Scientific contribution

Spinopelvic Alignment and Sagittal Balance in Adolescent Patients with Structural Hyperkyphosis

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Abstract:

Sagittal spinopelvic configuration and global alignment have previously been investigated in healthy children, adolescents, and adults to understand biomechanics or to guide fusion surgery. However, no studies were found in the literature assessing patients with structural hyperkyphosis (HK) from the perspective of global alignment and spinopelvic parameters. The research question is: How does structural HK affect spinopelvic parameters, global tilt(GT), global alignment, and proportion (GAP) score in skeletally immature adolescents? This was a retrospective analysis of prospectively collected data. Thirty-two structural HK patients(19 male, 13 female) with a mean age of 13.8 years and an initial curve magnitude between 55-75° were included in the study. Radiographic measurements including thoracic kyphosis(TK) angle, L1-S1 lumbar lordosis(LL) and L4-S1 lower arch lordosis angles, pelvic incidence, sacral slope, global tilt were measured from lateral spine radiographs by a blinded orthopedic spine surgeon at the first visit, and GAP score was calculated using these parameters. The mean TK was 59.5°, LL was 66.7°, and the mean GT was 7.2° at baseline. There was a correlation between TK and LL, meaning that patients who have higher TK have also a higher degree of LL. There was also a correlation between PT and SS with the PI at baseline. Structural HK may affect pelvic development resulting in lower values of PI. Higher values of TK or thoracolumbar kyphosis may be sufficiently compensated by LL to maintain a neutral sagittal balance when PI has lower values. Clinicians should focus on global alignment to maintain the global sagittal balance rather than TK alone.

Keywords: Scheuermann's disease, hyperkyphosis, global alignment, sagittal balance, spinopelvic configuration

1. Introduction

Hyperkyphosis(HK) is the structural abnormal curvature of the spine in the sagittal plane beyond the physiological limits, due to Scheuermann's disease or other causes (Tribus, 1998). Scheuermann's disease is a common cause of HK in adolescents that involves the vertebral bodies and discs of the spine. Scheuermann's disease is identified by anterior wedging greater than or equal to 5° between endplates of three or more adjacent vertebral bodies (Mansfield, 2023). Structural HK deformity develops before puberty in the thoracic or thoracolumbar spine and, it reaches the peak deformation during the adolescent growth spurt. Posterior components grow at a faster pace than their anterior counterparts during the development processes of hyperkyphotic deformity. Thus compressive forces on the anterior portion of thoracic vertebral bodies increase and resulting in an uneven distribution of forces in the thoracic region (Fotiadis et al., 2008).

Sagittal alignment and spatial pelvic parameters are directly affected in HK. Due to close anatomical relationships, the segmental alterations result in a compensated posture to minimize energy expenditure (Mac-Thiong et al., 2007; Tyrakowski et al., 2014). The interaction existing between the spine and the pelvis is a key point in the understanding of the sagittal balance of spinal deformities. In case of imbalance, the compensatory mechanisms are activated to maintain the balance. Compensation begins at the spinal level (modifications of spinal curves), and if these compensations are not sufficient, the pelvis tilts backward, increasing the PT value (Obeid et al., 2016).

Untreated hyperkyphosis in the growing spine might result in progressive deformity and back pain. The symptom severity increases with a progressive sagittal imbalance in patients with kyphosis-related back pain (de Mauroy et al., 2010). The biomechanical concept for treatment focuses to decrease the mechanical stress load on the anterior wall of the vertebral body. Thorocolumbosacral hyperkyphosis brace and hyperkyphosis-specific exercises reduce the axial load and shift the center of gravity to the posterior, and prevent the collapse of the anterior wall of the vertebral body (de Mauroy et al., 2010).

Sagittal malalignment is commonly recognized by lumbar lordosis (LL), thoracic kyphosis (TK), pelvic tilt (PT), sagittal vertical axis, and knee flexion (Le Huec et al., 2011). These parameters are used in daily practice however lumbar lordosis and thoracic kyphosis alone are insufficient to explain the effects of the spinopelvic configuration on biomechanical loading on the spine. While spinal loading can easily change in different positions depending on gravity, the angle of the kyphosis may be numerically the same (Schlösser et al., 2015). In spite of the close interaction between the spinal balance and the compensatory mechanisms, assessment of the global spinopelvic balance ignored either the spinal part or the pelvic part until the development of new global approaches. Eventually, new parameters such as the global tilt (GT) and global alignment and proportion (GAP) score were developed in recent years for the global spinopelvic balance that takes into account both the spinal part and the pelvic part (Obeid et al., 2016). The GT is a modified version of the spinopelvic angle (SPA), which analyzes malalignment, considering spinal and pelvic imbalance together. GAP score, is a new pelvic incidence-based proportional method to analyze sagittal alignment and balance, and it gives relative deviations from PI-based normative data (Gupta et al., 2021; Obeid et al., 2016; Yilgor et al., 2017a).

