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Evaluating Psoas Muscle Index and Spinal Sagittal Alignment as Predictors of Fall Risk in Adults: A Comprehensive Analysis

Yetişkinlerde Düşme Riskinin Tahmin Edicileri Olarak Psoas Kas İndeksi ve Omurga Sagital Hizalanmasının Değerlendirilmesi: Kapsamlı Bir Analiz

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Abstract

Objective: This study aims to evaluate the psoas muscle index and spine sagittal alignment as predictors of fall risk in adults.
Materials and Methods: A total of 126 patients who visited the physical medicine and rehabilitation outpatient clinic between January and May 2024 were included. Standing lateral spine radiographs, lumbar magnetic resonance imaging (MRI), and lumbar computed tomography (CT) images were analyzed. Sagittal vertical axis, thoracic kyphosis, cervical and lumbar lordosis angles, pelvic incidence, sacral slope, lumbosacral angle, and pelvic tilt were measured. The psoas muscle index was calculated from lumbar MRI and CT images. Participants were grouped based on the Tinetti fall risk index, and differences in sagittal alignment and psoas muscle index were assessed.
Results: In this cross-sectional descriptive study, significant differences were found between fall risk groups in terms of gender and age. The medium-risk group had more women, while the high-risk group had more men and was older. Sagittal vertical axis, sacral slope, and pelvic tilt angle showed statistically significant differences between fall risk groups. Positive sagittal vertical axis was more common in medium- and high-risk groups than in the low-risk group. Sacral slope values were lower, and pelvic tilt angle was higher in the high-risk group compared to the low-risk group. Psoas muscle AP/ML values at the L4-5 level positively correlated with fall risk. A negative correlation was found between fall risk groups and anterior margin gap and center gap values at L3-4 and L2-3 levels. Additionally, psoas muscle position at L3-4 and L2-3 levels was more negative in high- and medium-risk groups.
Conclusion: Determining the relationship of these changes in psoas muscle analysis and spinal alignment with the risk of falling in adult individuals will enable the creation of appropriate rehabilitation strategies.
Keywords: Fall risk, pelvic parameters, psoas muscle index, spine sagittal alignment, spinopelvic sagittal balance

Öz

Amaç: Bu çalışmanın amacı yetişkinlerde düşme riskinin öngörücüleri olarak psoas kas indeksi ve omurga sagital hizalanmasını değerlendirmektir.
Gereç ve Yöntem: Ocak ve Mayıs 2024 arasında fiziksel tıp ve rehabilitasyon polikliniğini ziyaret eden toplam 126 hasta çalışmaya dahil edildi. Ayakta lateral omurga radyografileri, lomber manyetik rezonans görüntüleme (MRG) ve lomber bilgisayarlı tomografi (BT) görüntüleri analiz edildi. Sagital dikey eksen, torasik kifoz, servikal ve lomber lordoz açıları, pelvik insidans, sakral eğim, lumbosakral açı ve pelvik eğim ölçüldü. Psoas kas indeksi lomber MRG ve BT görüntülerinden hesaplandı. Katılımcılar Tinetti düşme risk indeksine göre gruplandırıldı ve sagital hizalama ve psoas kas indeksindeki farklılıklar değerlendirildi.
Bulgular: Bu kesitsel tanımlayıcı çalışmada, düşme risk grupları arasında cinsiyet ve yaş açısından anlamlı farklılıklar bulundu. Orta risk grubunda daha fazla kadın, yüksek risk grubunda ise daha fazla erkek ve daha yaşlıydı. Sagital dikey eksen, sakral eğim ve pelvik eğim açısı düşme riski grupları arasında istatistiksel olarak anlamlı farklılıklar gösterdi. Pozitif sagital dikey eksen orta ve yüksek riskli gruplarda düşük riskli gruba göre daha yaygındı. Sakral eğim değerleri düşüktü ve pelvik eğim açısı yüksek riskli grupta düşük riskli gruba göre daha yüksekti. Psoas kası AP/ML değerleri L4-5 seviyesinde düşme riski ile pozitif korelasyon gösterdi. Düşme riski grupları ile L3-4 ve L2-3 seviyelerinde anterior kenar boşluğu ve merkez boşluğu değerleri arasında negatif korelasyon bulundu. Ek olarak, psoas kası pozisyonu L3-4 ve L2-3 seviyelerinde yüksek ve orta riskli gruplarda daha negatifti.
Sonuç: Psoas kası analizi ve omurga hizalamasındaki bu değişikliklerin yetişkin bireylerde düşme riski ile ilişkisinin belirlenmesi uygun rehabilitasyon stratejilerinin oluşturulmasını sağlayacaktır.
Anahtar kelimeler: Düşme riski, pelvik parametreler, psoas kas indeksi, omurga sagital hizalaması, spinopelvik sagital denge

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Introduction

A fall is defined as an individual descending to a lower level than the ground or floor as a result of an involuntary change in position. The main factors that cause falls are divided into four groups: Biological, behavioral, environmental, and socioeconomic factors (1). Studies states that the frequency of falls increases with advancing age and level of weakness (1,2). In a study, the prevalence of falling in the previous year was found to be 25%, with a prevalence of 21.7% in men and 27.1% in women. Additionally, the prevalence of fear of falling was reported to be 41.5% (2). Falls result in negative consequences such as injury to the individual, decreased quality of life, prolonged hospital stays, and increased treatment costs, and are considered an important patient safety criterion worldwide (2).

Preventing falls, an important element of patient safety is a process that begins with diagnosing the risk of falling and evaluating the associated risk factors. The human spine maintains a relatively stable posture for minimal energy consumption when standing or exercising. The sagittal balance of the trunk is determined primarily by the alignment of the spine and pelvis, which is necessary to maintain normal spinal biomechanics. Proper lumbosacral alignment is crucial for optimal spinal function. If the spinal alignment and balance are disrupted, the human body must exert more effort to stand upright. Changes in spinal alignment can adversely affect body biomechanics, leading to pain, reduced quality of life, compromised sagittal balance, and an increased risk of falls (3,4). Sarcopenia, characterized by the loss of skeletal muscle mass and strength, is an important risk factor associated with the development of osteoporosis (5,6). Sarcopenia can be determined by the muscle mass of the extremities, walking speed, and grip strength (7).

