Fractional Curve in Adult Spinal Deformity

Is it a Driver of or a Compensation for Coronal Malalignment?

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Study Design: This was a retrospective review of the multicenter adult spine deformity database.

Objective: The objective of this study was to investigate the role of the fractional curve (FC) on global coronal malalignment.

Summary of Background Data: Despite being very common, the role of the coronal FC as either a driver or compensation for global coronal malalignment is not well documented

Materials and Methods: Patients with the following characteristics were extracted from a prospective multicenter database: lumbar/thoracolumbar (TL) major coronal curve >15 degrees, apex at T11–L3, lower end vertebra at L3 or L4, above 45 years old, and FC >5 degrees. In addition to the classic radiographic parameters, baseline analysis included Cobb angle, pelvic obliquity (PO), fractional ratio (fractional Cobb/main Cobb), the sum of PO and FC, as well as the coronal Qiu classification. Curves distribution (TL vs. FC) were compared across the 3 Qui types, and the role of the FC was investigated.

Results: A total of 404 patients (63 y old, 83.3% female) were included: 43 patients were classified as type B, 120 as type C, and 241 were coronally balanced (type A). Compared with the balanced patients, type C patients had similar major TL Cobb angles but significantly larger fractional Cobb angles (17.5 vs. 22.3 degrees, $P<0.001$). By opposition, type B patients had significantly larger major TL Cobb angles (49 vs. 41 degrees, $P=0.001$) but smaller fractional Cobb angles ($P<0.001$). PO>5 degrees in the same direction as FC was more common in type B patients (20%) than in type C patients (7.5%), which suggests the preferential role of pelvic compensation.

Conclusions: Our findings challenge the idea that FC is only a compensatory curve below a main lumbar or TL curve. In type B patients, FC acts as a compensation mechanism but fails to maintain coronal alignment despite the presence of PO. In type C patients, however, the lumbosacral FC acts as a primary driver of coronal malalignment.

Level of Evidence: Level III.

Key Words: adult spine deformity, scoliosis, global coronal alignment, coronal malalignment, primary patients, pelvic obliquity, pelvic compensation, coronal Qiu classification

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Spinal deformity in the adult population is common[1,2] with reported rates as high as 68% in individuals over 65 years old. In the context of an aging population and demographic shifts, the burden of spinal deformity treatment on health care systems is increasing and warrants the need to better understand the factors that drive spinal deformities, affect functional scores and impact treatment selection and effectiveness.

Over the last decade, spinal alignment has emerged as an important concept, with sagittal alignment being recognized as a key determinant of health status.[3–8] Sagittal plane deformities have been associated with an increased risk of complications.[9] Multiple radiographic parameters assessing spinal alignment as a whole have been defined and clinically relevant guidelines have been established.[10,11]

Although research on global coronal malalignment (GCM) has been much less prolific than research on the sagittal plane, its impact on health status has been documented. Glassman et al[12] observed that in patients without previous surgery, the presence of GCM >4 cm was associated with

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increased pain and worse functional scores. Plais et al[13] have recently reported that GCM significantly affects the health-related quality of life of patients when the offset is > 3 cm in the same direction of the curve concavity. Finally, GCM has been associated with dissatisfaction in terms of appearance, need for more complex surgery for correction, poorer outcomes after surgery, and increased risk of postoperative malalignment.[14,15]

The incidence of GCM is high in adult spinal deformity (ASD) patients, with a reported rate of 34.8%.[15] However, its etiology is likely multifactorial and remains poorly understood. Although many contributing factors have been suggested, the magnitude of the main coronal curve, measured by the Cobb angle, is thought to be the most relevant factor. Other potentially important biomechanical factors include asymmetrical disk degeneration,[16,17] lateral listhesis and rotatory subluxation,[18] pelvic and sacral deformity,[19] and coronal shift of the trunk resulting from leg length discrepancy. Finally, osteoporosis, neuromuscular diseases, and other neurological or systemic disorders may also contribute to GCM.[20,21]

In this context of coronal deformity evaluation, the coronal fractional curve (FC) is defined as a curve at the lumbosacral junction, spanning from S1 to L4 or L3, and occurring below a lumbar major curve. It is frequently considered to be a compensatory curve[22] and its flexibility tends to decrease with aging.[23] The presence of an FC is associated with poorer functional scores[12,24] and is often associated with nerve compression and radiculopathy. Despite being common in ASD patients, this lumbosacral curve is often neglected and its impact on global coronal alignment has not been well documented.

