines:

sagepub.com/journals-permissions

DOI: 10.1177/0300060518771825

journals.sagepub.com/home/imr



María Orosia Lucha-López¹ ,
José Miguel Tricás-Moreno¹,
Elena Gaspar-Calvo¹,
Ana Carmen Lucha-López¹,
Concepción Vidal-Peracho^{2,3},
César Hidalgo-García¹,
Santos Caudevilla-Polo¹ and
Pablo Fanlo-Mazas¹

Abstract

Objective: To assess the relationship between static frontal knee alignment in asymptomatic subjects and flexibility of the main muscles functionally related to the knee.

Methods: A descriptive cross-sectional study was performed in 33 healthy adults (19–31 years). The frontal knee angle (valgus/varus angle) was measured by photogrammetry and it was measured in the lateral side. Therefore, high values were assigned for genu varum and low values for genu valgum. Iliopsoas, gluteus maximus and medius, rectus femoris, biceps femoris, vastus of the quadriceps, and gastrocnemius muscles were stretched. Muscles were classified as normal, reflex hypomobile, or structural hypomobile.

Results: Women had significantly greater valgus than did men (right angle, women: 174.41°/men: 177.41°; left angle, women: 174.20°/men: 178.70°). The right frontal plane knee angle was higher

³Physiotherapy Research Unit, University of Zaragoza, C/Domingo Miral s/n, Zaragoza, Spain

¹Faculty of Health Sciences, Physiotherapy Research Unit, University of Zaragoza, C/Domingo Miral s/n, Zaragoza, Spain

²Specialty Medical Center Grande Covián, SALUD, Avda. Alcalde Caballero Zaragoza, Spain

Corresponding author:

María Orosia Lucha-López, Faculty of Health Sciences, Physiotherapy Research Unit, University of Zaragoza, C/Domingo Miral s/n, 50009, Zaragoza, Spain.
Email: orolucha@unizar.es



in women with structural hypomobile vastus. The left frontal plane knee angle was higher in women with structural hypomobile iliopsoas. No relationships were found in men.

Conclusions: A tighter vastus of the quadriceps and tighter iliopsoas are related to greater genu varum in adult women. Stretching the vastus of the quadriceps and iliopsoas when there is a tendency for excess varus in the knee, to prevent overuse injury or early osteoarthritis, might be clinically relevant.

Keywords

Knee injury, osteoarthritis, genu varum, muscle stretching, physical therapy, quadriceps, iliopsoas

Date received: 26 June 2017; accepted: 27 March 2018

Introduction

Static knee alignment is determined by genetic, demographic, biomechanical, and activity-specific factors. Greater anterior pelvic tilt, thigh internal rotation, knee valgus, and genu recurvatum have been observed in women.^{1,2} Varus alignment is determined by the proximal tibia, and is probably due to adjustments in loads applied to the knees during skeletal growth. Varus alignment is associated with high-activity sports participation during youth in boys.³ Obesity is associated with greater valgus knee alignment in girls.⁴

Different neuromuscular characteristics (muscle activation, muscle strength, flexibility) may be associated with static knee alignment. Passive extensibility of aponeurotic and muscle tissue against stretching may be a muscular physical parameter that is related to static alignment of the body segments for static body posture, and scapular or shoulder alignment.⁵⁻¹² There is a lack of evidence on the manner in which static alignment of the knee can be affected by flexibility (or passive extensibility) of the main muscles that are functionally related to knee motion.

Correct alignment is a substantial factor affecting prevention of injury in sports and age-related joint pathologies. Static frontal

alignment of the lower limb, particularly that of the knee, is related to anterior cruciate ligament injury,¹³ meniscal tears,¹⁴ patellofemoral pain syndrome¹⁵ and adverse biomechanical stresses upon the cartilage.¹⁶ An increase in a valgus direction alignment is associated with a reduced risk of the presence of cartilage defects in the medial compartment of subjects with knee osteoarthritis and healthy subjects.¹⁷

To successfully maintain correct alignment in the knee, understanding the flexibility characteristics related to misalignment is important for helping clinicians identify which stretching or reinforcement training should be prescribed. Qualitative assessment of flexibility can be performed by stretching and taking into account the quality of tension at the end of range of motion (ROM). Manual assessment of the quality of movement at the end of ROM is called "end-feel". End-feel is the sensation imparted to the therapist's hand at the limit of the available ROM.¹⁸ End-feel is felt as the resistance at the end of ROM.¹⁹ When skeletal muscles are passively stretched, they exhibit evaluable resistance that depends on the size (mass) and length of muscle fibres, on the amount and arrangement of the connective tissues,²⁰ and on the muscle tone. The stiffness of

end-feel allows recording of muscle rigidity, taking into account the personal characteristics of the subject.²¹

This study aimed to examine the association between static frontal knee alignment in asymptomatic subjects and the quality of tension at the end of the ROM when stretching the main muscles that are functionally related to the knee.

