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Is sagittal spinopelvic alignment a cause of low back pain in pediatric spine pathologies? A review

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Abstract

Purpose: Altered spinopelvic morphology is observed in many spine pathologies occurring during growth. The aim of the study is to better understand the sagittal compensatory mechanisms and their possible influence on the occurrence of pain in selected pediatric spine pathologies.

Methods: A bibliographic search in the PubMed database included articles published between September 1965 and July 2023. The keywords contained in the search were "spondylolysis," "spondylolisthesis," "scoliosis," "kypho," "sagittal," "pediatric," "child," "adolescent," "grow," "development," and "pain."

Results: The largest diversity in sagittal alignment patterns was reported in idiopathic scoliosis, with global flattening of the spine being the most common. Kyphotic deformations occurring during growth are characterized by structural thoracic or thoracolumbar kyphosis compensated by lumbar hyperlordosis and lower pelvic incidence. Whereas in spondylolisthesis, altered morphology of the spinopelvic junction with high values of pelvic incidence is observed. Pain does not seem to be related to sagittal alignment in idiopathic scoliosis. In Scheuermann disease, it is localized at the apex of the deformity and is associated with the curve pattern, whereas in spondylolisthesis, sagittal alignment correlates with pain scores only in high-grade slips.

Conclusion: Most of the patients with spine disorders that occurred during growth present a clinically balanced posture in the sagittal plane. It suggests that compensatory mechanisms before achieving skeletal maturity are really significant. A comprehension of sagittal alignment in spine deformities and its relationship to pain is essential for the proper assessment and treatment of these disorders.

Keywords: Sagittal alignment, pelvic incidence, low back pain, idiopathic scoliosis, spondylolisthesis, kyphosis, spine deformity

Introduction

Recently, we have observed a growing interest in the sagittal balance of the spine and pelvis in various pathologies, which is even referred to as a "sagittal plane analysis revolution."[1] Current studies have analyzed spinopelvic parameters trying to explain their influence on the occurrence and progression of the disease, and the patterns of the compensatory mechanisms essential for keeping spinal balance. The physiological shape of the human spine with double S curvatures in the sagittal plane is crucial for maintaining the balance of the entire body while standing and walking.[2] The sagittal spinopelvic alignment assessment is performed on lateral radiographs of the spine and pelvis in a free-standing position, using various anatomic and positional parameters.[3]

One of the crucial radiographic anatomic parameters is pelvic incidence (PI). PI is defined as the angle contained

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between the line connecting the center of the proximal endplate of the first sacral vertebra (S1) to the center of the bicoxofemoral axis and the line perpendicular to the proximal endplate of S1. PI is an anatomical parameter, it is fixed and individual for each mature person and does not depend on the orientation of the pelvis in the sagittal plane while taking a radiograph.[3] As it is proved, PI increases during developmental age, reaching its definitive value with bone maturity.[3] The mean values of PI in the normal population are 54° and 49°, for adults and children, respectively.[4,5] It is believed that PI is the fundamental parameter determining other curvatures of the spine in the sagittal plane[6] and it is widely used in preoperative planning of spinal fusion surgeries in adults and in children.[7,8] Rose et al.[8] in 2009 proposed a mathematical formula to determine lumbar lordosis (LL) based on PI and thoracic kyphosis (TK) values:

$$\mathrm{PI} + \mathrm{LL} + \mathrm{TK} \leq 45 \text{ degrees}$$

It enables us to maintain the spinal balance in the sagittal plane with 91% sensitivity. Alterations in pelvic morphology and higher values of PI were observed in patients with spondylolisthesis and idiopathic scoliosis (IS).[9–12] Whereas, lower PI was associated with kyphotic deformities due to Scheuermann disease (SD), tuberculosis, or congenital defects.[13,14]

It is well-documented that global sagittal alignment is associated with the quality of life of adult patients with spine deformities.[15,16]

Understanding the influence of PI on the sagittal balance of the spine is crucial to avoid iatrogenic misalignments, which apart from neurological deficits and infections are the most common and important complications of pediatric deformity treatment.[1] Evaluation of sagittal parameters may be helpful in identifying the source of pain in pediatric spine pathologies and allowing for comprehensive treatment of these complex deformities.

The aim of the study is to better comprehend the sagittal compensatory mechanisms and their role in the occurrence of pain in selected pediatric spine pathologies.