The decrease in skeletal muscle mass, which seriously affects the daily behavioral ability and quality of life of individuals, also affects spinal alignment (8). This is because the musculoskeletal system interacts with each other through various chemical events at paracrine and endocrine levels. These chemical events secondary to aging can lead to decreased muscle strength and increased fracture incidence; nutritional deficiencies can accelerate bone loss and reduce muscle protein synthesis; decreased individual exercise and decreased neuromuscular function can indirectly affect muscle and bone anabolism (5). In addition, due to disc and ligament degeneration, spinal mechanical distribution often changes in elderly patients and paravertebral muscle strength decreases (8). Studies have shown that sagittal spinal misalignment and sarcopenia are associated with falls in older individuals (8,9). For this reason, measuring the overall alignment of the spine and evaluation the presence of sarcopenia allows individuals at high risk of falling to be identified.

Current literature predominantly focuses on fall risk assessment in individuals aged 65 and older, with limited investigation into younger adult populations. Furthermore, there is a noticeable gap in research exploring the effects of sarcopenia and sagittal spinal alignment which are both recognized as potential risk factors for falls. Therefore, this study aims to explore the potential association between the psoas muscle index, sagittal spinal alignment, and fall risk in adults.

Materials and Methods

This descriptive cross-sectional study was conducted at a Kütahya Health Sciences University Hospital Physical Medicine and Rehabilitation Clinic between January and May 2024. All data were collected by the same evaluator at the same facility. Approval for the study was obtained from the Local Ethical Committee (Kütahya Health Sciences University Non-Interventional Research Ethics Committee, no. 2023/05-07, dated: April 25, 2023). All individuals included in the study signed an informed consent form, stating that they participated in the study voluntarily.

Participant

This study included 126 patients aged 18 years and older who applied to our hospital's outpatient clinics with complaints of myalgia and who underwent lumbar magnetic resonance imaging (MRI), computerized tomography (CT) scans, and whole spine lateral radiographs due to low back and neck pain within the last year. The exclusion criteria for the study are as follows: (a) Refusal to participate in the study, (b) Inadequate communication ability, (c) Severe cognitive impairment, (d) History of any previous spinal and lower extremity operations, (e) Cobb angle >20° indicating any scoliotic deformity, spondylolisthesis, spinal tumor, infection, fracture, or trauma, (f) Participants with missing or unmeasurable radiographic imaging, (g) Knee flexion contracture (extension <0°), hip flexion contracture (extension <10°), or leg length difference (>1 cm), and (h) History of diseases causing balance problems.

After recording demographic data, all participants were assessed using the Tinetti Balance and Gait Questionnaire to determine their balance, walking abilities, and fall risk. The questionnaire has been validated for reliability and validity and its Turkish version study was conducted by Ağırcan (10), and Tinetti (11). The first 9 questions of this questionnaire focused on balance, while the next 7 questions pertain to walking. The questionnaire score is calculated as follows: the total score of the first 9 items determines the balance score, the total score of the next 7 items determines the walking score, and the sum of these scores provides the total score. A total score of 18 and below indicates a high risk of falling, a score of 19-24 points indicates a moderate risk of falling, and a score of 25 and above indicates a low risk of falling (10,11). The patients included in the study were assessed based on the questionnaire results and categorized into three groups: Low, medium, and high-risk groups.

Psoas muscle cross-sectional analysis and spine sagittal alignment evaluation were performed using whole spine lateral radiographs, MRI, and CT scans for all patients, and the results were compared between groups. The evaluation of spine sagittal alignment included examination of the sagittal vertical axis (SVA), thoracic kyphosis angle (TKA), lumbar lordosis angle (LLA), cervical lordosis angle, pelvic incidence (PI), sacral slope angle (SSA), and pelvic tilt angle (PTA) (12,13) (Figures 1, 2). All radiographs were taken under standardized conditions with patients instructed to assume a comfortable standing position for lateral spine radiographs. Lumbar MRI and CT imaging data were utilized for psoas muscle cross-sectional analyses (14,15) (Figures 3, 4). In lumbar MRI, each variable was measured on T2-weighted axial images at the intervertebral disc-bisection levels of L2-3, L3-4 and L4-5. Since the psoas muscle shape and edges cannot be clearly distinguished at the L1-2 and L5-S1 levels, they were excluded from evaluation. Since the right psoas muscle may be affected by anatomical variability in the inferior vena cava and right common iliac vein, only the left psoas muscle was measured (15). In addition, the total volume of the psoas muscle was calculated from CT images by summing the cross-sectional areas of the right and left psoas muscles at the mid-level of the L3 vertebra and normalizing the value by the square of the individual's height (16). All measurements were conducted using software tools integrated into a picture archiving and communications system (PACS viewer).

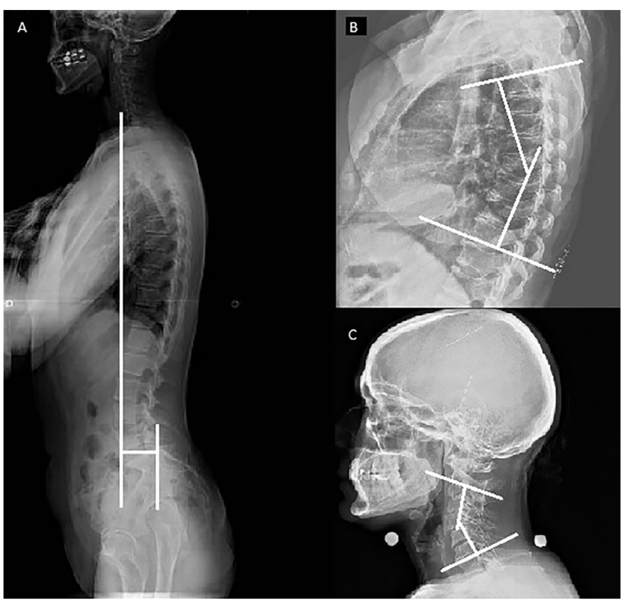

Figure 1. (A) Sagittal vertical axis (SVA): The line drawn vertically from the middle of the C7 vertebral body or the midpoint of the C7 interior endplate to the horizontal plane passing through the postero-superior corner of S1. Neutral sagittal balanece: Between 2 cm anterior or posterior of the postero-superior corner of the sacrum. Positive sagittal imbalance: >2 cm anterior to the postero-superior corner of S1. Negative sagittal imbalance: >2 cm posterior the postero-superior corner of S1. (B) Thoracic kyphosis angle (TKA): The angle between the horizontal line drawn on the upper edge of the T4 vertebra and the lines drawn perpendicular to the horizontal line drawn on the lower edge of the T12 vertebra. In measurements made when T7 is considered as the peak, the thoracic kyphosis angle should be between 20° and 50° on average. (C) Cervial lordosis angle (CLA): The angle between the horizontal line drawn on the lower edge of the C2 vertebra and the lines drawn perpendicular to the horizontal line drawn on the lower edge of the C7 vertebra. In the evaluation made by accepting C4 as the vertex, the cervial lordosis angle should be 25°-50°