Materials and methods

Participants

A non-experimental cross-sectional study was performed with a descriptive and comparative analysis. A sample of 33 European adults, with ages ranging from 19 to 31 years, was recruited from the university community in Zaragoza. Researchers performed presentations about the study to the university population. Simple random sampling was used to recruit subjects. Participants voluntarily accepted participation and they gave informed consent after receiving information on the study. Subjects had no previous or current serious pathological findings in the lower extremity that would have affected alignment, such as an unexplained raised temperature, swelling and redness of the knee joint (possible bacterial infection), unexplained severe pain in the hip, knee and/or ankle joint, swelling in the groin (possible malignancy), severe blocking of the knee joint, severe pain at rest and swelling,²² major trauma, previous surgery in the joints, and structural deformation.

Measures

Assessment of knee alignment by photogrammetry. Knee alignment was analysed using photographs. Photographic posture analysis is recommended because it is a reliable,²³ accurate, and objective method²⁴ compared with other methods, such as

X-rays.²⁵ The following points were selected and marked before taking photographs: malleolus, patella centre, centre of the lateral knee joint line, greater trochanter of the femur, and anterior superior iliac spine, as suggested in previous studies.^{2,25} Marker points were fixed onto the indicated anatomical reference points. The subjects were asked to stand in their habitual posture, look straight ahead, and keep their arms to the side of their body.

A camera (EOS 700D; Canon, Madrid, Spain) was placed 1.5 m away from the subjects on a tripod, at a height of 115 cm.²⁶ Two marks on the ground, with the profile of the heels, 10 cm apart, were marked for the subjects to stand. A measuring wall was used to calibrate the camera image on a horizontal plane.²⁷

Frontal knee alignment was studied based on the posture image of the knee frontal plane projection angle, which considers the position of the femur and the tibia.²⁸ The knee frontal plane projection angle was calculated as the angle (β) between the thigh segment and the shank segment (Figure 1).

Valgus was defined as knee adduction and varus was defined as knee abduction. Therefore, high values were assigned for genu varum and low values for genu valgum. The knee frontal plane projection angle (valgus/varus angle) was measured by a single examiner with free specific software to assist posture assessment from digitalized pictures (Postural Assessment Software [PAS]; School of Physical Education and Sports, University of São Paulo, São Paulo, Brazil). PAS is a reliable tool for postural analysis.²⁹ PAS, within the analysis menu, allows measurement of angles. The vertex of the angle was located in the midpoint of the patella. A line drawn from the midpoint of the patella to the anterior superior iliac spine was defined as the thigh segment. A line drawn from the midpoint of the patella to the midpoint

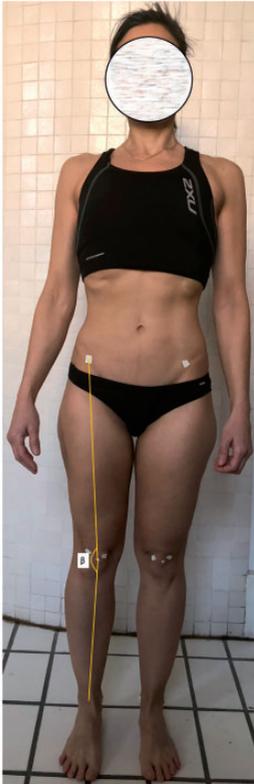


Figure 1. Knee frontal plane projection angle. Positions of markers are seen as white dots. The knee frontal plane projection angle was calculated as the angle (β) between the thigh segment and the shank segment.

between the malleoli was defined as the shank segment.³⁰

The angular parameters are expressed in degrees. Measurements were taken on both limbs. The intra-examiner reliability of the photography-based PAS method was determined with the intraclass correlation coefficient (ICC). Agreement between two repeated measures was almost perfect (ICC = 0.970 in the right limb and ICC = 0.984 in the left limb).

Assessment of length of the lower limbs by photogrammetry. Length of the lower limbs was evaluated with PAS software to assist

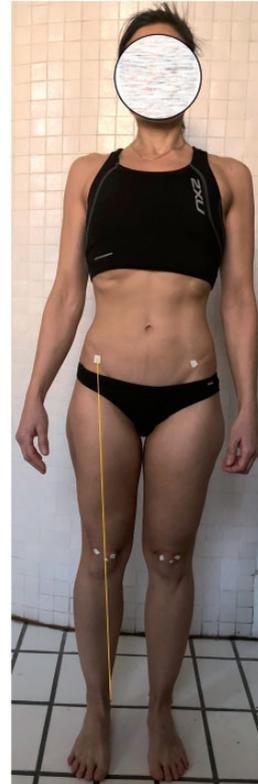


Figure 2. Photograph in the frontal view. Positions of markers are seen as white dots. The length of the lower limb was calculated as the length between the medial malleolus and the anterior superior iliac spine.

posture assessment from digitalized images. PAS, within the analysis menu, allows measurement of length. Methodology published by Milanese et al. in 2011³¹ was used as follows. The distance between the medial malleolus and the anterior superior iliac spine was measured for assessing the length of the lower limbs (Figure 2).

