A Classification for Kyphosis Based on Column Deficiency, Curve Magnitude, and Osteotomy Requirement

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Background: There is a lack of a classification system providing uniformity in description and guiding management decisions for kyphotic spinal deformities. We developed such a classification based on column deficiency, flexibility of disc spaces, curve magnitude, and correlation with the corrective osteotomy required.

Methods: A classification was developed based on analysis of 180 patients with thoracolumbar kyphosis requiring osteotomy. The deformity was classified as Type I if the anterior and posterior columns were intact (IA indicated mobile disc spaces and IB, ankylosed segments). Type II indicated deficiency of only 1 column (IIA = anterior column and IIB = posterior column). Type III indicated deficiency of both columns (IIIA = kyphosis of ≤60°, IIIB = kyphosis of >60°, and IIIC = buckling collapse). A prospective analysis of 76 patients was performed to determine interobserver variability and the ability of the classification to guide selection of osteotomies of increasing complexity, including the Ponte osteotomy, pedicle subtraction osteotomy, disc bone osteotomy, single vertebrectomy, multiple vertebrectomies, and anterior in situ strut fusion procedure.

Results: The mean age of the 76 patients was 21.2 years, the mean kyphosis was 69.9° (range, 26° to 120°), and the mean follow-up duration was 30 months. Six deformities were classified as IA, 5 as IB, 5 as IIA, 2 as IIB, 13 as IIIA, 35 as IIIB, and 10 as IIIC. Four surgeons classifying the deformities had a high agreement rate (kappa = 0.83), with the highest agreement for Types IA, IB, and IIIB. A correlation between the type of deformity and the osteotomy performed demonstrated that the classification could indicate the type of osteotomy required. All 18 patients with Type-I or II kyphosis were treated with Ponte, pedicle subtraction, or disc bone osteotomy. Forty-three (90%) of the 48 patients with Type IIIA or IIIB underwent vertebrectomy (single in 27 [56%] and multiple in 16 [33%]), and only 5 (10%) underwent disc bone osteotomy. Seven of the 10 patients with Type-IIIC kyphosis were treated with multiple vertebrectomies, with 5 of them needing preoperative halo gravity traction; the other 3 patients underwent an anterior in situ strut fusion procedure.

Conclusions: The proposed classification based on the morphology of column deficiency, flexibility, and curve magnitude demonstrated a high interobserver agreement and ability to guide selection of the appropriate osteotomy.

Clinical Relevance: A novel classification system for kyphosis based on spinal column deficiency, flexibility of disc spaces, and curve magnitude would bring uniformity in management and help guide surgeons in the choice of the appropriate corrective osteotomy.

Kyphotic deformities of the spine are a common disorder with a diverse etiology[1-7]. The severity, nature, and surgical planning of the different subtypes of kyphosis are distinctly different. Ankylosing spondylitis is not associated with column deficiency, affects the spine diffusely, and causes substantial sagittal imbalance[6,7]. Tuberculosis, in contrast, affects limited segments of the spine, causing acute, sharp angular curves; however, interestingly, global sagittal balance is maintained[3,4].

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Iatrogenic post-laminectomy kyphosis in children involves posterior column loss, whereas congenital kyphosis is due to partial or complete segmental loss with or without a sagittal component[8,9]. In the assessment of such deformities, it must be kept in mind that, in addition to the magnitude of the kyphosis, the integrity of the anterior and posterior columns and the mobility of the spine play a pivotal role in determining the appropriate treatment.

The King[10] and Lenke[11] classifications for coronal deformities brought about uniformity of thought processes and discussions[10,11]. The present classifications of kyphosis[12-16], based solely on the patient's global sagittal balance, are incomplete and do not take into account flexibility, the magnitude of the sagittal curve, or the intactness of the anterior and posterior columns. In this report, we propose a classification for kyphotic deformities based on the extent of anterior and posterior column deficiency, flexibility of the disc spaces, curve magnitude, and correlation with the type of osteotomy typically required. These factors are important when deciding on the type of osteotomy.