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) 22 package program. Descriptive statistics are expressed as the mean and standard deviation for normally distributed continuous variables, and as number and percentage for categorical variables. Normally distributed continuous variables were analyzed using the "One-Way Analysis of Variance" between groups, while non-normally distributed continuous variables were compared between groups using the "Kruskal-Wallis H test". "Chi-square analysis" was used to compare categorical variables. In correlation analyses, if the data were normally distributed, the "Pearson correlation test" was preferred; if the data were not normally distributed, the "Spearman correlation test" was preferred. In the statistical analysis of the study, $p<0.05$ was considered significant. Correlation analyses were classified according to the coefficient (r) values as follows: 0-0.25 indicates a weak correlation, 0.25-0.50 indicates a moderate correlation, 0.50-0.75 indicates a strong correlation, and 0.75-1.00 indicates a very strong correlation.

Sample Size

To determine the appropriate sample size for this study, a power analysis was conducted using the G*Power 3.1.7 program (Kiel University, Kiel, Germany). Based on the study by Ishikawa et al. (17) which examined the relationships between spinal

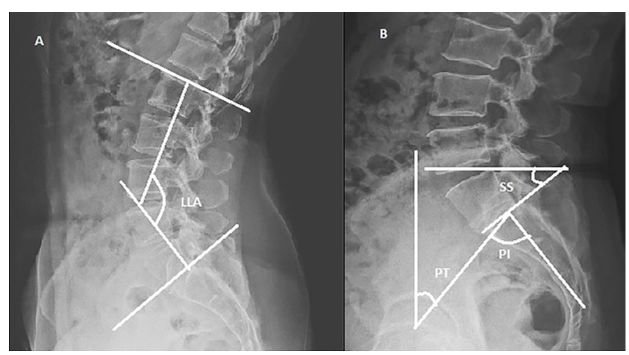

Figure 2. (A) Lumbar lordosis angle (LLA): The angle between the horizontal line drawn on the upper egde of the L1 vertebra and the lines drawn perpendicular to the horizontal line drawn on the upped egde of the S1 vertebra. Normal lumbar lordosis is between 40° and 70°, considering the L3-4 distance as the peak. (B) Saceal slope (SS) angle: The angle between the line drawn on the upper edge of the S1 vertebra and the horizontal line drawn from the midpoint of the upper edge of the S1 vertebra. (B) Pelvic tilt (PT) angle: The angle between the vertical line passing through the femoral head axis and the line connecting the femoral head axis to the upper midpoint of the S1 verebra. (B) Pelvic incidence (PI) angle: The angle between the perpendicular line passing through the upper midpoint of the S1 vertebra and the line connecting the femoral head axis to this midpoint. (B) Sagittal classification of back type: Type I: Lumbar apex in the middle od L5, SS angle in the spine <35 degrees; Type II: Lumbar apex inferior to L4, SS <35 degrees; Type III: Lumbar apex in the middle of L4, 35 < SD <45 degreees; Type III AP (anteverted): PI <50° and SS >35°; Type IV: Lumbar apex at the base of L3, SS >45 degrees

mobility, sagittal alignment, quality of life, and fall risk, the LLA in extension was identified as a key parameter due to its significant association with fall risk (p=0.038). Using the reported means and standard deviations of lumbar lordosis angles in extension the effect size (Cohen's d=0.81) was calculated. For a two-tailed t-test with a 5% type I error (α=0.05) and 80% power (1-β=0.80), the required sample size was calculated to be 47 participants per group (total=94). To enhance the study's robustness and account for potential participant dropouts, a total of 126 individuals were enrolled in the study.

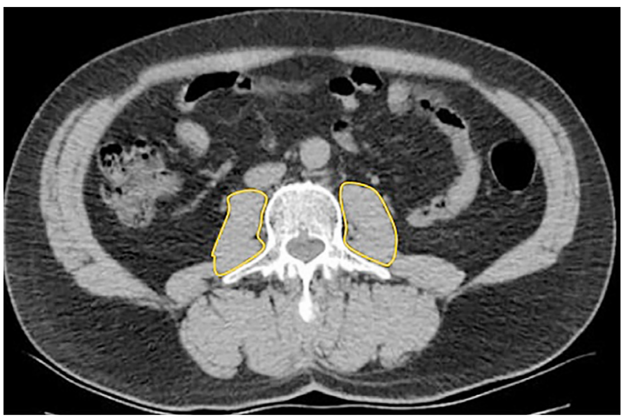

Figure 3. Psoas muscle index evaluation on lumbar computed tomography. The outer edge of the major psosas muscle was traced manually to assess the psoas cross-sectional area at the lumbar third vertebral level with the free hand region of interest. The sum of the left and right psoas cross-sectional area (cm^2) was divided by the square of the individual's height (m^2)

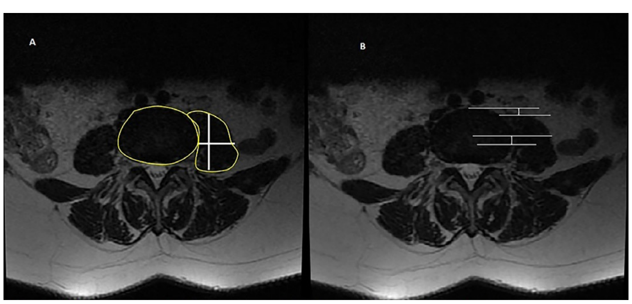

Figure 4. Anaysis of psosas muscle cross-sectional areas at L2-3, L3-4 and L4-5 intervertebral disc levels in lumber magnetic resonance imaging (A) Psosas muscle anteroposterior length/medial-lateral width raito and cross-sectional area (each measured cross-secitonal area is divided by the cross-sectional area of the intervertebral disc at the same level to minimize differences based on individual phyical characteristics and gender). (B) Evaluation of the position of the psosas muscle relative to the intervertebral disch in the axial plane. The measurement includes the verticla distance between the anterior edge of the psosas mucle and the anterior edge of the intervertebral disc, as weel as the vertical distance between the midpoints of the psoas muscle and the midpoints of the intervertebral disch. The distance is recorded ad positive (+) if the anterior edge or center of the psoas muscle is more anterior than the intervertebral disc, as negative (-) if it is further back

Results

Fall Risk and Demographic Data

Statistically significant differences were found between the fall risk groups regarding gender distribution and age. Post-hoc analyses showed a higher proportion of women in the medium-risk group compared to the high-risk group. Correlation analyses revealed a moderate negative correlation between age and Tinetti scores (Balance, Gait, and Total Scores) (r=-0.367, -0.324, and -0.366, respectively, and p<0.01). In addition, there was a moderate positive correlation between age and fall risk groups (r=0.392, p<0.01). There were no statistically significant differences between the fall risk groups in terms of weight, height, and BMI. All data are given in Table 1. Multivariate logistic regression analysis revealed that approximately 14.9% of the fall risk could be explained by demographic data. In these analyses, age was determined as a significant predictor of fall risk and was found to have a positive relationship; 11.1% of the fall risk could be explained by age alone (B=0.018, p=0.001).