Sagittal spinopelvic configuration and global alignment have been investigated mostly in adults and skeletally mature young adults. For the adolescent population, studies have not been on hyperkyphosis but on adolescent idiopathic scoliosis. All of these studies have been conducted primarily to guide fusion surgery or to understand biomechanics (Yilgor et al., 2017b). Currently, no study investigated spinopelvic parameters and global alignment in skeletally immature hyperkyphosis patients with a global alignment standpoint (Aulisa et al., 2016; de Mauroy et al., 2010; Weiss et al., 2009). This study aimed to assess spinopelvic parameters, GT, GAP scores and, to determine the relationship between hyperkyphosis and these parameters in patients with structural HK.

2. Methods

This is a retrospective analysis of patients' data between December 2015-2022. Out of 44 patients diagnosed with structural HK (Scheuermann's disease or other causes), 32 of those who met the inclusion criteria were analyzed in this study. The demographic and clinical data of the patients were recorded. Physical examinations of the patient's spine were performed and the differential diagnosis of HK was made according to thoracic spine magnetic resonance imaging as described in the literature (Haddadi et al., 2018). Patients who do not meet yet Scheuermann's disease diagnosis criteria due to the early phase of the disease development, presented as structural HK. The presence of pain was recorded. The primary outcomes were a GAP score and GT.

1.1. Participants

1.1.1. Inclusion Criteria

- Subjects who were diagnosed with structural HK (Scheuermann's disease or other causes)
- Ages between 10-18 years
- Initial curve magnitude between 55-75°

1.1.2. Exclusion Criteria

- Cobb angle ≥20 in the coronal plane
- History of spinal surgery or trauma
- Patients having kyphosis due to congenital, neuromuscular, traumatic, tumor, infection causes
- Ankylosing spondylitis and other spondyloarthropathies.
- The lack of appropriate full-length lateral radiography with acceptable quality at the baseline assessment.

1.2. Radiographic measurements

Full-length (posteroanterior and lateral) standing digital radiographs of the spine were evaluated at the first visit. All radiographic measurements were performed by a blinded orthopaedic spine surgeon using Surgimap® Spine(Nemaris™ Inc, New York), a validated software (Lafage et al., 2015) . Skeletal maturity was defined according to the Risser sign using a posteroanterior spine radiograph. Risser sign is based on the iliac apophysis pattern of ossification during adolescence. It is classified on a scale from 0(immature) to 5(fusion), indicating different stages of skeletal development. The other radiographic measurements, including kyphosis angle, lumbar lordosis (L1-S1) and L4-S1 lordosis angle of the inferior arch, pelvic incidence, sacral slope and GT were measured from lateral spine radiographs and the GAP score was calculated from these parameters as described in the literature (Obeid et al., 2016; O'Brien et al., 2008; Yilgor et al., 2017b). GT is a modified version of the spinopelvic angle, which analyzes malalignment considering spinal and pelvic imbalance together (Obeid et al., 2016). GAP score is a new pelvic incidence-based proportional method developed by the European Spine Study Group (ESSG) to analyze sagittal alignment and balance. The GAP score assesses the spatial orientation of the pelvis, magnitude and distribution of lumbar lordosis, and the global spinopelvic alignment of the spine and pelvis relative to normative targets rather than as an absolute numerical value in relation to the ideal values calculated for any individual. The GAP score includes five domains, including relative pelvic version, relative lumbar lordosis,

lordosis distribution index, relative spinopelvic alignment, and age factor. The scores for each of the four domains vary from 0 to 3, and the age factor varies from 0 to 1. The total GAP score ranges from 0 to 13 points and is calculated by adding the scores of these five domains. If the total score is 0 to 2, the alignment is considered proportional, for 3 to 6, moderate disproportion, and for ≥7, severely disproportionate spine (Yilgor et al., 2017b).

