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ORIGINAL ARTICLE

Morphometric Evaluation of Thoracic Vertebrae Using Multidetector Computed Tomography in Patients with Scoliosis

Skolyozlu Hastalarda Torasik Vertebraların Multidetektör Bilgisayarlı Tomografi ile Morfometrik Değerlendirilmesi

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ABSTRACT

Aim: Many people have congenital and acquired deformities associated with the vertebral column. Vertebral surgery is practiced in cases like scoliosis, traffic accidents, falling down from height, cancer, and disc hernia. We aimed to reduce morbidity and mortality by creating alternative predictions for surgery and treatment with the findings and results we obtained in our study in patients with scoliosis.
Methods: Patients with scoliosis (eight male, eight female) who underwent thoracic vertebrae imaging by multidetector computed tomography at Selcuk University Faculty of Medicine between 2013 and 2017 and who were not operated and those without scoliosis (eight male and nine female) who underwent imaging for other reasons were retrospectively evaluated. The group aged >15 years was created in a similar way. Similarly, groups with thoracic X-ray and tomography were created; Cobb angles and the width, height, and distance between the dorsal tips of the transverse process were measured in 12 thoracic vertebrae. Lateral distances from the midline junction of the right lamina of vertebra to the lateral of the right transverse process and pedicle of vertebra junction were measured; measurements were repeated for the left side and recorded. Measurements were made in 780 thoracic vertebrae.
Results: Mean Cobb angle of 8 in 10–14-year-old male patients with thoracic scoliosis was 30.9° and mean age was 13 years. Mean Cobb angle of 8 in 10–14-year-old female patients with thoracic scoliosis was 32.72° and the mean age was 12.75 years.
Conclusion: Our findings will help for manufacturers create personalized screws and plates, and help surgeons make operational choices.

Keywords: Multidetector computed tomography; Scoliosis; Vertebral column; Vertebral morphometry

ÖZ

Amaç: Pek çok insan doğuştan ve sonradan edinilmiş vertebral kolon deformitelerine sahiptir. Omurga cerrahisi; skolyoz, trafik kazaları, yüksekten düşme, kanser, bel fıtığı gibi durumlarda uygulanmaktadır. Skolyozlu hastalarda yaptığımız çalışmamızın bulgu ve sonuçlarına dayanarak cerrahi ve tedavi için alternatif öngörüler geliştirerek morbidite ve mortalitenin azaltılmasına katkıda bulunmayı amaçladık.
Gereç ve Yöntemler: 2013-2017 yılları arasında Selçuk Üniversitesi Tıp Fakültesi'nde multidetektör bilgisayarlı tomografi (MDCT) ile toraks vertebra görüntülemesi yapılan ancak opere edilmeyen skolyozlu hastalar ile başka nedenlerle görüntüleme yapılan skolyozu olmayan hastalar retrospektif olarak değerlendirildi. 10-14 yaşları arasında skolyozu olan 8 erkek ve 8 kadın hasta ile skolyozu olmayan 8 erkek ve 9 kadın değerlendirildi. 15 yaşından büyük grup da benzer şekilde oluşturuldu. Bu şekilde thoraks grafi ve tomografisi olan gruplar oluşturularak Cobb açıları ölçüldü. MDCT görüntülerinde 12 torakal vertebranın sağ ve solda processus transversus'ların genişlik, yükseklik, uç kısım ile foramen vertebrale arası mesafeleri ölçüldü. Sağ ve sol lamina arcus vertebrae'ların genişlik ve uzunlukları ölçüldü. Ayrıca literatürde olmayan lamina arcus vertebrae'nın orta hat birleşim yeri ortasından ve lateralinden processus transversus ile pediculus arcus vertebrae birleşim yerinin lateraline uzaklıklar iki taraflı ölçüldü. Toplamda 780 vertebrae thoracica'da ölçümler yapıldı.
Bulgular: 10-14 yaş arası 8 erkek torasik skolyozlu hastanın ortalama Cobb açısı 30.9° ve ortalama yaş 13 idi. 10-14 yaş arası 8 kadın torasik skolyozlu hastanın ortalama Cobb açısı 32.72° ve yaş ortalaması 12.75 idi.
Sonuç: Bulgularımız, üreticilerin kişiselleştirilmiş vidalar ve plakalar oluşturmasına ve cerrahların operasyonel seçimler yapmasına yardımcı olacaktır.

Anahtar Kelimeler: Çok dedektörlü bilgisayarlı tomografi, Skolyoz, Omurga, Vertebral morfometri

Introduction

Scoliosis is the most common spine deformity, defined as lateral curvature of the vertebral column with a Cobb angle of ≥10° (1). Ninety percent of all scoliosis cases are adolescent idiopathic scoliosis (2). In those aged <8 years, the female–male ratio is equal, whereas the prevalence in those aged >8 years is 4.6/1,000 in women and 0.2/1,000 in men (3). Screws inserted into the vertebral pedicle are currently used in the surgical treatment of scoliosis. In some cases, additional pedicular screw applications are required or can be used alternatively. Scoliosis patients have surgical interventions for vertebral injuries caused by traumas and disk hernias. For these operations to be successful, it is necessary to understand the differences in the vertebral anatomy and morphometric measurements of people with scoliosis. In many cases, the vertebral column is stabilized. Vertebral morphometric measurements can be taken with a caliper in cadaver bones, multidetector computed tomography (MDCT), magnetic resonance imaging, and at radiology workstations where the images are evaluated in three dimensions (3D). In this study, morphometric measurements were taken on the thoracic vertebrae of people with and without scoliosis, and gender and age data were compared.

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Materials and methods

With the approval of non-interventional research ethics committee, Selcuk University Faculty of Medicine (no. 2017/374), this retrospective single-center study was launched. A 256-slice multidetector computed tomographic scanner was used for the scans (Siemens Somatom Flash, Erlangen, Germany). The following display parameters were used: kV = 120; mA = 160; rotation time = 0.5 s; collimation = 64 × 0.625; and FOV = 220 mm. A radiologist used a Workstation (Snygo Via, Siemens, Germany) to analyze vertebral column images with axial and coronal sections.

Patient selection

The Cobb method was used to measure the degree of curvature in unoperated individuals who underwent vertebral thoracic MDCT vertebral imaging, and those with a Cobb angle of >10° were diagnosed with scoliosis (Figure 1) (1). Patients with and without scoliosis who underwent MDCT imaging for other reasons were chosen. As exclusion criteria, trauma, fracture, tumor, and midline fusion anomaly were identified. The study included 32 unoperated scoliosis patients who underwent thoracic MDCT imaging and 33 non-scoliosis patients who underwent thoracic MDCT for other indications between 2013 and 2017. Measurements were made in 780 vertebrae of 65 patients. Gender and age were recorded at the time of imaging (Table 1). Segmental and special development of the vertebral column and prepubertal and postpubertal, preadolescent, and adolescent development were considered when determining age groups (4-6).