Fall Risk and Spinal Alignment

SVA was statistically significantly different between the fall risk groups, with positive SVA being significantly more common in the moderate and high-risk groups compared to the low-risk group. Correlation analyses revealed a statistically significant weak positive correlation between SVA and Tinetti gait score (r=0.208, p=0.019), but no significant association with other Tinetti scores. Statistically significant differences were also found between the SSA and risk groups; the mean SSA was significantly lower in the high-risk group compared to the low-risk group. Furthermore, significant differences were observed between groups based on the Sagittal back type classification; Type II back type was more common in the high-risk group, while Type I back type was less common. A statistically significant association was found between the PTA and the fall risk groups, and post-hoc analyses revealed that this angle was significantly higher in the high-risk group compared to both the low-risk and moderate-risk groups. In correlation analyses, statistically significant but moderate negative correlations were found between the PTA and the Tinetti balance score, Tinetti gait score, and Tinetti total score (r=-0.332, -0.320, -0.308, respectively; p<0.01). In the assessment of spinopelvic (PI-LL) mismatch, no significant difference was observed between the groups in terms of mean PI-LL values. However, the distribution of spinopelvic mismatch levels between the fall-risk groups showed that the rate of high spinopelvic mismatch was greater in the high-risk group. Additionally, a statistically significant but weak negative correlation was found between the PI-LL Difference and the Tinetti total score (r=-0.126, p<0.01). All data are given in Table 2. Multivariate logistic regression analysis revealed that spine and pelvic measurement variables could explain 22.6% of the fall risk. In these analyses, PI-LL difference was determined to be a predictor of fall risk and showed a negative relationship; 4.4% of the fall risk can be explained by PI-LL Difference alone

Table 1. Relationship between fall risk groups and demographic data

	Total (n=126)	Low-risk fall group (n=42)	Medium-risk fall group (n=42)	High-risk fall group (n=42)	p-value
Gender					**0.014#**
Female (n/%)	105 (83.3%)	35 (83.3%)	40 (95.2%)	30 (71.4%)	
Male (n/%)	21 (16.7%)	7 (16.7%)	2 (4.8%)	12 (28.6%)	
Age (years) (mean ± SD)	59.98±13.59	55.26±11.72	58.38±13.57	66.31±13.24	**<0.001¥**
Height (m) (mean ± SD)	163.65±7.34	163.55±7.03	161.76±5.67	165.64±8.64	0.127¥
Weight (kg) (mean ± SD)	74.93±10.96	74.67±13.72	73.31±9.86	76.81±8.63	0.189¥
BMI (mean ± SD)	28.06±4.29	27.93±5.01	28.07±3.94	28.15±3.95	0.955¥
Normal ideal (18.5-24.9) (n/%)	34 (27%)	13 (31%)	12 (28.6%)	9 (21.4%)	0.844#
Overweight (25.0-29.9) (n/%)	57 (45.2%)	16 (38.1%)	19 (45.2%)	22 (52.4%)	
First degree obesity (30.0-34.9) (n/%)	27 (21.4%)	9 (21.4%)	9 (21.4%)	9 (21.4%)	
Second degree obesity (35.0-39.9) (n/%)	8 (6.3%)	4 (9.5%)	2 (4.8%)	2 (4.8%)	

Data presented as mean (±SD) or number (n/%) of patients. BMI: Body mass index, SD: Standard deviation, The p-value refers to the difference between the groups, p<0.05 statistically significant. #: Chi-square test, ¥: Kruskal-Wallis-H test

(B=-0.046, p=0.009). Similarly, the SSA explains 7.9% of the fall risk, with a significant negative association between increasing SSA and decreasing fall risk (B=-0.037, p=0.011). PTA explains 10.4% of the fall risk and shows a positive association; that is, as the PTA increases, the risk of falling also increases (B=0.028, p<0.001).

Fall Risk and Psoas Muscle Measurements at Various Levels on CT and MRI

A difference was found between the groups in the mean anteroposterior/mediolateral (AP/ML) values at the L4-5 level of the psoas muscle, and it was determined that this variable showed a statistically significant low positive correlation with the risk of falling (r=0.227). This value was highest in the high-risk fall group and lowest in the low-risk fall group. A significant difference was observed between the groups in the mean cross-sectional area (CSA) values at the L4-5 and L2-3 levels of the psoas muscle, while a borderline significant difference was found between the groups in the mean CSA at the L3-4 level. At all levels, the highest mean CSA values were found in the low-risk fall group, and the lowest mean CSA values in the moderate risk fall group. A statistically significant difference was found between the groups in terms of psoas muscle index (PMI), with the highest PMI value in the low-risk fall group and the lowest in the moderate risk fall group. At the L3-4 and L2-3 levels, a statistically significant moderate negative correlation was found between the groups for both the anterior margin gap and center gap (r=-0.293, -0.293, -0.339, -0.343). More negative Anterior Margin and Center Gap values were observed at these levels in the high risk fall group. A statistically significant difference was also found between the groups in the position of the psoas muscle at the L3-4 and L2-3 levels, with more negative positions detected in the moderate and high risk groups at both levels. All data are given in Table 3.

Multivariate logistic regression analysis revealed that variables at the L4-5 level explained 8.5% of the fall risk, though this result was borderline significant (p=0.056). Specifically, the mean AP/ML values at the L4-5 level had a statistically significant positive effect on fall risk, accounting for 5% of the risk, with an increase in AP/ML values leading to a higher fall risk (B=0.724, p=0.012). At the L3-4 level, variables explained 13.2% of the fall risk (p=0.004), with mean CSA values demonstrating a statistically significant negative effect, reducing the fall risk by 3.5% as CSA values increased (B=-0.062, p=0.036). Additionally, the position of the psoas muscle relative to the disc at L3-4 had a significant negative impact on fall risk, accounting for 5.5% of the risk, with a positive displacement in muscle position decreasing fall risk (B=-0.514, p=0.008). At the same level, the mean anterior margin gap (B=-0.052, p=0.002) and center gap (B=-0.047, p<0.001) also showed statistically significant negative effects on fall risk, explaining 7.4% and 9.6% of the risk, respectively. Meanwhile variables at the L2-3 level were found to explain 18.8% of the fall risk (p<0.001), with both the mean anterior margin gap (B=-0.421, p<0.001) and center gap (B=-0.414, p<0.001) having statistically significant negative effects, leading to a decreased fall risk as these values increased. Furthermore, the position of the psoas muscle relative to the disc at the L2-3 level had a statistically significant negative effect on fall risk, explaining 13.3% of the risk (B=-0.364, p=0.008).