1.3. Statistical analyses

Parametric data were presented as mean and standard deviation (SD). Nonparametric data were presented as median and percentage. The Spearman's correlation coefficient was used to examine correlations between parameters. A p-value of ≤0.05 was considered statistically significant. Statistical analysis was performed using IBM SPSS Statistics® (version 23; Armonk, NY: IBM Corp.)

3. Results

Among 32 patients (19 male, 13 female), 16 had Scheurmann's HK and 16 had structural HK. The mean age was 13.8 years. The baseline characteristics of the patients are shown in **Table 1.**

Table 1: Baseline Characteristics of Patients

	All	Female (n=13)	Male(n=19)	p value*
Variables	Mean±SD	Mean±SD	Mean±SD	*U*
BMI	19.7±3.7	19.4±3.7	19.9±3.8	0.985
Scheuermann/structural	16/16	5/8	11/8	
Age	13.8±1.4	12.9±1.7	14.5±0.7	**0.020**
Presence of pain(yes/no)	18/14	6/7	12/7	
Concurrent scoliosis(yes/no)	19/13	5/8	14/5	
$Cobb°_{max}$	11.4±10.6	5.6±8.2	15.3±10.5	**0.014**
$Risser_{baseline}$	2.1±1.8	1.4±1.7	2.6±1.7	0.051

BMI: body mass index, *Statistically significant at p ≤ 0.05, *U*: Mann-Whitney *U* test

Radiographic measurements are shown in **Table 2**. The mean TK was 59.5°, LL was 66.7° and the mean GT was 7.2° at baseline. GT measurement from the x-ray results of one patient, who was taking conservative treatment for a year, presented to show the difference globally (**Figure 1**).

Table 2. Descriptive results of spinopelvic parameters in adolescents with HK

	Baseline
Variables	Mean±SD
Kyphosis angle	59.5±9.4
L1-S1 lordosis angle	66.7±11.5
L4-S1 lordosis angle	40.7±7.3
Pelvic tilt	9.06±9.1
Sacral slope	30.4±15.5
Pelvic incidence	38.4±16.1
Global tilt	7.2±12.0
GAP score	3.4±1.9

L1-S1:Lumbar1-Sacral1 vertebra levels; L5-S1 Lumbar5asfd-Sacral1 vertebra levels; GAP: global alignment and proportion

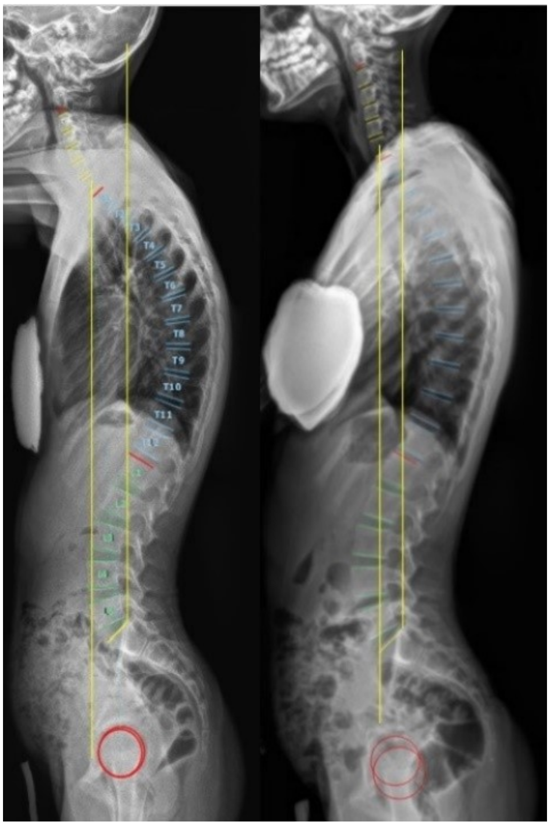

Figure 1 Sagittal spinal alignment before and after 1-year treatment in standing full-spine lateral radiography

There was a correlation between TK and LL; and also PT and SS with the PI at baseline (**Table 3**).

