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Examination of inclinations of the spine at childhood and adolescence

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Background: *Spine is a column that consists of consecutively lined up vertebras. It includes medulla spinalis. It contributes the motions of head, neck and body. Spine is not a straight column. There is a convexity towards the front of the spine (lordosis) at cervical and lumbar areas in adults and a convexity towards the back of the spine (kyphosis) at thoracic and sacral spine areas.*

Materials and methods: *In this study, lateral magnetic resonance images of 731 children between 1 and 16 years of age were examined and their cervical lordosis, thoracic kyphosis and lumbar lordosis angles were measured with Cobb method using ImageJ programme for every age group.*

Results: *The mean calculated cervical lordosis angles in 1–16-year-old children were found to be 20.51° ± 6.11° (minimum 17.96° ± 6.29°, maximum 23.50° ± ± 4.14°). It has been observed that cervical angle values decrease with age. The mean thoracic kyphosis angle measured was 28.71° ± 6.99° (minimum 24.55° ± ± 5.65°, maximum 30.44° ± 4.68°). Lumbar lordosis angle was 28.08° ± 7.39° (minimum 20.36° ± 6.59°, maximum 32.68° ± 6.03°). Thoracic kyphosis and lumbar lordosis angle values increased with age. In our study, a statistical difference was found in increasing thoracic kyphosis angle between 1-year-old group and 14-year-old group. Statistical difference was also found in decreasing cervical lordosis angle value between 1-year-old group and 16-year-old group. When we compare our study results with literature values, cervical lordosis values were similar, but lumbar lordosis values were lower.*

Conclusions: *In summary, we think that knowing sagittal plane inclinations of the spine developing in childhood and adolescence will contribute to earlier determination of pathologies. We also hope that it will contribute to clinical stages and other studies in this field.* (Folia Morphol 2019; 78, 1: 47–53)

Key words: spine, radiography, kyphosis, lordosis

INTRODUCTION

The spine, which plays an important role in standing up against gravity in daily life, is an important part of the skeletal system. The spine functions in all movements of the body as well as movements of the head, neck and trunk. It is an important structure that carries the majority of body weight, transfers this weight to lower limbs through the pelvis and

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maintains the balance of the body. In addition to its mechanical support, it helps protect the spinal cord.

The spine is not a straight column. In adults, there is a convexity towards the front of the spine (lordosis) in the cervical and lumbar regions and a convexity towards the back of the spine (kyphosis) in the thoracic and sacral regions [2]. These curvatures are physiological. The curvatures in the neck and waist are formed by the thickening of the anterior parts of the discus intervertebralis. These are also seen in the foetal period, but until childhood they are not as obvious as others. The curvature in the neck becomes more apparent when the child begins to hold the head up. The curvature in the waist becomes more apparent when the child begins to stand up. Moreover, a right or left curvature of the spine, which is called scoliosis, is seen in some people [25]. The abnormal curvatures seen in the spine during childhood and adolescence can lead to significant health problems. The congenital anomalies may cause the spine to grow unevenly. This can lead to serious problems in childhood, from mild curvatures to severe curvatures (life-threatening) [15].

This study aimed to examine the curvatures seen in the spine during childhood and adolescence, to calculate the angular change in these curvatures by using radiographs, and to reveal the normal values.

MATERIALS AND METHODS

This study was carried out within the scope of the approval and information of the Erciyes University Clinical Research Ethical Committee (Date/Decision No: 2012/392). A total of 813 lateral magnetic resonance images (MRI) from children aged 1–16 years were used in our study, of which 251 were obtained from the Department of Paediatric Radiology at Erciyes University Medical Faculty, and 562 were obtained from the Department of Radiology at Kayseri Training and Research Hospital. Spinal MRIs that were transferred to a computer were examined by a specialist in the Department of Radiology at Erciyes University Medical Faculty. As a result of this examination, patients who had no pathology relating to the spine and/or spinal cord on spinal MRI were included in the study. Eighty-two children with pathological findings on MRI we excluded from our study; therefore, we used 784 lateral MRIs of 731 children. While some of these images showed the entire spine, some of them included neck and thorax, but most of the images presented only to one region. On sagittal T1 or T2 weighted images, the anteroposterior curvatures (angles) of the neck (cervical), chest (thoracic) and waist (lumbar) areas of the columna vertebralis were measured by the Cobb method. This was performed using the ImageJ programme, a java-based programme developed by the National Institutes of Health.

