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Research Article

# Sagittal spinopelvic alignment and psoas muscle thickness in young adults: insights from a cross-sectional CT analysis

Zeynep Nilufer Tekin[1], Bilinc Dogruoz Karatekin[2]

1 *Department of Radiology, Goztepe Prof Dr Suleyman Yalcin City Hospital, Istanbul, Turkey*

2 *Department of Physical Medicine and Rehabilitation, Goztepe Prof Dr Suleyman Yalcin City Hospital, Istanbul, Turkey*

**Corresponding author:** Bilinc Dogruoz Karatekin, Department of Physical Medicine and Rehabilitation, Goztepe Prof Dr Suleyman Yalcin City Hospital, Istanbul, Turkey; Email: bilincdogruoz@hotmail.com

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## Abstract

**Introduction:** To ensure optimal alignment between the spine and pelvis, it is essential to understand the sagittal spinal and spinopelvic parameters as well as the interrelationships among these parameters.

**Aim:** The aim is to provide normative values for spinopelvic parameters in healthy adults and to investigate the relationship between psoas muscle thickness index (PMTI) and spinopelvic parameters on whole spine CT imaging.

**Materials and methods:** Pelvic tilt (PT), sacral slope (SS), pelvic incidence (PI), lumbar lordosis (LL), thoracic kyphosis (TK), sagittal vertical axis (SVA), T1-S1 length, L1-S1 length, and psoas muscle thickness (PMT) were measured on whole spine CT, and the PMT/T1-S1 length (mm/m) formula was used to calculate PMTI. PI minus LL (PI–LL) values of the cases were calculated; PI–LL>10 were considered as spinopelvic mismatch, and the cases were compared accordingly.

**Results:** The mean age of the 113 cases was 28.09±6.55 years. The mean values of spinopelvic parameters were as follows: PT: 12.50±6.04, SD: 39.67±7.10, PI: 52.17±8.87, LL: 47.36±9.21, TK: 26.80±6.81, SVA: 36.37±13.26, T1-S1: 463.57±24.82, and L1-S1: 187.97±9.81. LL was correlated with SS and PI ($p$<0.001), and SVA with TK and PT ($p$<0.001 and $p$<0.01, respectively). In cases with PI–LL>10, PMTI, PT, and SVA were significantly higher, while SS was significantly lower ($p$<0.05, $p$<0.001, $p$<0.01, and $p$<0.01, respectively).

**Conclusion:** This study established normative values for spinopelvic parameters in healthy adults and demonstrated that spinopelvic mismatch is associated with increased psoas muscle thickness index. These findings suggest that compensatory muscle activity in young adults differs from age-related changes observed in degenerative spinal conditions.

## Keywords

computed tomography, psoas, sagittal balance, spinopelvic parameters, spinopelvic mismatch

## Introduction

One of the most important providers of balance is undoubtedly the spine. However, it is insufficient to consider the spine alone to examine the global sagittal balance. Dubousset et al. refers to the pelvis as the ‘pelvic vertebra’ to emphasize the functional integrity of the pelvis with the vertebral column.[1]

Walking on two legs caused marked adaptations to the human locomotor system. The pelvis has become vertical, and the pelvis is opened to the sides to increase the active moment arm of the muscles attached to this region. The hips, with their strong muscle structure, have become the most important dynamic components of erect posture.[2] Lordoses are formed in the vertebral column to increase the mechanical advantage against gravity. LL is one of the most important parameters of this adaptation and is a physiological phenomenon unique to humans.

Individual differences in LL create biomechanical advantages or disadvantages related to degenerative disorders that may occur. To understand these individual differences, sagittal balance and compensation mechanisms must be figured out. The two main variables in compensation mechanisms are PT and SS. The pelvic incidence (PI) concept, first defined by Duval-Beaupere et al., is equal to the sum of the two variables, PT and SS.[3] PI is individual and does not change for life unless there is a fracture that will impair the sacropelvic mechanism.[4] Thus, maintenance of sagittal balance occurs using the changes between PT and SS, but the sum of both will not change.