Methods

A bibliographic search through the PubMed database included articles published between September 1965 and July 2023. The keywords included in the search were "spondylolysis," "spondylolisthesis," "scoliosis," "kypho," "sagittal," "pediatric," "child," "adolescent," "grow," "development," and "pain." From 3059 abstracts analyzed by the authors, the most relevant to the topic were chosen, then analyzed and summarized in this article.

Sagittal alignment in IS

Idiopathic scoliosis is defined as a complex deformity of the spinal column in three planes. IS includes a curvature in the coronal plane described with the Cobb angle, rotation in the axial plane, usually the greatest at the apex of the curve, and abnormalities observed in the sagittal plane, which are difficult to adequately assess, especially in the severe deformations. Understanding the three-dimensional (3D) character of the deformity is essential to truly evaluate the sagittal profile of the spine in IS. The assessment of the sagittal parameters of the spine and pelvis is usually based on the measurements performed on standard lateral radiographs of the spine, but according to the study by Newton et al.,[17] in the group of patients with thoracic adolescent idiopathic scoliosis (AIS) and significant hypokyphosis, the values of TK angle were significantly overestimated on the standard 2D method versus the 3D segmental method. The greater differences between the two methods of measurements were observed with increasing apical vertebral rotation. Thus, sagittal plane deformity is more underestimated in patients with larger curves and bigger rotation of the vertebrae. Another phenomenon associated with AIS is the anterior overgrowth, which is observed mainly at the apex of the primary and the compensatory curves. Greater coronal Cobb angles correlate with greater rotation and more anterior lengthening of the spine.[18] Because of accelerated anterior growth, TK is replaced by lordosis, which needs to rotate around the posterior axis to balance the patient's head over the pelvis.[19–21] The spinal cord is thought to act as a tether with a normal length in the presence of an abnormally long anterior spinal column. It supports the concept of asynchronous neuro-osseous growth as one of the etiopathogenetic mechanisms of AIS.[22–24]

Many authors studied the relation of the spine and pelvis on sagittal balance in AIS according to coronal curve type, but it is still not clear.[10,25,26] Mac-Thiong et al.[10] and Upasani et al.[26] revealed greater values of PI in patients with AIS compared to normal adolescents (57.3° versus 55.5° in Lenke 1 and 53.2° in Lenke 5), whereas Brink et al.[27] documented significantly higher PI in Lenke type 5 curves (46.8°, $p=0.025$), and no significant differences in Lenke type 1 (45.9°, $p=0.141$) in comparison with the control group (41.3°) (Table 1). According to the study by Mac-Thiong et al.,[10] TK tends to be smaller for thoracic than for lumbar AIS, and it is mainly influenced by the spinal deformity. Whereas, LL is mainly influenced by the sagittal alignment of the pelvis. The coronal scoliotic curve type was not related to any specific sagittal pelvic configuration. The increased values of PI observed both in thoracic and thoracolumbar curves in comparison to the normal adolescent population may be a risk factor but does not appear to be the determinant of the development of thoracic versus thoracolumbar AIS.[26] The theory of anterior overgrowth of the spinal column as a "driver" for the development of thoracic AIS may be supported by the presence of thoracic hypokyphosis, despite the presence of an increased PI and LL.[26] Also, Clement et al.[28] considered that the proximal part of the lordosis depends mostly on

Table 1. Summary table of literature review describing the values of PI in a normal population, idiopathic scoliosis, kyphotic deformities, and spondylolisthesis.