The Relationship Between the Psoas Muscle and Sagittal Alignment Parameters, and Its Impact on Fall Risk

the relationship between the psoas muscle and sagittal alignment parameters, and its impact on fall risk our study evaluated the relationships between psoas muscle measurements at specific spinal segments and various spinal and pelvic alignment parameters. Significant differences and correlations were

Table 2. Relationship between fall risk groups and spinal alignment

	Total (n=126)	Low-risk fall group (n=42)	Medium-risk fall group (n=42)	High-risk fall group (n=42)	p-value
SVA					**0.016#**
Positive (n/%)	48 (38.1%)	9 (21.4%)	19 (45.2%)	20 (47.6%)	
Neutral (n/%)	49 (38.9%)	25 (59.5%)	13 (31%)	11 (26.2%)	
Negative (n/%)	29 (23%)	8 (19.1%)	10 (23.8%)	11 (26.2%)	
TKA					
Mean ± SD	39.13±12.23	37.33±8.15	40.89±13.23	39.16±14.44	0.413*
Decreased (n/%)	8 (6.3%)	1 (2.4%)	4 (9.5%)	3 (7.1%)	0.063#
Normal (n/%)	98 (77.8%)	39 (92.9%)	28 (66.7%)	31 (78.3%)	
Increased (n/%)	20 (15.9%)	2 (4.8%)	10 (23.8%)	8 (19%)	
LLA					
Mean ± SD	48.72±13.36	48.76±13.19	51.29±12.93	46.11±13.78	0.092¥
Decreased (n/%)	32 (25.4)	11 (26.2%)	7 (16.7%)	14 (33.3%)	0.459#
Normal (n/%)	71 (56.3%)	22 (52.4%)	27 (64.3%)	22 (52.4%)	
Increased (n/%)	23 (18.3%)	9 (21.4%)	8 (19%)	6 (14.3 %)	
CLA					
Mean ± SD	26.07±12.56	22.86±12.14	27.87±13.06	27.49±12.12	0.125*
Decreased (n/%)	50 (39.7%)	20 (47.6%)	14 (33.3%)	16 (38.1%)	0.485#
Normal (n/%)	72 (57.1%)	22 (52.4%)	26 (61.9%)	24 (57.1%)	
Increased (n/%)	4 (3.2%)	0 (0%)	2 (4.8%)	2 (4.8%)	
PI					
Mean ± SD	56.77±11.31	56.19±12.51	55.95±12.03	58.16±9.29	0.621*
Decreased (n/%)	25 (19.8%)	7 (16.7%)	12 (28.6%)	6 (14.3%)	0.086#
Normal (n/%)	27 (21.4%)	14 (33.3%)	5 (11.9%)	8 (19%)	
Increased (n/%)	74 58.7%)	21 (50%)	25 (59.5%)	28 (66.7%)	
SSA					
Mean ± SD	32.83±9.41	34.94±9.35	33.61±8.55	29.93±9.76	**0.035¥**
Decreased (n/%)	76 (60.3%)	24 (57.1%)	22 (52.4%)	30 (71.4%)	**0.040#**
Normal (n/%)	35 (27.8%)	10 (23.8%)	17 (40.5%)	8 (19%)	
Increased (n/%)	15 (11.9%)	8 (19%)	3 (7.1%)	4 (9.5%)	
Sagittal classification of back type					
Type I	13 (10.3%)	7 (16.7%)	5 (11.9%)	1 (2.4%)	**<0.01#**
Type II	62 (49.2%)	17 (40.5%)	15 (35.7%)	30 (71.4%)	
Type III	30 (23.8%)	9 (21.4%)	14 (33.3%)	7 (16.7%)	
Type IIIAP	6 (4.8%)	1 (2.4%)	5 (11.9%)	0 (0%)	
Type IV	15 (11.9%)	8 (19%)	3 (7.1%)	4 (9.5%)	
Pelvic tilt angle					
Mean ± SD	24.49±9.52	21.67±8.65	22.62±8.91	29.17±9.36	**0.01¥**
Decreased (n/%)	9 (7.1%)	4 (9.5%)	5 (11.9%)	0 (0%)	**<0.01#**
Normal (n/%)	30 (23.8%)	16 (38.1%)	8 (19%)	6 (14.3%)	
Increased (n/%)	87 (69.1%)	22 (52.4%)	29 (69.1%)	36 (85.7%)	
Spinopelvic (PI-LL) mismatch					
Mean ± SD	8.04±13.14	7.42±12.02	4.66±9.94	12.05±15.95	**0.066¥**
Low-normal mismatch (n/%)	76 (60.3%)	28 (66.7%)	31 (73.8%)	17 (40.5%)	**<0.01#**
Medium mismatch (n/%)	26 (20.6%)	6 (14.3%)	9 (21.4%)	11 (26.2%)	
High mismatch (n/%)	24 (19.1%)	8 (19%)	2 (4.8%)	14 (33.3%)	