Recent studies have shown that the sagittal spinopelvic alignment has a critical importance in adult spinal deformity.[5,6] However, there is no standard sagittal balance in a normal population.[7] The most economical posture around the gravitational force vector determines that person's ideal sagittal balance. Some measurement methods have been developed considering the average values of the populations.[7-9]

To ensure the harmony between the spine and pelvis, we need to know the sagittal spinal and spinopelvic parameters and their relationships. On lateral radiographs, cervical lordosis, TK, LL, SVA, PT, PI, and SS are the main sagittal parameters.

Muscle factors such as back extensor muscle strength and paraspinal muscle volume have been reported to be associated with decreased LL and spinal sagittal imbalance; however, it remains unclear what causes or accelerates spinal sagittal imbalance.[10]

Sagittal imbalance causes increased muscle effort and energy expenditure, resulting in pain and disability. In the literature, an annual loss of muscle mass of approximately 1% has been demonstrated after the age of 40.[11] As a result of muscle weakness, spinal balance deteriorates, and therefore elderly individuals have difficulties in supporting their weight in the lower extremities. The association of trunk muscle mass with low back pain has also been reported in elderly individuals.[12] However, it is necessary to show the connection between spinal sagittal parameters and muscle mass in healthy individuals based on the initial point of origin.

## Aim

The aim of this study was to provide normative values for spinopelvic parameters in adults and to investigate the relationship between PMTI and spinopelvic parameters in young adults using whole spine CT imaging.

## Materials and methods

### Study design

This retrospective study was approved by the University Ethics Committee in accordance with the Declaration of Helsinki (2021/0649). The informed consent requirement was waived in keeping with the policies for a retrospective study.

The study is retrospective, so no treatment was given to the participants, and the manuscript does not contain any personally identifiable information about them.

### Patient selection

One hundred and thirteen consecutive non-spinal trauma patients under 41 years old (98 males and 15 females; mean age 28.09 years, age range 18-41 years) who received cervical, thoracic, and lumbar spine CT between January 2021 and January 2022 were retrospectively enrolled.

Patients lacking complete cervical, thoracic, and lumbar spine or abdominal CT scans, patients with inadequate image quality for radiological evaluation, patients with lumbar spinal pathology, and those under the age of 18 or above the age of 40 were excluded from the study.

Sex and age were investigated as case characteristics, and sagittal cervical, dorsal, and lumbar spine CT images were evaluated by a senior radiologist.

### CT imaging analysis

All multi-slice cervical, thoracic, and lumbar spine CT examinations were obtained using a 64-detector CT scanner (GE Optima CT660 GE Healthcare, Milwaukee, WI) with/without IV contrast medium by using trauma protocol. The CT image data was collected with a GE system equipped with a 512 × 512 matrix detector. The helical scanning region was performed in the supine position without the gantry angle, from above the temporal bone to the hip. The images were acquired using a CT scanner with the following settings: a 24×1.2 mm acquisition, a slice collimation of 1.2 mm, a slice width of 2.5 mm, a pitch of 0.98, a tube voltage of 120 kV, and a tube current-time product of 75 mAs. Axial imaging data was post-processed (GE workstation, GE Healthcare, Milwaukee, WI), and 1.25 mm coronal and sagittal reconstructions were performed.

The Cobb angles between superior endplates of T4-T12 and L1-S1 vertebrae were measured as TK and LL, respectively. In a healthy population, the TK angle is around 42°, and a deviation of ±8° is considered within the normal range.[13] The mean value of LL was 53±16° in healthy adults.[13]

The angle between the S1 superior endplate and the horizontal line was determined as SS. PT was measured as the angle between the vertical reference line and the line connecting the midpoint of the S1 superior endplate to the midpoint of a line between the femoral heads. PI was defined as the angle between a line perpendicular to the S1 superior endplate at its midpoint and the line connecting this midpoint to the femoral heads' middle axis. In this study, pelvic incidence was defined as the total values of PT and SS and was calculated according to the formula: PT+SS. The normal values for PI, PT, and SS in the adults aged 21-40 years were 52°±10, 13°±7, and 39°±9, respectively.[7]

T1-S1 and L1-S1 lengths were defined as vertical distances from the anterior tip of superior endplates of T1 to S1 and L1 to S1 vertebrae on sagittal CT images.