Study	Study group	Control group	p-value
Normal			
Kuntz et al.[4]	54°	–	–
Mac-Thiong et al.[5]	49.1°	–	–
Idiopathic scoliosis			
Mac-Thiong et al.[10]	57.3°	–	–
Upasani et al.[26]	55.5° (Lenke 1)	45.5°	<0.001
	53.2° (Lenke 5)	45.5°	<0.001
Brink et al.[27]	45.9° (Lenke 1)	41.3°	0.141
	46.8° (Lenke 5)	41.3°	0.025
Clément et al.[28]	49.2°	45.5°–49.1° (adolescents)	Non-significant
		52.0° (adults)	Non-significant
Ries et al.[29]	55.7°	48.8°	0.06
Pasha et al.[30]	48.5° (Lenke 1)	45.7°	0.3
	44.2° (Lenke 2)		–
	45.0° (Lenke 3)		–
	47.1° (Lenke 4)		–
	47.0° (Lenke 5)		0.6
	43.0° (Lenke 6)		–
Kyphosis			
Tyrakowski et al.[13]	40.0°	49.3°–50.0° (adults)	<0.001
		39.5° (children)	0.44
Tyrakowski et al.[42]	36.6° (immature)	43.7° (children)	<0.0001
		46.9° (adolescents)	<0.0001
		54.7° (adults)	<0.0001
	39.4° (mature)	43.7° (children)	0.06
		46.9° (adolescents)	<0.0001
		54.7° (adults)	<0.0001
Jiang et al.[43]	32.0°	45.0°	<0.001
Cahill et al.[46]	42.0°	46.0°	0.84
Bederman et al.[47]	55.3° (TK)	–	–
	44.1° (thoracolumbar kyphosis)	–	–
Li et al.[14]	35.1°	Other studies	<0.001 (adolescents)
			0.001 < p < 0.05 (children < 10 years)
Spondylolisthesis			
Hanson et al.[9]	68.5° (low-grade)	47.4° (children)	0.0001
	79.0° (high-grade)	57.0° (adults)	0.0001
Roussouly et al.[53]	65.53°	51.91°	<0.05
Labelle et al.[54]	71.6°	51.8°	<0.01
Vialle et al.[56]	73.05°	54.67°	<0.0001

the TK and the distal part on the PI. The hypokyphosis in AIS is estimated independent of the pelvic parameters and could be described as a structural parameter, characteristic of the scoliotic deformity. Other studies document rather normal sagittal alignment of the spine in AIS patients in comparison to healthy controls.[29,30] Sagittal classification in AIS published by Abelin-Genevois et al.[31] in 2018 summarizes all the main pathological types of sagittal alignment in AIS in four patterns. Three sagittal parameters were strongly differentiating the four patterns. These were thoracic sagittal angles (T1–T12 and T4–T12 angles, TKmax), T10–L2 angle, and C7 slope. Almost half (44%) of the patients had a normal sagittal alignment of the spine—type 1, with a distribution of Lenke types comparable to the reference series of Lenke et al.[32], which may indicate that this pattern is not related to a certain type of scoliosis. More than half of the AIS patients presented a pathological sagittal profile. Within this group, type 2 is characterized by thoracic hypokyphosis, Type 2a (thoracic hypokyphosis) included mostly Lenke type 1 or 2 curves, and type 2b (thoracic hypokyphosis with thoracolumbar kyphosis) was seen specifically in a double major or thoracolumbar/lumbar curves. Type 3 is defined with a two-curve sagittal shape with cervicothoracic kyphosis and thoracolumbar lordosis (9%), observed mainly in Lenke type 1 curves.[31] According to the authors, sagittal malalignment may be related to structural deformity, whereas junctional modifications can be the compensatory mechanisms on the above and underlying segments.[31] Although most of the AIS patients are clinically balanced, up to 50% present a minor radiological posterior imbalance, especially observed in the group of patients with severe hypokyphosis.[29,33]

Several studies analyzed the relationship between coronal and sagittal malalignment and the quality of life of children with AIS. According to the study by Mak et al.,[34] it was the coronal Cobb angle that negatively correlated with the SRS-22r pain domain scores, and not the sagittal profile of the spine. Also, other studies have not found statistically significant correlations between sagittal alignment and back pain.[35–37] However, a greater spinal deformity with increased radiological parameters of coronal Cobb angle, torsion index, and right thoracic translation did correlate with the likelihood of developing back pain.[36,37]

To summarize, even though AIS patients are mostly clinically balanced in the sagittal plane, sagittal spinopelvic alignment is altered, with global flattening and anterior overgrowth of the spine. The occurrence of back pain in AIS seems to correlate more with the deformity in the coronal plane than the sagittal alignment. The role of PI and the potential compensatory mechanisms of the spinopelvic complex still need to be clarified.[1]

Sagittal alignment in kyphotic deformities

SD, defined as a rigid kyphosis of the thoracic or thoracolumbar spine occurring in adolescence, was initially described in 1920.[38] SD is most commonly determined with the presence of three consecutive vertebrae with an anterior wedging of their bodies of 5° and it is the most common cause of structural hyperkyphotic deformity in the pediatric population.[39] SD occurs in two different patterns: the typical (TK) pattern and the atypical (thoracolumbar kyphosis) pattern. The typical pattern is more common and usually associated with the non-structural hyperlordosis of the cervical and lumbar spine. Whereas, the atypical pattern is less common, but is thought to have a bigger risk of progression in adulthood.[39–41]