Material and Methods

A prospective study of 76 consecutive patients was conducted from March 2013 to March 2015 with approval of the institutional ethics committee and was performed in accordance with the ethical standards as laid down in the Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all participants. The patients were surgically treated by the 2 senior authors (S.R. and A.P.S.) at a single center. All patients presenting with kyphotic spinal deformity, irrespective of etiology, were enrolled in the study. Accompanying coronal plane deformity was allowed as long as the predominant deformity was sagittal plane deformity.

The classification was developed by the lead author through retrospective analysis of the radiographs and records of 180 patients seen between 2008 and 2013. Four observers (fellowship-trained spine surgeons) working in the unit were trained on the new classification and then assigned a test folder containing the radiographs of 20 cases of kyphotic deformity from the 180 retrospectively reviewed cases. The prospective study was then initiated for assessment of reliability.

In addition to the findings of the clinical examination, the severity of the deformity, flexibility of the spine, mobility of the disc spaces, and presence or absence of coronal imbalance were assessed on full-length standing radiographs and stress radiographs. Column deficiency was assessed with radiographs, computed tomography (CT), and magnetic resonance imaging (MRI) scans. The patients were classified independently by the 4 observers to assess intraobserver and interobserver variability. The surgical treatment approaches were

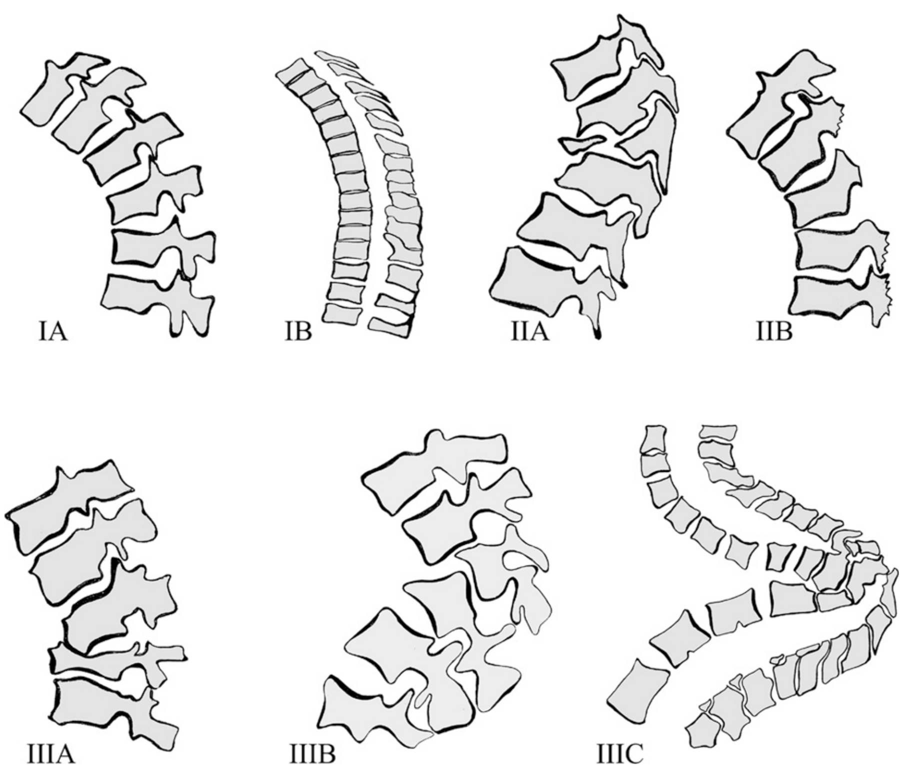

Fig. 1
Graphical illustration of the types of kyphosis in the developed classification. Type IA = no column deficiency with mobile, flexible disc spaces, Type IB = no column deficiency with fused and immobile disc spaces, Type IIA = anterior column deficiency only, Type IIB = posterior column deficiency only, Type IIIA = both anterior and posterior column deficiency with a Cobb angle of ≤60°, Type IIIB = both anterior and posterior column deficiency with a Cobb angle of >60°, and Type IIIC = both anterior and posterior column deficiency with buckling collapse.

planned by the 2 senior authors independent of the classification and its reliability assessment. Any disagreement was settled by mutual discussion.