Morphometric measurement parameters

The lateral-to-lateral distance (distance between transverse process [TPD]) between the dorsal ends of each vertebrae was measured from the dorsal view parallel to the frontal plane (Figure 2a). The transverse process width (TPW) was calculated by dividing the TPW on the right by the TPW on the left (Figure 2b). TPH, TPH on the right, and TPH on the left measurements were taken (Figure 3a). TPD and TPW were edited in accordance with the literature (7,8). Two clinical contribution morphometric parameters were measured and recorded. The distance between the middle of the midline junction of the vertebral lamina and the transverse process (TP) and the pedicle of vertebra junction lateral was measured as OL-r on the right and OL-l on the left (Figure 3b). The lateral distance between the midline junction of the vertebral lamina and the junction of the (TP) and pedicle of vertebrae was measured as ODL-r on the right and ODL-l on the left (Figure 3b).

Statistical analysis

For all statistical analyses, the commercially available SPSS version 22 (SPSS, Inc.) program was used. The Kolmogorov–Smirnov test was used to determine whether the data was suitable for normal distribution. To investigate intergroup comparisons between variables with normal distribution, the independent samples t test was used, and Mann–Whitney U test was used to investigate intergroup comparisons between variables without normal distribution.

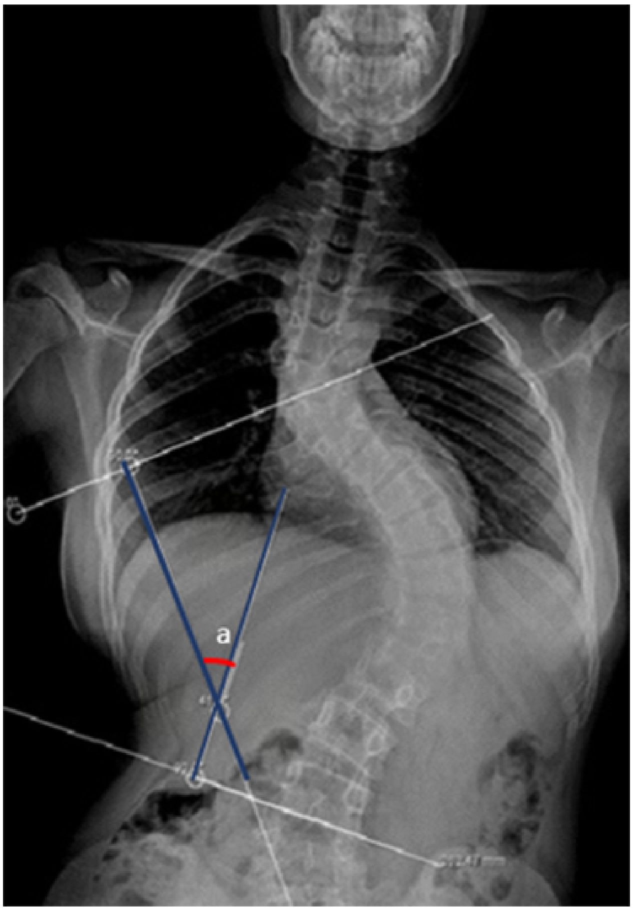

Figure 1. Cobb angle measurement a. Scoliosis X-ray and b. Sample drawing.(posterior-anterior scoliosis radiography)

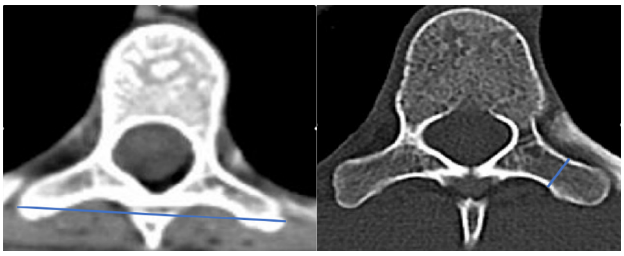

Figure 2. Parameters used in vertebral morphometric measurements with multidetector computed tomography (MDCT) a. Distance between transverse process (TPD) (axial section) and b. transverse process width (TPW) (axial section)

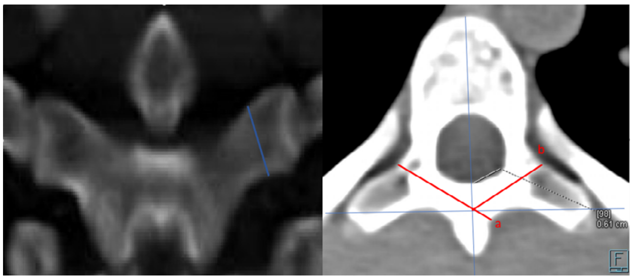

Figure 3. Parameters used in vertebrae morphometric measurements with multidetector computed tomography (MDCT) a. TP height (coronal section) and b. a: OL b: ODL(axial section)

Results

Cobb angle measurements were performed on patients who were classified as scoliotic or not. Cobb angle measurements in the scoliosis group were significantly higher than in the control group across all age and gender categories (p ≤ 0.05; Table 2). The highest mean TPD was found in the T1 vertebra of 10- to 14-year-old males with scoliosis (67.13 ± 7.60 mm), whereas the lowest mean TPD was found in the females and in the T12 vertebra in the control group (41.23 ± 5.73 mm). The T1 vertebra in control group males had the highest mean (77.58 ± 4.05 mm), while the T12 vertebra in the control group females had the lowest mean (47.86 ± 4.68 mm). TPD measurements in T4 vertebrae were significantly higher in 10- to 14-year-old males with scoliosis (60.96 ± 6.45 mm) than in the control group (53.84 ± 4.29 mm, p ≤ 0.05; Table 3).