The analyses of spinopelvic alignment in SD revealed significantly lower values of PI in mature and immature patients[13,42,43] (Table 1). According to a study by Tyrakowski et al.,[13] the mean PI in the group of young adults (mean age 25 years) was 40° and it was significantly lower than that reported for healthy adults and adolescents ($p < 0.0001$) and not significantly different than the reported for healthy children ($p = 0.44$). Another study by the same author proved that there is no significant difference in sagittal spinopelvic parameters between skeletally immature and mature patients with SD, with both groups presenting significantly lower PI than normal adults, adolescents, and children.[42] Jiang et al.[43] confirmed that SD adolescents demonstrated significantly lower PI than normal controls (32.0° versus 45.0°, $p < 0.001$). The sagittal profile of the spinal column differed according to SD pattern. Typical SD had cervical and lumbar hyperlordosis, whereas atypical SD patients presented significantly lower values of TK and LL, but still lower PI. The above-mentioned studies did not find any correlation between spinopelvic parameters and LL,[13,43] in contrast to the data concerning adults without SD where PI highly correlated with LL, and was suggested to indicate values of desirable postoperative LL after posterior spinal fusion surgery.[6,44,45] Tyrakowski et al.[13] hypothesized that a negligible correlation between PI and LL in SD patients with thoracic hyperkyphosis which occurred during growth was compensated by increased LL, which helped to maintain a neutral sagittal balance. At a certain moment, a constant increase in LL must be compensated by a decrease in sacral slope angle (SS). A decreased SS induces higher pelvic tilt (PT) and moves the center of gravity posteriorly to the hip joints. Thus, maintaining a neutral sagittal balance induces changes in the pelvic shape during growth—lower SS and lower PT are achieved by a lower PI.

PI in SD patients was significantly lower than that reported for unaffected adolescents and adults, and no significant differences were found in comparison to healthy children. It may suggest that because SD occurs in the period of growth, it may affect the subsequent development of the pelvis resulting in lower PI.[13]

The atypical pattern of SD presents a strong correlation between TK and LL. Due to a lower (thoracolumbar) position of the apex of the kyphotic deformity, there are fewer segments left in the lumbar spine for the deformity compensation. That is possibly why pelvic compensation plays an essential role in maintaining sagittal balance in patients with thoracolumbar SD.[43]

In opposition, the study by Cahill et al.[46] compared the spinopelvic alignment of 47 SD patients and 50 controls, and did not find significant differences in PI (SD PI = 42° and controls PI = 46°, $p = 0.84$), but the control group was significantly younger (13.5 years) than the SD group (16.1 years).

Bederman et al.[47] reported that excessive LL beyond what would be determined by PI is comparable with the excessive TK in SD. They proposed a formula:

$$(TK - 45°) + (TLK - 0°) + (PI - LL) \text{ maintained within} \pm 10$$

which can be useful in evaluating the global sagittal balance in patients with SD.

The mean sagittal vertical axis (SVA) in SD patients indicates a rather balanced spinal column, despite increased thoracic or thoracolumbar kyphosis. It may suggest that LL can sufficiently compensate TK when the PI angle is lower. It implicates careful planning of surgical correction of the deformity not to exaggerate LL, so it would finally achieve lower-than-normal values and maintain the sagittal balance of the spinal column.[13]

The compensation mechanism observed in SD stays in line with the data reported by Li et al.[14] in patients with post-tubercular and congenital kyphotic deformity. The authors analyzed patients with thoracic and thoracolumbar kyphotic deformities that occurred during the growth period. In this specific group of patients, PI was significantly lower than in the normal population (Table 1). Other observed compensatory mechanisms were lumbar hyperlordosis and pelvic anteversion. Analysis of this particular group of patients suggests that lower PI is rather the effect not a cause of kyphotic spinal deformity.

Pain in patients with SD is most commonly localized at the apex of the deformity, though hyperlordotic compensatory curves above and below the kyphosis may also be a cause of pain.[48] What is more, patients with SD report more pain than patients with AIS and controls, according to preoperative SRS-22 scores.[48] The pattern of the deformity also matters, patients with thoracolumbar apex of the deformity experience more pain than those with thoracic apex. Interestingly, the magnitude of the kyphosis in SD does not correlate to any subdomain of the SRS-22 quality of life questionnaire.[48] Pain associated with moderate ($<80°$) and severe ($>80°$) hyperkyphosis was significantly greater than in the control group, but the SRS-22 scores did not significantly differ between the hyperkyphotic groups.[48,49]

All the above considerations lead us to the conclusion that thoracic or thoracolumbar kyphosis occurring during growth may lead to an altered pelvic morphology in the sagittal plane. Pain observed in kyphotic deformities is greater than in AIS patients and healthy individuals, does not depend on the amount of kyphosis, but is related to the pattern of the deformity.

