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Research Article

Examination of Age and Gender-Related Changes in Spinopelvic Parameters in Children and Adolescents Using Computed Tomography Images

Burak Oguzhan Karapinar[1], Niyazi Acer[2], Hatice Susar Guler[3], Adem Tokpinar[4], Sureyya Burcu Gorkem[5]

[1]Ondokuz Mayıs University, Health Services of Vocational School, Department of Medical Services and Techniques, Samsun, Türkiye
[2]İstanbul Arel University Faculty of Medicine, Department of Anatomy, İstanbul, Türkiye
[3]Erciyes University, Faculty of Medicine, Department of Anatomy, Kayseri, Türkiye
[4]Ordu University, Faculty of Medicine, Department of Anatomy, Yozgat, Türkiye
[5]Erciyes University, Faculty of Medicine, Department of Radiology, Kayseri, Türkiye

Abstract

Aim: In order for a person to stand in a balanced way, the pelvis and spine must be in harmony. The aim of this study was to determine the normal ranges of spinopelvic parameters in children and adolescents in Türkiye.
Material and Method: In our study, computed tomography images of 1018 healthy 7-17 year olds were examined. As a result of this examination, sacrum pubic incidence, lumbar lordosis, sacral slope, sacral kyphosis, pelvic tilt and pelvic incidence were measured.
Results: The sacrum pubic incidence was 58.71±6.17°, sacral slope 37.26±5.77, lumbar lordosis 42.98±8.06°, sacral kyphosis 21.27±9.96°, pelvic incidence 46.77±6.38, and pelvic tilt 9.51±5.06°. The calculations revealed that, with age, all parameters except pelvic tilt increased significantly. A statistically significant difference was found between the age groups.
Conclusion: The results of this study will contribute to the existing literature and may give clinicians insight into sagittal corrections in spine and pelvic surgery.

Keywords: Sagittal balance, spinopelvic parameters, sacral slope, pelvic incidence

INTRODUCTION

In recent years, numerous studies have emphasized the significance of pelvis morphology in balanced walking and standing upright (1-4). Understanding the morphology of the pelvis in healthy individuals provides important information for planned surgery operations for patients with spinal deformity.

The spine and pelvis must be delicately balanced in order to maintain a proper standing posture. The spine and pelvis, which are lined up to provide the least energy consumption, will also provide a balanced posture (5).

Basic parameters used in the evaluation of spinopelvic balance are sacral slope (SS), pelvic tilt (PT) and pelvic incidence. Pelvic incidence (PI) is often used to assess the sagittal balance of the spine because It is a constant parameter unaffected by the pelvic and spine's positions (6). In hip osteoarthritis or when the femoral head is not spherical, two new parameters have been proposed, namely sacrum pubic posterior angle and sacrum pubic incidence, to replace pelvic incidence (7).

Numerous studies have shown a significant relationship between spinal sagittal balance and pelvic parameters, particularly sacral kyphosis (SK) and lumbar lordosis (LL). It is necessary to consider the spine and pelvis as a whole (8-11).

The presence of abnormal spinopelvic parameters are lumbar disc hernia, low back pain, degenerative and isthmic spondylolisthesis, degenerative disc disease, hip osteoarthrosis and similar pathologies affect the formation and progression. In patients with deformity, spinopelvic parameters fall outside the normal range (12).

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Corresponding Author: Burak Oguzhan Karapinar, Ondokuz Mayıs University, Health Services of Vocational School, Department of Medical Services and Techniques, Samsun, Türkiye
E-mail: burakkarapinar@hotmail.com

Spinopelvic parameters normative values by age groups and population have been reported in numerous research (13-17). However, there have been few studies conducted on the Turkish population of children and adolescents, and these studies have utilized lateral radiography. No study has been found regarding 3D computed tomography (CT) images.

This study aims to determine the normative ranges of spinopelvic parameters using 3D CT images and to examine the development of these parameters in the Turkish child and adolescent population.

MATERIAL AND METHOD

This study was carried out with the scope of the approval and information of Erciyes University Clinical Research Ethics Committee (Date and Decision No: 2019/587).

