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Is spinopelvic sagittal alignment correlated with pain level, functional disability and frontal plane projection angle in women with patellofemoral pain syndrome? A cross-sectional study

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ABSTRACT

There is a growing interest concerning the understanding of measurements of spinal and leg alignment in patients with patellofemoral pain syndrome (PFPS). However, evaluating spinopelvic alignment in the sagittal plane with pain level, functional disability and frontal plane projection angle (FPPA) in PFPS has not been adequately addressed. The aim of the study was to identify the correlation of spinopelvic parameters with pain level, functional disability and frontal plane projection angle in women with PFPS. This was a cross–sectional study involving sixty female patients diagnosed with PEPS, with a mean age of 32±6.47. The measurements used in the study included: radiographic parameters (X-Ray), the numeric pain rating scale (NPRS), the Arabic anterior knee pain scale (AAKP/Kujala) and the 2D-FPPA. Spearman correlation analysis was conducted to evaluate the relationship between these parameters. The results of our study demonstrated a strong positive correlation of lumbar lordosis (LL) with pain level and FPPA (r=0.825, r=0.812, p=0.0001). Also, a strong positive correlation of sacral slope (SS) with pain level

(r = 0.0.820) and FPPA (r= 0.783). Pelvic tilt (PT) showed a moderate correlation with pain level (r = 0.0.614) and FPPA (r= 0.605), while a weak negative correlation was found between LL, SS and PT and functional disability score (r=-0.397, r=-0.385 and, r=-0.215 p=0.002). It was concluded that LL, SS and PT were significantly related to the pain level, functional disability and frontal plane projection angle in women with PFPS. These spinal alignments should be considered in clinical evaluation of knee-related disorders associated with PFPS.

KEYWORDS

Lumbar Spine; Sacral Slope; Anterior Knee Pain; Frontal Plane Projection Angle; Patellofemoral Pain Syndrome.

1. INTRODUCTION

Patellofemoral pain syndrome (PFPS) is extensively used to designate pain conditions localized at the patellofemoral compartment (Collins et al., 2018). It is described as anterior knee pain non-related to trauma and associated with overload activities including stairs climbing and descending, squatting and long period of sitting (Crossley et al., 2016). An estimated 20% to 40% of physical therapy visits are related to knee conditions (Earl & Hoch, 2011).

PFPS is thought to affect the general population (Brechter & Powers, 2002). However, a higher prevalence of women compared to men has been recorded and estimated to be 2 to 3 times higher. This prevalence rate has been correlated to anatomical and biomechanical gender differences making females more liable to suffer from PFPS (Rathleff, Rathleff, Olesen, Rasmussen & Roos, 2016).

In 2007, a concept named regional interdependence has been introduced in order to explain many musculoskeletal pain syndromes. This concept considers that many musculoskeletal complaints are sometimes correlated to remote anatomical disturbances and consequently any intervention approach must address such symptom free remote areas in order to attain treatment goals (Wainner, Whitman, Cleland & Flynn, 2007).

Many research reports have suggested that knee conditions, particularly PFPS, might be caused by disorders that are more proximal. In females, it has been reported that women suffering from PFPS had weak hip muscles (Powers, 2010). Others correlated PFPS in females with impaired control of femoral rotation when compared to asymptomatic age matched individuals (Powers, 2003).

Recently, increasing reports have been published verifying interactions between knee, hip, and spine and the main emphasis was on compensatory mechanisms between studied regions.

Particularly, a compensatory pelvis change in position has been identified and correlated to deviations in the spinal alignment. More specifically, increase in lumbar lordosis produces anterior pelvic tilt and increase in the kyphotic angles at the thoracic level. In contrast, lumbar lordosis decrease has been associated with posterior pelvic tilt and knee flexion (Oshima et al., 2019). These observations have led to a conclusion that pelvis plays a compensatory and regulator role between the spine and the lower limbs (Iyer et al., 2018).