Table 3: Correlation Between Pelvic Incidence and Other Spinopelvic Parameters

	Baseline	
Variables	r	p value
PI vs TK	-0,253	0,162
PI vs LL	-0,053	0,774
PI vs LL_{L5-S1}	-0,255	0,159
PI vs PT	0,549**	0,002*
PI vs SS	0,490**	0,004*
PI vs GT	0,215	0,238
PI vs GAP	0,124	0,498

PI: pelvic incidence, TK: thoracic kyphosis, LL: lumbar lordosis, PT: pelvic tilt, SS: sacral slope, GT: global tilt, GAP: global alignment and proportion, *Statistically significant at $p \leq 0.05$, r: Spearman's Rho correlation coefficient

4. Discussion

Spinopelvic balance depends on the combination of pelvic and spinal shape (Roussouly and Pinheiro-Franco, 2011). Berthonnaud et al. (2005) have proposed the concept of a linear chain connecting the head to the pelvis, where the shape and orientation of each anatomical segment are closely linked and influence the adjacent segment to maintain a stable posture with minimal energy expenditure. According to this concept, a change in the shape or orientation of one anatomical segment results in a change in the shape and/or orientation of the adjacent segments of the spine and pelvis (Mac-Thiong et al., 2007)

The importance of sagittal alignment of the spine in relation to its normal function and the etiopathogenesis of spinal deformities has been increasingly recognized (Schlösser et al., 2015). The main reasons for the increasing recognition are the high rate of mechanical complications and associated morbidities and mortalities, the need for secondary surgeries, and the increased healthcare costs. It was critical to reduce mechanical complications and associated health problems. At that time, the GAP score was created using a mathematical formula that considered proportional alignment rather than using fixed numerical values for anyone. Although the restoration of normal sagittal alignment is a crucial goal of conservative and surgical treatment, it seems clinicians still focus mostly on kyphosis angle, in-brace correction, and pain (Aulisa et al., 2016; Berdishevsky, 2016; de Mauroy et al., 2010; Weiss et al., 2009). For this reason, in the present study, we wanted to provide a different viewpoint and investigated the relationship between sagittal alignment and spinopelvic parameters using relatively new measurement parameters such as GT and GAP in skeletally immature patients with structural HK.

Cil et al.(2005) found that thoracic kyphosis and lumbar lordosis increase during growth and the thoracic apex is lower in late adolescence than at younger ages in healthy children. Furthermore, they observed that the development of lumbar lordosis begins before puberty and thoracic kyphosis develops later (Schlösser et al., 2015). Many studies have reported that during the physiological growth phase, thoracic kyphosis and pelvic incidence increase slightly, and reach adult configuration at the end of growth (Cil et al., 2005; Mac-Thiong et al., 2007; Mangione et al., 1997; Mendoza-Lattes et al., 2010). Lee et al. (2012)found that thoracic kyphosis was 31.8° and 33.4°; lumbar lordosis was 50.0° and 48.1° in 8-12 years and 13-17 years respectively. They have found a positive correlation between thoracic kyphosis and lumbar lordosis in asymptomatic young people 3-20 years of age ($r=0.485$, $p<0.001$). There was a correlation between TK and LL in our adolescent HK sample too. Weiss et al. (2009) reported that the mean kyphosis angle was 55.6° (43-80°) in patients with Scheuermann kyphosis at 12-17 years of age. Similarly, Aulisa et al.(Aulisa et al., 2016) reported the TK as 57.8° at 12 years of age. However, the LL angle was ignored in either of these studies before or after conservative treatment.

PI is a morphological pelvic parameter for the three-dimensional regulation of sagittal spinal curves. Despite some reports stating that PI may change by the end of skeletal growth, it is widely accepted that PI becomes fixed at about 10 years of age and remains constant during adolescence and adulthood unless there is a pathological process that may alter the shape of the pelvis (Tyrakowski et al., 2014). Lee et al. (2012) reported that the PI in asymptomatic adolescents was 43.6° at 8-12 years of age and 46.4° at 13-17 years of age. Tyrakowski et al. (2014) reported that the average PI in skeletally mature patients with Scheuermann's disease was 40° and significantly lower than in healthy adults and adolescents ($p < 0.0001$) . They suggested that Scheuermann's disease occurring in adolescent individuals may affect further pelvic development of the pelvis resulting in lower values of PI. In addition, higher values of TK or thoracolumbar kyphosis may be sufficiently compensated by LL to maintain a neutral sagittal balance when PI has lower values(Tyrakowski et al., 2014). Significantly lower PI values were also found in patients with post-tuberculosis or congenital thoracic and thoracolumbar kyphosis (Li et al., 2013). Similarly, PI was lower in our study than in reported healthy subjects, the mean value of PI was 38.4°, and no statistically significant correlation was found between TK, LL, and LLL5-S1 with PI, either at baseline or after treatment, and our results are consistent with the literature (Table 3).

