SAGITTAL BALANCE IN ADOLESCENT IDIOPATHIC SCOLIOSIS

ABSTRACT

Objective: The objective of this study is to achieve a better understanding of the parameters that influence sagittal balance in a population with adolescent idiopathic scoliosis (AIS). Methods: A retrospective study of 80 patients with adolescent idiopathic scoliosis (AIS) was conducted. The parameters evaluated were: age, sex, pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), sagittal balance (SB), coronal balance (CB), lumbar lordosis (LL), thoracic kyphosis (TK) divided into upper (between T1 and T5) and lower (between T5 and T12), cervical spine alignment (CSA), and Cobb’s coronal angle (CCA) of primary scoliotic curvature. Results: Regarding the sagittal balance, this study demonstrated a significant statistical positive correlation with cervical shape (p<0.01) and upper thoracic kyphosis (from T1 to T5) (p<0.05), but not with the other variables. LL had a strong influence on lower thoracic curvature (from T5 to T12) and was strongly influenced by the PI and SS. Conclusions: Sagittal balance is a parameter that is influenced by multiple factors. In fact, it is closely related to cervical shape and the upper thoracic curvature (from T1 to T5), which in turn, is closely linked to the severity of the scoliotic kyphosis. The Cobb angle of the lower thoracic spine (from T5 to T12) is more closely correlated with the angle of lumbar lordosis than with the upper thoracic kyphosis (from T1 to T5). Level of evidence IV; Case Series.

Keywords: Scoliosis; Spine; Kyphosis; Adolescent.

RESUMO

Objetivo: O objetivo deste estudo é obter uma melhor compreensão dos parâmetros que influenciam o equilíbrio sagital em uma população com escoliose idiopática do adolescente (AIS). Métodos: Foi realizado um estudo retrospectivo de 80 pacientes com escoliose idiopática do adolescente (AIS). Os parâmetros avaliados foram: idade, sexo, incidência pélvica (PI), sacral slope (SS), pelvic tilt (PT), equilíbrio sagital (SB), balanço coronal (CB), lordose lombar (LL), cifose torácica (TK) dividida em alta (entre T1 e T5) e baixa (entre T5 e T12), alinhamento da coluna cervical (CSA) e ângulo de Cobb coronal de curvatura escoliótica principal (CCA). Resultados: Em relação ao equilíbrio sagital, demonstrou-se uma correlação positiva significativamente estatística com o formato da coluna cervical (p <0.01) e com o ângulo de cifose da porção superior da coluna torácica (de T1 para T5) (p <0.05), mas não com as demais variáveis. LL exerce uma forte influência sobre a porção inferior da curvatura torácica (de T5 a T12) e é fortemente influenciada pela PI e SS. Conclusões: O equilíbrio sagital é um parâmetro influenciado por múltiplos fatores. De fato, está extremamente relacionado com o formato da coluna cervical e com a coluna torácica superior (de T1 a T5) que, por sua vez, apresenta uma simbiose com a gravidade da curvatura escoliótica. O ângulo de Cobb da porção inferior da coluna torácica (de T5 a T12) apresenta uma relação maior com o ângulo da lordose lombar que com a curvatura torácica superior (de T1 a T5). Nível de evidência IV; Série de Casos.

Descritores: Escoliose; Coluna Vertebral; Cifose; Adolescente.

RESUMEN

Objetivo: El objetivo de este estudio es lograr una mejor comprensión de los parámetros que influyen en el equilibrio sagital en una población con escoliosis idiopática del adolescente (EIA). Métodos: Se realizó un estudio retrospectivo de 80 pacientes con escoliosis idiopática del adolescente (EIA). Los parámetros evaluados fueron: edad, sexo, incidencia pélvica (IP), inclinación sacra (IS), inclinación pélvica (IP), balance sagital (BS), balance coronal (BC), lordosis lumbar (LL), cifosis torácica (CT) divididos en alta (entre T1 y T5) y baja (entre T5 y T12), alineación de la columna cervical (AC) y ángulo coronal de Cobb (ACC) de curvatura escoliótica primaria. Resultados: Con respecto al balance sagital, este estudio demostró una correlación positiva estadísticamente significativa con la forma cervical (p < 0,01) y cifosis de la porción superior de la columna (de T1 a T5) (p < 0,05), pero no con las otras variables. LL tuvo una fuerte influencia en la parte inferior de la curvatura torácica (de T5 a T12) y fue fuertemente influenciada por la IP y la IS. Conclusiones: El balance sagital es un parámetro influenciado por múltiples factores. De hecho, está estrechamente relacionado con la forma cervical y la curvatura torácica superior (de T1 a T5), que a su vez, está estrechamente relacionada con la gravedad de la cifosis escoliótica. El ángulo de Cobb de la porción inferior de la columna torácica (de T5 a T12) presenta mayor relación con el ángulo de lordosis lumbar que con la cifosis torácica superior (de T1 a T5). Nivel de evidencia IV; Serie de Casos.