Obtaining MRI

Magnetic resonance images were obtained from a 1.5 T MRI scanner (Philips Intera, Netherlands).

MRI protocol. For sagittal and axial T1 and T2 weighted imaging measurements taken in the supine position, repetition time (TR) was 3500, echo delay time (TE) was 120, matrix was 256 × 255, field of view (FOV) was 275 × 232, and flip angle was 90°. For sagittal and axial T1 weighted imaging measurements taken in the supine position, TR was 400, TE was 10, matrix was 256 × 255, FOV was 275 × 232, number of sagital averages was 4, and flip angle was 90°. The measurements were performed on the sagittal plane.

Creating groups

Each age range was considered as a group for the cervical and lumbar regions. However, two age ranges were considered as a group for the thoracic region because the number of images was insufficient in some age groups. While some of spinal MRIs included the entire spine, other images presented only one region. After the box plots were drawn for quantitative variables in the groups and the outlier values were removed, the angle values for 349 cervical, 114 thoracic and 321 lumbar regions were evaluated statistically.

Statistical analysis

The arithmetic mean and standard deviation values were obtained by entering the data of the groups into the SPSS 15.0 for Windows. The angle values for the cervical, thoracic and lumbar regions of children aged 1–16 years were compared using the independent samples t-test. A p value of < 0.05 was considered statistically significant.

RESULTS

The values of cervical lordosis. When 349 lateral MRIs for the cervical region were examined (Fig. 1, Table 1), the mean cervical lordosis angle was calculated as 20.51° ± 6.11°. When the values of the cervical lordosis angle in the groups were examined, it was seen that the cervical lordosis angle ranged between

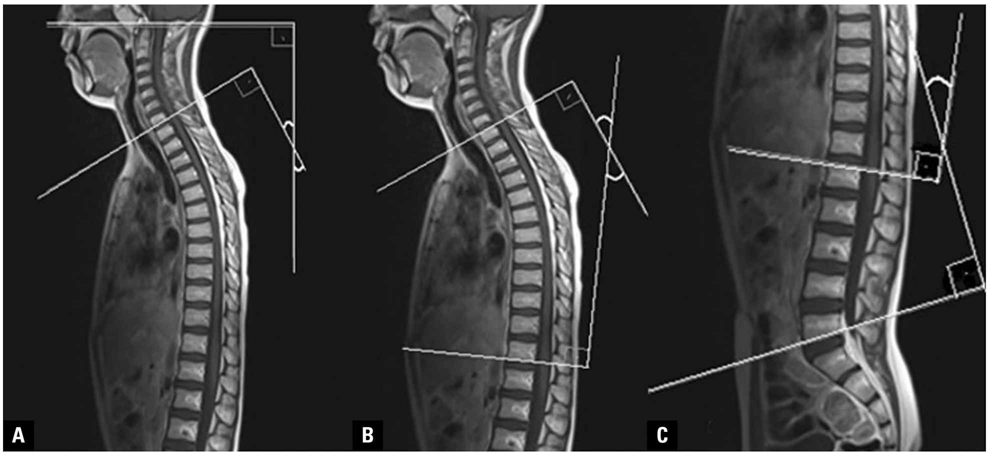

Figure 1. Measurement of Cobb angle for cervical, thoracic, and lumbar regions; **A.** Cervical angle; **B.** Thoracic angle; **C.** Lumbar angle.

Table 1. The measurements of the cervical angle in children aged 1–16 years

Age	Number of people	Mean angle value ± standard deviation	Minimum value of the angle	Maximum value of the angle
1	19	22.10° ± 5.68°	12°	32°
2	18	23.50° ± 4.14°	16°	31°
3	13	23.38° ± 6.19°	14°	32°
4	13	20.92° ± 7.49°	9°	32°
5	22	23.27° ± 7.03°	11°	35°
6	16	22.12° ± 5.31°	10°	30°
7	22	20.68° ± 6.39°	10°	32°
8	25	20.64° ± 5.61°	11°	33°
9	25	20.00° ± 5.86°	10°	32°
10	25	20.48° ± 7.50°	10°	35°
11	21	19.00° ± 4.51°	10°	29°
12	26	20.73° ± 5.83°	12°	32°
13	32	19.00° ± 6.69°	10°	38°
14	23	19.86° ± 5.93°	13°	32°
15	26	17.96° ± 6.29°	6°	28°
16	23	18.30° ± 4.21°	11°	25°
Total	349	20.51° ± 6.11°	6°	38°