The objective of this study is to investigate the role of the FC on GCM and to investigate if the FC should be considered a driver of or compensation for coronal malalignment.

MATERIALS AND METHODS

Patient Population

This is a retrospective review of a prospective multicenter database of ASD patients enrolled across 11 US institutions. Patients were prospectively enrolled through an institutional review board–approved study at each site. Inclusion criteria for the overall database were patients above 18 years with at least one of the following criteria of spinal deformity: coronal Cobb angle > 20 degrees, C7–S1 sagittal vertical axis > 5 cm, pelvic tilt > 25 degrees, or thoracic kyphosis > 60 degrees. In addition to the database inclusion criteria, patients retained for the current analysis presented the following parameters: primary deformity without previous surgery, thoracolumbar (TL) or lumbar main curve > 15 degrees with an apex below T11 and a lower end vertebra at L3 or L4, patients older than 45 years, and an FC > 5 degrees.

Data Collection and Radiographic Parameters

Extracted data included basic demographics, such as age, sex, and body mass index and radiographic parameters. Baseline radiographic parameters were measured on full-length free-standing radiographs using validated software.[25] Evaluation of the coronal deformity was based on Cobb angles of the main curve and the FC, GCM, defined as the offset of the C7 plumbline relative to the central sacral vertical line, and the pelvic obliquity (PO), defined as the angle between a line tangent to the 2 iliac crests and the horizontal.

In addition to the classic coronal measurements, the fractional ratio (FR), a parameter defined as the Cobb angle of the FC divided by the Cobb angle of the main TL or lumbar curve was calculated. This ratio illustrates the relative severity of the FC and provides a means of comparison between the magnitude of the main curve and the FC. The overall angle at the base of the spine, formed by the sum of the PO+FC Cobb angle, was also calculated. As it combines the effect of the PO and the FC, this angle provides information about a possible oblique take-off of the lumbar spine with respect to the pelvis.

As the flexibility of the curves cannot be assessed in our study, the notion of compensation in this paper can be understood as secondary. The curve with the major impact on the coronal alignment (primary) produces a curve in the opposite direction, secondary to this first driver of the deformity. In ASD patients, curves which were initially flexible can become rigid. For this reason, both the lumbar curve and the FC may be nonflexible. Finally, patients were classified according to the Qiu classification,[26] which categorizes patients into 3 types of coronal alignment according to the GCM and its relation to the concavity or the convexity of the main coronal curve. Type A: GCM <3 cm or well-aligned patients, type B: GCM > 3 cm ipsilateral to the concave side of the major coronal curve, and type C: GCM > 3 cm ipsilateral to the convex side of the major coronal curve. When reporting the relationship between FC and C7PL, the type B group was composed of patients with a GCM towards the convexity of the FC, and the type C group included patients with a GCM in the opposite direction of the FC (Fig. 1).

Statistical Analysis

Frequency distribution and summary statistics were calculated for all demographic and radiographic variables. Groups' comparisons (type A, B, and C) were carried out using χ^2 tests and analysis of variance. Finally, the Pearson correlations were used to analyze the factors associated with GCM.

RESULTS

Patient Population

Of the 1413 patients in the prospective database, 404 met the inclusion criteria and had complete data available for analysis. Stratification based on coronal alignment identified 241 (59.6%) well-aligned patients (type A), while 43 (10.6%) patients were classified as type B, and 120 (29.7%) patients as type C. Overall, 83.3% of the study patients were women; the mean age was 63.0 years and the mean body mass index was 26.9 kg/m^2 (Table 1). Type C patients were significantly older in comparison with the other groups (65.7 vs. 62 y, $P=0.077$).