More recently, it was found that patients with PFPS, hip abductor weakness and lumbar hyperlordosis, lead to a change in the mechanical advantage of hip abductor into internal rotator that aggravates symptoms of patellofemoral pain syndrome, so we assumed that may increase the frontal plane projection angle (Stephen, Ephgrave, Ball & Church, 2020).

Many authors tried to uncover the association between spinopelvic alignment and lower limbs, together with the sagittal alignment of the knee (Murata, Takahashi, Yamagata, Hanaoka & Moriya, 2003; Tsuji et al., 2002). More recently, a study concluded poor lumbo-pelvic alignment in the sagittal plane in older adult women diagnosed with severe knee osteoarthritis (Yasuda et al., 2020).

From the available literature, and to our knowledge, it appears that there are few studies that investigated the correlation between the spinopelvic alignment in the sagittal plane with pain level, functional disability and the frontal plane projection angle (FPPA) in patients with patellofemoral pain syndrome. The purpose of this study is to investigate if there is any association between spinal measurements (lumbar lordosis, sacral slope and pelvic tilt) with pain level, functional disability and FPPA in women with PFPS.

2. METHODS

2.1. Study Design and Participants

This was a cross-sectional case-control study involving 60 women between 18 to 35 years old who were referred by an orthopedist as suffering from PFPS. All participants were oriented about all study procedures and steps, and were asked to sign a written informed consent before being enrolled in the study. The study was conducted in the orthopedic physical therapy clinics at the Faculty of Physical Therapy, Cairo University, Egypt, from September 1, 2019, to January 1, 2021, and it abided to the ethical considerations according to the declaration of Helsinki for human research and

approved by the institutional review board of the Faculty of Physical Therapy (No: P.T.REC/012/002371).

Participants were chosen females between 18 and 38 years old to limit the possibility that PFPS over age 38 could be complicated by arthritic changes, and to ensure that they had closed epiphyseal growth plates (Robinson & Smyth, 2007). Clinically, participants were chosen with patellofemoral pain during the previous week with minimum score of 3 on an 10-point numerical pain scale (NPR) (Bolgla, Malone, Umberger, & Uhl, 2008). They were referred from an orthopedic clinic confirming a history of anterior or retropatellar knee pain that was aggravated by at least 2 of the following functional activities**:** 1. prolonged sitting, 2. stairs use, 3. squatting, 4. running, 5. kneeling, 6. hopping/jumping**,** and/or insidious onset of symptoms unrelated to any traumatic incident and persistent for at least 6 weeks.

Participants were excluded if they reported any of the following conditions: body mass index (BMI) greater than 30 kg/m^2, history of patellar dislocation or subluxation, osteoarthritis in the patellofemoral joint, meniscal or other intraarticular pathologic conditions, cruciate or collateral ligament involvement, lower limb surgery, fracture, low back pain condition e.g. spondylolisthesis and spondylosis or neurological deficits, and/or traumatic injury or any abnormality at the level of the hip or ankle.

The sample size was estimated and calculated using G*POWER statistical software. The appropriate sample size for this study was N=50 to detect a 4.5 FPPA difference with observed power equal to 0.8 and 95% of confidence (Willson & Davis, 2008). For the calculations, α was considered at 0.05, β at 0.2, and an effect size of 0.3.

2.2. Outcome Measures and Procedures

The interview was arranged for the study participants and the details of the study and its importance were explained to them. Then the anthropometric data concerning with weight and height were recorded using the equation [weight (kg)/height (m^2)]. We used the following measurements:

2.2.1. Assessment of Spinopelvic Alignment in the Sagittal Plane

Spinopelvic alignment was measured by plain X-Ray (lateral view). Radiographs were taken laterally with the participant standing upright, right body side facing the film, arms crossed on the chest, and hands resting on the opposite shoulder. Participants were advised to fully extend the knees

in a way to position hips in a perpendicular position to the film. Similar conditions were applied during all X-rays capture.