17.96° ± 6.29° and 23.50° ± 4.14°. The smallest cervical angle (6°) belonged to the age group of 15 years whereas the largest cervical angle (38°) belonged to the age group of 13 years. When the cervical lordosis angle was compared between the age groups, there was a statistically significant difference only between the age groups of 2 years and 16 years ($p < 0.05$). No statistically significant difference was found between the other age groups. When the relationship between the age and the cervical angle was examined, it was seen that the value of the cervical angle decreased with increasing age ($R^2 = 0.053$) (Fig. 2).

The values of thoracic kyphosis. The values of the thoracic kyphosis angle were calculated from 114 lateral MRIs. Two age ranges were considered as a group for the thoracic region because the number of images was insufficient in some age groups. Eight groups were formed. When the values of these groups were examined (Table 2), it was seen that the thoracic kyphosis angle ranged between 24.55° ± 5.65° and

30.44° ± 4.68**°**. The smallest thoracic angle (10°) belonged to the age group of 9–10 years whereas the largest thoracic angle (46°) belonged to the age group of 15–16 years. When the thoracic kyphosis angle was compared between the age groups, there was no statistically significant difference between them. When the relationship between the age and the thoracic angle was examined, it was seen that the value of the thoracic angle increased with increasing age ($R^2 = 0.001$) (Fig. 3).

The values of lumbar lordosis. When 321 lateral MRIs for the lumbar region in the 16 groups were examined (Table 3), it was seen that the lumbar lordosis angle ranged between 20.36° ± 6.59**°** and 32.68° ± ± 6.03**°**. The smallest lumbar angle (8°) belonged to the age group of 13 years whereas the largest lumbar angle (50°) belonged to the age group of 5 years. When the lumbar lordosis angle was compared between the age groups, there was a statistically significant difference only between the age groups of 1 year and 14, 15, 16 years ($p < 0.05$). No statistically significant difference was found between the other age groups. When the relationship between the age and the lumbar angle was examined, it was seen that the value of the lumbar angle increased with increasing age ($R^2 = 0.092$) (Fig. 4).

DISCUSSION

The spine, which plays an important role in standing up against gravity in daily life, transfers the weight of the head and trunk to lower extremities and allows enough movement of other parts of the body. It also wraps and protects the spinal cord [2, 6, 20].

Human standing posture is the consequence of balance between the spine and the pelvis [16]. The position of the spine in maintaining this balance is important. The spine is a straight column when you look at it from behind in a healthy adult. However, when you look at it from lateral side, there is a convexity towards the front of the spine in two regions (cervical and lumbar lordosis) and a convexity towards the back of the spine in two regions (thoracic and sacral kyphosis). It is reported that there are four normal curves in the adult human: lordosis of 30°–50° in the cervical region, kyphosis of 30°–50° in the thoracic region, lordosis of 40°–60° in the lumbar region and kyphosis of 40°–50° in the sacral region. Values above and below these limits lead to pathology on the sagittal plane. There are many studies that measure spinal inclinations [16, 19]. Lateral radiographs were

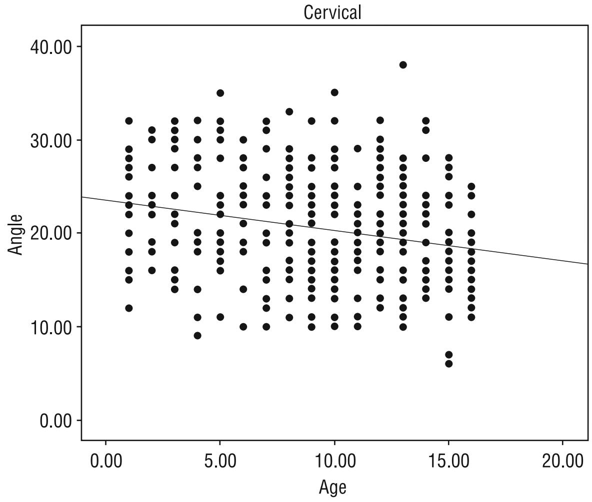

Figure 2. Correlation chart showing the relationship between the age and the cervical angle in children aged 1–16 years.