Radiologic Parameters

The radiologic assessment highlighted the fact that, compared with the coronally well-aligned patients, the type B

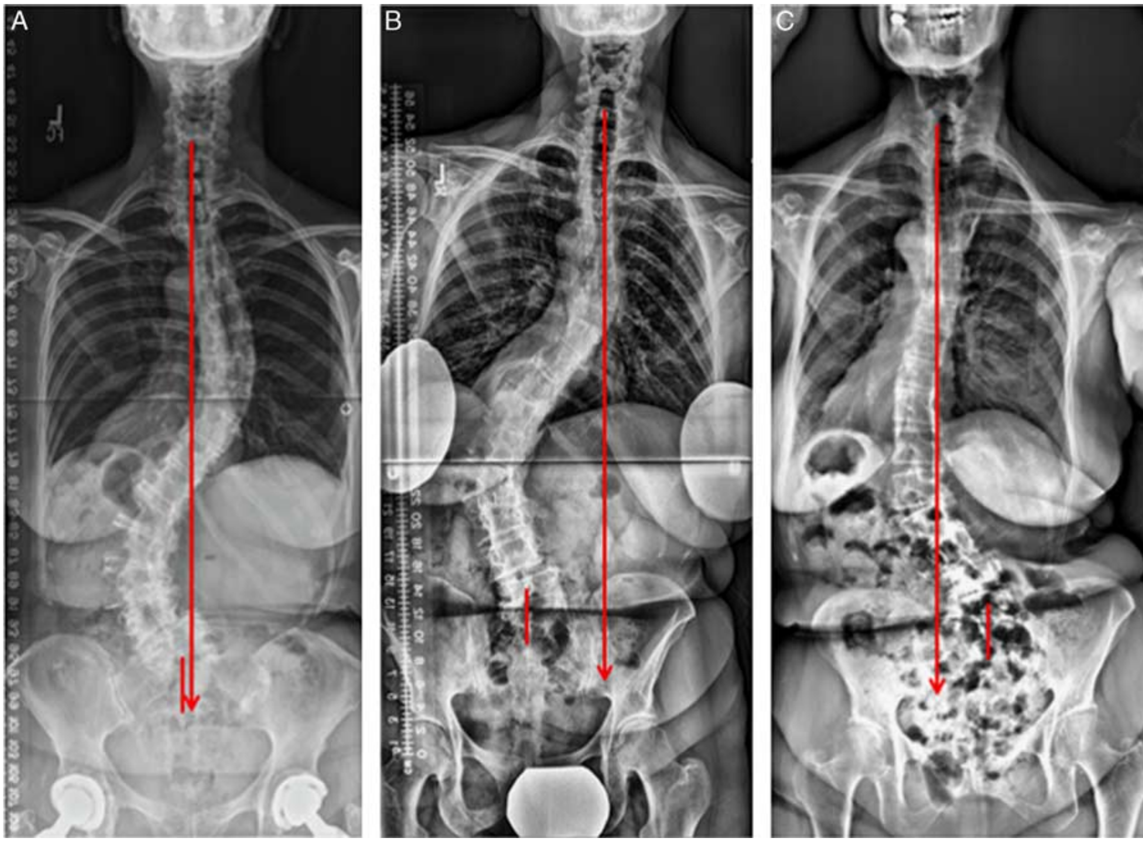

FIGURE 1. Stratification according to the direction of the fractional curve based on the Qui classification.[15] A, Type A: global coronal malalignment <3 cm or well-aligned patients. B, Type B: global coronal malalignment >3 cm ipsilateral to the concave side of the major coronal curve. C, Type C: global coronal malalignment >3 cm ipsilateral to the convex side of the major coronal curve.

and C groups presented specific characteristics (Table 2). Type B patients had significantly larger major lumbar and TL coronal Cobb angles (49 vs. 41 degrees and 42 degrees for type A and C, respectively, $P<0.001$) but smaller fractional Cobb angles (14.84 vs. 17.53 degrees and 22.28 degrees for the type A and C, respectively, $P<0.001$) and FRs ($P<0.001$). Type B patients combine the presence of GCM with a large lumbar or TL deformity and a relatively small FC. The data suggest that in the type B patients, compared with type A patients, the 2 curves do not fully compensate each other resulting in GCM.

In contrast, type C patients have similar major TL Cobb angles compared with the type A patients, but they present significantly larger fractional Cobb angles (22.3 vs. 17.5 degrees for type A, $P<0.001$) and larger FRs (0.55 vs. 0.31 and 0.44 for type B and A groups, $P<0.001$). Type C patients have a relatively sharper oblique take-off than the other groups. This inclination at the base of the

TABLE 1. Demographic Variables Stratified by the Qiu Classification

Demographics	Classification	N	Mean	SD	P
Age	Type A	241	62.92	8.62	0.077
	Type B	43	65.73	9.64	
	Type C	120	62.08	9.65	
	Total	404	62.97	9.08	
Body mass index	Type A	237	27.32	5.53	0.258
	Type B	43	26.28	5.74	
	Type C	116	26.43	5.41	
	Total	396	26.94	5.52	