The X-ray was developed and the cobb angle was calculated to measure spinopelvic parameters in the sagittal plane. The lumbar lordosis (LL) angle defined as the angle between the superior end plates of L1 and S1, and the sacral slope (SS) measured as the angle between the superior end plate of S1 and a horizontal line. Finally**,** the pelvic tilt (PT) was considered the angle between a drawn line from the sacral endplate midpoint to the center of the femoral head with the vertical axis.

2.2.2. Pain Level Assessment Using the Numeric Pain Rating Scale (NPRS)

The NPRS has been extensively used to assess pain severity. It is usually administered to the patient graphically or verbally. In this study, we registered the graphical reporting's by the patient and the numbers were enclosed in boxes (Williamson & Hoggart, 2005).

The Arabic version of NPRS, has been culturally adapted and validated, and made simple and understandable by Arabic-speaking patient's especially elderly and less educated ones (Alghadir, Anwer & Iqbal, 2016).

2.2.3. Assessment of Knee Dysfunction by the Arabic Anterior Knee Pain Scale (AAKP/Kujala)

Kujala Scale, also known as anterior knee pain questionnaire (AKPS), is a self-report tool including 13 knee-specific questions. It has been claimed to record patients' responses about six functional activities including walking, running, jumping, climbing stairs, squatting, and sitting for long periods. It also documents symptoms such that are related to other clinical and functional findings associated with anterior knee pain. The patient is asked the questionnaire questions, and the answers are recorded on a scale between zero and 100, with the lowest the scoring the highest is the disability and pain. Additionally, some parts of the questionnaire include information's about walking and running (Kujala et al., 1993). It has been claimed that this tool is user-friendly and rapidly filled (Bennell, Wee, Crossley, Stillman & Hodges, 2005), and the test-retest reliability is highly acceptable. The authors of the AKP scale have demonstrated its validity (Kujala et al., 1993). Others reported that this tool is valid and sensitive for research purposes (Bennell et al., 2005) and the Arabic version (AAKPS) has been tested for its validity and reliability in Arabian patients (Alshehri et al., 2017).

2.2.4. Measurement of 2D Frontal Plane Projection Angle (2D-FPPA)

Frontal plane projection angle (2D-FPPA) used is a low cost, easy and uses a single camera. It was claimed to measure the dynamic knee stability (Willson & Davis, 2008). The system tracks markers placed on subject's joint landmarks for calculation of the angle. All data captured are consequently processed by a related software (Maykut, Taylor-Haas, Paterno, DiCesare & Ford, 2015).

This system has been tested for validity and reliability in measuring lower limb dynamic valgus of the (Munro, Herrington & Carolan, 2012). In addition, the 2-D system when compared with similar 3-D system, has been shown to provide more accurate lower extremity dynamic pa measures. It has good consistency and provide a valid measure for lower limb alignment parameters (Gwynne & Curran, 2014).

Three markers (approximately 15 mm wide arranged in a cross) were attached at the anatomic the following body landmarks: anterior Superior Iliac spine, patellar center, and the midpoint of the line between ankle malleoli. Participants were asked to perform the test bare feet to remove any effect on lower limb mechanics.

Each participant was asked to cross his/her arms across the chest and requested to step down from an adjustable step of height of 10% of the his/her height with the untested leg, and squat with the tested leg (Souza & Powers, 2009) to a 30° of knee flexion (Willson & Davis, 2008). This movement was repeated three times. The timing was set to two seconds for the descent, one second for the foot to reach the ground and two seconds to reassume the starting position using a timer. Participants were allowed to perform three trials before the test, and received verbal feedback on their performance. The whole task was filmed and recorded through a digital camera fixed on a tripod 2 meters away from the testing scene to guarantee cleanness of the recorded pictures. The FPPA was then measured using a snapshot at the moment of maximum knee valgus (Bailon, Damas, Pomares & Banos, 2016).

The captured shots downloaded onto a PC then imported to Kinovea software program and the concluded data was exported to a spreadsheet. Kinovea software program has proved to obtain accurate and reliable measurements (Balsalobre-Fernandez, Tejero-Gonzalez, del Campo-Vecino & Bavaresco, 2014).