In this study, pelvis-abdominal CT images taken for any indication of the Turkish population aged 7-17 years were examined. After the examination, individuals with pelvic trauma, hip dislocation, vertebral fracture and scoliosis were excluded and 1018 pelvis-abdominal CT images were selected. The study examined pelvic-abdominal CT images of 1018 healthy children and adolescents (503 female, 515 male, aged 7-17 years) from the Turkish population. The study measured sacral kyphosis, lumbar lordosis, sacral slope, pelvic tilt, pelvic incidence and sacrum pubic incidence (SPI). Each age range is regarded as a group when evaluating by age and divided into 11 groups. The differences between the groups were evaluated statistically.

Creation of 3D Pelvis Skeleton and Measurement of Angles

Three-dimensional pelvis skeleton model was created from pelvis-abdomen CT images for 3D measurement. From this model, anatomical structures other than the reference points required for measurement were excluded from this skeleton model. The measurement of the parameters was performed on the sagittal plane through this image.

While measuring the sacral slope, pelvic tilt and pelvic incidence, the wings of the sacrum and femoral heads were adjusted on top of the sagittal plane. Then, the screen shot was taken and the measurement of the parameters was carried out in the ImageJ program with the Duval-Beaupère method (Figure 1) (6).

Lumbal lordosis and sacral kyphosis were measured using Picture Archiving and Communication System (PACS). In the lumbal lordosis measurement using the Cobb method, the angle between the line drawn tangent to the superior endplate of L1 and the line drawn tangent to the superior endplate of S1 was calculated (8). Sacral kyphosis is defined as the angle formed by a line connecting the midpoint of the inferior and superior borders of S1 and a line connecting the inferior borders of S2 and S4. (Figure 2) (9,18).

While measuring the SPI, the sacrum wings were adjusted to overlap and the created pelvic skeleton was cut in half in a horizontal plane. The left part was removed and the sacrum pubic incidence was measured in the ImageJ program through this image. To measure the sacrum pubic incidence, the vertical line passing through the midpoint between the anterior and posterior edges of the upper surface of S1 and the angle between this point and the line connecting the upper edge of the symphysis pubis are measured (Figure 1) (7).

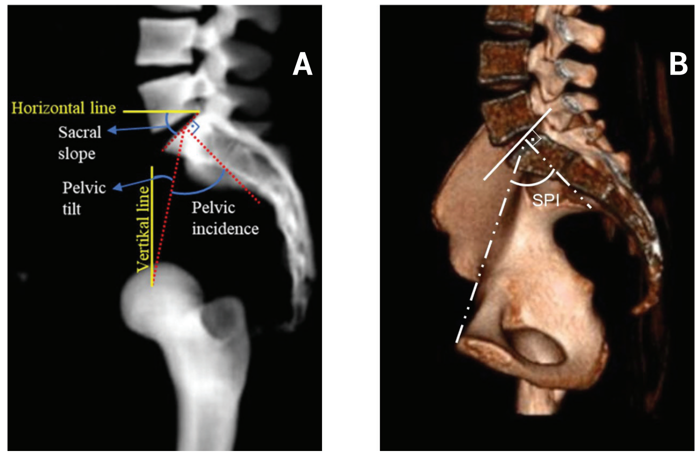

Figure 1. 1A. Measurement of PI, PT and SS with the Duval-Beaupère method. In PI measurement, the midpoint of the superior endplate of S1 is determined and a perpendicular line is drawn from this point. Then, a line is drawn from this determined point to the femoral head. The angle between this line and the vertical line gives the pelvic incidence. In PT measurement, the angle created by a vertical line that passes through the sacral endplate's midpoint, the center of the femoral axis, and the center of the femoral head is measured. In SS measurement, the angle between the line tangent to the superior endplate of S1 and the horizontal line passing through the rear point of the superior endplate of S1 is measured **1B.** In SPI measurement, the vertical line passing through the midpoint between the anterior and posterior edges of the superior endplate of S1 and the angle between this point and the line connecting the upper edge of the symphysis pubis is measured.