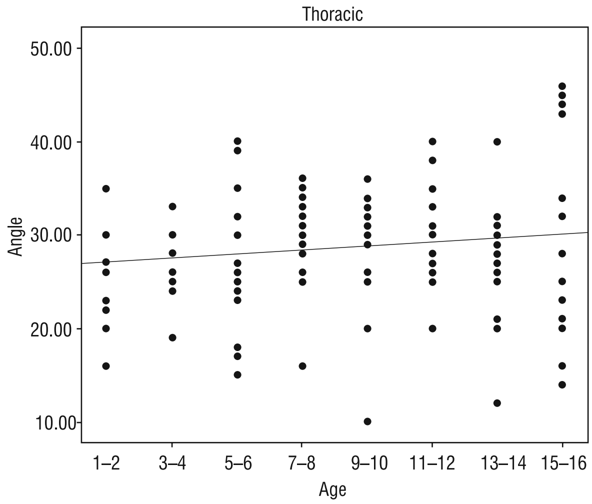

Figure 3. Correlation chart showing the relationship between the age and the thoracic angle in children aged 1–16 years.

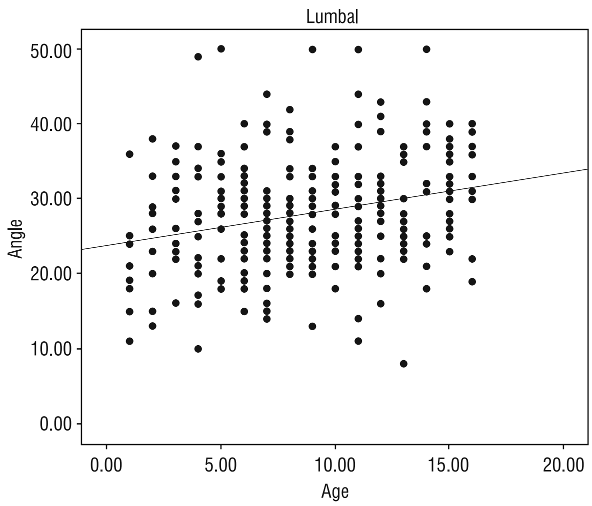

Figure 4. Correlation chart showing the relationship between the age and the lumbar angle in children aged 1–16 years.

Table 2. The measurements of the thoracic angle in children aged 1–16 years

Age	Number of people	Mean angle value ± standard deviation	Minimum value of the angle	Maximum value of the angle
1–2	9	24.55° ± 5.65°	16°	35°
3–4	10	27.2° ± 4.23°	19°	33°
5–6	18	28.27° ± 8.04°	15°	40°
7–8	18	30.44° ± 4.68°	16°	36°
9–10	14	28.92° ± 6.95°	10°	36°
11–12	13	30.07° ± 5.45°	20°	40°
13–14	16	28.31° ± 6.95°	12°	40°
15–16	16	29.68° ± 10.46°	14°	46°
Total	114	28.71° ± 6.99°	10°	46°

Table 3. The measurements of the lumbar angle in children aged 1–16 years

Age	Number of people	Mean angle value ± standard deviation	Minimum value of the angle	Maximum value of the angle
1	11	20.36° ± 6.59°	11°	36°
2	10	25.4° ± 7.79°	13°	38°
3	11	27.27° ± 6.42°	16°	37°
4	15	27.06° ± 9.92°	10°	49°
5	22	28.13° ± 7.33°	18°	50°
6	29	27.17° ± 6.27°	15°	40°
7	25	25.52° ± 7.66°	14°	44°
8	35	27.6° ± 5.56°	20°	42°
9	21	28.57° ± 7.31°	13°	50°
10	17	27.82° ± 5.74°	18°	37°
11	29	28.82° ± 8.02°	11°	50°
12	26	28.50° ± 7.3°	16°	43°
13	20	28.05° ± 6.84°	8°	37°
14	16	32.50° ± 10.33°	18°	50°
15	18	31.44° ± 5.05°	23°	40°
16	16	32.68° ± 6.03°	19°	40°
Total	321	28.08° ± 7.39°	8°	50°

usually used in these studies. The angles of the different regions of the spine on these lateral radiographs were measured, and these angles were compared to show the relationship of these regions to each other. In the clinical practice, the most common of these calculations is the Cobb angle [21, 24].