The intra-examiner reliability of the photography-based PAS method for length of the lower limbs was determined with the ICC. Agreement between two repeated measures was almost perfect (ICC = 0.988 in the right limb and ICC = 0.991 in the left limb).

Qualitative assessment of flexibility by end-feel of the stretching tests. In this study, two researchers stretched the muscles until the terminal ROM and/or in response to self-reporting by the subject that the movement was at the maximal end range.³² Researchers were trained physiotherapists in standardization of perception of muscle stretching end-feel. These researchers participated in a session where repeated measurements were performed by the same two examiners and correction was addressed to ensure consensus on the classification criteria. End-feel was classified in one of the three possible categories of normal, reflex hypomobile, or structural hypomobile.

Muscles with a functional relationship with the knee joint and with a larger anatomical cross-sectional area³³ were stretched. These muscles included the iliopsoas, gluteus maximus, gluteus medius, rectus femoris, biceps femoris, vastus of the quadriceps, and gastrocnemius, and were tested with muscle stretching tests by Professor Olaf Evjenth's methodology³⁴ (Figure 3).

Assessment was performed on both limbs. End-feel was perceived at the limit of the available ROM where the researcher's hand performed stretching of the muscle.¹⁸

Procedure

Demographics, clinical history, and outcome measures were collected for each subject in the Faculty of Health Sciences and all measurement procedures were carried out in the same session. Photographs were taken first, and immediately after stretching, tests were accomplished. Before participation, subjects gave informed consent and they were told that they could leave the study at any time and for any reason. The study, which complied with the ethical requirements of the Declaration of Helsinki, was approved by the

Department of Physiotherapy and Nursing institutional board.

Statistical analysis

Data were analysed with IBM SPSS Statistics, version 22.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set as two-sided $p \leq 0.05$. Initial analyses included descriptive statistics of frontal knee angles consisting of means and 95% confidence intervals (CIs). The Kolmogorov–Smirnov test ($n > 30$) was performed to study the distribution of the data. The independent samples Student's *t* test was used to compare the frontal angle between women and men.

We compared the frontal knee angle between end-feel categories with analysis of variance (ANOVA) separately for women and men. The independent variable was end-feel classification. The dependent variables were right and left frontal knee angles. Therefore, end-feel classification of the stretching test of iliopsoas, gluteus maximus, gluteus medius, rectus femoris, biceps femoris, vastus of the quadriceps, and gastrocnemius muscles as independent variables generated seven ANOVA models for the right knee and seven for the left knee. Post-hoc pairwise comparisons were performed using Fisher's test.

For each of the end-feel classifications that showed significant differences in ANOVA analysis, a multivariable analysis of covariance (ANCOVA) model was used. The dependent variables were right and left frontal knee angles. The independent variable was end-feel classification. Differences in length between the lower limbs and age were included as covariates.

Cohen's *d* was used to calculate effect size between means with statistical significant differences. Effect sizes were classified as small (0.2–0.5), medium (0.6–0.8), and large (≥ 0.8).³⁵