Descritores: Escoliosis; Columna Vertebral; Cifosis; Adolescente.
INTRODUCTION

The human standing posture involves a delicate balance between the spine and the pelvis. Although all primates are able to place themselves in the orthostatic position, Homo sapiens is the only able to travel long distances andsteadily in this way.1 The reason for this occurrence is that humans have a unique lumbar lordotic curve. A balanced posture is obtained when these body segments are aligned in a way that minimizes energy expenditure.2,4 The importance of sagittal spinopelvic organization in spine pathology, and the crucial need to restore it after surgical treatment, are now recognized in the literature.5

Some authors have reported the normal values of sagittal spinal curves in children and adolescents.6,8 Other studies have also characterized the pelvic orientation and morphology in the sagittal plane of paediatric subjects.9,5 Upasani et al. presented a relation between lumbar spine lordosis and pelvic geometry. Effectively, the lumbar spine has a close relationship with the pelvic orientation, expressed in particular by the sacral slope, which is influenced by the pelvic incidence (PI).10 The sagittal curvature of the spine and the pelvic balance swing together to maintain a stable posture and horizontal gaze. Once this sagittal alignment is lost, more energy is needed for the body to remain balanced without any external support.11 The pelvic incidence is unique in each individual, and is independent of the spatial alignment of the pelvis. Therefore, it reflects the anatomy of the pelvis and does not modify with changes in pelvic or spinal position.12-16 Several studies have shown that PI is closely related to the sacral slope (SS) and pelvic tilt (PT), and that it remains relatively constant during childhood. It increases significantly during adolescence, reaching its maximum value in adulthood.17 Others defend that there is no correlation between the PT and SS in patients with AIS.18

Idiopathic scoliosis is a three-dimensional deformity of the torso consisting of lateral curvature of the spine and vertebral rotation.18 Satisfactory treatment for AIS includes maximum correction in the coronal plane, in addition to adequate restoration of the sagittal spinal alignment and vertebral rotation. Many studies19-22 have demonstrated that sagittal balance, rather than coronal balance (CB), is significantly correlated with health-related quality of life (HRQOL). Others have found great impacts of lumbar lordosis (LL) and thoracic kyphosis (TK) on the maintenance and prediction of sagittal balance, which are considered novel regional predictors for sagittal balance.23,24

The C7 plumb line is the most commonly used index of global balance. This parameter has been historically quantified by measuring the position of a vertical line originating in the center of the C7 vertebral body with respect to the posterior superior corner of S1.25-27 In a systematic literature review, Kuntz et al.28 noted that as a global parameter, the C7 plumb line was a stable, reliable index of sagittal balance, being maintained in narrow ranges for alignment of the spine over the pelvis and femoral heads. Furthermore, the morphology of the pelvis, and the position of the pelvis relative to the spine, may also influence sagittal spinal alignment and balance.29-33 Glassman et al.34 reported that a positive sagittal balance is related to symptomatology and quality of life in patients with spinal deformities. Berthonnaud et al.35 have proposed the concept of a linear chain linking the head to the pelvis, in which the shape and orientation of each anatomic segment are closely related and influence the adjacent segment to maintain a stable posture with minimum energy expenditure. Accordingly, a change in the shape or orientation of any anatomic segment will modify the shape and/or orientation of adjacent segments of the spine and pelvis. The differences between normal and pathologic curvatures are less clear in the sagittal plane than in the coronal plane.36

METHODS

Population

The sample was composed by 80 patients. Inclusion criteria were patients with a diagnosis of AIS, a PA, and lateral full-length radiographs. Exclusion criteria were having undergone surgery, having initiated orthotic treatment, and a low quality radiography (without inclusion from C1 to S1 and without inclusion of femoral heads or incorrect positioning, mainly of the upper limbs).

Radiography

All the radiographs were performed in the same hospital and requested by the same doctor. As recommended by the Scoliosis Research Society, plain full-length radiographs were performed in the upright standing position, with the anterior superior iliac spines and hips parallel to the cassette and the beam aimed at T10. Lateral radiographs were performed with the patient in a similar position as possible to the PA radiograph, with the beam at 90° to that used for the PA radiography, anterior superior iliac spines and hips perpendicular to the film, and the right side of the patient parallel to the cassette. Both feet were on the same alignment, 20 to 25 cm between each other, with the fingertips resting on the collarbones.