The highest mean TPH was in the T10 vertebra of 10- to 14-year-old males with scoliosis (10.69 ± 1.79 mm), and the lowest mean TPH was in the T1 vertebra of control group males (7.11 ± 1.14 mm). The highest mean in the group aged >15 years was on the right in the T11 vertebra in the control group males (11.90 ± 1.12 mm), and the lowest mean was on the right in the T1 vertebra in females with scoliosis (7.59 ± 2.16 mm). TPH-r measurements in T1 and T3 vertebrae were significantly higher in 10- to 14-year-old males with scoliosis (8.71 ± 1.58 and 9.66 ± 1.09 mm, respectively) than in the control group (7.11 ± 1.14 and 7.98 ± 1.85 mm, respectively; p ≤ 0.05; Table 4). TPH-r measurements in T2 vertebrae were significantly lower in women with scoliosis aged >15 years (7.86 ± 0.76 mm) than in the control group (8.56 ± 1.07 mm, p ≤ 0.05; Table 4).

TPH-l measurements of T1 and T2 vertebrae were significantly higher in the scoliosis-affected 10- to 14-year-old male group (9.23 ± 1.65 and 10.18 ± 1.52 mm, respectively) than in the control group (7.35 ± 1.35 and 8.20 ± 1.85 mm, respectively, p ≤ 0.05; Table 5).

When TPW was measured, the highest mean was on the right in 10- to 14-year-old males with T9 scoliosis (9.53 ± 1.03 mm), and the lowest mean was on the left in the females with T4 scoliosis (6.21 ± 1.16 mm). The highest mean was on the left in males with scoliosis in the T9 vertebrae (10.78 ± 1.58 mm), and the lowest mean was on the left in females with scoliosis in the T3 vertebrae (6.68 ± 0.91 mm; Tables 6 and 7).

Left TPW measurements of T4 and T11 vertebrae in 10- to 14-year-old females with scoliosis were significantly lower (6.99 ± 1.25 and 6.91 ± 0.94 mm, respectively) than in the control group (7.52 ± 1.65 and 8.47 ± 1.69 mm, respectively, p ≤ 0.05; Table 7). Females with scoliosis aged >15 years had significantly lower left TPW measurements of T3 vertebrae (6.68 ± 0.91 mm) than in the control group (7.79 ± 0.70 mm, p ≤ 0.05; Table 7). The right TPW measurements had no statistical significance (Table 6).

The highest mean in OL measurements was on the right in 10- to 14-year-old scoliosis males with in the T1 vertebrae (27.73 ± 3.42 mm), and the lowest mean was on the left in control group males in the T9 vertebrae (16.01 ± 2.91 mm). The highest mean was on the right in control group males in the T1 vertebrae (27.24 ± 1.81 mm), and the lowest mean was on the left in females with scoliosis in the T4 vertebrae (16.69 ± 1.89 mm). The 10- to 14-year-old male group with scoliosis in the T8 vertebrae had significantly higher OL-r measurements (19.68 ± 0.63 mm) than the control group (17.25 ± 1.60 mm, p ≤ 0.05). Women with scoliosis aged >15 years had significantly higher OL-r measurements in T2 vertebrae (24.26 ± 2.67 mm) than the control group (21.50 ± 2.08 mm, p ≤ 0.05; Table 8).

OL-l measurements in T4 to T6 vertebrae were significantly higher in 10- to 14-year-old males with scoliosis (21.13 ± 1.87, 21.68 ± 3.41, and 20.28 ± 1.55 mm, respectively) than in the control group (18.76 ± 1.56, 17.83 ± 1.61, and 18.29 ± 2.01 mm, respectively, p ≤ 0.05; Table 9).

The highest mean in ODL measurements was on the right in scoliosis males in the T1 vertebrae (32.15 ± 4.16 mm), and the lowest mean was on the left in control group females in the T8 vertebrae (20.12 ± 1.74 mm). The highest mean was on the left in control group males in the T1 vertebrae (32.80 ± 2.93 mm), and the lowest mean was on the left in scoliosis females in the T9 vertebrae (20.33 ± 1.82 mm). ODL-r measurements in the T4 vertebrae were significantly higher in 10- to 14-year-old males with scoliosis (25.58 ± 2.47 mm) than in the control group (22.31 ± 2.48 mm, p ≤ 0.05; Table 10).

ODL-l measurements were significantly higher in 10- to 14-year-old males with scoliosis in T4 and T5 vertebrae (25.54 ± 2.64 and 26.15 ± 4.32 mm, respectively) than in the control group (23.00 ± 1.99 and 22.05 ± 2.29 mm, respectively, p ≤ 0.05; Table 11).

Table 1. Gender distribution and mean age (years) (mean± standard deviation) of groups (mean± standard deviation)

	Scoliotic (n=32)	Control (n=33)	p-value
10-14 years male	13±0.53 (n=8)	12.25±1.38 (n=8)	0.234
10-14 years female	12.75±0.70 (n=8)	12.22±1.39 (n=9)	0.321
Over 15 years male	25.12±12.46 (n=8)	17.75±1.16 (n=8)	0.161
Over 15 years female	20±7.36 (n=8)	21.25±5.94 (n=8)	0.382

Table 2. Cobb angle distribution of groups (mean± standard deviation)

	Scoliotic (n=32)	Control (n=33)	p-value
10-14 years male	30.90±16.23 (n=8)	2.33±1.66 (n=8)	0.002*
10-14 years female	32.72±21.49 (n=8)	5.29±4.61 (n=9)	0.001*
Over 15 years male	25.74±10.00 (n=8)	2.94±1.45 (n=8)	0.002*
Over 15 years female	23.64±5.87 (n=8)	2.11±1.09 (n=8)	0.000*

Table 3. Transverse Process Distance (TPD), mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	67.13±7.60	64.99±6.09	0.545	64.00±5.85	64.50±8.18	0.888
T2	63.99±8.56	58.47±4.90	0.136	60.60±4.69	58.66±6.01	0.473
T3	60.86±5.72	55.60±4.24	0.055	54.74±4.50	54.52±5.02	0.927
T4	60.96±6.45	53.84±4.29	0.021*	53.36±3.30	51.56±4.80	0.236
T5	61.10±6.12	54.60±6.20	0.053	56.70±7.43	52.21±4.40	0.167
T6	60.41±5.80	55.79±6.22	0.146	55.05±5.89	53.58±4.64	0.815
T7	59.00±5.57	56.22±7.35	0.409	56.40±6.81	53.59±3.89	0.327
T8	57.43±4.69	55.27±6.57	0.464	53.70±6.09	54.07±4.61	0.89
T9	56.24±3.22	54.08±6.62	0.279	52.90±4.22	52.93±4.16	0.987
T10	56.45±3.37	53.68±5.85	0.264	50.69±4.09	50.14±3.93	0.781
T11	53.58±5.08	51.56±6.66	0.508	46.43±5.07	46.24±3.78	0.934
T12	47.75±4.59	44.85±6.27	0.309	46.74±6.13	41.23±5.73	0.075
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	73.06±5.62	77.58±4.05	0.087	69.00±7.14	69.89±3.47	0.756
T2	67.91±6.48	71.54±2.80	0.168	65.06±5.48	63.20±3.05	0.415
T3	62.15±7.05	65.65±4.46	0.574	55.55±8.50	59.30±2.20	0.247
T4	61.35±5.31	63.79±4.60	0.343	54.36±4.93	57.96±2.48	0.065
T5	62.58±5.98	65.61±3.69	0.242	57.23±5.88	58.74±2.89	0.195
T6	63.05±5.57	65.63±3.97	0.645	58.39±7.73	58.39±1.84	0.195
T7	62.29±7.16	64.95±4.17	0.379	59.30±6.65	57.20±3.50	0.721
T8	62.98±6.86	63.45±3.27	0.862	58.70±5.61	56.51±1.90	0.325
T9	60.73±6.29	61.99±2.84	0.613	57.10±3.72	55.65±3.33	0.425
T10	57.88±6.56	57.85±3.46	0.993	54.61±4.53	52.54±3.75	0.335
T11	51.94±4.65	53.44±5.08	0.548	51.49±9.70	49.29±4.08	0.564
T12	52.40±9.84	49.78±3.32	0.487	48.33±10.31	47.86±4.68	0.91