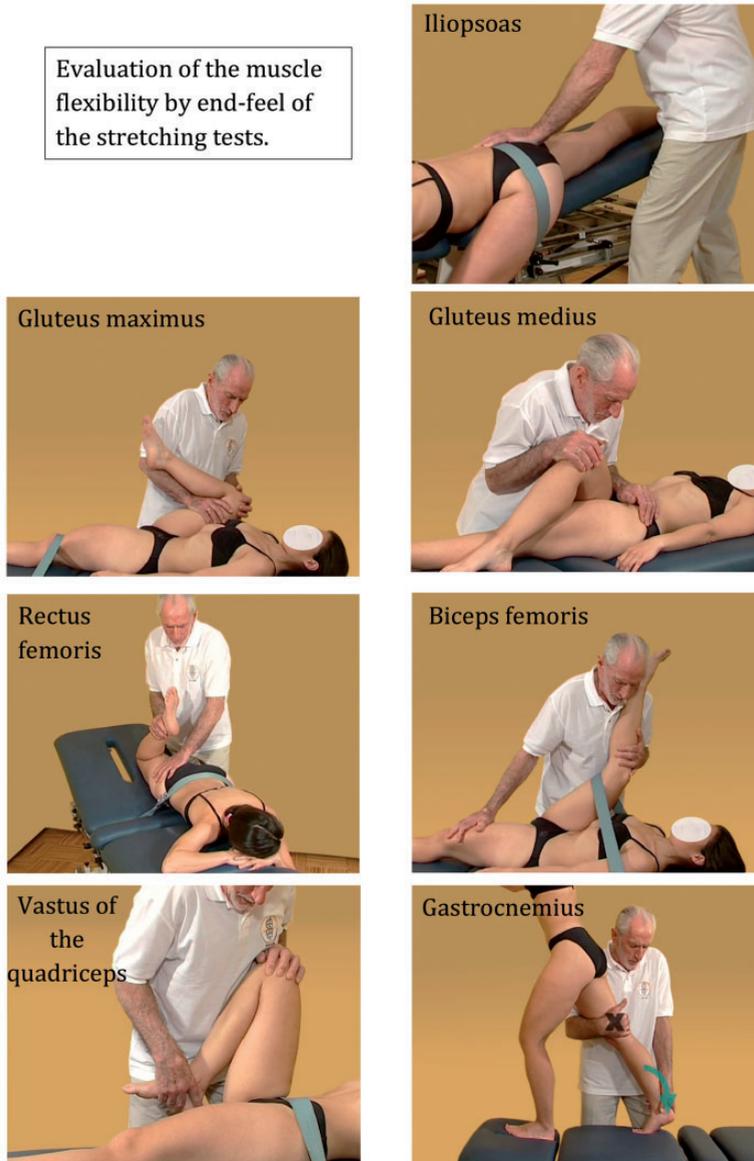


Figure 3. Stretching tests by Professor Olaf Evjenth
Qualitative assessment of flexibility by classifying end-feel at the end of the muscle length.

Results

Thirty-three subjects agreed to participate in the study. There were 11 men and 22 women. When analysing all subjects, the mean (\pm SD) age was 22.33 ± 3.62 years.

The mean age of men was 23.82 ± 4.14 years and that of women was 21.59 ± 3.17 years ($p = 0.076$). Information on the measures of knee alignment is shown in Table 1. We found that women had significantly lower frontal angles (more valgus) in the

Table 1. Frontal plane knee angles.

| | n | Mean | 95% CI | Sex | n | Mean | 95% CI | p |
|------------------------------------|----|---------|-----------------------|-------|----|---------|--------------------|--------|
| Frontal plane knee angle: right | 33 | 175.41° | 174.25° to 176.57° | Women | 22 | 174.41° | 173.17° to 175.65° | 0.011 |
| | | | | Men | 11 | 177.41° | 175.16° to 179.66° | |
| Frontal plane knee angle: left | 33 | 175.69° | 174.55° to 176.84° | Women | 22 | 174.20° | 173.09° to 175.30° | <0.001 |
| | | | | Men | 11 | 178.70° | 177.14° to 180.24° | |

CI: confidence interval.

right and left knees than did men ($p = 0.011$ and $p < 0.001$, respectively, Table 1).

Women

In the right limb, when the independent variable was end-feel of the vastus of the quadriceps stretching test, the proportion of structural hypomobile end-feel was significantly higher than that of normal end-feel ($p = 0.022$) (Table 2). The effect size (using Cohen's d) was medium (0.67). In ANCOVA, one significant factor of the difference between normal and structural end-feel of the vastus ($p = 0.049$) was retained. Neither the covariate of age nor the difference in length between the lower limbs was retained.

In the left limb, the proportion of structural hypomobile iliopsoas was significantly higher than that of normal iliopsoas ($p = 0.017$) (Table 2). Cohen's d value was 1.9 and the effect size was medium (0.69). ANCOVA retained one significant factor of the difference between normal and structural end-feel of the iliopsoas ($p = 0.027$) and one covariate of age ($p = 0.048$).

Men

Frontal knee angles were not significantly different among the end-feel categories in any of the muscles (Table 3).

Discussion

Our study showed that women had greater valgus than did men. A more firm end-feel

against stretching of the vastus of the quadriceps was related to a higher angle in the right limb in women. A more firm end-feel against stretching of the iliopsoas was related to a higher angle in the left limb in women. No other relationships were observed between the end-feel of muscle stretching tests and the angles of knee alignment. These relationships were maintained, regardless of age and difference in length of the lower limbs.

Our finding that women had greater valgus than did men is consistent with the finding of differences in knee alignment between men and women shown by Nguyen in 2007.² Although these sex differences are not entirely understood, they may be developmental and related to changes occurring during puberty.³⁶ Limb length discrepancy may be potentially associated with compensation at the knee frontal angle,³⁷ but we did not find any such association in our sample. No other previous studies have clarified parameters that would determine this relationship.

Previous studies have investigated the association between proximal stabilization of the lower limbs with knee alignment.³⁸ Women show more associated movement into knee valgus and hip internal rotation compared with men.³⁹ These motions might be able to be controlled with the proximal muscle groups that are antagonistic to these movement tendencies (iliopsoas, as a hip external rotator, to control hip internal rotation). In the present study, women showed this motor pattern as a stiffer

Table 2. Mean frontal plane knee angle values in the different categories of muscle end-feel in women.