Parameters

The parameters evaluated were: age, sex, pelvic incidence, sacral slop, pelvic tilt, global sagittal and coronal balance, sagittal Cobb angle between T1 and T5, and sagittal Cobb angle between T5 and T12. Regarding the parameters evaluated, and their description, the shape of the cervical spine was obtained through the angle between two lines parallel to the posterior margins of the vertebral bodies of C2 and C7 (Jackson physiological stress lines). Thoracic kyphosis was evaluated from the Cobb angle between two lines; one along the upper platform of the body of T1 and the other along the lower platform of the body of T5 that measured the upper thoracic kyphosis, and two other lines; one along the superior end plate of T5 vertebral body and the other along the inferior end plate of T12 vertebral body (19), which measured the inferior thoracic kyphosis. Lumbar lordosis was assessed through the Cobb angle between a line along the superior L1 end plate and another along the upper sacral plate. Regarding the pelvic parameters, the pelvic incidence is the angle between the perpendicular to the sacral plate and the line connecting the sacral end plate midpoint to the hip axis. The sacral slope is the angle between the superior end plate of S1 and the horizontal plane. The pelvic tilt is the angle between the line connecting the midpoint of the sacral plate to the hip axis and the vertical plane. The sagittal balance is assessed by the horizontal distance or misalignment of a vertical line passing from the center of C7 vertebral body to the posterolateral part of the S1 superior end plate. It was considered positive vs negative as it presented an anterior vs posterior deviation from the previously stipulated line. To assess coronal balance, a vertical line is drawn downwards from the midpoint of the C7 vertebral body. The horizontal distance between this plumb line and the midline of the sacrum or central sacral vertical line is measured and the position of this line is then named positive, neutral or negative, depending on the distance and direction from the midline.

Statistical analysis

SPSS Statistics V21 MacOSX was used to perform this study. A descriptive statistical analysis of all variables was collected. Subsequently, a separate analysis of the sagittal balance and the remaining variables under study was performed using the Spearman test. The assessment of the difference between the positive vs negative sagittal balance relative to the different variables was obtained through an independent-sample T test (Levene’s Test for Equality of Variances and T-test for Equality of Means). The differences between sex were also obtained from this last test.

As this work is retrospective, based solely on imaging study without direct contact with patients, interviews, or application of scores, the hospital where the study was performed does not require approval by the ethics committee.
RESULTS
The idiopathic scoliosis group showed a mean age of 12.44 years, a mean sagittal balance of -1.14±3.30 cm and 29 patients with a negative sagittal deviation (<-2 cm), only 9 with a positive deviation (>2 cm) and the remainder were considered balanced (with SB greater than -2 cm and less than 2 cm). The mean coronal balance was -0.49±1.34 cm and LL 58.08±12.47°. (Table 1)

Thoracic kyphosis presented a mean value between T1-T5 of 19.46±9.26° and between T5-T12 of 26.99±11.13°. (Table 1) The main coronal curvatures had a mean value of 21.83±15.68° and were later divided into 3 groups: patients with scoliotic angles of 10-20°, 20-45° and >45°, each presenting a prevalence of 72.5%, 15.0% and 12.5%, respectively. Regarding the location of the main curvatures, 32.5% were thoracic, 53.8% thoracolumbar and 13.8% lumbar. The spinopelvic parameters presented mean values similar to those found in previous studies, with a PI of 50.79±14.31°, an SS of 42.48±10.51° and a mean PT of 8.68±9.94°. (Table 1)