Kasai et al. [13] measured the cervical lordosis angle in 20 individuals aged 2–18 years. They reported that this angle decreased from 2 years to 9 years depending on age and remained the same after 10 years but showed a tendency to increase slightly [13]. While this change is similar to our study, it is seen that these angle values are smaller than those in our study. Harrison (2011) [9] measured the cervical lordosis angle using the Cobb technique in children and adolescents aged 2–18 years. In the study of Harisson [9], it was seen that the value of the cervical angle decreased with increasing age. The values of the cervical angle in our study are similar to those in this study.

McAviney et al. [19] found that there was a relationship between cervical lordosis and acute and chronic pain in subjects aged 9 or over. They reported that the severity of diseases such as asthma, ear infection, headache, and neck pain can be reduced by correcting cervical lordosis [19]. Abelin-Genevois et al. [1] created two groups (under 11 years old and over 11 years old) in 150 children under the age of 18. They reported that the mean cervical lordosis angle was 32.7° ± 11.3° and 30.5° ± 10.1°, respectively. In our study, the mean cervical lordosis angle in children between the ages of 1 and 16 was calculated as 20.51° ± ± 6.11°. Because the values we found according to age in children were different from each other, it was predicted to cause acute and chronic pain in later ages. This study is important for early detection of anomalies in children's posture.

Mac-Thiong et al. [18] investigated spinal inclinations and sacropelvic alignment in children and performed a broad literature review on this subject. Then, they reported that the thoracic kyphosis angle was 42.0° for children aged 3–10 years (mean age: 8.1) and 45.8° for children aged 11–18 years (mean age: 13.6), respectively. Moreover, they stated that the value of the thoracic angle tended to increase with age.

In another study, Mac-Thiong et al. [17] examined thoracic kyphosis on lateral MRI in 180 normal individuals aged 4–18 years. They found that it was 38.3° for children under 10 years of age and 45.6° for children over 10 years of age, respectively. They reported that the thoracic kyphosis angle did not show any significant difference between the genders.

Bernhardt and Bridwell [3] reported that thoracic kyphosis (T3–T12) was 36° ± 10° in 102 normal subjects aged 4.6–29.8 years (mean: 12.8 years).

Boseker et al. [4] evaluated 121 normal children aged 5–19 years, with approximately equal numbers of girls and boys. They reported that the mean thoracic kyphosis angle was 33° (17°–51°) and that the difference between the genders was not observed.

Voutsinas and MacEwen [26] evaluated the sagittal spinal alignment of 670 normal subjects aged 5–20 years on MRI using the Cobb method. They found that thoracic kyphosis was, respectively, 37° ± 7°, 38° ± 8°, and 39° ± 8° in subjects aged 5–9 years, 10–14 years, and 15–20 years.

Abelin-Genevois et al. [1] examined 150 children under 18 years of age. They reported that the mean thoracic kyphosis angle was 36.6° ± 7.1° for children under 11 years of age and 38.6° ± 8.6° for children over 11 years of age, respectively.

Cil et al. [5] assessed 151 children aged 3–15 years. They reported that thoracic kyphosis (T1–T12) was, respectively, 45° ± 11°, 48° ± 11°, 46° ± 11°, and 53° ± 9° in subjects aged 3–6 years, 7–9 years, 10–12 years, and 13–15 years.

A curvature more than 50° to 60° in the thoracic spine is considered abnormal, and this is the most common deformity in the spine in pathological conditions. Increased thoracic kyphosis not only reduces enlargement of the thoracic cavity but also reduces movement at the shoulder joint. Previous studies reported that the thoracic kyphosis angle ranged 34°–47° in adult subjects [7]. In our study, the mean thoracic kyphosis angle in children between the ages of 1 to 16 was calculated as 28.71° ± 6.99°. It was observed that the mean thoracic kyphosis angle of our study was lower than that found by Voutsinas and MacEwen [26].

Abelin-Genevois et al. [1] examined 150 children under 18 years of age. They reported that the mean lumbar lordosis angle was 42.5° ± 9.1° for children under 11 years of age and 46.0° ± 7.3° for children over 11 years of age, respectively. Mac-Thiong et al. [18] reported that the mean lumbar lordosis angle was 53.8° for children aged 3–10 years (mean: 8.1 years) and 57.7° for children aged 11–18 years (mean: 13.6 years), respectively. They reported that lumbar lordosis tended to increase with age.