SVA was determined on sagittal spine CT by drawing a vertical line from the midpoint of the C7 corpus down to the sacral plate and then measured as the horizontal distance between this vertical line and the posterosuperior corner of the S1 corpus. For adult patients, this limit is considered normal up to 5 cm.[14]

Measurements of spinopelvic parameters for assessment of sagittal balance are shown in **Fig. 1**.

PMT was defined as the largest transverse diameter of the psoas muscle perpendicular to the longest diameter (anterior-posterior oblique) of the psoas muscle at the transverse process of the third lumbar vertebra. PMTs were measured bilaterally on the Radx PACS system (Simplex Radx 3D, Ankara, Turkey) by a board-certified radiologist with 15 years of experience (Z.N.T.) (**Fig. 2**).

Since the study was retrospective and the height data of the cases could not be accessed, standardization according to height could not be made in the comparison of PMT. In order to reach a more objective conclusion, the PMT/T1-S1 length (mm/m) formula was used to calculate PMTI.

## Statistical analysis

All statistical analyses were performed with SPSS Statistics Version 25.0 software (IBM, Chicago, IL). Descriptive statistics were presented as mean, standard deviation, and maximum-minimum values. The relationship among spinopelvic parameters was analyzed using Pearson's *r* correlation, and the relationship between demographics and spinopelvic parameters was analyzed by using Spearman's r correlation. The effect size of the relationship is the correlation coefficient according to Cohen's classification: between 0.10 and 0.29 is defined as small, between 0.30 and 0.49 as moderate, and 0.50 to 1.0 as high correlation.[15] To investigate the difference in continuous variables between PI–LL groups, independent sample t-tests were used. The results were evaluated bilaterally at a 95% confidence interval, with significance levels at $p<0.05$ and $p<0.01$.

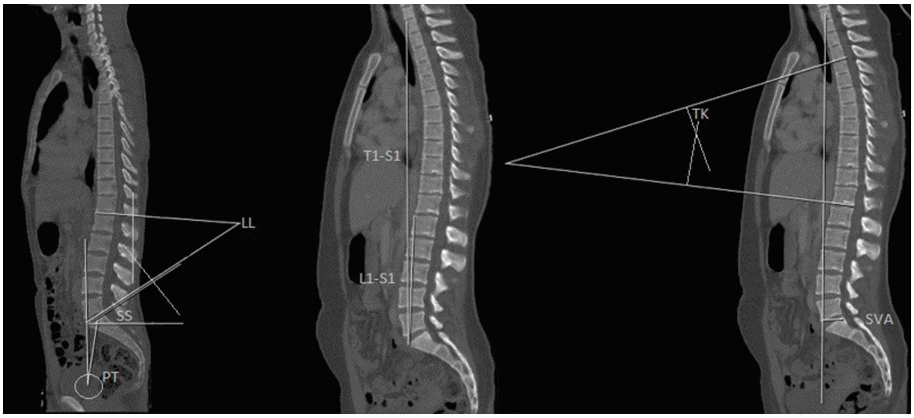


**Figure 1.** Demonstration of measurements of spinopelvic parameters.

**Figure 2.** Demonstration of measurement of psoas muscle thickness on CT.

## Results

Descriptive statistics of 113 consecutive cases (98 males, 15 females) are shown in **Table 1**. Distributions of all the parameters were normal except age and sex.