$p \leq \alpha = 0,05$

Table 4. Transverse process height PTH-r measurements mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.71±1.58	7.11±1.14	0.036*	8.01±2.00	7.64±0.91	0.625
T2	9.69±1.28	7.93±2.17	0.067	8.02±1.62	7.12±1.25	0.215
T3	9.66±1.09	7.98±1.85	0.043*	8.48±1.19	8.58±1.31	0.868
T4	9.44±1.78	8.98±2.31	0.661	9.03±1.25	9.06±1.25	0.961
T5	9.73±0.96	9.24±1.90	0.528	9.36±0.86	8.98±1.57	0.547
T6	9.60±1.56	9.40±2.22	0.838	8.95±1.74	9.27±1.38	0.682
T7	10.58±1.17	9.41±2.40	0.238	9.29±1.33	10.20±1.67	0.235
T8	10.53±0.97	9.75±1.95	0.331	9.73±1.98	9.70±1.49	0.977
T9	9.86±0.87	9.85±2.18	0.988	9.01±1.23	9.87±1.52	0.226
T10	10.69±1.79	9.74±2.34	0.377	8.83±1.10	9.51±1.55	0.314
T11	10.23±1.72	9.76±1.56	0.582	8.00±1.99	8.70±0.92	0.357
T12	9.03±2.27	9.15±1.56	0.9	9.21±1.18	8.91±1.46	0.649
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.02±2.06	9.08±0.73	0.209	7.59±2.16	8.45±0.86	0.32
T2	9.05±1.50	9.54±0.88	0.44	7.86±0.76	8.56±1.07	0.050*
T3	10.59±1.96	10.85±1.18	0.75	8.88±1.20	9.31±0.82	0.328
T4	10.15±1.16	10.59±1.42	0.511	8.71±1.59	9.61±1.38	0.247
T5	9.46±1.46	10.71±0.89	0.057	9.04±0.62	9.31±1.06	1
T6	9.78±1.21	10.81±1.61	0.168	8.73±1.50	9.76±1.15	0.142
T7	10.14±2.01	11.54±1.18	0.112	8.95±1.68	9.10±0.77	0.645
T8	9.79±1.87	11.09±1.30	0.129	9.58±0.98	9.55±1.19	0.964
T9	10.96±2.34	11.54±1.19	0.546	9.55±1.16	9.51±1.04	0.947
T10	10.71±1.45	11.04±1.24	0.637	9.88±0.97	10.48±1.27	0.306
T11	10.58±1.65	11.90±1.12	0.081	9.44±1.82	8.61±0.78	0.234
T12	10.55±2.09	9.80±1.45	0.418	9.01±1.20	8.66±0.79	0.501

$p \leq \alpha = 0,05$

Table 5. Transverse process height PTH-l measurements, mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	9.23±1.65	7.35±1.35	0.026*	7.51±1.25	8.00±1.02	0.391
T2	10.18±1.52	8.20±1.85	0.035*	7.95±1.51	7.66±1.44	0.687
T3	9.35±1.71	8.44±1.38	0.26	8.45±1.54	8.31±1.17	0.836
T4	10.02±1.55	9.25±2.19	0.426	9.11±1.28	8.76±0.75	0.487
T5	9.87±1.13	9.36±2.37	0.589	8.55±1.17	9.13±1.01	0.289
T6	9.98±1.24	9.60±2.42	0.702	8.58±1.30	9.21±1.53	0.375
T7	10.00±0.92	9.56±2.51	0.65	9.02±1.37	9.47±1.81	0.583
T8	10.33±1.24	9.99±2.43	0.442	8.51±1.30	9.44±1.53	0.199
T9	9.96±1.35	9.54±2.44	0.673	8.58±1.02	9.72±1.82	1.136
T10	10.34±1.22	9.74±1.55	0.404	8.61±1.26	9.79±1.35	0.084
T11	10.24±1.17	10.26±1.52	0.971	8.51±1.17	8.90±0.85	0.444
T12	9.23±1.44	9.36±1.63	0.861	9.35±1.32	8.22±1.04	0.068
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.61±2.02	9.39±0.87	0.344	8.28±1.68	8.30±0.89	0.971
T2	9.34±1.23	9.77±1.48	0.532	8.14±1.16	8.11±1.03	0.964
T3	9.89±1.32	11.14±1.31	0.78	8.44±1.71	8.96±0.99	0.464
T4	9.63±1.10	10.06±1.13	0.445	8.30±1.43	9.44±0.93	0.081
T5	9.51±1.19	10.29±1.32	0.238	9.19±0.94	9.46±0.66	0.51
T6	9.46±1.10	9.86±1.06	0.471	9.26±1.19	9.21±1.00	0.929
T7	9.74±1.61	11.13±0.89	0.051	9.39±1.30	9.10±0.99	0.626
T8	9.93±1.59	11.26±1.96	0.161	9.40±0.68	9.31±1.28	0.867
T9	10.86±2.11	11.40±1.46	0.563	9.49±1.11	10.41±1.40	0.164
T10	10.43±1.26	10.65±0.82	0.679	9.06±1.25	9.85±1.38	0.251
T11	10.61±1.69	11.18±0.74	0.403	9.58±0.87	8.91±1.29	0.248
T12	9.51±2.11	9.85±1.67	0.728	8.84±1.20	8.90±0.74	0.902