The kyphosis was classified as Type I when both columns were intact, with Type IA assigned to a flexible kyphotic segment with mobile disc spaces and Type IB given for a fixed kyphosis with ankylosed disc spaces. The kyphosis was classified as Type II when there was deficiency of either the anterior (Type IIA) or posterior (Type IIB) column. Type III indicated insufficiency of both columns to varying degrees (Type IIIA = kyphosis of ≤60°, Type IIIB = kyphosis of >60°, and Type IIIC = buckling collapse) (Fig. 1).

Anterior column deficiency was defined as a structural loss of bone, disc, or a combination of both. Posterior column deficiency is more complex, as it can be either due to a "structural failure" caused by the actual loss of the posterior ligamentous/osseous anatomy or due to a "functional failure" caused by gradual facet joint subluxation/dislocation (Fig. 2). Posterior column structural deficiency includes congenital posterior element deficiencies such as myelomeningocele or iatrogenic deficiencies such as post-laminectomy kyphosis and traumatic facet subluxation/dislocation. A functional posterior column loss includes an intact column that fails because of a single or multiple facet subluxation/dislocation due to progressive kyphosis and is common in children (Fig. 2).

Two modifiers were included in the classification, 1 for global sagittal balance and 1 for coronal deformity. Global sagittal balance was assigned M− (sagittal vertical axis deviation [SVA] of <5 cm) or M+ (SVA of ≥5 cm). The coronal modifier was C−, for a coronal curve with a Cobb angle of <20°, or C+, for a Cobb angle of ≥20°.

Five different osteotomies of increasing complexity, based on a classification system proposed by Schwab et al.[17], as well as a procedure that we added for Type-III deformities, were used for deformity correction in these patients. These procedures included Ponte osteotomy, pedicle subtraction osteotomy, disc bone osteotomy, single vertebrectomy, and multiple vertebrectomies (with or without previous halo traction) as well as our addition of anterior in situ strut fusion without a major correction to provide stability and fusion for some patients with Type-III deformity (Fig. 3). The type of deformity according to the classification was correlated with the type of surgical procedure. The rate of interobserver agreement and the rate of intraobserver agreement with 6 weeks between assessments were determined for the classification.

Results

The mean age of the 76 patients was 21.2 years, the mean kyphosis was 69.9° (range, 26° to 120°), and the mean follow-up duration was 30 months.

Type I

Eleven patients had Type-I kyphosis. Three of them had Scheuermann kyphosis (flexible disc spaces; Type IA), with a mean kyphosis of 62° (range, 46° to 87°). Eight patients had ankylosing spondylitis, with a mean kyphosis of 53° (range, 26° to 76°); 5 had completely fused discs (Type IB), and 3 had partially mobile disc spaces (Type IA). All 6 Type-IA deformities were treated with Ponte osteotomy, and the 5 Type-IB deformities were treated with pedicle subtraction osteotomy. No patient underwent vertebrectomy. The patients who had a pedicle subtraction osteotomy had substantially