Bracing has been used for the treatment of deformity and to relieve pain in HK. In one study, a Milwaukee brace was applied on patients with Scheuermann's disease and reported a 40% decrease in mean thoracic kyphosis, a 35% decrease in mean lumbar lordosis after an average of thirty-five months of brace wearing (Weiss et al., 2009). Weiss et al. (2009) showed that. An average in-brace correction of >15° was achieved using the kyphologic™ brace. There are a very small number of studies on the conservative treatment of structural HK and all of those studies clearly ignored the global spinopelvic alignment and balance approaches and only focused angle of kyphosis. Sagittal spinal balance was greatly affected rather than physiological kyphosis in patients with structural HK (Tyrakowski et al., 2014). Pain and other symptoms could have been caused by spinal disproportion. A patient with HK may be well adjusted so that he may be proportionally aligned even if his kyphosis angle was defined as "hyper". Each individual has their own normality and adaptations, so more than just the kyphosis angle is needed for the patient's assessment and treatment plan. Clinicians need to evaluate whole sagittal parameters and balance, taking into account the PI value, and not just the kyphosis angle or the correction by brace alone.

Although global deformity is evaluated clinically in adolescents with HK, the kyphosis angle is a determinant in deciding conservative treatment. We believe that the GAP score, which has an important place in surgical planning, could also be useful in conservative treatment. We suggest that spinopelvic parameters and integrative assessment parameters such as GT or GAP score should also be included in the guidelines for these patients.

4.1. Limitations

This study has obvious limitations including not presenting follow-up time and a small sample size. However, this result is based on baseline measurements from an ongoing study in which patients are currently taking conservative treatment. In the future, we will present the effects of treatment on global balance and spinopelvic parameters after a follow-up period of 2 years.

5. Conclusions

A sagittal profile is well studied in adults, however, there is limited knowledge on adolescents and children, especially the ones with structural HK deformity. The present study can give some more understanding of this neglected area of research. Clinicians should focus on global alignment to protect the global sagittal balance rather than kyphosis angle or in-brace correction alone.

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Institutional Review Board Statement: The study was conducted with ethical approval from the Haliç University Medical Ethics Committee (date: 4/29/2021, number:71)

Conflicts of Interest: The authors declare no conflict of interest.