The sagittal Cobb angle of T1-T5 showed a statistically significant (p<0.05) and positive correlation with the sagittal balance, indicating that an increase in the sagittal Cobb angle in the upper portion of the thoracic spine would lead to an increase in sagittal decompensation in a positive direction, which did not occur with the lower portion of the thoracic spine (T5-T12), lumbar lordosis curvature, or other variables. (Table 2) Moreover, a detailed analysis of these two variables showed that AIS patients with negative sagittal balances had a lower kyphotic Cobb angle in both the upper and lower thoracic spine compared to those with positive sagittal balances, although the difference was only statistically significant (p<0.05) in the upper thoracic region (T1 to T5). On the other hand, scoliotic patients with sagittal balance <2 cm vs >=2 cm presented, respectively, upper thoracic kyphosis (T1 to T5) angles of 18.56±9.32° vs 25.78±6.05°. (Table 3) Regarding the curvature of the cervical spine, 38.8% of the AIS patients presented lordotic curvature, 28.8% were straight, and 23.8% were kyphotic. Five patients were excluded from the data set in relation to this last variable because they were at the borderline between two cervical shape groups. The data were also cross-checked, to verify whether patients with a positive sagittal balance had spinopelvic parameters, LL, or thoracic sagittal curvature that differed significantly from those with a negative (<-2 cm) or normal (between -2 cm and 2 cm) SB. We used an independent sample test (Levene’s Test for Equality of Variances and T-test for Equality of Means), which concluded that patients with SB>2 cm presented significantly different Cobb values of the upper thoracic portion (T1 to T5) (p<0.05) and SS (p<0.05) from those of the remaining population (with SB <2cm). Using the same test, we verified that scoliotic patients with kyphotic vs lordotic cervical curvatures presented with

Table 1. Descriptive statistics of all numeric variables analyzed.

| Variable | Mean | Std. Dev. |
|----------|------|----------|
| Age      | 12.44 | -1.14    |
| SB       | 21.83 | 9.26     |
| CC       | 15.68 | 13.4052  |
| SC D1-D5 | 26.99 | 11.1330  |
| SC D5-D12 | 58.08 | 12.4750  |
| LL       | 54.28 | 44.2230  |
| LLD      | 50.79 | 49.7230  |
| PO       | 10.51 | 14.3160  |
| PI       | 42.48 | 9.50     |
| SS       | 8.68  | 10.1620  |
| PT       | 9.50  | 8.6520   |

Table 2. Direct correlations between variables using Pearson Test.

| SB    | Mean | Std. Deviation | Std. Error Mean |
|-------|------|----------------|-----------------|
| SC from T1 to T5 | 25.78 | 6.058 | 2.019 |
| SC from T5 to T12 | 23.33 | 12.659 | 4.220 |
| LL     | 61.31 | 15.348 | 5.426 |
| PI     | 69.88 | 15.348 | 5.426 |
| SS     | 49.22 | 13.860 | 1.789 |
| PT     | 9.50  | 8.652 | 3.059 |

Table 3. Differences of AIS patients with sagittal balance <2 cm vs >=2 cm regarding thoracic kyphosis, lumbar lordosis and spinopelvic parameters.

| Variable | Mean | Std. Deviation | Std. Error Mean |
|----------|------|----------------|-----------------|
| SB       | 25.78 | 6.058 | 2.019 |
| CB       | -15.99 | 9.324 | 1.175 |
| CB       | 23.33 | 12.659 | 4.220 |
| CCA      | 61.31 | 15.348 | 5.426 |
| CCA      | 69.88 | 15.348 | 5.426 |
| CCA      | 49.22 | 13.860 | 1.789 |
| CCA      | 9.50  | 8.652 | 3.059 |

SB sagittal balance. SC sagittal Cobb angle. CB coronal Cobb angle. CCA coronal Cobb angle of the main scoliotic curvature. SCA sagittal Cobb angle. LL lumbar lordosis. LLD leg length discrepancy evaluated between the femoral heads. PO pelvic obliquity. PI pelvic incidence. SS sacral slope. PT pelvic tilt.

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed).
Table 4. Analysis of sagittal balance between patients with kyphotic cervical shape comparatively to lordotic cervical shape.

| Sagittal balance | Cervical shape | N  | Mean | Std. Deviation | Std. Error Mean |
|------------------|----------------|----|------|----------------|-----------------|
| Kyphotic         | 19             | -3.667 | 3.152 | 723            |                 |
| Lordotic         | 31             | 0.730  | 2.244 | 403            |                 |

Table 5. Analysis of SB differences between patients with kyphotic cervical shape comparatively to lordotic cervical shape (through Levene’s Test for Equality of Variances and T-test for Equality of Means).

| Sagittal balance | Levene’s Test for Equality of Variances | T-test for Equality of Means |
|------------------|----------------------------------------|-----------------------------|
|                  | F  | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference | Lower | Upper |
|                  |    |                |               |                         |                         |       |       |
| Sagittal balance | 5.632 | 0.022 | 0.00 | -4.39789 | 76397 | -5.93395 | -2.86184 |
work to take public responsibility for the suitability of the experimental design and method and the collection, analysis and interpretation of the data, and that this final version was reviewed and approved for submission and/or publication. *ORCID (Open Researcher and Contributor ID).

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