| | Right frontal plane knee angle | | | Left frontal plane knee angle | | |
|---------------------------------|--------------------------------|----------|---------|-------------------------------|----------|---------|
| | Percentage of category | Mean (°) | p value | Percentage of category | Mean (°) | p value |
| Iliopsoas | | | | | | |
| Normal | 22.70% | 173.1 | 0.251 | 22.70% | 171.9 | 0.017* |
| Reflex hypo | 0.00% | | | 0.00% | | |
| Structural hypo | 77.30% | 174.8 | | 77.30% | 174.9 | |
| Gluteus maximus | | | | | | |
| Normal | 63.60% | 174.5 | 0.676 | 68.20% | 174.4 | 0.614 |
| Reflex hypo | 31.80% | 173.9 | | 22.70% | 173.2 | |
| Structural hypo | 4.50% | 176.6 | | 9.10% | 175 | |
| Gluteus medius | | | | | | |
| Normal | 45.50% | 174 | 0.739 | 47.60% | 174.3 | 0.753 |
| Reflex hypo | 31.80% | 174.5 | | 33.30% | 174 | |
| Structural hypo | 22.70% | 175.2 | | 19.00% | 175.2 | |
| Biceps femoris | | | | | | |
| Normal | 9.10% | 175.1 | 0.94 | 9.10% | 175.9 | 0.635 |
| Reflex hypo | 50.00% | 174.3 | | 50.00% | 174 | |
| Structural hypo | 40.90% | 174.4 | | 40.90% | 174.1 | |
| Vastus of the quadriceps | | | | | | |
| Normal | 33.30% | 172.7 | 0.022* | 33.30% | 173.6 | 0.576 |
| Reflex hypo | 23.80% | 174.2 | | 23.80% | 173.7 | |
| Structural hypo | 42.90% | 176 | | 42.90% | 174.9 | |
| Rectus femoris | | | | | | |
| Normal | 0.00% | | 0.7 | 0.00% | | 0.313 |
| Reflex hypo | 31.80% | 174.8 | | 31.80% | 175 | |
| Structural hypo | 68.20% | 174.2 | | 68.20% | 173.8 | |
| Gastrocnemius | | | | | | |
| Normal | 36.40% | 174.9 | 0.807 | 36.40% | 174.5 | 0.942 |
| Reflex hypo | 36.40% | 174.2 | | 36.40% | 174.1 | |
| Structural hypo | 27.30% | 174 | | 27.30% | 174 | |

*Significant p value by analysis of variance.

Hypo: hypomobile.

iliopsoas muscle related to less genu valgum in the left limb.

Age has little effect on axial alignment of the knee in healthy subjects.⁴⁰ However, age-related tensile strength of cartilage loss⁴¹ and increased stress on articular cartilage and the subchondral bone due to malalignment⁴² may play an important role in progression of malalignment with age. We found a small influence of age on the increase in the varus angle in the left limb in women, but this was probably

only due to the youth and healthy condition of the sample. The importance of the quadriceps on knee alignment was shown in a recent study.⁴³ By mathematical modelling, this recent study showed that the vector of quadriceps function may be a guide for kinematic alignment in total knee arthroplasty.

The higher frontal angle found our study, which was related to a more firm end-feel in the right stretching test of the vastus of the quadriceps in women, may

Table 3. Mean frontal plane knee angle values in the different categories of muscle end-feel in men.

| | Right frontal plane knee angle | | | Left frontal plane knee angle | | |
|---------------------------------|--------------------------------|----------|---------|-------------------------------|----------|---------|
| | Percentage of category | Mean (°) | p value | Percentage of category | Mean (°) | p value |
| Iliopsoas | | | | | | |
| Normal | 18.20% | 176.4 | 0.662 | 18.20% | 178 | 0.641 |
| Reflex hypo | 0.00% | | | 0.00% | | |
| Structural hypo | 81.80% | 177.6 | | 81.80% | 178.9 | |
| Gluteus maximus | | | | | | |
| Normal | 70.00% | 178.4 | 0.499 | 70.00% | 178.9 | 0.885 |
| Reflex hypo | 0.00% | | | 0.00% | | |
| Structural hypo | 30.00% | 176.9 | | 30.00% | 179.2 | |
| Gluteus medius | | | | | | |
| Normal | 27.30% | 176.6 | 0.715 | 18.20% | 176.5 | 0.356 |
| Reflex hypo | 27.30% | 178.9 | | 27.30% | 179.5 | |
| Structural hypo | 45.50% | 177 | | 54.50% | 179 | |
| Biceps femoris | | | | | | |
| Normal | 9.10% | 175.5 | 0.17 | 9.10% | 174.6 | 0.1 |
| Reflex hypo | 18.20% | 181.4 | | 18.20% | 180.5 | |
| Structural hypo | 72.70% | 176.7 | | 72.70% | 178.8 | |
| Vastus of the quadriceps | | | | | | |
| Normal | 9.10% | 175.5 | 0.586 | 9.10% | 174.6 | 0.151 |
| Reflex hypo | 9.10% | 180.6 | | 9.10% | 180.3 | |
| Structural hypo | 81.80% | 177.3 | | 81.80% | 179 | |
| Rectus femoris | | | | | | |
| Normal | 0.00% | | 0.782 | 0.00% | | 0.429 |
| Reflex hypo | 18.20% | 178.1 | | 18.20% | 177.5 | |
| Structural hypo | 81.80% | 177.3 | | 81.80% | 179 | |
| Gastrocnemius | | | | | | |
| Normal | 54.50% | 176.9 | 0.868 | 54.50% | 179.1 | 0.582 |
| Reflex hypo | 36.40% | 178 | | 45.50% | 178.2 | |
| Structural hypo | 9.10% | 178.2 | | 0.00% | | |

p values were obtained by analysis of variance.