### Correlations among sagittal spinopelvic parameters and age and sex

Correlations of sagittal spinopelvic parameters with each other are shown in **Table 2**. According to the Pearson cor-

**Table 1.** Descriptive statistics of the participants

| | n | Min. | Max. | Mean | SD |
|---|---|---|---|---|---|
| Age | 113 | 18 | 41 | 28.09 | 6.55 |
| Psoas thickness index | 113 | 3.64 | 12.38 | 7.00 | 1.43 |
| Pelvic tilt | 107 | 0 | 29.60 | 12.50 | 6.04 |
| Sacral slope | 113 | 24.80 | 57.20 | 39.67 | 7.10 |
| Pelvic incidence | 108 | 36.00 | 73.50 | 52.17 | 8.87 |
| Lumbar lordosis | 113 | 25.70 | 70.70 | 47.36 | 9.21 |
| PI–LL | 108 | -12.20 | 28.90 | 4.81 | 7.34 |
| Thoracic kyphosis | 107 | 7.80 | 45.60 | 26.80 | 6.81 |
| Sagittal vertebral axis | 101 | 3.20 | 71.60 | 36.37 | 13.26 |
| T1-S1 length | 101 | 392.80 | 518.10 | 463.57 | 24.82 |
| L1-S1 length | 113 | 165.60 | 215.50 | 187.97 | 9.81 |

PI: pelvic incidence; LL: lumbar lordosis; PI–LL: PI minus LL

**Table 2.** Correlation analysis of the spinopelvic alignment parameters

| | | PT | SS | PI | LL | PI–LL | TK | SVA | T1-S1 | L1-S1 |
|---|---|---|---|---|---|---|---|---|---|---|
| PT | rho | 1.000 | | | | | | | | |
| | *p* | | | | | | | | | |
| SS | rho | −0.119 | 1.000 | | | | | | | |
| | *p* | 0.202 | | | | | | | | |
| PI | rho | 0.611** | 0.713** | 1.000 | | | | | | |
| | *p* | 0.000 | 0.000 | | | | | | | |
| LL | rho | −0.147 | 0.914** | 0.622** | 1.000 | | | | | |
| | *p* | 0.131 | 0.000 | 0.000 | | | | | | |
| PI–LL | rho | 0.857** | −0.273** | 0.388** | −0.481** | 1.000 | | | | |
| | *p* | 0.000 | 0.005 | 0.000 | 0.000 | | | | | |
| TK | rho | 0.000 | 0.022 | −0.005 | 0.178 | −0.185 | 1.000 | | | |
| | *p* | 1.000 | 0.818 | 0.962 | 0.065 | 0.062 | | | | |
| SVA | rho | 0.300* | −0.174 | 0.058 | -0.136 | 0.260* | 0.506** | 1.000 | | |
| | *p* | 0.003 | 0.082 | 0.578 | 0.174 | 0.011 | 0.000 | | | |
| T1-S1 | rho | 0.116 | 0.051 | 0.102 | 0.057 | 0.067 | −0.151 | 0.081 | 1.000 | |
| | *p* | 0.262 | 0.612 | 0.324 | 0.569 | 0.519 | 0.134 | 0.423 | | |
| L1-S1 | rho | −0.053 | 0.086 | 0.024 | 0.094 | −0.085 | −0.023 | 0.087 | 0.830** | 1.000 |
| | *p* | 0.591 | 0.364 | 0.805 | 0.322 | 0.383 | 0.814 | 0.379 | 0.000 | |

PT: pelvic tilt; SS: sacral slope; PI: pelvic incidence; LL: lumbar lordosis; TK: thoracic kyphosis; SVA: sagittal vertical axis; PI–LL: PI minus LL; *$p<0.05$, **$p<0.001$

relation analysis, the correlation between LL and SS and LL and PI was high ($p<0.001$, rho=0.914; $p<0.001$, rho=0.622, respectively). The correlation between TK and SVA was high ($p<0.001$, rho=0.506). The correlation between SVA and PT was moderate ($p<0.01$, rho=0.300). The correlation between PI–LL and PT was high, PI–LL and SS was low, and PI–LL and PI and PI–LL and LL were moderate ($p<0.001$, rho=0.857; $p<0.01$, rho=−0.283; $p<0.001$, rho=0.388; $p<0.001$, rho=−0.481, respectively).