Data presented as mean (±SD) or number (n/%) of patients. CLA: Cervical lordosis angle, LLA: Lumbar lordosis angle, PI: Pelvic incidence, SSA: Sacral slope angle, SVA: Sagittal vertical axis, TKA: Thoracic kyphosis angle. The p-value refers to the difference between the groups, $p<0.05$ statistically significant. *: ANOVA, #: Chi-square test, ¥: Kruskal-Wallis-H test found between the psoas muscle and TKA, PI, PTA, SSA, and PI-LL mismatch. A positive correlation was identified between the AP/ML ratio of the psoas muscle at the L4/5 level and the TKA (r=0.178, p=0.046). Conversely, a negative correlation was found between TKA and the anterior gap of the psoas muscle at the L3/4 and L2/3 levels (p=0.045, 0.011; r=-0.179, -0.226, respectively). A statistically significant positive correlation was observed between the CSA of the psoas muscle at the L3/4 level and the PI (r=0.180, p=0.044). When analyzed across different PI groups, the AP/ML ratio at the L2/3 level showed a significant difference between groups (p<0.01), with individuals with a higher PI angle exhibiting a greater AP/ML ratio at this level. Significant positive correlations were found between PTA and the CSA of the psoas muscle at the L3/4 and L4/5 levels (r=0.197, 0.242; p=0.027, <0.01). Additionally, a negative correlation was observed between PTA and the anterior gap of the psoas at the L2/3 and L3/4 levels (r=-0.183, -0.194; p=0.040, 0.030). Significant differences were noted between PTA groups concerning the CSA of the psoas muscle at the L4/5 and L3/4 levels (p=0.012, 0.037). Specifically, individuals with a high PTA showed an increase in psoas muscle CSA at these levels. Across different SSA groups, significant differences were observed in the anterior gap at the L4/5 level (p=0.043), with individuals with a higher SSA showing a greater anterior gap at this level. The CSA of the psoas muscle at the L3/4 and L4/5 levels and the PMI were significantly positively correlated with the PI-LL mismatch (r=0.199, 0.220, 0.182; p=0.026, 0.013, 0.041, respectively). In addition, significant differences in psoas muscle CSA at the L2/3

Table 3. Relationship between fall risk groups and psoas muscle measurements at various levels on CT and MRI

	Total (n=126)	Low-risk fall group (n=42)	Medium-risk fall group (n=42)	High-risk fall group (n=42)	p-value
AP/ML ratio (mm)					
L4-5 Level (mean ± SD)	1.18±0.25	1.13±0.20	1.14±0,26	1.27±0.27	**0.015¥**
L3-4 Level (mean ± SD)	1.73±0.45	1.81±0.51	1.70±0.44	1.68±0.40	0.486¥
L2-3 Level (mean ± SD)	2.51±0.62	2.65±0.74	2.37±0.53	2.51±0.55	0.323*
CSA (cm^2)					
L4-5 Level (mean ± SD)	6.45±3.78	7.82±4.59	5.26±2.77	6.26±3.36	**<0.01¥**
L3-4 Level (mean ± SD)	3.59±2.49	4.51±3.32	2.89±1.53	3.38±2.02	**0.060¥**
L2-3 Level (mean ± SD)	1.521.17	1.91±1.59	1.19±0.73	1.47±0.89	**<0.01¥**
PMI at the L3 vertebra level (cm^2/m^2)					
Mean ± SD (min-max)	4.07±3.27	5.044.32	2.98±1.60	4.19±3.03	**0.041¥**
Anterior margin gap (mm)					
L4-5 Level (mean ± SD)	-0.06±6,95	-1.88±5.04	-0.89±6.48	-0.34±7.54	0.800¥
L3-4 Level (mean ± SD)	-3.47±4.28	1.06±6.82	-3.84±3.39	-4.70±3.84	**<0.01¥**
L2-3 Level (mean ± SD)	-3.19±2.71	-1.65±3.66	-3.48±1.69	-4.44±1.38	**0.001¥**
Center gap (mm)					
L4-5 Level (mean ± SD)	-0.23±6.77	0.90±6.53	-1.15±6.48	-0.44±7.27	0.546¥
L3-4 Level (mean ± SD)	-3.77±5.41	-1.48±6.15	-4.283.96	-5.575.17	**<0.01¥**
L2-3 Level (mean ± SD)	-2.20±1.77	-1.23±2.44	-2.35±1.07	-3.02±0.89	**<0.001¥**
Position of the psoas muscle					
L4-5 Level (n/%)					0.211#
Negative	64 (50.8%)	17 (40.5%)	25 (59.5%)	22 (52.4%)	
Positive	62 (49.2%)	25 (59.5%)	17 (40.5%)	20 (47.6%)	
L3-4 Level (n/%)					**0.010#**
Negative	105 (83.3%)	29 (69%)	38 (90.5%)	38 (90.5%)	
Positive	21 (16.7%)	13 (31%)	4 (9.5%)	4 (9.5%)	
L2-3 Level (n/%)					**<0.001#**
Negative	114 (90.5%)	31 (73.8%)	41 (97.6%)	42 (100%)	
Positive	12 (9.5%)	11 (26.2%)	1 (2.4%)	0 (0%)	

Data presented as mean (±SD) or number (n/%) of patients. AP: Anterior-posterior, cCSA: Cross-sectional area, CT: Computed tomography, L: Lumbar, ML: Medial lateral, MRI: Magnetic resonance imaging, PMI: Psoas muscle index, SD: Standard deviation, The p-value refers to the difference between the groups, p<0.05 statistically significant. #: Chi-square test, ¥: Kruskal-Wallis-H test level were observed among PI-LL mismatch groups (p=0.041), with individuals with a high spinopelvic mismatch showing a decrease in psoas muscle CSA at this level.

Discussion

It is essential to diagnose fall risk and assess the associated risk factors to prevent falls. Research has demonstrated that sagittal spinal misalignment and sarcopenia are linked to an increased risk of falls in older adults, aiding in the identification of individuals at high risk (8,9). Therefore, in our study, we examined the relationship between sagittal alignment, psoas muscle cross-sectional analysis, and fall risk across groups classified by the Tinetti balance and gait questionnaire.

Fall Risk and Demographic Data

Studies have reported that risk factors for falls in older adults include advanced age, female gender, physical frailty, muscle weakness, unsteady gait and balance, impaired cognition, and depressive symptoms (18,19). Consistent with this, our study found statistically significant differences in gender distribution and age among different fall risk groups. Specifically, a higher proportion of females was observed in the medium-risk group, while the high-risk group had a greater proportion of males. Additionally, a significant negative correlation was found between age and Tinetti scores (balance, gait, and total), alongside a positive correlation between age and fall risk, indicating that as age increases, physical performance decreases, leading to higher fall risk. Regression analyses further underscored the importance of age in predicting fall risk, suggesting that age alone accounts for a significant portion of the risk. This highlights the need to prioritize age as a key factor in fall prevention strategies. Additionally, one study reported a positive correlation between age and the risk of falls and fracture incidence but found no significant differences in age, gender, body weight, or height between fallers and non-fallers (17). Similarly, in our study, no significant differences were observed among the fall risk groups in terms of weight, height, and BMI.