The FPPA was measured in degrees by calculating the angle formed between the line drawn between the hip and knee markers, and the other line between the ankle and knee markers (Gwynne & Curran, 2014).

2.3. Statistical Analysis

The statistical Package for Social Studies (SPSS) version 25 was used for data processing and analysis. Descriptive statistics were conducted for mean age, weight, height, BMI. Shapiro-Wilk test for all variables was performed for normal distribution of the data. There were no univariate outliers in the data, as assessed by inspection of a boxplot. Additionally, the Kolmogorov-Smirnov test was used to test for normality, indicating that the data was not normally distributed for all variables ($p<0.05$). The Spearman correlation coefficient r was calculated between different variables so we determined the relationship between lumbar lordosis, sacral slope and pelvic tilting with pain level, functional disability and the frontal plane projection angle (FPPA). For all the statistical tests, a p-value of <0.05 was considered statistically significant.

3. RESULTS

Sixty female with PFPS, with a mean age of 35.4±3.45 years, mean weight of 68.15±10.69, mean height of 168.07±9.30, mean BMI of 24.12±4.059 and mean duration of symptoms of 3.76±1.874 were included in this study (Table 1).

Table 1. Baseline characteristics of participants

Items	Mean	SD
Age (years)	26.10	5.148
Weight (Kg)	68.15	10.69
Height (cm)	168.07	9.30
BMI (Kg/m^2)	24.12	4.059
Duration of symptoms (Months)	3.76	1.874

SD (Standard Deviation)

The descriptive values of the independent variables (lumbar lordosis, sacral slope and pelvic tilt), three subscales (pain level, functional disability and the frontal plane projection angle (FPPA) are presented in Table 2.

Table 2. Descriptive statistics of all measured variables

Variables	Mean	SD
Lumbar Lordosis (LL)	62.40°	17.175°
Sacral Slope (SS)	40.56°	11.383°
Pelvic tilt (PT)	13.58°	0.39°

Frontal Plane Projection Angle (FPPA)	13.53°	4.942°
Pain Level	6.58	1.544
Functional Disability	58.75	5.522

SD (Standard Deviation)

Spearman correlation revealed that that there is a strong positive correlation of LL with pain level and FPPA (r=0.825, r=0.812, p=0.0001) respectively, also, a strong positive correlation of SS with pain level (r = 0.0.820), and FPPA (r= 0.783). With regard to correlations between PT, there were moderate correlations of PT with pain level (r = 0.0.614), and FPPA (r= 0.605). There is weak negative correlation of lumbar lordosis, sacral slope and pelvic tilt with functional disability score (r=-0.397, r=-0.385 and, r=-0.215 p=0.002) (Table 3).

Table 3. The relationship of spin-pelvic parameters with pain level, functional disability and frontal plane projection angle (FPPA)

Variables	**Lumbar Lordosis (LL)**	**Sacral Slope (SS)**	**Pelvic tilt (PT)**	**P value**
Pain Level	0.825	0.820	0.614	0.0001 *
Functional Disability (Kujala scale)	-0.397	-0.385	-0.215	0.002 *
Frontal Plane Projection Angle (FPPA)	0.812	0.783	0.605	0.001 *

**Significance level considered at p<.05*

4. DISCUSSION

To our knowledge, this is the first study aimed to correlate the degree of lumbar lordosis, sacral slope and pelvic tilt with degree of pain level, functional disability and frontal plane projection angle in women with PFPS. The results of our study demonstrated a strong positive correlation of lumbar lordosis (LL) with pain level and FPPA (r=0.825, r=0.812, p=0.0001), also a strong positive correlation of sacral slope (SS) with pain level (r = 0.0.820), and (FPPA) (r= 0.783). Pelvic tilt (PT) showed moderate correlations with the pain level (r = 0.0.614), and (FPPA) (r= 0.605) while there was a weak negative correlation between LL, SS and PT, and functional disability score (r=-0.397, r=-0.385 and, r=-0.215 p=0.002).