$p \leq \alpha = 0,05$

Table 6. Transverse process width TPW-r measurements, mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.38±0.79	8.63±1.49	0.442	7.23 ±1.47	8.50 ±1.62	0.111
T2	7.98±1.18	7.56±0.99	0.461	7.26 ±1.08	7.89 ±1.06	0.139
T3	7.71±1.00	7.39±0.90	0.506	6.74 ±1.49	7.34 ±0.91	0.32
T4	7.90±1.26	7.88±1.34	0.97	6.39 ±1.18	7.12 ±1.34	0.252
T5	7.88±1.54	8.39±1.36	0.492	7.14 ±0.99	7.39 ±1.49	0.692
T6	7.63±1.56	8.61±1.07	0.161	7.23 ±1.21	7.49 ±1.31	0.673
T7	8.55±1.39	8.91±1.37	0.607	7.40 ±1.20	7.39 ±1.37	0.986
T8	9.48±2.08	8.54±0.91	0.263	7.09 ±0.76	7.94 ±1.48	0.163
T9	9.53±1.03	9.04±2.14	0.575	7.86 ±1.33	8.21 ±1.93	0.675
T10	9.04±0.76	8.54±1.20	0.336	7.51 ±1.63	7.97 ±1.93	0.61
T11	9.11±1.24	8.24±1.18	0.171	7.33 ±1.17	7.83 ±1.47	0.446
T12	8.09±1.50	8.61±1.23	0.458	6.62 ±2.39	7.89 ±2.18	0.272
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.70±1.54	9.24±1.82	0.534	7.56±2.35	8.44±0.75	0.333
T2	8.79±1.77	8.74±1.04	0.946	7.98±0.95	7.48±0.58	0.225
T3	8.25±1.18	8.65±0.49	0.13	6.65±1.07	7.52±0.70	0.074
T4	9.11±1.24	8.50±1.22	0.337	7.49±1.05	8.23±1.37	0.195
T5	8.65±1.15	8.70±0.70	0.918	7.95±0.58	7.85±0.56	0.73
T6	9.40±1.33	9.08±0.76	0.558	8.13±1.11	7.79±0.71	0.481
T7	9.40±1.30	9.20±0.92	0.728	7.96±1.01	8.24±0.70	0.537
T8	9.95±1.92	9.39±1.40	0.514	7.95±1.17	7.95±0.50	1
T9	10.01±1.33	9.92±1.11	0.888	8.11±0.82	8.25±1.07	0.776
T10	9.34±1.57	9.50±1.20	0.82	8.11±1.31	8.43±1.01	0.601
T11	9.00±1.31	9.59±1.02	0.334	7.59±1.23	7.77±0.65	0.709
T12	8.36±1.62	9.69±1.47	0.109	7.69±1.11	8.90±1.30	0.065

$p \leq \alpha = 0,05$

Table 7. Transverse process width (TPW) measurements mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.46±0.68	8.85±1.77	0.573	7.36±1.28	8.28±1.64	0.222
T2	7.84±1.11	7.86±1.33	0.968	7.10±1.76	8.17±0.73	0.116
T3	7.06±1.02	7.64±0.81	0.232	6.82±0.97	7.63±1.21	0.093
T4	7.77±1.09	7.86±1.36	0.889	6.21±1.16	7.52±1.65	0.021*
T5	8.21±1.06	7.95±1.11	0.636	6.99±1.25	7.48±0.84	0.351
T6	8.31±1.33	8.26±1.03	0.934	6.93±1.32	7.59±1.25	0.303
T7	8.53±1.11	8.94±1.56	0.552	7.73±1.21	7.40±1.19	0.585
T8	8.28±1.19	7.77±1.20	0.416	7.40±1.37	8.19±1.50	0.278
T9	8.63±1.80	8.25±1.34	0.644	7.98±1.76	8.29±2.00	0.738
T10	9.49±1.11	8.51±1.83	0.219	8.44±1.71	7.78±1.93	0.47
T11	8.63±1.17	7.83±1.56	0.265	6.91±0.94	8.47±1.69	0.036*
T12	8.23±1.85	8.73±1.97	0.609	6.75±1.45	8.22±1.85	0.09
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	8.86±1.43	9.39±1.21	0.442	8.53±2.40	7.57±1.69	0.442
T2	9.20±1.73	9.08±1.14	0.645	8.42±1.28	7.85±0.92	0.321
T3	9.06±1.10	9.35±0.92	0.58	6.68±0.91	7.79±0.70	0.016*
T4	8.74±1.25	9.16±0.83	0.436	7.65±1.65	8.08±0.51	0.505
T5	9.44±1.67	9.46±0.63	0.969	7.40±1.13	8.05±0.58	0.178
T6	9.06±1.78	9.04±0.98	0.973	7.49±0.87	7.84±0.54	0.352
T7	9.66±1.59	9.96±0.69	0.635	7.94±0.94	7.84±0.92	0.832
T8	9.56±1.87	9.72±1.13	0.836	7.84±1.39	8.15±1.40	0.662
T9	10.78±1.58	9.81±0.70	0.146	8.38±1.64	8.53±1.28	0.841
T10	9.54±1.89	9.76±0.97	0.769	8.46±1.21	8.43±1.18	0.951
T11	8.86±2.06	9.46±1.28	0.496	8.01±1.74	8.15±0.95	0.847
T12	9.06±2.41	9.50±1.83	0.689	8.23±2.10	8.80±1.10	0.503