Fall Risk and Spinal Alignment

Mechanical limitations in lumbar extension, often due to back muscle weakness and/or vertebral deformities, can result in a rigid spine, decreased lumbar lordosis, and increased thoracic or thoracolumbar kyphosis. These spinal alterations are associated with a greater risk of falls, as they lead to an increased spinal and whole-body curvature, an anterior shift in the center of gravity, postural instability, and restricted horizontal gaze. To compensate for these changes and restore postural stability, compensatory mechanisms such as posterior pelvic tilt, hip extension, and knee flexion are adopted. However, the resulting knee-flexed posture demands increased energy expenditure from the lower extremity muscles during standing and walking, leading to fatigue and, consequently, a higher risk of falls. Furthermore, spinal misalignment reduces spinal mobility, limiting the body's ability to respond effectively to postural sway caused by external forces, further contributing to fall risk (17,20,21). The following radiological parameters have been identified in studies as significant risk factors for falls or fractures: decreased TKA (22), decreased LLA (20-23), decreased lumbar range of motion, decreased SSA, increased TKA/LLA ratios, increased PI and PTA (24), and increased SVA.

Our study examined the distribution of different spine and pelvic parameters among fall risk groups and evaluated the possible relationships between these parameters and fall risk. The findings show that spine and pelvic alignment features exhibit certain patterns, especially in high fall risk groups, and these patterns may be associated with balance and gait dysfunctions.

SVA is an important parameter reflecting global spinal sagittal balance. In a study, it has shown that individuals who experience falls have poorer body balance, spinal sagittal alignment, muscle strength, and walking speed compared to those who do not fall (23). Studies have shown that in patients with osteoporotic vertebral compression fractures, the center of gravity of the body moves forward due to the compression of the fractured vertebral body and the increase in kyphosis deformity. Consequently, it was found that the SVA in these patients is higher than in healthy individuals (25,26). In our study, SVA was significantly different among fall-risk groups, with a higher prevalence of positive SVA in the moderate and high-risk groups compared to the low-risk group. This suggests that individuals at higher risk of falling may exhibit more pronounced postural deviations, potentially contributing to an increased risk of falls. Regarding the relationship between SVA and the Tinetti Gait Score, there was a statistically significant positive correlation, indicating that walking performance tends to decrease as SVA increases. This finding underscores the importance of spinal alignment in understanding the risk of falls associated with walking performance.

In their study, Imagama et al. (23) found a negative correlation between SSA and walking speed. They also indicated that optimal spinal sagittal alignment can enhance body balance and reduce the risk of falls by increasing muscle strength and improving 10-meter walking speed (23). Similarly, in our study, it was found statistically significant differences in SSA across fall-risk groups, with the high-risk group exhibiting a significantly lower mean SSA compared to the low-risk group. This suggests that individuals in the high-risk category may have more pronounced spinal misalignments, which could contribute to their increased risk of falling.

Maintaining balanced spinal sagittal alignment is essential for preventing falls, given its strong connection to back muscle strength, body stability, and clear forward vision (23,24). The sagittal back type classification used in evaluating normal sagittal alignment was determined according to SSA and PI, and five subtypes were defined (13). Upon reviewing the literature, we did not find any studies evaluating the relationship between sagittal back types and fall risk. In our study, significant differences were observed among the fall-risk groups based on the Sagittal back type classification. Specifically, Type II back type was more prevalent in the high-risk group, while Type I back type was less common. These findings suggest that variations in sagittal back types may be associated with differing fall risk.

Lumbosacral alignment, particularly LLA, significantly impacts the quality of life, sagittal balance, and fall risk in the geriatric population (27,28). Studies indicate that individuals with a history of falls exhibit reduced LLA compared to those without, and a loss of lumbar lordosis is linked to increased fall risk (17,21). For optimal spinal balance, the PTA should be less than half of the PI, while the SSA should exceed half of the PI (29). Additionally, the spinopelvic mismatch, defined as the difference between PI and LL, indicates normal alignment when the difference is less than 10 degrees; a difference greater than 10 degrees suggests malalignment or mismatch (30). Changes in pelvic position play a crucial role in compensating for spinal imbalance. The occurrence of osteoporotic vertebral compression fractures leads to a decrease in lumbar lordosis and an increase in C7-SVA, resulting in forward trunk lean. To maintain spinal balance, compensatory posterior pelvic rotation occurs, accompanied by corresponding adjustments in the hip and knee joints. Sagittal imbalance arises when spinal kyphosis and hip degeneration in elderly patients exceed the capacity of these compensatory mechanisms (31,32). In patients with sagittal imbalance, loss of LLA is a key factor that triggers the compensation mechanism, while PI reflects the compensatory capacity to maintain overall spinal balance and reduce forward trunk bending. To achieve balance between the spine and pelvis, thoracic kyphosis is reduced, and pelvic tilt is increased, which helps to pull the trunk backward and align the center of gravity with the midline (33,34).

In our study, statistically significant but moderate negative relationships were found between PTA and various measures of balance and gait, indicating that increased PTA is associated with decreased performance in these parameters. Regarding spinopelvic mismatch, no significant differences were found in mean values between the groups. However, the distribution of spinopelvic mismatch levels across fall-risk groups demonstrated a higher prevalence of spinopelvic mismatch in those at greater risk for falls. A weak negative correlation was also identified between spinopelvic alignment and overall functional scores, suggesting that misalignment may contribute to impaired balance and gait. Multivariate logistic regression analysis revealed that spinal and pelvic alignment measurements could account for a portion of the overall fall risk. Specifically, PI-LL difference emerged as a predictor of fall risk, with greater mismatch linked to a higher risk of falling. Similarly, the SSA exhibited a negative association with fall risk, where improved sacral alignment was linked to a lower likelihood of falls. Conversely, increased PTA was positively associated with fall risk, implying that greater pelvic tilt contributes to a higher likelihood of falls. Moreover, significant differences were observed between fall-risk groups in terms of spinal and pelvic alignment characteristics, including sagittal classification, pelvic tilt, and spinopelvic alignment. These results suggest that pelvic and spinal alignment variables, particularly PI-LL difference, SSA, and PTA, are critical factors in predicting fall risk. Additionally, the findings highlight a strong relationship between these alignment parameters and dysfunctions in balance and gait, emphasizing the interrelated nature of posture and fall risk.

Fall Risk and Psoas Muscle Measurements at Various Levels on CT and MRI

Sarcopenia is a progressive and systemic skeletal muscle disorder characterized by a decline in muscle mass and function (35). The European Working Group on Sarcopenia in Older People advocates the use of advanced imaging techniques, such as CT and MRI, as the preferred modalities for assessing muscle mass and fat infiltration associated with sarcopenia (35). A study has stated that measurements at a single anatomic site, such as the extremities or abdominal muscles, can provide a reasonably accurate measure of whole-body muscle mass in the assessment of muscle mass (36). Appendicular muscle mass, which includes limb muscles, is strongly influenced by an individual's activity level. In contrast, the measurement of psoas and abdominal muscle mass via CT or MRI has gained prominence in sarcopenia assessment, as these muscle groups are considered less dependent on physical activity levels (35-37). In addition, the CSA of the right and left psoas muscle, particularly at the mid-level of the L3 vertebra, when normalized to the individual's height squared, has been shown to correlate strongly with total skeletal muscle volume (18).