Our results are in accordance with a study by Yasuda et al. (2020), reporting that patients aged 50 years or more, suffering from severe knee osteoarthritis displayed strong relationship with

lumbar flattening. Lumbar flattening has been correlated to hip external rotation and varus knee deformity in standing position (Tonnis & Heinecke, 1999). It has been claimed that varus knee alignment increases the medial tibio-femoral load, and consequently leads to knee osteoarthritis (Brouwer et al., 2007). So, it can be hypothesized that increasing lumbar lordosis will possibly lead to hip internal rotation, valgus knee deformity and consequently lead to compression at the lateral portion of PF joint resulting in increasing pain and thus affecting the patient daily performance.

A study about the impact of abnormal hip mechanics on knee injuries in the sagittal plane concluded that individuals with PFP might perform weight-bearing activities with reduced hip flexion and larger lumbar lordosis and trunk extension, this has been also correlated to a posterior shift of the center of mass and an exaggerated external knee flexor moment (Powers, 2010). Such motion pattern has been associated with inhibition of the hip and trunk extensor muscles and greater quadriceps muscle activity (Pollard, Sigward & Powers, 2010), resulting in an increased patellofemoral joint compression, pain severity and functional disability in these patients.

Other researchers implemented these concepts when designing rehabilitation exercises in patients with PFP and instructed patients to perform exercises with lower limbs in neutral alignment (Baldon, Serrao, Scattone Silva & Piva, 2014). They also advised patients to avoid quadriceps dominance by inclining the trunk forward. Such correction of the excessive lordosis has been claimed to transfer the ground reaction force ventrally, increasing the load on hip extensors, and at the same time reducing the demand on the quadriceps. Such mechanical adjustment has been claimed to decrease the compressive force on PF joint leading to reduced pain intensity and subsequently improving of functional ability.

In contrast, when researchers investigated the correlation between lumbar lordosis and the knee extension in patients with knee pain and low back pain in elderlies, they reported that increasing level of knee pain as a result of degenerative changes that affected knee function is compensated at the level of the spine by reducing the lumbar lordosis and sacral inclination (Murata et al., 2003). However, it is so difficult to generalize these results throughout all age categories and it seems difficult to determine whether the deformity at the level of the lumbar spine due to flexion posture of old ages and LBP or the knee is the primary factor.

Regarding the results related to FPPA, our findings are in accordance with others, reporting that PFPS patients with hip abductor weakness and lumbar hyperlordosis demonstrated changing in mechanical advantage of hip abductor into internal rotator. Such mechanical disturbance possibly aggravates symptoms and pain. They added that correction for excessive lumbar lordosis during strengthening exercises of hip abductors would eventually lead to a reduction of excessive hip

internal rotation, less FPPA, greater mechanical advantage and less effort required by the gluteus medius muscle (Stephen et al., 2020). In addition, others reported that during the running action there is increasing in anterior pelvic tilt and lumbar lordosis due to tightness of the hip flexor musculature which reduces hip extension flexibility (Schache, Blanch & Murphy, 2000). It has also been reported the occurrence of greater hip adduction and internal rotation in habitual female runners with PFPS. These findings may explain why PFPS is most common among runners (Noehren, Pohl, Sanchez, Cunningham & Lattermann, 2012).

On the other hand, it has been reported that there was significant positive correlation between increasing in degree of lumbar lordosis, degree of hip adduction, knee abduction angle in subjects with increasing angle of knee flexion and step height during step down task (Lewis, Foch, Luko, Loverro & Khuu, 2015). That makes these findings in the same line with the present study and may explain the aggravation of FPPA in PFPS patients.

5. LIMITATIONS

This study was limited to the assessment of pain and functional disability only in patients with PFP. Future studies are needed investigate other clinical manifestations such as range of motion of the knee and proprioception. Also, this study investigated the sagittal plane of the lumbar spine only urging the need to investigate in other planes. In addition, our study included only female patients, which makes it difficult to generalize conclusions to larger population.