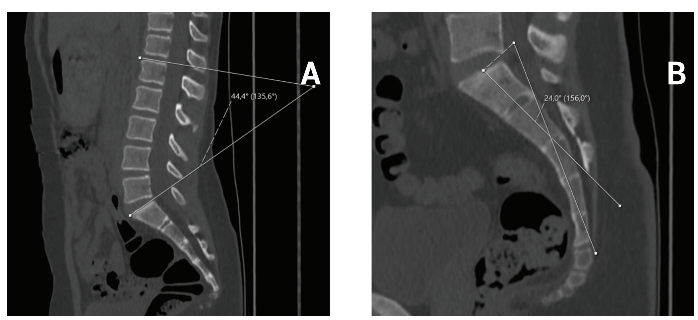

Figure 2. 2A. Measurement of lumbar lordosis by the Cobb method, In the LL measurement, the angle between the line drawn tangent to the upper surface of L1 and the line drawn tangent to the upper surface of S1 was measured **2B.** In SC measurement, the angle formed by the midpoint of the inferior and superior borders of S1 and the line connecting the inferior borders of S2 and S4 was measured

Statistical Analysis

The normal distribution suitability of the data was assessed using histograms, Q-Q plots, and the Shapiro-Wilk test. Levene's test was used to test for variance homogeneity. For quantitative variables, two independent samples t-tests were used to compare groups. Method comparisons were performed using Passing-Bablok regression analysis. The statistical software TURCOSA (Turcosa Analytical Solutions Ltd. Co., www.turcosa.com.tr) was used for data analysis. The significance level was set at $p<0.05$.

Correlation coefficient levels: 0.0≤r<0.20 very poor relationship, 0.20<r<0.40 weak level relationship, 0.40<r<0.60 medium level relationship, 0.60≤r<0.80 good level relationship, 0.80≤r<1.00 very good relationship.

RESULTS

Comparison of Spinopelvic Parameters by Gender

PI, PT, SS, LL, SK and SPI values of 1018 (503 female, 515 male) healthy individuals included in the study were measured. Table 1 shows the mean values and standard deviations of the spinopelvic parameters for males and females. The LL value was higher in women than in men and this statistical difference was significant ($p<0.01$). PI, PT, SS, SK and SPI values were not statistically significant in men and women ($p>0.05$).

Table 1. Comparison of spinopelvic parameters by gender

Parameters	Gender		p value
	Female (n=503)	Male (n=515)	
PI (°)	47.03±6.68	46.52±6.07	0.202
PT (°)	9.49±5.21	9.54±4.91	0.873
SS (°)	37.54±5.93	36.98±5.60	0.120
LL (°)	43.97±8.41	42.01±7.58	<0.01*
SK (°)	21.44±10.06	21.10±9.88	0.583
SPI (°)	58.9±6.50	58.54±5.84	0.350

Data are shown as mean±standard deviation. PI: pelvic incidence, PT: pelvic tilt, SS: sacral slope, LL: lumbar lordosis, SK: sacral kyphosis, SPI: sacrum pubic incidence

Values of Spinopelvic Parameters

Table 2 presents the measured spinopelvic parameters results. The PI, PT, SS, LL, SK and SPI means (± standard deviation) were 46.77±6.38°, 9.51±5.06°, 37.26±5.77°, 42.98±8.06°, 21.27±9.96° and 58.71±6.17° respectively. PI, SS, LL, SK and SPI tend to increase with age. This increase in PI and SPI becomes particularly evident with the onset of puberty (Figure 3). The PI value shows a statistically significant difference between the 7-11 and 13-17 age groups and between the 12 and 15-17 age groups ($p<0.01$). SS and SPI values show statistically significant differences between 7-9 and 13-17 age groups ($p<0.01$). Age-related changes and statistical significance of spinopelvic parameters are shown in Figure 3.