$p \leq \alpha = 0,05$

Table 8. Lateral distance from the midline junction of the right lamina of vertebra to the right transverse process (TP) and the pedicle of vertebra junction OL-r mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	27.73±3.42	25.96±2.64	0.268	23.26±3.27	24.26±3.12	0.531
T2	24.16±2.36	23.67±3.09	0.728	20.93±2.68	21.91±2.78	0.469
T3	20.65±1.82	20.55±1.39	0.904	17.66±1.42	19.24±2.82	0.174
T4	20.55±1.71	18.68±2.13	0.072	16.84±0.79	18.08±2.25	0.152
T5	19.51±1.50	17.72±1.96	0.06	18.16±2.46	17.21±1.83	0.377
T6	19.98±2.32	18.29±1.75	0.123	17.71±1.93	17.50±2.42	0.845
T7	20.26±2.35	18.34±1.88	0.093	17.68±3.80	17.02±2.23	0.667
T8	19.68±0.63	17.25±1.60	0.001*	18.22±1.83	17.13±2.26	0.295
T9	19.29±2.22	17.75±1.62	0.135	19.55±4.46	17.88±2.15	0.331
T10	20.61±3.04	18.76±1.78	0.159	19.97±2.74	17.91±2.05	0.139
T11	20.63±3.23	19.10±1.71	0.258	20.59±4.01	18.36±1.60	0.144
T12	20.31±2.37	20.11±3.76	0.901	19.54±3.15	18.36±2.29	0.386
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	26.72±1.79	27.24±1.81	0.578	26.28±2.27	24.88±2.23	0.234
T2	24.11±2.16	24.58±2.08	0.67	24.26±2.67	21.50±2.08	0.037*
T3	20.33±2.09	20.91±1.95	0.571	18.96±2.74	19.86±1.65	0.44
T4	19.29±1.60	19.76±1.59	0.561	17.61±1.70	17.31±1.13	0.684
T5	19.19±2.18	19.88±1.54	0.479	18.16±5.03	17.33±1.42	0.505
T6	19.60±1.50	19.61±1.60	0.987	17.73±3.11	17.44±1.42	0.645
T7	19.83±2.29	19.00±1.91	0.446	18.81±4.44	16.75±1.49	0.234
T8	19.51±1.65	19.06±1.74	0.604	17.29±2.64	16.76±1.44	1
T9	19.32±1.54	19.64±1.54	0.691	16.99±1.28	17.25±1.59	0.722
T10	19.61±1.45	19.90±1.88	0.738	18.12±2.06	18.73±1.69	0.535
T11	19.75±1.71	21.39±1.81	0.085	20.13±4.82	18.96±1.24	0.878
T12	20.98±1.47	21.95±2.63	0.375	20.40±5.21	21.04±3.19	0.328

$p \leq \alpha = 0,05$

Table 9. Lateral distance from the midline junction of the left lamina of vertebra to the left transverse process (TP) and the pedicle of vertebra junction OL-l mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	26.35±1.43	25.51±2.76	0.458	23.70±1.38	23.89±3.15	0.878
T2	23.69±2.80	22.44±1.98	0.319	21.40±1.67	20.51±1.91	0.326
T3	21.31±1.73	19.99±1.50	0.123	18.36±2.15	18.84±3.12	0.719
T4	21.13±1.87	18.76±1.56	0.016*	17.70±1.12	17.60±1.71	0.673
T5	21.68±3.41	17.83±1.61	0.016*	18.23±2.60	17.06±2.34	0.345
T6	20.28±1.55	18.29±2.01	0.044*	18.09±2.26	16.98±1.83	0.281
T7	19.47±2.08	17.67±2.09	0.106	18.34±2.78	16.11±1.33	0.114
T8	18.05±0.54	16.95±1.59	0.085	18.28±3.21	16.03±1.47	0.101
T9	18.43±2.03	16.01±2.91	0.075	19.48±2.26	17.08±2.67	0.066
T10	19.43±2.59	17.61±2.08	0.146	19.10±3.48	16.76±1.74	0.094
T11	20.38±3.77	18.68±1.56	0.195	19.09±3.37	17.77±2.14	0.344
T12	21.18±2.36	19.69±4.08	0.387	20.50±3.89	17.56±2.38	0.076
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	25.98±2.92	27.13±2.12	0.382	26.51±2.57	24.34±2.70	0.109
T2	22.74±2.46	23.66±2.08	0.442	22.64±1.59	21.25±1.12	0.063
T3	20.96±1.84	20.71±1.30	0.758	18.21±2.88	19.25±1.56	0.386
T4	19.01±1.39	18.99±1.85	0.976	16.69±1.89	17.55±1.46	0.324
T5	19.01±3.01	19.08±1.72	0.96	18.42±5.68	17.06±1.41	0.574
T6	19.36±2.68	19.06±1.64	0.791	18.98±7.02	16.92±1.46	0.878
T7	19.25±1.62	18.68±1.56	0.481	18.23±4.66	17.15±3.09	0.382
T8	18.71±1.94	18.14±1.33	0.501	18.29±3.91	17.63±3.00	0.721
T9	19.11±1.53	18.28±1.58	0.3	16.78±1.61	17.34±1.50	0.482
T10	19.15±2.14	19.41±1.01	0.758	18.41±1.40	18.15±1.41	0.714
T11	20.46±1.02	20.41±1.58	0.741	19.25±3.06	18.25±1.61	0.426
T12	21.40±2.25	20.94±2.02	0.672	20.38±4.02	20.49±1.97	0.505

$p \leq \alpha = 0,05$

Table 10. Lateral distance from the midline junction of the right lamina of vertebra to the right transverse process (TP) and pedicle of vertebra junction lateral ODL-r, mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	32.15±4.16	30.30±2.62	0.305	28.48±4.19	27.98±3.88	0.803
T2	28.93±3.24	28.21±2.59	0.721	25.60±3.74	26.30±3.20	0.683
T3	25.59±2.26	24.27±1.84	0.222	21.22±1.91	23.02±3.47	0.203
T4	25.58±2.47	22.31±2.48	0.020*	20.84±1.09	21.01±3.82	0.899
T5	24.00±2.26	21.59±2.48	0.061	21.75±2.86	20.78±2.68	0.481
T6	24.36±3.03	22.12±2.23	0.115	20.30±2.48	20.56±3.24	0.859
T7	24.43±2.86	22.44±2.78	0.18	22.29±3.70	20.77±3.93	0.277
T8	22.89±1.84	21.14±2.18	0.105	21.86±2.78	20.17±2.20	0.181
T9	22.40±2.14	21.35±2.56	0.388	22.59±4.26	21.06±2.66	0.382
T10	23.61±3.51	22.47±2.59	0.473	23.86±3.81	20.96±2.79	0.9
T11	24.22±4.12	22.97±2.25	0.464	24.20±4.78	21.47±2.04	0.138
T12	23.99±2.71	23.20±4.87	0.696	22.40±4.12	21.72±2.99	0.701
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	32.33±2.58	32.49±2.48	0.9	30.61±2.98	28.86±2.91	0.255
T2	29.06±2.77	29.79±3.67	0.66	27.56±3.50	25.19±2.69	0.15
T3	24.80±2.99	25.51±2.77	0.629	23.53±2.34	23.78±1.63	0.808
T4	24.46±3.18	24.30±2.67	0.913	20.95±1.57	21.70±1.62	0.364
T5	24.34±3.57	24.24±3.04	0.721	21.81±4.49	21.59±1.07	0.083
T6	24.20±1.43	23.94±2.62	0.807	20.90±3.19	21.46±1.72	0.668
T7	23.64±2.04	23.37±2.35	0.815	22.16±4.37	20.68±1.62	0.645
T8	22.73±1.76	23.09±2.20	0.721	20.86±2.73	20.59±1.45	0.721
T9	23.35±1.23	23.86±1.82	0.721	19.88±1.33	21.36±1.68	0.07
T10	22.96±1.22	24.05±2.51	0.289	20.89±2.78	22.55±1.66	0.168
T11	23.03±2.50	24.59±1.90	0.181	24.88±8.21	22.75±1.16	0.519
T12	24.26±1.81	25.81±2.46	0.173	22.71±4.60	23.95±3.17	0.772