Hypo: hypomobile.

have been affected mainly by the vastus medialis. Park et al.⁴⁴⁻⁴⁶ found predominance in vastus medialis function in subjects with genu varum. Further research should attempt to differentiate the end-feel coming from each of the vastus of the quadriceps to determine the relative importance of each of them in alignment.

Asymmetrical neuromuscular function has been found between the non-dominant lower limb and dominant lower limb, and also between antagonist movements as

flexion and extension of the knee within the same limb.⁴⁷ This is caused by preferences of use for different functions on each side. This asymmetry in neuromuscular parameters supports our finding that different muscles were related to alignment in the frontal plane of the knee on each side of the body. However, further studies are required to clarify this issue.

Preventive neuromuscular function⁴⁸ might be associated with spontaneous motor unit discharges related to reflex

hypomobile end-feel. We did not find a relation between reflex hypomobile end-feel and knee alignment. This lack of finding could be because this increased firing rate is a protective response of the muscle, but its effect over time is not as constant as that of structural hypomobility.

Our results support the clinical importance of maintaining adequate flexibility in the quadriceps and iliopsoas muscles to maintain physiological knee alignment. A clinical recommendation that may be drawn from our study is to stretch the vastus of the quadriceps and iliopsoas when there is a tendency for excess varus in the knee. This may have implications in clinical and performance settings to prevent clinical situations, such as overuse injury,⁴⁹ chronic knee pain,⁵⁰ or early osteoarthritis.⁵¹

A limitation of this study is that we lacked data from the tensor fasciae latae muscle. A recent study showed that an increase in iliotibial band load, assumed to transmit tensor fasciae latae and gluteus maximus strength, could increase valgus when tested in a non-weight-bearing condition in a cadaveric model.⁵² A major limitation of this study is the relatively small sample size, which is too limited for broad generalization. Although no effects of muscle tension were detected in men, the sample size was probably insufficient to detect such relationships.

Although previous studies classified dysfunction according to the perceived end-feel at the end of the ROM,⁵³ this could be a subjective method. In experiments in humans, more objective methodologies have been used in the literature to quantify the relationship of tension-length of a muscle, such as passive torque joint angle measurements or ultrasound shear wave elastography.⁵⁴ Although these methods are undoubtedly more objective, providing a clinical interpretation for the data obtained is difficult. Objective data showing similar tension could be considered normal

for a person with high muscle fibre density and could be considered hypomobile for a person with an elevation of tension secondary to intramuscular contracture. Therefore, although considering the limitations of our results, we consider that our research might be a useful for clinical management of the effect of muscle tension on postural alterations, and it might be fundamental for future research.

In conclusion, tighter vastus of the quadriceps in the right limb and tighter iliopsoas in the left limb in healthy, young, adult women are related to more genu varum.

Authors' contributions

JMTM and CVP contributed to the conception and design of the work, conceived and coordinated the broader study under which this project was undertaken, reviewed and greatly contributed to the interpretation of results, and revised the manuscript critically for important intellectual content. MOLL, EGC, and ACLL, organized the sample collection and data preparation, performed data collection, performed statistical analyses, and wrote the first draft of the manuscript. CHG organized data preparation and revised the manuscript critically for important intellectual content. SCP and PFM revised the manuscript for important intellectual content and checked the statistical analysis. All authors actively discussed the manuscript, critically reviewed its comprehensive content, and finally approved the version to be submitted for publication.

Acknowledgements

We wish to acknowledge the extensive help of the volunteers, without whom the present registry would not have been possible. The study was supported by materials from the Physiotherapy Research Unit, Faculty of Health Sciences - University of Zaragoza. We thank our mentor in stretching techniques, Professor Olaf Evjenth, for his lifelong efforts dedicated to the development of training for maintaining health.

Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Availability of data and material

The datasets generated during and/or analysed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