Table 2. Values of spinopelvic parameters

Age	n	PI (°)	PT (°)	SS (°)	LL (°)	SK (°)	SPI (°)
7	83	44.08±5.47	10.43±5.56	33.64±6.24	38.65±7.13	16.33±7.93	55.78±5.20
8	96	43.73±5.81	8.77±5.67	34.96±5.26	41.25±8.30	18.90±8.38	56.07±5.60
9	84	43.45±5.14	8.38±5.11	35.07±5.59	42.29±8.16	21.33±9.09	55.51±5.27
10	85	44.64±6.40	8.20±5.48	36.44±5.24	42.46±7.57	20.65±8.56	56.73±6.22
11	85	44.61±6.51	8.47±5.45	36.15±6.21	43.22±9.22	21.96±11.01	57.66±6.29
12	83	46.09±6.43	8.74±5.08	37.35±6.48	42.91±8.70	20.25±10.38	58.99±6.21
13	102	48.65±6.27	10.43±4.95	38.22±5.23	43.51±8.24	23.58±10.90	60.87±6.24
14	100	48.69±5.62	10.31±4.22	38.38±5.27	43.94±7.76	22.19±9.89	60.14±5.46
15	100	49.41±5.50	10.15±4.61	39.27±4.90	44.51±7.10	23.27±9.95	61.03±5.28
16	100	49.46±5.72	10.22±4.39	39.23±4.97	44.70±7.44	22.00±9.87	60.33±5.72
17	100	49.78±5.98	9.99±4.60	39.78±4.84	44.37±7.53	22.38±11.03	61.17±6.23
Total	1018	46.77±6.38	9.51±5.06	37.26±5.77	42.98±8.06	21.27±9.96	58.71±6.17

Data are shown as mean±standard deviation. PI: pelvic incidence, PT: pelvic tilt, SS: sacral slope, LL: lumbar lordosis, SK: sacral kyphosis, SPI: sacrum pubic incidence

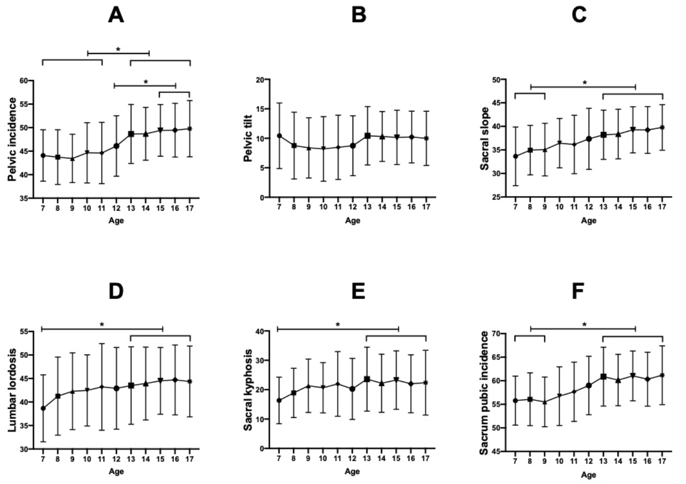

Figure 3. 3A. Age-related change of PI. PI values show a statistically significant difference between the 7-11 and 13-17 age groups and between the 12 and 15-17 age groups (p<0.01) **3B.** Age-related change of PT. PT values did not differ statistically between age groups (p > 0.05) **3C.** Age-related change of SS. SS values show statistically significant differences between 7-9 and 13-17 age groups (p<0.01) **3D.** Age-related change of LL. LL values show statistically significant differences between 7 and 13-17 age groups (p<0.01) **3E.** Age-related change of SK. SK values show statistically significant differences between 7 and 13-17 age groups (p<0.01) **3F.** Age-related change of SPI. SPI values show statistically significant differences between 7-9 and 13-17 age groups (p<0.01)

Method Comparison and Estimating of Pelvic Incidence

The SPI shows a very strong positive correlation with the PI (Figure 4). SPI cannot be used as a substitute for PI. However, this value is sensitive for the estimation of the PI value in cases where the PI cannot be measured. For PI estimation, the formula SPI=0.97(PI)+13.38 can be used (Table 3).