Studies have reported that sarcopenia is associated with functional impairment, and physical disability, and its negative effects on balance and muscle strength increase the risk of falls and, consequently, the likelihood of complications related to osteoporotic fractures (38,39). In addition, several studies have reported an association between spinal sagittal malalignment and decreased muscle mass in patients with spinal conditions, suggesting that reduced muscle mass may contribute to the underlying mechanism of spinal sagittal malalignment in patients without vertebral fractures (39,40). However, the decrease in appendicular skeletal muscle mass index was found to not affect sagittal spinal malalignment (39,40). Miyakoshi et al. (41) evaluated the factors contributing to spinal mobility in postmenopausal osteoporotic patients. They found that age, lumbar kyphosis angle, back extensor strength, lumbar paravertebral muscle thickness measured using ultrasound, and the number of vertebral fractures were significantly associated with total spinal range of motion. One study reported that PT is significantly correlated with the lumbar paraspinal muscle CSA (42), while another study found that the paraspinal functional cross-sectional area—calculated by subtracting the fat tissue area from the CSA on magnetic resonance imaging—was lower in the sagittal imbalance group (43).

In literature, PMI values have been standardized in certain studies based on age and gender (37,44). However, in our study, the psoas muscle was evaluated across different age groups within fall risk categories, and as such, group differences were assessed instead of applying standardized values for specific age or gender cohorts. The low-risk group was generally found to have lower AP/ML ratios, larger CSA values, and fewer negative gaps; while the high risk group had higher AP/ML ratios, smaller CSA values at certain levels, and more negative gaps. These findings suggest that certain anatomical and muscle mass characteristics may be associated with the risk of falling. These findings show that the characteristics of the psoas muscle at different anatomical levels are significantly associated with the risk of falling. In particular, variables such as the AP/ML ratio of the psoas muscle at the L4-5 level stand out as factors that increase the risk of falling. At the same time, the psoas muscle characteristics at the L3-4 and L2-3 levels, especially CSA and gap measurements, were determined as factors that reduce the risk of falling. These results suggest that the anatomical structure and muscle mass of the psoas muscle may have a significant effect on the risk of falling in individuals. Such findings suggest that measurements of the psoas muscle can be used in the assessment and management of the risk of falling in elderly individuals. At the same time, these data may help identify potential areas of intervention to develop strategies to reduce the risk of falling.

The Relationship Between the Psoas Muscle and Sagittal Alignment Parameters, and Its Impact on Fall Risk

Our findings highlight that the size, shape, and positioning of the psoas muscle significantly influence thoracic curvature, pelvic orientation, and overall sagittal balance, which are essential for postural stability. A positive correlation was observed between the AP/ML ratio of the psoas muscle at the L4/5 level and TKA. This finding suggests that structural adaptations at this level, possibly to enhance lateral stability, are associated with a more pronounced thoracic kyphosis. In contrast, a negative correlation between TKA and the anterior gap of the psoas at the L2/3 and L3/4 levels indicates that increased anterior muscle spacing may counteract excessive thoracic curvature. The CSA of the psoas muscle at the L3/4 level was positively correlated with PI, indicating that larger psoas muscles may influence pelvic orientation and the spine-pelvis relationship. Furthermore, individuals with higher PI also exhibited a greater AP/ML ratio, suggesting a shift in postural strategies driven by altered pelvic alignment. Our results demonstrate that individuals with a higher SSA tend to have a larger anterior gap at the L4/5 level, suggesting that changes in SSA affect lumbar segment positioning and spinal mechanics. A positive correlation was found between PTA and the CSA of the psoas at both L3/4 and L4/5 levels, indicating that increased muscle volume may serve as a compensatory mechanism to support altered pelvic tilt. Conversely, a negative correlation between PTA and the anterior gap at the L2/3 and L3/4 levels suggests that greater anterior spacing could reduce pelvic tilt, promoting a more balanced posture. Our study found a positive correlation between the CSA of the psoas at L3/4 and L4/5 levels and the PI-LL mismatch, indicating that larger muscle size may contribute to spinopelvic imbalance. Additionally, individuals with significant spinopelvic mismatch exhibited reduced psoas CSA at the L2/3 level, possibly reflecting muscle atrophy or functional decline due to chronic misalignment. This reduction may impair core stability and increase the risk of falls. Our findings, similar the literatüre (39-43), demonstrate that specific structural characteristics of the psoas muscle are significantly associated with sagittal alignment parameters, including TKA, PI, PTA, SSA, and the PI-LL mismatch, and emphasize the importance of the psoas muscle in regulating sagittal alignment and postural balance.

Study Limitations

Our study has some limitations. Since participants were assessed solely for fall risk, their fall history was not questioned. Additionally, lower extremity alignment disorders secondary to sagittal alignment disorders of the spine were not evaluated. However, the strengths of our study include the assessment of fall risk in young adults and the consideration of preventable factors that increase fall risk, such as spinal alignment disorders and psoas muscle measurements.

Conclusion

Our findings suggest that the presence of sarcopenia and sagittal malalignment contribute significantly to fall risk. Additionally, the influence of the psoas muscle on spinopelvic alignment highlights its crucial role in maintaining postural balance and underscores the need for considering muscular factors in evaluating fall risk and sagittal imbalance. Evaluating these variables could provide crucial insights for fall risk prediction and the development of preventive strategies in clinical practice. Treatment efforts should focus on improving muscle mass, strength, and overall physical condition. Screening patients for spinal malalignment and sarcopenia, followed by the implementation of functional exercise therapy aimed at restoring spinal mobility and enhancing muscular strength, may help reduce the incidence of falls.

Ethics

Ethics Committee Approval: Approval for the study was obtained from the Local Ethical Committee (Kütahya Health Sciences University Non-Interventional Research Ethics Committee, no. 2023/05-07, dated: April 25, 2023).

Informed Consent: All individuals included in the study signed an informed consent form, stating that they participated in the study voluntarily.

Footnotes

Authorship Contributions

Surgical and Medical Practices: H.T., Concept: H.T., Design: H.T., Data Collection or Processing: H.T., H.H.G., Analysis or Interpretation: H.T., H.H.G., Literature Search: H.T., H.H.G., Writing: H.T., H.H.G.

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