Correlations of sagittal spinopelvic parameters with age and gender are shown in **Table 3**.

Age and TK were correlated to a low degree ($p<0.01$, rho=0.255). Sex and PMTI, sex and T1-S1 length, and sex and L1-S1 length were moderately correlated ($p<0.001$, rho=0.494; $p<0.001$, rho=0.434; $p<0.01$, =0.360, respectively).

## Evaluation of PI vs LL

**Table 3.** Spearman correlation analysis of the pelvic alignment parameters, demographics and PMTI

| | | PMTI | PT | SS | PI | LL | PI–LL | TK | SVA | T1-S1 | L1-S1 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Age | rho | −0.068 | 0.036 | 0.028 | 0.127 | 0.106 | −0.056 | 0.255* | 0.098 | 0.035 | 0.140 |
| | *p* | 0.499 | 0.714 | 0.767 | 0.194 | 0.264 | 0.569 | 0.008 | 0.331 | 0.732 | 0.138 |
| Sex | rho | 0.494** | 0.005 | −0.077 | −0.098 | −0.072 | 0.004 | 0.100 | 0.132 | 0.434** | 0.360** |
| | *p* | 0.000 | 0.958 | 0.419 | 0.312 | 0.446 | 0.966 | 0.301 | 0.188 | 0.000 | 0.000 |

PMTI: psoas muscle thickness index; PT: pelvic tilt; SS: sacral slope; PI: pelvic incidence; LL: lumbar lordosis; TK: thoracic kyphosis; SVA: sagittal vertical axis; *$p<0.05$, **$p<0.001$

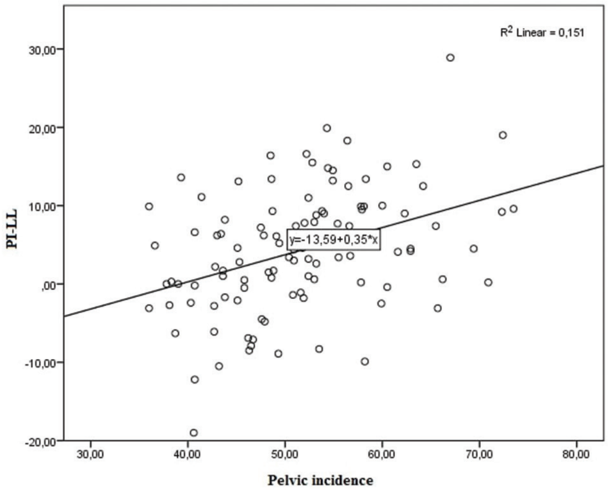


**Figure 3.** Scatterplot diagram showing PI–LL and PI correlation.

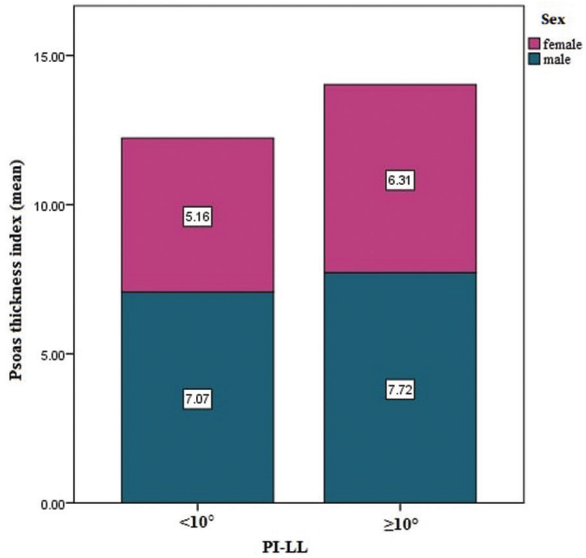


**Figure 4.** Distribution of psoas muscle thickness index values by gender.

A moderate correlation was obtained ($p<0.001$, $rho=0.481$) with the correlation between PI–LL and PI. According to this result, the explanatory power ($R^2$) was 0.151. According to our data, PI–LL was moderately related to PI **(Fig. 3)**.