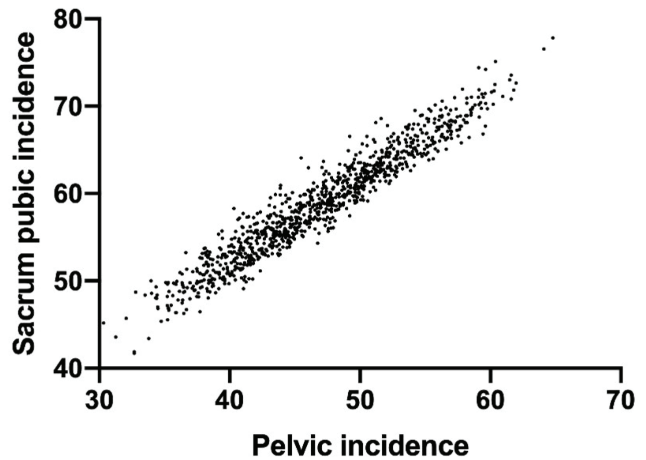

Figure 4. Correlations of PI and SPI. The clustering of points close to a linear line indicates a very strong positive correlation between PI and SPI

Table 3. Method comparison

Variable	Passing-Bablok		ICC		CCC
	β_0 (95%)	β_1 (95%)	Coefficient	p value	Coefficient
PI-SPI	13.38 (12.55-14.26)	0.97 (0.95-0.98)	0.96 (0.96-0.97)	<0.001	0.34 (0.32-0.36)

PI: pelvic incidence, SPI: sacrum pubic incidence, ICC: intraclass correlation coefficient, CCC: concordance correlation coefficient

DISCUSSION

In order to follow the progression of deformities in patients with spinal deformities and to plan appropriate treatment for these disorders, it is necessary to know the normal value ranges of spinopelvic parameters in individuals without spinal deformities. Many studies have shown that pelvic parameters are in a great relationship with the spinal sagittal balance, especially lumbar lordosis, and the importance of considering the spine and pelvis as a whole has been mentioned (8,10). There are few studies examining the spinopelvic parameters of healthy children and adolescents in the Turkish population. Our aim in this study is to determine the normal spinopelvic parameter ranges in healthy Turkish child and adolescent population and to use them as an aid in surgical planning in pediatric individuals with spinal deformity.

In studies in the literature, lateral radiography images, magnetic resonance images and three-dimensional CT images were used to calculate spinopelvic parameter values. On lateral radiographs, rotation of the pelvic skeleton may occur during acquisition, and therefore the two femoral heads do not always coincide. In such cases, the intersection of the two femoral heads is taken as a reference for measurement.

Iplikcioglu et al., showed that spinopelvic parameters measured using CT have high validity and reliability (19). Tyrakowski et al., Vrtovec et al. and Chen et al., reported that there is less margin of error in the measurement of pelvic parameters using three-dimensional CT compared to lateral radiography (20-22). Therefore, in our study, the measurement of pelvic parameters was made using a three-dimensional pelvic skeleton model.

In the literature, there are studies examining the change in pelvic incidence in healthy children and adolescents belonging to the Turkish population or other populations (Table 4). In the studies reviewed, Bailey et al. reported that pelvic incidence did not increase with age; other studies reported that pelvic incidence increases with age and a statistically significant difference was found between age groups (5,8,15,23-25). In addition, Mac-Thiong et al., Tonbul et al. and Abelin-Genevois et al. reported in their study that there was no statistically significant difference between the mean pelvic incidence values in male and female individuals (5,15,23,25). In our study, the mean pelvic incidence value in men and women was found to be 46.52±6.0 and 47.03±6.6, respectively, while the mean pelvic incidence value of all individuals included in the study was found to be 46.77±6.3. In our study, it is seen that the pelvic incidence increases with age, and there is no statistically significant difference between the mean pelvic incidence values in male and female individuals. Our results are compatible with the literature.