TABLE 2. Radiographic Parameters Stratified by Groups According to the Qiu Classification

Radiographic Parameters	Classification	N	Mean	SD	P
Cobb angle of the major TL curve	Type A	241	41.49	13.97	<0.001
	Type B	43	49.47	12.6	
	Type C	120	42.36	13.7	
	Total	404	42.6	13.92	
Cobb angle of the FG	Type A	241	17.53	7.44	<0.001
	Type B	43	14.84	4.87	
	Type C	120	22.28	8.05	
	Total	404	18.65	7.8	
FC ratio	Type A	241	0.44	0.15	<0.001
	Type B	43	0.31	0.12	
	Type C	120	0.55	0.19	
	Total	404	0.46	0.18	
	Type A	241	2.35	1.93	<0.001
	Type B	43	9.47	5.08	
Global coronal malalignment	Type C	120	3.38	2.56	
	Total	404	3.41	3.38	

FC indicates fractional curve; TL, thoracolumbar.

TABLE 3. Role of Pelvic Obliquity

Radiographic Parameters	Classification	N	Mean	SD	P
FC Cobb+pelvic obliquity	Type A	241	19.07	7.91	< 0.001
	Type B	43	16.89	5.5	
	Type C	120	24.17	8.14	
	Total	404	20.35	8.16	
FC+pelvic obliquity ratio	Type A	241	0.47	0.15	< 0.001
	Type B	43	0.35	0.12	
	Type C	120	0.6	0.19	
	Total	404	0.5	0.18	

FC indicates fractional curve.

spine is not compensated at the upper levels and thus leads to GCM, which is lateralized in the concavity of the FC. In this group, the FC may work as a driver of the GCM.

The analysis of PO demonstrates several interesting findings. POs > 5 degrees with an inclination in the same direction as the FC are more common in type B patients (20%) than in type C patients (7.5%) ($P=0.033$). Even when the PO is <5 degrees, the overall angle at the base of the spine (formed by the addition of PO and the curvature of FC) increased in both type B and C patients. In type B patients, it increased from 14.89 to 16.89 degrees (Table 3), and in type C patients, it increased from 22.8 to 24.17 degrees. Moreover, in this last category of patients, the relative impact of FC+PO, calculated as the ratio of [(FC+PO)/Cobb angle of the main curve], also increased from 0.55 to 0.6. Interestingly, in both groups where GCM is present (type B and C), these results show that even when the PO is <5 degrees, the PO tends to magnify the original effect of the FC.

Correlation Analysis

The correlation analysis (Table 4) revealed that GCM (offset > 3 cm) correlated with FRs ($r=0.46$, $P<0.01$) and fractional Cobb angles ($r=0.35$, $P<0.01$) in type C patients, while it only correlated with the major TL Cobb angle in type B patients ($r=0.36$, $P=0.02$).

TABLE 4. Correlation Analysis

Type of Scoliosis	Coronal Offset	Cobb Angle TL Curve	Cobb Angle FC	FC Ratio
Type B				
Coronal offset				
Pearson correlation	1	0.362*	0.073	−0.152
Significance (2 tailed)		0.017	0.643	0.331
N	43	43	43	43
Type C				
Coronal offset				
Pearson correlation	1	−0.084	0.351†	0.462†
Significance (2 tailed)		0.364	0	0
N	120	120	120	120

*$P=0.02$.
†$P<0.01$.
FC indicates fractional curve; TL, thoracolumbar.

DISCUSSION

This study analyzes the impact of the FC on the GCM in a population of primary ASD patients. It is well known that compensatory or secondary curves appear above and below primary curves.[27–29] The FC has classically been considered as one of them.[27] Our results introduce a different concept and a new understanding of these lumbosacral curves.

In type C patients, our results show that the FC contributes to an increased coronal malalignment in the same direction as the FC (ie, in the concavity of FC). Moreover, the FC combines with the PO to create an oblique take-off that is not compensated at the upper adjacent levels. The overall angle at the base of the spine increases as well as the relative impact of FC+PO. PO reinforces the role of the FC, and together they contribute to increase the oblique start of the spine, worsening the coronal alignment. This last point suggests that both PO and FC act as drivers of the deformity by creating an oblique take-off at the basis of the spine. FC can be understood as a driver of coronal malalignment.