## Evaluation of spinopelvic mismatch and PMTI

The mean value of PI–LL was 4.81 (SD: 7.34). When PI–LL >10 was considered as the cut-off value[7], spinopelvic mismatch was detected in 23.4% (n=25) of the cases. Comparison of cases with and without spinopelvic mismatch in terms of spinopelvic parameters and PMTI is given in **Table 4**.

The PMTI, PT, and SVA values were found to be significantly higher in patients with spinopelvic mismatch than in those without ($p<0.05$). However, SS values were statistically significantly lower in patients with spinopelvic mismatch ($p<0.05$). The distribution of PMTI values by sex is shown in **Fig. 4**.

# Discussion

**Table 4.** Comparison of the PMTI and spinopelvic parameters of the groups according to PI–LL

| | PI–LL<10 Mean (SD) | PI–LL>10 Mean (SD) | P* |
|---|---|---|---|
| PMTI | 6.78 (1.33) | 7.65 (1.59) | 0.012 |
| Pelvic tilt | 9.97 (5.02) | 18.61 (4.84) | 0.000 |
| Sacral slope | 40.64 (6.76) | 36.08 (6.57) | 0.004 |
| L1-S1 length | 188.53 (9.75) | 187.37 (10.38) | 0.607 |
| T1-S1 length | 462.83 (22.84) | 466.23 (30.52) | 0.574 |
| SVA | 34.15 (11.70) | 60.48 (79.11) | 0.007 |
| Thoracic kyphosis | 27.22 (7.06) | 26.49 (6.58) | 0.656 |

*Independent sample t test; PI: pelvic incidence; LL: lumbar lordosis; PMTI: psoas muscle thickness index; SVA: sagittal vertical axis

This study provided physiological values for pelvic and spinal parameters describing sagittal spinal alignment and PMTI in a cohort of 113 adults. The descriptive values of sagittal balance parameters were comparable to the studies of Hasegawa et al. and Huec et al., except for lower TK values.[8,9]

It was found that LL was correlated with SS and PI, and SVA was correlated with TK and PT. Also, PI−LL was determined to correlate with PI, LL, PT, SVA, and SS. Correlations between sagittal spinopelvic parameters were comparable with previous reports.[7,8,16]

The ability of the human body to maintain its center of gravity with minimum energy expenditure is due to spinal sagittal balance.[2] Spinal sagittal imbalance[17], which causes low back pain and poor quality of life, is also one of the biggest concerns in the field of spine surgery. Insufficient compensation for spinopelvic alignment problems due to the decrease in LL has been indicated as the cause of spinal sagittal imbalance.[18]

LL and the forces forming LL are very important to maintain balance in the sagittal plane.[19] Among them, pelvic incidence is a critical parameter in changing the degree of LL.[20,21] Schwab et al.[7] formulated the relationship between LL and PI with ‘LL=PI±9°’. A cut-off value of 10° for PI−LL mismatch and the predictive value of this cutoff in the success of lumbopelvic fixation operations were also shown.[7,22] In this current study, PI−LL is found to be related to PI. This result is supported by Hyun et al.[23], who reported the ideal LL value in asymptomatic elderly, in contrast to the studies of Schwab et al.[7] and Rothenfuh et al.[22], who investigated the PI−LL value desired to be corrected in people with lumbar spinal pathology. Therefore, this formula needs to be supported by further studies for young adults, the elderly, asymptomatic people, and various pathological conditions.