There are studies in the literature examining the pelvic tilt changes of healthy children and adolescents from the Turkish population or other populations (Table 4). In the studies reviewed, Abelin-Genevois et al. reported that pelvic tilt value did not increase with age in their study, while Mac-Thiong et al. and Tonbul et al. reported that pelvic tilt value increases with age and a statistically significant difference was found between age groups (5,15,23). In our study, there was no increase in pelvic tilt value with age. We think that this may be due to the method used and the fact that our study includes a more limited age group compared to other studies. It has been reported that there is no statistically significant difference between the mean pelvic tilt values in men and women in all studies examined. The results of our study are also compatible with the literature.

Table 4. Comparison of studies in the literature

Studies	Age groups	UM and n	PI		PT		SS		LL	
			Mean±SD	M/F	Mean±SD	M/F	Mean±SD	M/F	Mean±SD	M/F
Hanson et al.	11-17 18-60	R- 40	47.4±7.5 57.0±11.5	-	-	-	-	-	58.2±11.5 58.3±10.8	-
Mac-Thiong et al. (2004)	4-9 10-18	R- 180 (68 M, 112 F)	44.6±10.6 49.3±11.2	-	4.3±8.1 7.9±7.7	-	40.3±8.7 41.4±8.5	-	45.6±12.1 49.2±12.4	-
Mac-Thiong et al. (2007)	3-18	R-341 (137 M, 204 F)	49.1±11.0	49.2±11.2 49.7±10.7	7.7±8.0	6.5±7.5 8.5±8.3	41.4±8.2	41.7±8.4 41.2±8.0	48.0±11.7	46.6±10.8 48.8±12.2
Tonbul et al.	3-18	R- 120 (60 M, 60 F)	49.0±10.0	49.4±11.4 49.6±10.8	7.8±8,1	6.7±7.8 8.7±8.4	42.4±8.6	42.8±8.7 42.2±8.3	-	-
Abelin-Genevois et al.	3-18	R- 85 (40 M, 45 F)	44.5±7.6	45.3 43.8	5.4±5.9	6.1 4.7	39.2±8.1	39.2 39.2	45.1±9.8	44.1 47.7
Bailey et al.	2-9 10-14 15-20	3CT-144 (118 M, 26 F)	44.0±6.5 48.1±8.5 46.6±8.4	-	-	-	-	-	34.2±6.9 42.4±8.7 43.1±8.0	-
Sevinc et al.	13-40	MR-413 (188 M, 225 F)	-	-	-	-	35.36±7.6	34.68±7.7 37.06±8.3	43.21±9.9	40.94±10.1 47.24±11.1
Tokpınar et al.	1-16	MR-321	-	-	-	-	-	-	28.0±7.3	-
Current study	7-17	3CT-1018 (515 M, 503 F)	46.77±6.3	46.52±6.0 47.03±6.6	9.51±5.06	9.54±4.91 9.49±5.21	37.26±5.7	36.98±5.6 37.54±5.9	42.98±8.0	42.01±7.5 43.97±8.4

UM: modality used, MR: magnetic resonance, 3CT: 3D computed tomography, R: radiography, M: male, F: female, n: number of samples, PI: pelvic incidence, PT: pelvic tilt, SS: sacral slope, LL: lumbar lordosis

In the literature, there are studies examining the change in the value of the sacral slope in healthy children and adolescents belonging to the Turkish population or other populations (Table 4). In the studies reviewed, Sevinç et al. and Abelin-Genevois et al. found a significant difference between the mean sacral slope values in men and women, Mac-Thiong et al. and Tonbul et al., on the other hand, reported that there was no significant difference between the mean sacral slope values in men and women in their studies (5,15,23,25,26). In our study, the mean sacral slope values in male and female individuals were calculated as 36.98±5.6 and 37.54±5.9, respectively, and no statistically significant difference was found between the two groups.

Studies have reported that the increase in sacral slope with age is not statistically significant. In our study, this increase was statistically significant between the 7 and 12-17 age groups. We think that this difference may be due to the narrower age group included in the study compared to other studies, the use of different modalities, and the differences between populations.