$p \leq \alpha = 0,05$

Table 11. Lateral distance from the midline junction of the left lamina of vertebra to the left transvers process (TP) and the pedicle of vertebra midline junction lateral ODL -l, mm, mean ± SD

	10–14 years old male			10–14 years old female		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	31.03±2.44	29.88±2.51	0.721	28.85±1.86	28.56±4.65	0.87
T2	28.63±3.40	28.29±2.45	0.823	25.68±2.14	25.51±2.83	0.896
T3	26.08±2.18	24.37±1.93	0.121	21.59±1.60	22.78±3.93	0.423
T4	25.54±2.64	23.00±1.99	0.048*	21.36±1.19	21.73±3.11	0.747
T5	26.15±4.32	22.05±2.29	0.033*	21.97±3.00	20.88±2.56	0.428
T6	24.34±2.03	22.26±3.16	0.14	20.61±2.26	20.98±2.55	0.76
T7	23.95±2.34	22.23±2.80	0.202	22.39±3.07	20.23±2.65	0.141
T8	22.06±0.69	21.19±2.52	0.36	22.99±4.51	20.12±1.74	0.126
T9	22.43±2.11	21.21±2.86	0.351	22.55±2.19	20.82±3.24	0.223
T10	23.85±3.74	21.40±2.72	0.156	23.11±4.20	20.76±2.49	0.174
T11	23.70±4.02	22.25±2.51	0.721	22.89±3.23	20.94±2.53	0.185
T12	24.73±2.37	22.71±4.84	0.309	24.78±4.53	21.23±2.92	0.071
	Male >15 years old			Female >15 years old		
	Scoliotic	Control	p-value	Scoliotic	Control	p-value
T1	31.65±3.68	32.80±2.93	0.5	31.31±2.92	28.56±3.17	0.093
T2	29.08±3.08	29.28±3.19	0.9	26.55±2.31	25.80±2.19	0.517
T3	25.94±3.09	25.60±2.31	0.808	22.71±3.38	23.86±1.31	0.384
T4	24.76±3.06	23.70±2.83	0.483	20.70±2.25	21.91±1.26	0.205
T5	24.96±4.00	23.89±2.69	0.538	22.55±6.47	21.86±1.30	0.234
T6	23.43±1.90	23.43±2.10	1	23.10±7.72	21.33±1.30	0.645
T7	24.58±1.71	23.88±2.89	0.565	22.33±6.34	20.79±1.79	0.798
T8	23.05±2.21	22.81±1.64	0.811	22.08±4.61	20.38±2.17	0.721
T9	23.39±2.13	22.86±1.64	0.589	20.33±1.82	21.46±1.58	0.203
T10	23.24±2.43	24.51±1.53	0.23	21.50±2.26	22.11±1.79	0.328
T11	24.23±1.66	23.86±1.47	0.652	24.48±5.81	22.26±1.45	0.505
T12	25.47±2.43	24.98±2.29	0.678	23.69±4.28	23.86±2.35	0.574

$p \leq \alpha = 0,05$

Discussion

Scoliosis, a three-dimensional spine deformity, progress to advanced stages if no measures are taken, causing serious health problems, and an increased likelihood of surgery. As with many diseases, early detection of scoliosis deformity is required for effective treatment. It is critical to screen school-aged children (9).

Morphological and morphometric evaluations of the affected thoracic and lumbar vertebrae of scoliosis patients assist the clinician during and after surgery. Morphometric measurements are critical for instrumentation in cases of progressive scoliosis and those undergoing to surgery, as well as trauma associated with vertebral surgery and congenital anomalies. The thoracic and lumbar vertebrae were morphometrically measured by the researchers. Cadaver studies, in particular, are prevalent in the literature (7,10). In addition to cadaver studies, vertebrae examinations on X-ray and CT images have been performed, and there are studies in the literature comparing different methods. Kunkel et al. (7) measured X-rays in 12 cases from a previous cadaver study developed equations for 3D images (11,12). They claimed that these equations could be used in biomechanical assessments of spinal deformities and scoliosis. Krag et al. (13) performed CT scans on cadavers and repeated caliper measurements on the vertebrae obtained from the cadavers, compared the results, and reported that the results were comparable. Misenheimer et al. (10) used axial and coronal CT images to measure thoracic and lumbar pedicle diameter in six freshly frozen human cadavers. They claimed that the measurements in the pedicle screw endosteal cortical CT images were accurate. According to the findings of comparative studies, evaluating vertebral measurements on CT images is extremely beneficial because they reflect actual measurements. As a result, in the current study, we used MDCT to perform vertebrae morphometric examinations on scoliosis patients.

Many researchers have studied corpus vertebrae and pedicle of vertebrae measurements in the literature because they are important for the installation of screws used in scoliosis surgery. (10,14) Morphometric measurements of the 10 to 14 age group of the current study are significant due to a lack of data in the literature. Changes in bone measurements between races increase the value of region and case profiling studies. We believe that the measurements in this study will contribute to scoliosis research and the literature. Although there have been numerous studies on morphometric measurements of vertebrae, there have been few studies on these measurements in scoliosis patient.

Brink et al. (15) compared patient measurements between 11- and 18-year-old male and female patients with adolescent idiopathic scoliosis (AIS), and Hong et al. (16,17) compared the measurements of patients with AIS, congenital scoliosis, cerebral palsy, and muscular dystrophy, and conducted morphometric studies on patients with similar demographic characteristics by performing measurements of the corpus vertebrae. The differences in measurements between age groups and gender were not evaluated but age and gender differences were investigated in the study of Hong et al. (17).

There are modeling studies that take CT measurements of normal people's cadaver vertebrae and use 3D imaging software. These examinations serve as a guide for patent work. Teo (8) studied a 71-year-old man's cadaver, whereas Chen et al. (18) studied 80 patients' CT images (25–76 years old, mean age of 52.51 years). These studies demonstrate the significance of CT scans in understanding vertebral anatomy.