In another study, Mac-Thiong et al. [17] examined lumbar lordosis on lateral MRI in 180 normal individuals aged 4–18 years. They found that it was 44.2° for children under 10 years of age and 49.2° for children over 10 years of age, respectively. They reported that the lumbar lordosis angle did not show any significant difference between the genders.

Bernhardt and Bridwell [3] reported that lumbar lordosis (L1–L5) was 44° ± 12° in 102 normal subjects aged 4.6–29.8 years (mean: 12.8 years).

Cil et al. [5] assessed 151 children aged 3–15 years. They reported that lumbar lordosis (L1–S1) was, respectively, 44° ± 11°, 52° ± 12°, 57° ± 10°, and 55° ± 10° in subjects aged 3–6 years, 7–9 years, 10–12 years, and 13–15 years.

There are many studies on lordosis in the lumbar region of the spine, and it was reported that the lumbar lordosis angle ranged between 32.9° and 48.1° [7, 22]. Okçu et al. [22] found that the mean lumbar lordosis angle was 47.74° ± 13.2°. In this study, it was stated that since the normal limits of the lumbar lordosis angle are large, it is appropriate to interpret the results by taking into account the normal distribution width rather than the mean values.

In our study, the mean lumbar lordosis angle in children between the ages of 1 and 16 was calculated as 28.08° ± 7.39°. The range of area affects the result of measurement in lumbar lordosis as in other regions. While Wiltse and Winter [27] reported that lumbar lordosis measured from L1 to L5, other studies [7, 8, 22, 27] reported that it measured from T12 to L5. It is clear that the selection of such different levels in the literature must have led to different results. The reasons for selecting different vertebrae may be covering the entire inclination or using the best visible vertebrae [12, 17, 23]. There are studies in the literature that show that decreased lumbar lordosis angle is associated with waist pain [10, 11, 14].

It was seen that the previously reported values for thoracic kyphosis and lumbar lordosis were higher than our values. We think that this is due to the fact that the age groups were different and the measurements were performed from different regions.

CONCLUSIONS

The importance of the spine is great in analysing posture. Our study aimed to diagnose posture disorders that occur in the spine at an early age. Thus, it has been suggested that the necessary precautions can be taken to prevent the complications that may arise in the posture during the later ages. We think that this study, in which we examined the development of cervical and lumbar lordosis and thoracic kyphosis from infancy to adolescence, would add to the existing body of knowledge and would be a guide before the surgical procedures to be performed in this area.

Our study concluded that Cobb angle can be measured using midsagittal MRI and we found normative values for cervical, lumbar and thoracic Cobb angle from infancy to adolescence.