6. CONCLUSIONS

In conclusion, there is a significant association of spinal measurements (sacral inclination and lumbar curvature) with pain intensity, functional disability and frontal plane projection angle in women with patellofemoral pain syndrome. It is recommended to assess spinal measurements during evaluation and rehabilitation of the patients that suffers from persistence of symptoms after traditional rehabilitation programs. This can eventually confirm the concept previously stated as knee–spine syndrome.

7. REFERENCES

1. Alghadir, A. H., Anwer, S., & Iqbal, Z. A. (2016). The psychometric properties of an Arabic numeric pain rating scale for measuring osteoarthritis knee pain. *Disability and Rehabilitation, 38*(24), 2392-2397. https://doi.org/10.3109/09638288.2015.1129441

2. Alshehri, A., Lohman, E., Daher, N. S., Bahijri, K., Alghamdi, A., Altorairi, N., . . . Matar, A. (2017). Cross-Cultural Adaptation and Psychometric Properties Testing of the Arabic Anterior Knee Pain Scale. *Medical Science Monitor, 23*, 1559-1582. https://doi.org/10.12659/msm.901264
3. Bailon, C., Damas, M., Pomares, H., & Banos, O. (2016). First approach to automatic measurement of frontal plane projection angle during single leg landing based on depth video. In *International Conference on Ubiquitous Computing and Ambient Intelligence* (pp. 44-55). Springer, Cham.
4. Baldon Rde, M., Serrao, F. V., Scattone Silva, R., & Piva, S. R. (2014). Effects of functional stabilization training on pain, function, and lower extremity biomechanics in women with patellofemoral pain: a randomized clinical trial. *The Journal of Orthopaedic and Sports Physical Therapy*, *44*(4), 240-251. https://doi.org/10.2519/jospt.2014.4940
5. Balsalobre-Fernandez, C., Tejero-Gonzalez, C. M., del Campo-Vecino, J., & Bavaresco, N. (2014). The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. *Journal of Strength and Conditioning Research, 28*(2), 528-533. https://doi.org/10.1519/JSC.0b013e318299a52e
6. Bennell, K., Wee, E., Crossley, K., Stillman, B., & Hodges, P. (2005). Effects of experimentally-induced anterior knee pain on knee joint position sense in healthy individuals. *Journal of Orthopaedic Research Society, 23*(1), 46-53. https://doi.org/10.1016/j.orthres.2004.06.008
7. Bolgla, L. A., Malone, T. R., Umberger, B. R., & Uhl, T. L. (2008). Hip strength and hip and knee kinematics during stair descent in females with and without patellofemoral pain syndrome. The *Journal of Orthopaedic and Sports Physical Therapy, 38*(1), 12-18. https://doi.org/10.2519/jospt.2008.2462
8. Brechter, J. H., & Powers, C. M. (2002). Patellofemoral joint stress during stair ascent and descent in persons with and without patellofemoral pain. *Gait Posture, 16*(2), 115-123. https://doi.org/10.1016/s0966-6362(02)00090-5
9. Brouwer, G. M., van Tol, A. W., Bergink, A. P., Belo, J. N., Bernsen, R. M., Reijman, M., . . . Bierma-Zeinstra, S. M. (2007). Association between valgus and varus alignment and the development and progression of radiographic osteoarthritis of the knee. *Arthritis Rheum, 56*(4), 1204-1211. https://doi.org/10.1002/art.22515
10. Collins, N. J., Barton, C. J., van Middelkoop, M., Callaghan, M. J., Rathleff, M. S., Vicenzino, B. T., . . . Crossley, K. M. (2018). 2018 Consensus statement on exercise therapy

and physical interventions (orthoses, taping and manual therapy) to treat patellofemoral pain: recommendations from the 5th International Patellofemoral Pain Research Retreat, Gold Coast, Australia, 2017. *British Journal of Sports Medicine, 52*(18), 1170-1178. https://doi.org/10.1136/bjsports-2018-099397