Sagittal alignment in spondylolysis and spondylolisthesis

Spondylolisthesis is defined as an anterior subluxation of a vertebral body versus an adjacent inferior vertebra. According to a classification by Marchetti and Bartolozzi, based on the etiology and degree of spinal dysplasia, developmental and acquired spondylolisthesis are distinguished.[50] The developmental spondylolisthesis is due to dysplastic morphology of the vertebra or defect of pars interarticularis (isthmic spondylolisthesis) resulting from a stress fracture or the elongation of the posterior elements after the fracture healed.[50]

It has been clearly demonstrated that an abnormal sacro-pelvic morphology combined with local lumbosacral junction deformity and increased global forces in the lumbo-sacral region results in the development of L5 isthmic spondylolisthesis.[51]

The differences in pelvic morphology in adolescents and young adults with low- and high-grade spondylolisthesis were reported by Hanson et al.[9] in 2002 (Table 1). The mean values of PI in low-grade (68.5°) and in high-grade spondylolisthesis (79°) were significantly higher in comparison to both pediatric (mean PI of 47.4°) and adult (mean PI of 57°) control group ($p=0.0001$). PI also differed significantly between low- and high-grade isthmic spondylolisthesis groups ($p=0.007$). Moreover, a significant correlation between PI and the degree of slip according to Meyerding[52] ($p=0.03$) was found. The authors concluded that increased PI values may be a predictive factor for the risk of progression of spondylolisthesis.[9]

Also, Roussouly et al.[53] identified significantly higher values of PI (65.53° versus 51.91°, $p<0.05$), LL (70.84° versus 61.43°, $p<0.05$), and lower values of L5–S1 segmental extension (6.56 versus 12.89, $p<0.05$), in patients with spondylolysis and low-grade spondylolisthesis (Table 1). The authors suggested that differences in the sagittal spinopelvic alignment may influence biomechanical forces that induce the development of spondylolysis and progressive spondylolisthesis.

According to the study by Labelle et al.,[54] spinopelvic parameters such as PI, PT, SS, and LL were significantly greater in patients with spondylolisthesis than in the control group (Table 1). The study revealed a direct linear correlation of PI (0.41–0.65) with SS, PT, and LL. What is more, the differences between patients and controls increased in a direct linear fashion with the degree of spondylolisthesis. Although current studies concordantly report greater values of PI in patients with higher-grade spondylolisthesis, Roussouly et al.[53] identified two types of sacro-pelvic alignment in patients with lower-grade spondylolisthesis according to a possible pathogenic mechanism. The authors assumed that in patients with increased PI, the shear forces acting on the lumbo-sacral region cause more tension on pars interarticularis resulting in spondylolysis (shear type). On the contrary, in patients with lower values of PI and smaller SS extension of the trunk caused impingement of posterior elements of the L5 vertebra between adjacent segments of L4 and S1, what is called a "nutcracker" effect (nutcracker type).[53]

Within the group of patients with high-grade spondylolisthesis, Hresko et al.[55] identified two subgroups of patients. In the first, the "retroverted" subgroup (with low SS and high PT) patients stand with significantly retroverted pelvis and a vertical sacrum and have a higher risk of spinal imbalance in the sagittal plane. The second one, the "balanced" subgroup (with high SS and low PT) is characterized by a balanced pelvis and a lower risk of global spinal imbalance. Similar findings were reported by Vialle et al.,[56] who revealed significantly higher values of PI (73.05° versus 54.67°, $p<0.0001$) and LL (70.22° versus 43.13°, $p<0.0001$), and lower TK (23.09 versus 40.66, $p<0.0001$) in patients with spondylolisthesis versus controls, but the correlation of PI with the degree of slip was not clear. The SS value gradually increased in grade I, II, and III slip, to decrease in grades IV and V due to pelvic retroversion.