REFERENCES

1. Abelin-Genevois K, Idjerouidene A, Roussouly P, et al. Cervical spine alignment in the pediatric population: a radiographic normative study of 150 asymptomatic patients. Eur Spine J. 2014; 23(7): 1442–1448, doi: 10.1007/s00586-013-3150-5, indexed in Pubmed: 24395005.
2. Arıncı K, Elhan A. Anatomi, 2.cilt, 4. baskı, Güneş Kitabevi, Ankara. 2006: 58–65.
3. Bernhardt M, Bridwell K. Segmental analysis of the sagittal plane alignment of the normal thoracic and lumbar spines and thoracolumbar junction. Spine. 1989; 14(7): 717–721, doi: 10.1097/00007632-198907000-00012.
4. Boseker EH, Moe JH, Winter RB, et al. Determination of "normal" thoracic kyphosis: a roentgenographic study of 121 "normal" children. J Pediatr Orthop. 2000; 20(6): 796–798, indexed in Pubmed: 11097257.
5. Cil A, Yazici M, Uzumcugil A, et al. The evolution of sagittal segmental alignment of the spine during childhood. Spine. 2005; 30(1): 93–100, indexed in Pubmed: 15626988.
6. Dere F. Anatomi Atlası ve Ders Kitabı. 5. Baskı, Nobel yayın evi, Adana. 1999: 765–766.
7. Ecerkale Ö. Postür Analizinde Symmetrigraf ile Orthoröntgenogram Sonuçlarının Değerlendirilmesi, Uzmanlık tezi, Okmeydanı Eğitim ve Araştırma Hastanesi Fizik Tedavi ve Rehabilitasyon Kliniği, İstanbul. 2006: 68–80.
8. Gelb DE, Lenke LG, Bridwell KH, et al. An analysis of sagittal spinal alignment in 100 asymptomatic middle and older aged volunteers. Spine. 1995; 20(12): 1351–1358, indexed in Pubmed: 7676332.
9. Harrison DE. Pediatric Cervical Lordosis: Values, Disorders, and Interventions. American Journal of Clinical Chiropractic (AJCC). http://www.chiropractic-biophysics.com/clinical_chiropractic/2011/2/11/pediatric-cervical-lordosis-values-disorders-and-interventio.html.
10. Hasday CA, Passoff TL, Perry J. Gait abnormalities arising from latrogenic loss of lumbar lordosis secondary to Harrington instrumentation in lumbar fractures. Spine. 1983; 8(5): 501–511, indexed in Pubmed: 6648700.
11. Itoi E. Roentgenographic analysis of posture in spinal osteoporotics. Spine. 1991; 16(7): 750–756, indexed in Pubmed: 1833827.
12. Jackson RP, McManus AC. Radiographic analysis of sagittal plane alignment and balance in standing volunteers and patients with low back pain matched for age, sex, and size. A prospective controlled clinical study. Spine. 1994; 19(14): 1611–1618, indexed in Pubmed: 7939998.
13. Kasai T, Ikata T, Katoh S, et al. Growth of the cervical spine with special reference to its lordosis and mobility. Spine. 1996; 21(18): 2067–2073, indexed in Pubmed: 8893429.
14. Kostuik JP, Hall BB. Spinal fusions to the sacrum in adults with scoliosis. Spine. 1983; 8(5): 489–500, indexed in Pubmed: 6648699.
15. Köse N, Sevencan A. Konjenital skolyoz ve torasik yetmezlik sendromu, Türk Ortopedi ve Travmatoloji Birliği Derneği Dergisi. 2007; 6: 3–4.
16. Legaye J, Duval-Beaupère G, Hecquet J, et al. Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J. 1998; 7(2): 99–103, indexed in Pubmed: 9629932.
17. Mac-Thiong JM, Berthonnaud E, Dimar JR, et al. Sagittal alignment of the spine and pelvis during growth. Spine. 2004; 29(15): 1642–1647, indexed in Pubmed: 15284510.
18. Mac-Thiong JM, Labelle H, Roussouly P. Pediatric sagittal alignment. Eur Spine J. 2011; 20 Suppl 5: 586–590, doi: 10.1007/s00586-011-1925-0, indexed in Pubmed: 21811824.
19. McAviney J. Determining the relationship between cervical lordosis and neck complaints. Manipulative Physiol Ther. 2005; 28: 187–193.
20. Moore KL, Persaud TVN. The Developing Human: Clinically Oriented Embryology, 5th edition. Philadelphia 1998: 354–360.
21. Morrissy RT, Goldsmith GS, Hall EC, et al. Measurement of the Cobb angle on radiographs of patients who have scoliosis. Evaluation of intrinsic error. J Bone Joint Surg Am. 1990; 72(3): 320–327, indexed in Pubmed: 2312527.
22. Okçu G, Yercan H, Yorulmaz İ. Lomber Omurganın Sagittal Planda Radyolojik Analizi. 2000: 146–150.
23. Polly DW, Kilkelly FX, McHale KA, et al. Measurement of lumbar lordosis. Evaluation of intraobserver, interobserver, and technique variability. Spine. 1996; 21(13): 1530–1535, indexed in Pubmed: 8817780.
24. Stagnara P, De Mauroy JC, Dran G, et al. Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for the evaluation of kyphosis and lordosis. Spine. 1982; 7(4): 335–342, indexed in Pubmed: 7135066.
25. Unur E, Ülger H, Ekinci N. Anatomi, 3. Baskı, Kıvılcım Kitapevi, Kayseri. 2009: 13–17.
26. Voutsinas SA, MacEwen GD. Sagittal profiles of the spine. Clin Orthop Relat Res. 1986(210): 235–242, indexed in Pubmed: 3757369.
27. Wiltse LL, Winter RB. Terminology and measurement of spondylolisthesis. J Bone Joint Surg Am. 1983; 65(6): 768–772, indexed in Pubmed: 6863359.