ORCID iD

María Orosia Lucha-López  <http://orcid.org/0000-0002-9930-3903>

References

1. Weltin E, Mornieux G and Gollhofer A. Influence of gender on trunk and lower limb biomechanics during lateral movements. *Res Sports Med* 2015; 23: 265–277.
2. Nguyen A and Shultz SJ. Sex differences in clinical measures of lower extremity alignment. *J Orthop Sports Phys Ther* 2007; 37: 389–398.
3. Colyn W, Agricola R, Arnout N, et al. How does lower leg alignment differ between soccer players, other athletes, and non-athletic controls? *Knee Surg Sports Traumatol Arthrosc* 2016; 24: 3619–3626.
4. Bout-Tabaku S, Shults J, Zemel BS, et al. Obesity is associated with greater valgus knee alignment in pubertal children, and higher body mass index is associated with greater variability in knee alignment in girls. *J Rheumatol* 2015; 42: 126–133.
5. Scarr G. Helical tensegrity as a structural mechanism in human anatomy. *Int J Osteopath Med* 2011; 14: 24–32.
6. Li F. Transforming traditional Tai Ji Quan techniques into integrative movement therapy—Tai Ji Quan: Moving for Better Balance. *J Sport Health Sci* 2014; 3: 9–15.
7. Liu J, Li B and Shnider R. Effects of TAI CHI training on improving physical function in patients with coronary heart diseases. *J Exerc Sci Fit* 2010; 8: 78–84.
8. Kluemper M, Uhl T and Hazelrigg H. Effect of stretching and strengthening shoulder muscles on forward shoulder posture in competitive swimmers. *J Sport Rehab* 2006; 15: 58–70.
9. Yoo W. Effect of thoracic stretching, thoracic extension exercise and exercises for cervical and scapular posture on thoracic kyphosis angle and upper thoracic pain. *J Phys Ther Sci* 2013; 25: 1509–1510.
10. Lee J, Cynn H, Yoon T, et al. The effect of scapular posterior tilt exercise, pectoralis minor stretching, and shoulder brace on scapular alignment and muscles activity in subjects with round-shoulder posture. *J Electromyogr Kinesiol* 2015; 25: 107–114.
11. Corrêa ECR and Bérzin F. Efficacy of physical therapy on cervical muscle activity and on body posture in school-age mouth breathing children. *Int J Pediatr Otorhinolaryngol* 2007; 71: 1527–1535.
12. Wyszyńska J, Podgórska-Bednarz J, Drzał-Grabiec J, et al. Analysis of relationship between the body mass composition and physical activity with body posture in children. *Biomed Res Int* 2016; 2016: 1851670.
13. Nguyen A, Shultz SJ and Schmitz RJ. Landing biomechanics in participants with different static lower extremity alignment profiles. *J Athl Train* 2015; 50: 498–507.
14. Englund M, Guermazi A, Gale D, et al. Incidental meniscal findings on knee MRI in middle-aged and elderly persons. *N Engl J Med* 2008; 359: 1108–1115.
15. Lun V, Meeuwisse WH, Stergiou P, et al. Relation between running injury and static lower limb alignment in recreational runners. *Br J Sports Med* 2004; 38: 576–580.
16. Sharma L, Chmiel JS, Almagor O, et al. The role of varus and valgus alignment in the initial development of knee cartilage damage by MRI: the MOST study. *Ann Rheum Dis* 2013; 72: 235–240.
17. Janakiraman N, Teichtahl AJ, Wluka AE, et al. Static knee alignment is associated with the risk of unicompartmental knee cartilage defects. *J Orthop Res* 2008; 26: 225–230.

18. Kaltenborn FM, Evjenth O, Kaltenborn TB, et al. *Manual Mobilization of the Joints. Joint Examination and Basic Treatment. Volume I. The extremities.* 8 ed. Oslo, Norway: Norli, 2014.
19. Lakhani E, Nook B, Haas M, et al. Motion palpation used as a postmanipulation assessment tool for monitoring end-feel improvement: a randomized controlled trial of test responsiveness. *J Manipulative Physiol Ther* 2009; 32: 549–555.
20. Gajdosik RL. Passive extensibility of skeletal muscle: review of the literature with clinical implications. *Clin Biomech* 2001; 16: 87–101.
21. Zito G, Jull G and Story I. Clinical tests of musculoskeletal dysfunction in the diagnosis of cervicogenic headache. *Man Ther* 2006; 11: 118–129.
22. Peter WF, Jansen MJ, Hurkmans EJ, et al. Physiotherapy in hip and knee osteoarthritis: development of a practice guideline concerning initial assessment, treatment and evaluation. *Acta Reumatol Port* 2011; 36: 268–281.
23. Zonnenberg A, Maanen CV, Oostendorp R, et al. Intra/interrater reliability of measurements on body posture photographs. *Cranio* 1996; 14: 326–331.
24. Hazar Z, Karabicak GO and Tiftikci U. Reliability of photographic posture analysis of adolescents. *J Phys Ther Sci* 2015; 27: 3123–3126.
25. do Rosário, José Luís Pimentel. Photographic analysis of human posture: a literature review. *J Bodyw Mov Ther* 2014; 18: 56–61.
26. Paušić J, Pedišić Ž and Dizdar D. Reliability of a photographic method for assessing standing posture of elementary school students. *J Manipulative Physiol Ther* 2010; 33: 425–431.
27. Ludwig O, Mazet C, Mazet D, et al. Changes in habitual and active sagittal posture in children and adolescents with and without visual input—implications for diagnostic analysis of posture. *J Clin Diagn Res* 2016; 10: SC14.
28. Scholtes SA and Salsich GB. A dynamic valgus index that combines hip and knee angles: assessment of utility in females with patellofemoral pain. *Int J Sports Phys Ther* 2017; 12: 333.
29. Ruivo R, Pezarat-Correia P, Carita A, et al. Reliability and validity of angular measures through the software for postural assessment. *Postural Assessment Software. Rehabilitación* 2013; 47: 223–228.
30. Oginni LM, Badru OS, Sharp CA, et al. Knee angles and rickets in Nigerian children. *J Pediatr Orthop* 2004; 24: 403–407.
31. Milanese JM, Borin G, Corrêa ECR, et al. Impact of the mouth breathing occurred during childhood in the adult age: Biophotogrammetric postural analysis. *Int J Pediatr Otorhinolaryngol* 2011; 75: 999–1004.
32. Simpson C, Arefin S, Smart R, et al. Duration of fascicle shortening is affected by muscle architecture and sex. *Eur J Appl Physiol* 2016; 116: 2237–2245.
33. Koo TK and Hug F. Factors that influence muscle shear modulus during passive stretch. *J Biomech* 2015; 48: 3539–3542.
34. Tricás JM, Evjenth O, Lucha MO, et al. *Estiramiento y autoestiramiento muscular en fisioterapia OMT.* 1a ed. Zaragoza: OMT-España, 2012.
35. Sullivan GM and Feinn R. Using effect size—or why the P value is not enough. *J Grad Med Educ* 2012; 4: 279–282.
36. Cahuzac JP, Vardon D and Sales de Gauzy J. Development of the clinical tibiofemoral angle in normal adolescents. A study of 427 normal subjects from 10 to 16 years of age. *J Bone Joint Surg Br* 1995; 77: 729–732.
37. Lioudakis E, Kenaway M, Doxastaki I, et al. Upright MRI measurement of mechanical axis and frontal plane alignment as a new technique: a comparative study with weight bearing full length radiographs. *Skeletal Radiol* 2011; 40: 885–889.
38. Avraham F, Aviv S, Ya'akobi P, et al. The efficacy of treatment of different intervention programs for patellofemoral pain syndrome—a single blinded randomized clinical trial. Pilot study. *Scientific World Journal* 2007; 7: 1256–1262.
39. Ireland ML, Willson JD, Ballantyne BT, et al. Hip strength in females with and without patellofemoral pain. *J Orthop Sports Phys Ther* 2003; 33: 671–676.