The relationship between spinal sagittal imbalance and trunk muscle strength has been demonstrated in elderly people.[24] However, the nature of this relationship in healthy young adults was obscure. Therefore, in this study the relationship between PMTI and spinopelvic parameters in healthy young adult individuals was also investigated. A person who has a sagittal balance disorder has to use compensatory mechanisms and contract the neck, back, waist, hip, and leg muscles more in order to get himself into a balanced state. Compensation mechanisms of the spinopelvic alignment problems are not innocent because they require a lot of energy, and the total load created by this energy is especially on the lumbosacral junction. Roussouly et al. used the crane model to describe the loads that the human spine is exposed to.[25]

In order to maintain the balance in crane mechanics, the weight of the “basal contact point” in contact with the ground must be quite high. If the basal contact point of the human spine is acknowledged as the lumbosacral joint, gravity and contraction of the paraspinal muscles are assumed as the two main forces acting on this point. For example, with pelvic retroversion, the vector of gravity is displaced anteriorly.[26] This change lengthens the moment arm of the gravity vector and increases the “basal contact load” acting on the basal contact point with the extended moment arm. To compensate for this, the contraction of the paraspinal and pelvic muscles will increase.

The psoas major muscle functions not only as a hip flexor but also as a stabilizer of the lumbar spine and thus plays an important role in maintaining ergonomic posture. PMT measurement was preferred because of its important dual task and easily applicable defined measurement method in imaging modalities.

In this study, an increase in PMTI, PT, and SVA and a decrease in SS were found in people with PI−LL >10. Ohyama et al. also investigated the relationship between sarcopenia and spinopelvic parameters in 126 individuals and reported greater SVA and TK in patients with spinopelvic mismatch in the sarcopenia group.[27] Since mean TK was found to be lower in this study group than other population norms, no association could be found between spinopelvic mismatch and TK.

In the literature, a negative relationship between pelvic tilt and skeletal muscle mass in degenerative lumbar and cervical disease in advanced age has been reported.[28] While SVA, TK, and PT tend to increase and LL tends to decrease with increasing age, the decrease in skeletal muscle mass is one of the important parameters affecting spinal misalignment.[29] However, according to this study, psoas muscle activity increases as a compensation for spinal misalignment in young healthy adults. Therefore, clinicians should be aware that the compensation mechanisms in young and elderly individuals may be different and should consider these mechanisms in surgical and clinical decision-making.

This study has several limitations. Since the young adult trauma patients admitted to our hospital were mostly male, the gender distribution was not homogeneous. Because the study was a cross-sectional rather than a longitudinal analysis, temporal changes could not be investigated. PMT was the only parameter used in muscle mass analysis due to the retrospective nature of the study. Muscle strength testing and performance analysis should also be added to the measurement of muscle mass in future prospective clinical studies. The PMT/T1-S1 length (mm/m) formula used in the PMTI calculation was produced for this study because the height data of the cases could not be reached. Therefore, it cannot be compared with other studies. Since this study is a single-center retrospective study conducted in a tertiary university hospital, its generalizability is limited.

## Conclusion

This study established normative values for spinopelvic parameters and PMTI in a healthy young adult population using whole spine CT imaging. Importantly, it revealed that the alterations in spinopelvic parameters and the associated increase in PMTI observed in cases of spinopelvic mismatch differ significantly from the patterns seen in elderly individuals and those with spinal pathologies. These findings highlight that compensatory muscle activity, particularly of the psoas major, plays a distinct role in maintaining sagittal alignment in younger populations, which may not directly parallel mechanisms in older adults. Understanding these age-related variations in spinopelvic alignment and muscular adaptation is critical for clinicians and spine surgeons in tailoring preventive, diagnostic, and therapeutic strategies.

## Funding

None

## Declaration of competing interest

There are no disclosures of the authors.

## Ethical statement

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

## Author contributions

Z.N.T. and B.D.K. designed the experiments, analyzed the data, and prepared the manuscript. Both authors approved the final manuscript.

## Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

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None

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