The studies of global spinal alignment revealed a relatively normal posture in low-grade spondylolisthesis and an abnormal one in the group of patients with high-grade spondylolisthesis. Again, spinopelvic alignment was particularly disrupted in the subgroup of patients with retroverted sacro-pelvis.[57]

Abnormal spinopelvic alignment observed in patients with spondylolisthesis changes the biomechanical forces acting on the lumbo-sacral junction and induces the compensatory mechanisms to maintain a balanced posture. As PI is significantly greater than normal in high-grade spondylolisthesis, the first compensation mechanism manifests in increasing LL and increasing the number of vertebrae included in the lordosis. Each subject has a maximal LL possible to reach, and beyond this point starts the second compensatory mechanism. To maintain sagittal balance, the pelvis will progressively retrovert. Since PI is fixed for each individual, SS decreases with the retroversion and PT increases, at some point the sacrum becomes vertical. After achieving the limit of these compensations, patients develop an imbalance of the trunk in the sagittal plane, usually compensated with hip flexion and anterior leaning of the trunk.[51,58]

The influence of global sagittal alignment on the quality of life of patients with spondylolisthesis depends on the degree of the slip. It is negligible in low-grade spondylolisthesis, whereas increasing positive global sagittal balance in high-grade patients is related to increased pain and poorer quality of life.[59] According to the study by Harroud et el.,[59] high-grade patients with C7 plumbline in front of the hip joint axis have significantly lower pain scores in SRS-22 and lower LL than those with C7 behind hip joints. Other spinopelvic parameters were similar in both groups. Lower values of LL observed in patients with C7 plumbline in front of the hip joints indicate insufficient compensation of the slip resulting in positive global sagittal alignment and increased pain. It leads to the conclusion that in spondylolisthesis, sagittal compensatory mechanisms not only enable a person to keep a balanced posture but may also play a protective role in occurrence and level of pain.

Sagittal misalignment and pain

Although it is well-documented that misalignments in the sagittal plane are associated with a poorer quality of life and likelihood of pain in the adult population, there seems to be not enough evidence for it in pediatric patients.[15,16] According to the study by Sainz de Barranda et al.,[60] children with higher values of LL have a slightly higher risk of low back pain (LBP). Also, non-neutral postures such as flat or sway-back postures increase the likelihood of LBP.[61] Other studies did not find any correlation between the magnitude of kyphosis, lordosis, or spinopelvic alignment and spinal pain.[62,63] However, all of these studies used clinical examination assisted with non-radiating methods. To our best knowledge, there are no radiographic studies analyzing the sagittal balance of the spine and pain in children who have no other spinal pathologies.

Conclusion

In this study, we presented the current state of knowledge concerning pelvic morphology and sagittal compensatory mechanisms observed in IS, kyphotic deformities, and spondylolisthesis and their relationship to spinal pain. The largest diversity in sagittal alignment patterns was reported in IS, with a relatively large group of patients presenting sagittal parameter values similar to the healthy population, but the most common disruptions resulted in global flattening of the spine. Many authors tried to identify correlations between PI values and IS curve patterns, but the results remain inconclusive. The role of pelvic morphology and its cause–effect relation in the etiopathogenesis of IS still needs to be clarified. Maybe future studies on the 3D analysis of this complex deformity will finally solve this problematic issue. The situation seems to be more clear in kyphotic deformations occurring during growth, where structural thoracic or thoracolumbar kyphosis induces a compensatory mechanism resulting in lumbar hyperlordosis and decreased values of PI. It is suggested that lower PI is not a cause, but rather an effect of compensation of the kyphotic deformity. The opposite situation has been observed in spondylolisthesis, where altered morphology of the spinopelvic junction with high values of PI seems rather a cause of the deformity inducing other compensations, especially lumbar hyperlordosis. Sagittal misalignments seem not to be related to the occurrence of back pain in IS. In kyphotic deformities, pain is greater than in IS and is related to the apex of the deformity. Whereas, in spondylolisthesis, sagittal alignment has an influence on quality of life only in high-grade slips, and sagittal compensatory mechanisms may play a protective role in the occurrence of pain.

Nevertheless, most of the patients with spine disorders that occurred during the growth period are clinically balanced in the sagittal plane. It suggests that compensatory mechanisms before achieving skeletal maturity are really significant. A thorough understanding of sagittal alignment in spine deformities is essential for the proper assessment and treatment of these disorders.

Author contributions

C.W.M. and T.M. contributed in study design. C.W.M., W.P., Z.M., and T.M. involved in data interpretation, article preparation, and literature search.

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Ethical statement

Not applicable—a review of the literature.

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