In the studies examined, it is seen that the mean lumbar lordosis value differs between men and women. Mac-Thiong et al. did not find this difference statistically significant, while other studies found this difference between genders statistically significant (8,15,23,26,27). In our study, mean lumbar lordosis values in male and female individuals were found to be 42.01±7.5 and 43.97±8.4, respectively, and a statistically significant difference was observed between the two groups. The result of our study is compatible with the literature.

Hanson et al. found the lumbar lordosis value by measuring the T12-S1 interval in their study (24). Sevinç et al. found the lumbar lordosis value by measuring the L1-S1 interval in their study (26). Tokpinar et al., on the other hand, found the lumbar lordosis value by measuring the L1-L5 interval in their study (27). In our study, the lumbar lordosis value was found by measuring the L1-S1 interval. Measurement values at the same level were found at different intervals in different studies. This is due to differences in measurement methods. (Table 4).

McKay et al. reported the mean pelvic incidence and sacral kyphosis values as 55.3° and 35.1°, respectively, in their study on healthy adults (11). They reported a statistically significant relationship between pelvic incidence and sacral kyphosis (r=0.636, p<0.001). Baker et al. reported mean pelvic incidence and sacral kyphosis values as 50.1±10.08° and 24.2±13.1°, respectively, in their study on healthy adults (9). They reported a statistically significant correlation between pelvic incidence and sacral kyphosis (r=0.796, p<0.05). In our study, mean pelvic incidence and sacral kyphosis values were calculated as 46.77±6.38° and 21.27±9.96°, respectively. There is a significant relationship between pelvic incidence and sacral kyphosis (r=0.606, p<0.01). The result of our study showed that the relationship between these parameters in children and adolescents is similar to the relationship in adults. Due to an anatomical relationship between sacral kyphosis and sacral slope, we think that the increase in sacral kyphosis will affect the sacral slope and therefore the pelvic incidence will be affected. The positive correlation they found between pelvic incidence and sacral kyphosis supports this.

Wang et al. reported mean pelvic incidence and sacrum pubic incidence values as 46.9±9.9°, 68.3±9.4° in women, and 44.6±9.0° and 64.4±9.5° in men, in a study they conducted on healthy adults (7). They reported that there was no statistically significant difference between mean pelvic incidence and sacrum pubic incidence values in men and women (p>0.05). They reported a statistically significant relationship between pelvic incidence and sacrum pubic incidence (r=0.958, p<0.01, respectively). They reported that sacrum pubic incidence is a sensitive parameter that can be used in the estimation of pelvic incidence. In our study, mean pelvic incidence and sacrum pubic incidence values were calculated as 47.03±6.68°, 58.9±6.50° in women and 46.52±6.07° and 58.54±5.84° in men, respectively. It is seen that there is no statistically significant difference between mean pelvic incidence and sacrum pubic incidence values in men and women (p>0.05). There is a statistically significant relationship between pelvic incidence and sacrum pubic incidence (r=0.962, p<0.001). We can say that sacrum pubic incidence has a very strong relationship with the pelvic incidence, and this parameter can be used to estimate the pelvic incidence.

CONCLUSION

As a result, it is important to know the normal sagittal values of the spine, which performs many functions in a healthy individual. Sacral slope, pelvic incidence, lumbar lordosis tend to increase with age during childhood and adolescence to maintain adequate sagittal balance during growth. Unlike other studies of the Turkish population, we used a larger sample size and evaluated more parameters to determine the normative values of spinopelvic parameters of the Turkish population. In addition, we performed our measurements on a three-dimensional model of the pelvis skeleton, which, unlike other studies, gave more precise results. We believe that this study, in which we examined the changes in spinopelvic parameters in healthy individuals during childhood and adolescence, will contribute to the literature and give clinicians ideas for sagittal corrections in spine and pelvis surgery.

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Conflict of interest: *The authors have no conflicts of interest to declare.*

Ethical approval: *This study was carried out with the scope of the approval and information of Erciyes University Clinical Research Ethics Committee (Date and Decision No: 2019/587).*

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