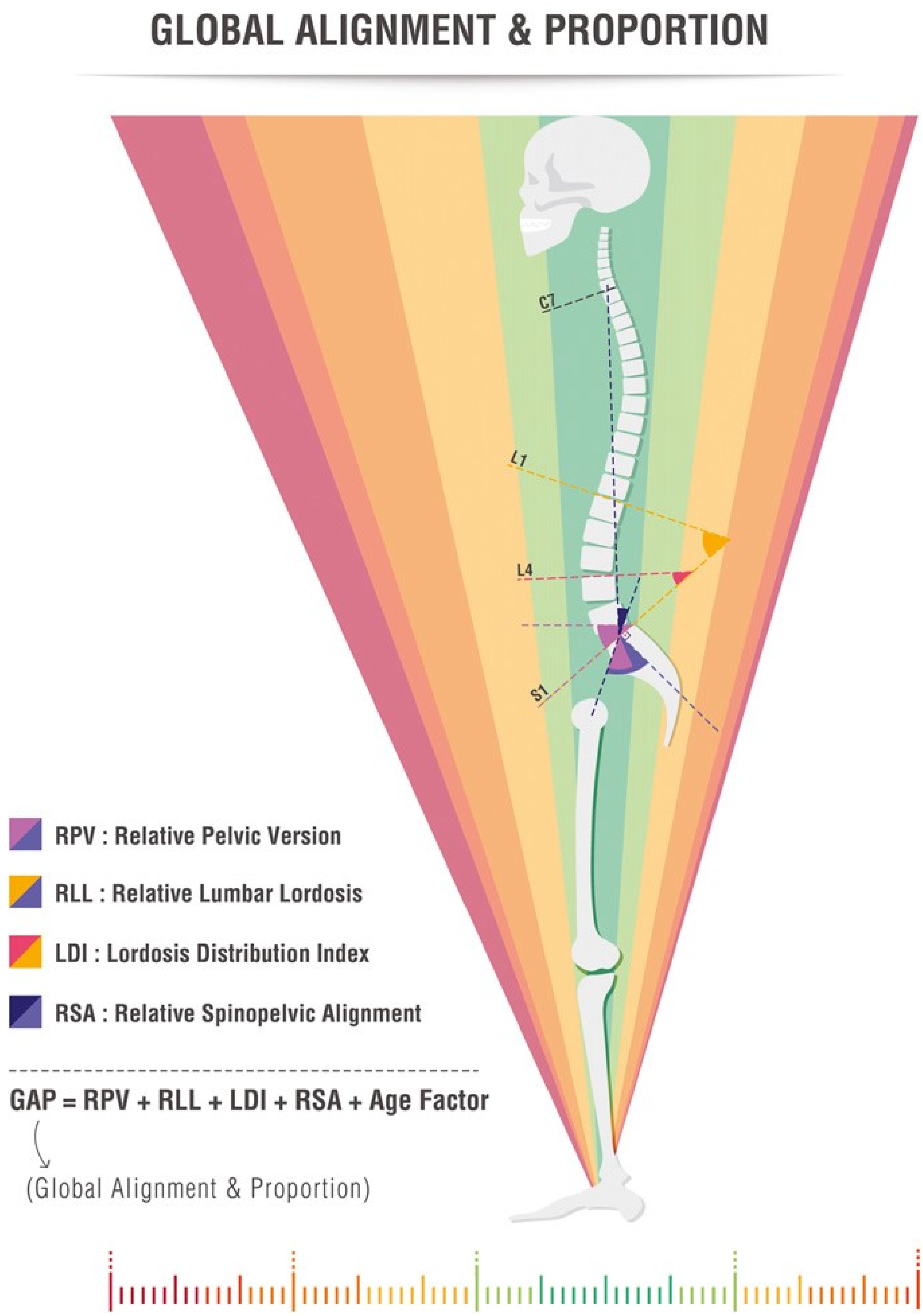
Appendix A: GAP score (10).