Studies on TPW measurements of thoracic vertebrae have been conducted in adult cadavers without taking into account age and gender differences. Tan et al. (19) measured C3-L5 in 10 Chinese and Singaporean cadavers with an average age of 65.7 years, and Panjabi et al. (11,12) measured 144 thoracic and 60 lumbar vertebrae (mean age of 46.3 years). When the results of these studies were compared, Tan et al. (19) had the shortest measurements in all thoracic segments while Panjabi et al. (12) (living in America) had the closest results to the current study (Figure 4). We believe that the differences between Tan et al. and the current study are due to the society from which the cases were drawn. Furthermore, when the TPD measurements from these studies and the current study are compared, T1 has the widest measurement average, and T12 has the smallest measurement value.

Cui et al. (14) measured TP width and height, as well as other morphometric parameters, in 450 dry vertebrae from 45 cadavers (average age of 39 years in 25 males and 20 females) between T1 and T10, without regarding for gender and side. In the current study, TPW measurements are comparable with the healthy control group. Cui et al. measured the widest TPW for T1 vertebrae at 10.78 mm and the narrowest for T7 at 7.86 mm. The largest measurements in the current study were obtained on the left at T7 in healthy male controls aged >15 years at 9.96 mm, and the smallest measurements were obtained on the right at T2 in female controls aged >15 years of age (Figure 5).

In terms of TPH measurements, Cui et al. (14) obtained higher results than we had. The highest measurement in the Cui et al. (14) study was 12.87 mm in the T3 vertebra, and the highest measurement in the current study was 11.54 mm on the right at T7 and T9 in male controls aged >15 years. The lowest measurement was 8.11 mm on the left at T2 in control females over the age of >15 (Figure 6).

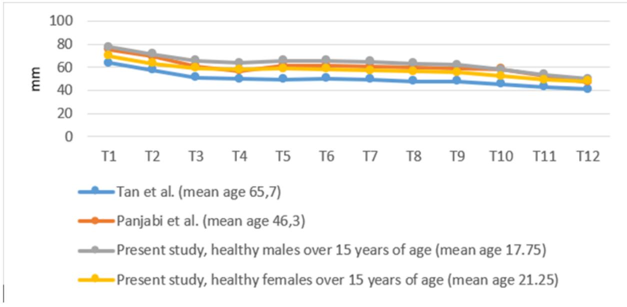

Figure 4. Comparison of the distance between the transverse process (TPD) measurements

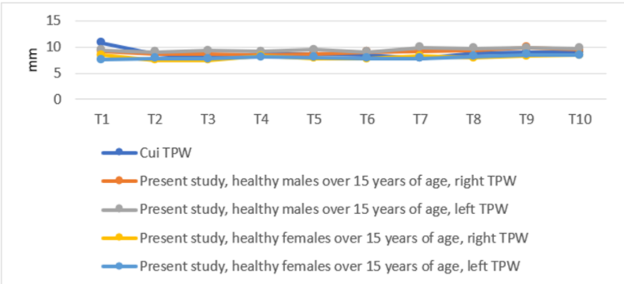

Figure 5. T1–T10 transverse process width (TPW) comparison

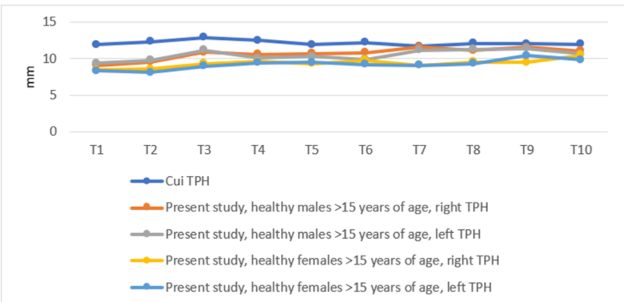

Figure 6. T1–T10 transverse process (TP) height comparison

Pedicle screws are still a valid and widely used method in scoliosis and vertebral surgery. Extra pedicular screws can also be used to pass through the side of TP and caput costae, reaching the corpus vertebra. Extrapedicular screws are used when intrapedicular screwing is not possible or there is pedicular damage. White et al. (20) compared the resistance of extra and intrapedicular screws in six cadavers' thoracic vertebrae and found that extrapedicular screws were a good alternative despite their low strength. The ODL and OL measurements used in this study have never been studied before in the literature. Significant findings obtained in T8 (Table 8), T4, T5, and T6 (Table 9), T4 (Table 10), and T4 and T5 (Table 11) vertebrae measurements in 10- to 14-year-old male group will be useful for clinical and surgical evaluation. Additional research is required to validate and apply the OL and ODL measurements obtained in this study in clinical settings. It is worthwhile to develop instrumentation associated with the vertebral lamina and TP for long-term stabilization of 10- to 14-year-old patients who require surgery.

Vertebral surgery is one of the most difficult surgeries and prone to complications (16,21). Advances in surgical techniques and material quality do not completely eliminate the risk of these surgeries. Although the ideal objective is to stop the progression of scoliosis, no complete cure has yet been discovered. Patient-centered evaluations of the patients who will receive surgical treatment and benefit assessments of the operation are performed.

Morphometric analysis of vertebrae is important and required for evaluating patients prior to surgery and selecting surgical instruments and materials. Screws placed on the pedicle of the vertebra provide spine stability. If these screws are separated from the bone during or after placement, they can cause damage to the surrounding neurovascular structures (16,21).

We believe that surgical evaluation of ODL and OL measurements we measured and evaluated in this study will be beneficial. In addition to these measurements, the development of a less complicated instrumentation system that takes into account the spinous process in conjunction with the vertebral lamina and TP is important for patients, orthopedists, and neurosurgeons.

Conclusions

Male and female vertebral column anatomy differs morphologically, as do age groups. Producing plates using these methods may be advantageous in spine surgery, particularly in plate, or screw application interventions. We believe that our study, in which we examined the vertebral anatomy of the people with basic scoliosis based on gender and age limit will help manufacturers create personalized screws and plates, and help surgeons make operational choices.

To ensure spine stability in scoliosis operations or to reduce the use of pedicle screws in vertebral surgery, it is necessary to consider and develop methods that include the pt and lamina of the vertebrae region as an alternative to pedicle screws.

Ethics approval: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval (approval number 2017/374.) was given by the Non-Invasive Clinical Research Ethics Committee of the Selcuk University Faculty of Medicine.

Conflicts of interest: The authors declare that they have no conflict of interest.

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