In type B patients, however, the FC is recruited as a more classic compensatory mechanism to counteract the magnitude of the main TL curve but fails to control coronal malalignment. As in type C patients, the PO contributes by increasing the effect produced by the FC and works as a secondary mechanism of compensation at the base of the spine to counteract the coronal malalignment created by the main TL curve. Interestingly, despite a greater absolute PO in type B patients (> 5 degrees), the PO remains insufficient to compensate for the larger lumbar or TL Cobb seen in these patients. The overall angle at the base of the spine increases, leading to an increase in the obliquity of the spine and pelvis below the main curve. In type B patients, despite the compensatory role of PO and FC, GCM occurs in the concavity of the main curve.

Radcliff et al[19] have shown that PO can be a physiological compensatory mechanism of coronal malalignment. Our results reached the same conclusions but only in type B patients. In the same way that pelvic retroversion can compensate for sagittal malalignment, FC and PO are recruited as compensatory mechanisms but these mechanisms prove insufficient to maintain a neutral coronal alignment. In type C patients, PO increases the impact of the FC and is also a contributing factor to the GCM. In this case, PO can also be considered as a driver of the deformity. An alternative view would be to consider them as a whole and to understand the complex FC–PO as a unique primary deformity at the base of the spine.

The presence of an FC has been associated with poorer clinical outcomes[12,24] and with an increased risk of adjacent segment breakdown.[30] Moreover, recent publications have demonstrated a high rate (up to 30%) of iatrogenic coronal malalignment in ASD patients[26,31] and have established the relationship between preoperative GCM and an increase in implant failures.[32,33] Moal et al[31] have also highlighted the variability in the likelihood of corrections in the coronal plane after surgery when an FC is present.

These previous reports, combined with the results drawn from this study, emphasize the need for the FC to be analyzed carefully, especially in the presence of a deformity with coronal malalignment. When compared with the sagittal plane, surgical planning is often suboptimal for the coronal plane correction. We believe that the analysis of the FC is of critical importance for surgical planning.

Many surgeons have given specific surgical recommendations to address the FC. Youssef et al[14] and Berjano and Lamartina[34] have recommended to always include the FC in the fusion when the coronal deformity is associated with a rigid FC. Bao et al[26] have advised the use of transforaminal lumbar interbody fusion to horizontally level L4 and L5 in patients with type C curves based on the Qiu classification.[26] Finally, Obeid et al[35] have suggested that, if indicated, the location of a pedicle subtraction osteotomy should be decided according to the type of coronal malalignment. Specifically, in type C patients (convex malalignment), this team recommends performing the osteotomy at the level of the FC.

We believe that a clear understanding of the role of the FC may aid in developing the best treatment plan to avoid postoperative coronal malalignment. When the FC is a mechanism of compensation, the attention of the surgeon should focus on the main lumbar or TL curve to reduce the risk of coronal malalignment. However, when the FC acts as a driver of the deformity, the FC must be corrected and the take-off of the spine must be leveled.

Limitations

One of the limitations of our study is the inability in our database to analyze the flexibility of the FC. As reported by Deviren et al,[36] the flexibility of the FC is predicted by age but not by the magnitude of deformity and it has important implications for surgical correction. An analysis of the flexibility of the FC in type B and C groups measured in bending x-rays could bring interesting data and should be included in future studies.

Finally, the FC is frequently associated with painful curves and neural compression. These aspects of the FC have not been addressed in our study although they are key aspects that must be taken into account when a surgical procedure is planned. Our assessment is focused on the radiologic aspects of the FC.

CONCLUSIONS

Our findings challenge the idea that the FC is only a compensatory curve below a main lumbar or TL curve. In fact, we have established that, according to the type of GCM, the FC can be a driver of the deformity or a compensatory mechanism: In patients with an offset >3 cm in the opposite direction of the curve concavity (type C patients), larger lumbosacral FC is the primary driver of coronal malalignment.

In contrast, in patients with an offset >3 cm in the same direction of the curve concavity (type B patients), the FC works as a compensation mechanism for a larger TL or lumbar curve but fails to maintain spinal coronal alignment. In both cases, PO may contribute by reinforcing the effect of the FC.

We believe that identifying the role of the FC and its impact on GCM in ASD patients is important. It is a key aspect of the overall assessment of the deformity and a basic step in the surgical planning that must be taken into account to decrease the risk of iatrogenic malalignment.

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