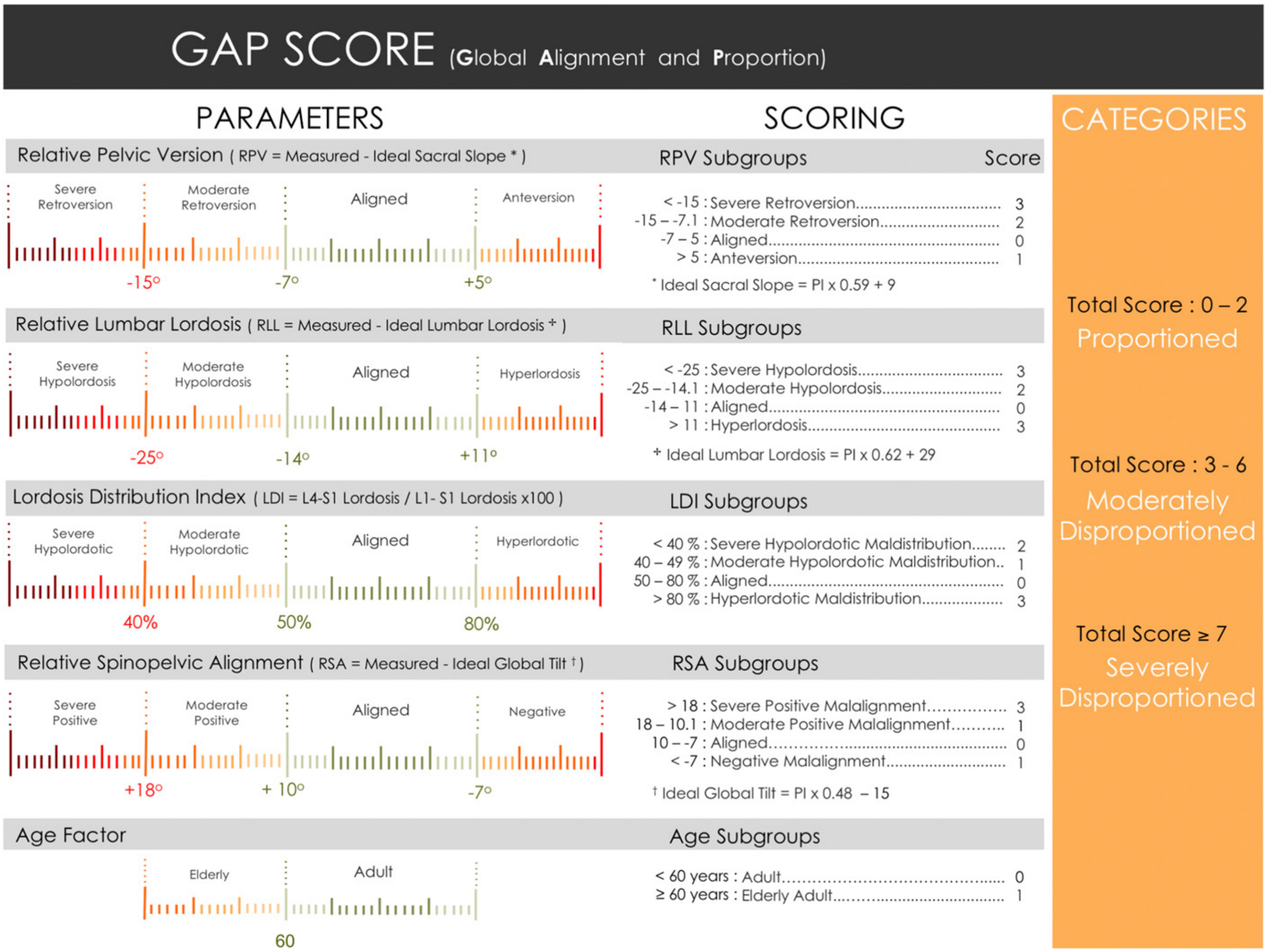
References

1. Aulisa AG, Falciglia F, Giordano M, et al. Conservative treatment in Scheuermann's kyphosis: comparison between lateral curve and variation of the vertebral geometry. Scoliosis Spinal Disord. 2016; 11(Suppl 2):33. DOI:10.1186/s13013-016-0089-4
2. Berdishevsky H. Outcome of intensive outpatient rehabilitation and bracing in an adult patient with Scheuermann's disease evaluated by radiologic imaging-a case report. Scoliosis and Spinal Disorders. 2016; 11: 1–5. DOI:https://doi.org/10.1186/s13013-016-0094-7
3. Berthonnaud E, Dimnet J, Roussouly P, Labelle H. Analysis of the sagittal balance of the spine and pelvis using shape and orientation parameters. J Spinal Disord Tech. 2005; 18:40-47. DOI:10.1097/01.bsd.0000117542.88865.77
4. Cil A, Yazici M, Uzumcugil A, et al. The evolution of sagittal segmental alignment of the spine during childhood. Spine. 2005; 30: 93–100. DOI: https://doi.org/10.1097/01.brs.0000149074.21550.32
5. Fotiadis E, Kenanidis E, Samoladas E et al. Scheuermann's disease: focus on weight and height role. Eur Spine J. 2008; 17:673-678. DOI:10.1007/s00586-008-0641-x
6. Gupta MC, Yilgor C, Moon HJ, et al. Evaluation of global alignment and proportion score in an independent database. Spine J. 2021; 21:1549-1558. DOI:10.1016/j.spinee.2021.04.004
7. Haddadi K, Kadam A, Tannoury C, Tannoury T. Scheuermann's Disease: New Impressions of Clinical and Radiological Evaluation and Treatment Approaches; A Narrative Review. Journal of Pediatrics Review. 2018; *6*:2. DOI: https://doi.org/10.5812/jpr.12102
8. Lafage R, Ferrero E, Henry JK, et al. Validation of a new computer-assisted tool to measure spino-pelvic parameters. Spine J. 2015; 15:2493-2502. DOI:10.1016/j.spinee.2015.08.067
9. Le Huec JC, Leijssen P, Duarte M, Aunoble S. Thoracolumbar imbalance analysis for osteotomy planification using a new method: FBI technique. Eur Spine J. 2011; 20 Suppl 5:669-680. DOI:10.1007/s00586-011-1935-y
10. Lee CS, Noh H, Lee DH, Hwang CJ, Kim H, Cho SK. Analysis of sagittal spinal alignment in 181 asymptomatic children. J Spinal Disord Tech. 2012; 25:E259-E263. DOI:10.1097/BSD.0b013e318261f346
11. Li W, Sun Z, Guo Z, et al. Analysis of spinopelvic sagittal alignment in patients with thoracic and thoracolumbar angular kyphosis. Spine (Phila Pa 1976). 2013; 38:E813-E818. DOI:10.1097/BRS.0b013e3182913219
12. Mac-Thiong JM, Labelle H, Berthonnaud E, Betz RR, Roussouly P. Sagittal spinopelvic balance in normal children and adolescents. Eur Spine J. 2007; 16:227-234. DOI:10.1007/s00586-005-0013-8