11. Crossley, K. M., van Middelkoop, M., Callaghan, M. J., Collins, N. J., Rathleff, M. S., & Barton, C. J. (2016). 2016 Patellofemoral pain consensus statement from the 4th International Patellofemoral Pain Research Retreat, Manchester. Part 2: recommended physical interventions (exercise, taping, bracing, foot orthoses and combined interventions). *British Journal of Sports Medicine, 50*(14), 844-852. https://doi.org/10.1136/bjsports-2016-096268
12. Earl, J. E., & Hoch, A. Z. (2011). A proximal strengthening program improves pain, function, and biomechanics in women with patellofemoral pain syndrome. *The Americal Journal of Sports Medicine, 39*(1), 154-163. https://doi.org/10.1177/0363546510379967
13. Gwynne, C. R., & Curran, S. A. (2014). Quantifying frontal plane knee motion during single limb squats: reliability and validity of 2-dimensional measures. *International Journal of Sports Physical Therapy, 9*(7), 898-906.
14. Iyer, S., Sheha, E., Fu, M. C., Varghese, J., Cunningham, M. E., Albert, T. J., . . . Kim, H. J. (2018). Sagittal Spinal Alignment in Adult Spinal Deformity: An Overview of Current Concepts and a Critical Analysis Review. *JBJS Rev, 6*(5), e2. https://doi.org/10.2106/JBJS.RVW.17.00117
15. Kujala, U. M., Jaakkola, L. H., Koskinen, S. K., Taimela, S., Hurme, M., & Nelimarkka, O. (1993). Scoring of patellofemoral disorders. *Arthroscopy, 9*(2), 159-163. https://doi.org/10.1016/s0749-8063(05)80366-4
16. Lewis, C. L., Foch, E., Luko, M. M., Loverro, K. L., & Khuu, A. (2015). Differences in Lower Extremity and Trunk Kinematics between Single Leg Squat and Step Down Tasks. *PLoS One, 10*(5), e0126258.https://doi.org/10.1371/journal.pone.0126258
17. Marquez-Lara, A., Nandyala, S. V., Sankaranarayanan, S., Noureldin, M., & Singh, K. (2014). Body mass index as a predictor of complications and mortality after lumbar spine surgery. *Spine (Phila Pa 1976), 39*(10), 798-804. https://doi.org/10.1097/BRS.0000000000000232
18. Maykut, J. N., Taylor-Haas, J. A., Paterno, M. V., DiCesare, C. A., & Ford, K. R. (2015). Concurrent validity and reliability of 2d kinematic analysis of frontal plane motion during running. *International Journal of Sports Physical Therapy, 10*(2), 136-146.