40. Hsu RW, Himeno S, Coventry MB, et al. Normal axial alignment of the lower extremity and load-bearing distribution at the knee. *Clin Orthop* 1990; 255: 215–227.
41. Kempson GE. Relationship between the tensile properties of articular cartilage from the human knee and age. *Ann Rheum Dis* 1982; 41: 508–511.
42. Eckstein F, Wirth W, Hudelmaier M, et al. Patterns of femorotibial cartilage loss in knees with neutral, varus, and valgus alignment. *Arthritis Rheum* 2008; 59: 1563–1570.
43. Mochizuki T, Blaha JD, Tanifuji O, et al. The quadriceps vector is most parallel to the spherical axis with minimal difference for gender or ethnicity. *J Arthroplasty* 2016; 31: 2031–2037.
44. Park S, Ko Y, Jang G, et al. A study on the differences of quadriceps femoris activities by knee alignment during isometric contraction. *J Phys Ther Sci* 2014; 26: 1685–1688.
45. Park S, Chung J, Kong Y, et al. Differences in onset time between the vastus medialis and lateralis during stair stepping in individuals with genu varum or valgum. *J Phys Ther Sci* 2015; 27: 2727–2730.
46. Park S, Kong Y, Ko Y, et al. Differences in onset timing between the vastus medialis and lateralis during concentric knee contraction in individuals with genu varum or valgum. *J Phys Ther Sci* 2015; 27: 1207–1210.
47. Lanshammar K and Ribom EL. Differences in muscle strength in dominant and non-dominant leg in females aged 20–39 years—A population-based study. *Phys Ther Sport* 2011; 12: 76–79.
48. Falla D and Farina D. Neural and muscular factors associated with motor impairment in neck pain. *Curr Rheumatol Rep* 2007; 9: 497–502.
49. Krivickas LS. Anatomical factors associated with overuse sports injuries. *Sports Medicine* 1997; 24: 132–146.
50. Uota S, Nguyen A, Aminaka N, et al. Relationship of knee motions with static leg alignments and hip motions in frontal and transverse planes during double-leg landing in healthy athletes. *J Sport Rehabil* 2016; 26: 396–405.
51. Heijink A, Gomoll AH, Madry H, et al. Biomechanical considerations in the pathogenesis of osteoarthritis of the knee. *Knee Surg Sports Traumatol Arthrosc* 2012; 20: 423–435.
52. Gadikota HR, Kikuta S, Qi W, et al. Effect of increased iliotibial band load on tibiofemoral kinematics and force distributions: a direct measurement in cadaveric knees. *J Orthop Sports Phys Ther* 2013; 43: 478–485.
53. Niere KR and Torney SK. Clinicians' perceptions of minor cervical instability. *Man Ther* 2004; 9: 144–150.
54. Miyamoto N, Hirata K, Kanehisa H. Effects of hamstring stretching on passive muscle stiffness vary between hip flexion and knee extension maneuvers. *Scandinavian Journal of Medicine & Science in Sports* 2017; 27: 99–106.