13. Mangione P, Gomez D, Senegas J. Study of the course of the incidence angle during growth. Eur Spine J. 1997; 6:163-167. DOI: 10.1007/BF01301430
14. Mansfield JT, Bennett M. Scheuermann Disease. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2023 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK499966/
15. de Mauroy J, Weiss H, Aulisa A, et al. 7th SOSORT consensus paper: conservative treatment of idiopathic & Scheuermann's kyphosis. Scoliosis. 2010; 5:9. Published 2010 May 30. doi:10.1186/1748-7161-5-9
16. Mendoza-Lattes S, Ries Z, Gao Y, Weinstein SL. Natural history of spinopelvic alignment differs from symptomatic deformity of the spine. Spine (Phila Pa 1976). 2010; 35:E792-E798. DOI:10.1097/BRS.0b013e3181d35ca9
17. Obeid I, Bourghli A, Larrieu D, et al. The global tilt: Evaluation of a parameter considering the global spinopelvic alignment. J Med Liban. 2016; 64:146-151. DOI:10.12816/0031523
18. O'Brien M, Kulklo T, Blanke K, Lenke L. Radiographic Measurement Manual. *Spinal Deformity Study Group Radiographic Measurement Manual*, 120. 2008. Available from: https://www.oref.org/docs/default-source/default-document-library/sdsg-radiographic-measuremnt-manual.pdf?sfvrsn=2&sfvrsn=2
19. Roussouly P, Pinheiro-Franco JL. Sagittal parameters of the spine: biomechanical approach. Eur Spine J. 2011; 20 Suppl 5:578-585. DOI:10.1007/s00586-011-1924-1
20. Schlösser TP, Vincken KL, Rogers K, Castelein RM, Shah SA. Natural sagittal spino-pelvic alignment in boys and girls before, at and after the adolescent growth spurt. Eur Spine J. 2015; 24:1158-1167. DOI:10.1007/s00586-014-3536-z
21. Tribus CB.Scheuermann's kyphosis in adolescents and adults: diagnosis and management. J Am Acad Orthop Surg. 1998; 6:36-43. DOI:10.5435/00124635-199801000-00004
22. Tyrakowski M, Mardjetko S, Siemionow K. Radiographic spinopelvic parameters in skeletally mature patients with Scheuermann disease. Spine (Phila Pa 1976). 2014; 39:E1080-E1085. DOI:10.1097/BRS.0000000000000460
23. Weiss HR, Turnbull D, Bohr S. Brace treatment for patients with Scheuermann's disease - A review of the literature and first experiences with a new brace design. Scoliosis. 2009a; 4:22. DOI: https://doi.org/10.1186/1748-7161-4-22
24. Yilgor C, Sogunmez N, Yavuz Y, et al. Global Alignment and Proportion (GAP) Score Better Correlates to HRQoL Scores and Better Predicts Mechanical Complications Compared to Schwab Sagittal Modifiers. The Spine Journal. 2017a; 17: S156. DOI: https://doi.org/10.1016/j.spinee.2017.07.235
25. Yilgor C, Sogunmez N, Boissiere L, et al. Global Alignment and Proportion (GAP) Score: Development and Validation of a New Method of Analyzing Spinopelvic Alignment to Predict Mechanical Complications After Adult Spinal Deformity Surgery. J Bone Joint Surg Am. 2017b; 99:1661-1672. DOI:10.2106/JBJS.16.01594

Appendix A


GLOBAL ALIGNMENT & PROPORTION
C7
L1
L4
S1
RPV : Relative Pelvic Version
RLL : Relative Lumbar Lordosis
LDI : Lordosis Distribution Index
RSA : Relative Spinopelvic Alignment
GAP = RPV + RLL + LDI + RSA + Age Factor
(Global Alignment & Proportion)



These two pictures were obtained from the original article: Yilgor C, Sogunmez N, et al., 2017b (25)