19. Munro, A., Herrington, L., & Carolan, M. (2012). Reliability of 2-dimensional video assessment of frontal-plane dynamic knee valgus during common athletic screening tasks. *Journal of Sport Rehabilitation, 21*(1), 7-11. https://doi.org/10.1123/jsr.21.1.7
20. Murata, Y., Takahashi, K., Yamagata, M., Hanaoka, E., & Moriya, H. (2003). The knee-spine syndrome. Association between lumbar lordosis and extension of the knee. *The Journal of Bone and Joint Surgery. British volume, 85*(1), 95-99. https://doi.org/10.1302/0301-620x.85b1.13389
21. Noehren, B., Pohl, M. B., Sanchez, Z., Cunningham, T., & Lattermann, C. (2012). Proximal and distal kinematics in female runners with patellofemoral pain. *Clinical Biomechanics (Bristol, Avon), 27*(4), 366-371. https://doi.org/10.1016/j.clinbiomech.2011.10.005
22. Oshima, Y., Watanabe, N., Iizawa, N., Majima, T., Kawata, M., & Takai, S. (2019). Knee-Hip-Spine Syndrome: Improvement in Preoperative Abnormal Posture following Total Knee Arthroplasty. *Advances in Orthopaedics, 2019*, 8484938. https://doi.org/10.1155/2019/8484938
23. Pollard, C. D., Sigward, S. M., & Powers, C. M. (2010). Limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments. *Clin Biomech (Bristol, Avon), 25*(2), 142-146.
24. Powers, C. M. (2003). The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *Journal of Orthopaedic and Sports Physical Therapy, 33*(11), 639-646. https://doi.org/10.1016/j.clinbiomech.2009.10.005
25. Powers, C. M. (2010). The influence of abnormal hip mechanics on knee injury: a biomechanical perspective. *The Journal of Orthopaedic and Sports Physical Therapy, 40*(2), 42-51. https://doi.org/10.2519/jospt.2010.3337
26. Rathleff, M. S., Rathleff, C. R., Olesen, J. L., Rasmussen, S., & Roos, E. M. (2016). Is Knee Pain During Adolescence a Self-limiting Condition? Prognosis of Patellofemoral Pain and Other Types of Knee Pain. *American Journal of Sports Medicine, 44*(5), 1165-1171. https://doi.org/10.1177/0363546515622456
27. Robinson, M. D., & Smyth, G. K. (2007). Moderated statistical tests for assessing differences in tag abundance. *Bioinformatics, 23*(21), 2881-2887. https://doi.org/10.1093/bioinformatics/btm453
28. Schache, A. G., Blanch, P. D., & Murphy, A. T. (2000). Relation of anterior pelvic tilt during running to clinical and kinematic measures of hip extension. *British Journal of Sports Medicine, 34*(4), 279-283. https://doi.org/10.1136/bjsm.34.4.279

29. Souza, R. B., & Powers, C. M. (2009). Differences in hip kinematics, muscle strength, and muscle activation between subjects with and without patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy*, *39*(1), 12-19. https://doi.org/10.2519/jospt.2009.2885
30. Stephen, J., Ephgrave, C., Ball, S., & Church, S. (2020). Current concepts in the management of patellofemoral pain - The role of alignment. *Knee*, *27*(2), 280-286. https://doi.org/10.1016/j.knee.2019.12.006
31. Tonnis, D., & Heinecke, A. (1999). Acetabular and femoral anteversion: relationship with osteoarthritis of the hip. The *Journal of Bone and Joint Surgery*, *81*(12), 1747-1770.
32. Tsuji, T., Matsuyama, Y., Goto, M., Yimin, Y., Sato, K., Hasegawa, Y., & Ishiguro, N. (2002). Knee-spine syndrome: correlation between sacral inclination and patellofemoral joint pain. *Journal of Orthopaedic Science*, *7*(5), 519-523. https://doi.org/10.1007/s007760200092
33. Wainner, R. S., Whitman, J. M., Cleland, J. A., & Flynn, T. W. (2007). Regional interdependence: a musculoskeletal examination model whose time has come. *The Journal of Orthopaedic and Sports Physical Therapy*, *37*(11), 658-660. https://doi.org/10.2519/jospt.2007.0110
34. Williamson, A., & Hoggart, B. (2005). Pain: a review of three commonly used pain rating scales. *Journal of Clinical Nursing*, *14*(7), 798-804. https://doi.org/10.1111/j.1365-2702.2005.01121.x
35. Willson, J. D., & Davis, I. S. (2008). Utility of the frontal plane projection angle in females with patellofemoral pain. *The Journal of Orthopaedic and Sports Physical Therapy*, *38*(10), 606-615. https://doi.org/10.2519/jospt.2008.2706
36. Yasuda, T., Togawa, D., Hasegawa, T., Yamato, Y., Kobayashi, S., Yoshida, G., . . . Matsuyama, Y. (2020). Relationship between Knee Osteoarthritis and Spinopelvic Sagittal Alignment in Volunteers over 50 Years of Age. *Asian Spine Journal*, *14*(4), 495-501. https://doi.org/10.31616/asj.2018.0266

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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