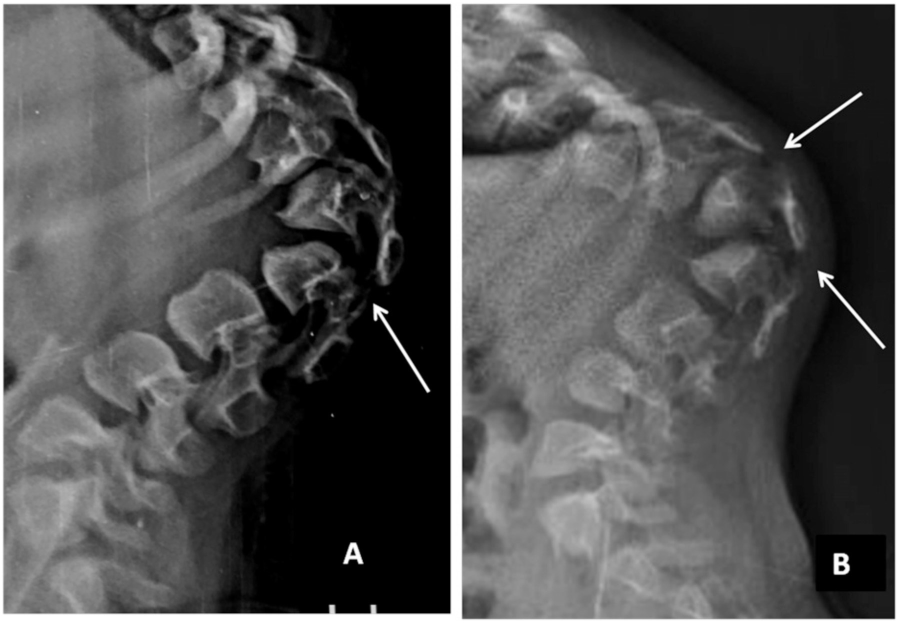

Fig. 2

Serial lateral radiographs of a 3-year-old boy with a congenital thoracolumbar junction kyphosis made 10 months apart. The images demonstrate the progressive and sequential facet subluxation (arrows) with an accompanying increase in the magnitude of the deformity suggesting a progressive functional posterior column failure.

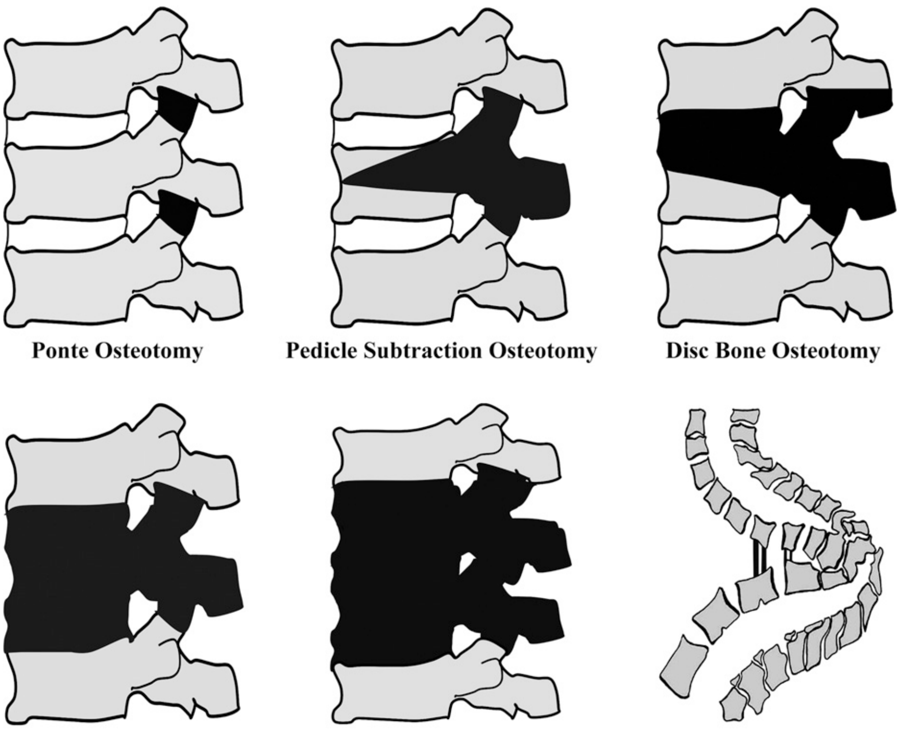

Fig. 3
The 5 surgical osteotomies of progressive complexity, based on the classification proposed by Schwab et al.[17], that are commonly performed for kyphosis as well as our added procedure—anterior in situ strut graft fusion—for severe buckling collapse in Type-IIIC kyphosis.

greater global sagittal imbalance (mean SVA = +18.7 cm) compared with the patients treated with Ponte osteotomy (mean SVA = +12.4 cm).

Type II

This group consisted of 7 patients. Five patients had a deformity with isolated anterior column deficiency (Type IIA), with a mean kyphosis (posttraumatic in 3 and post-tubercular in 2) of 34.2°. Isolated posterior column deficiency (Type IIB) was seen in 2 patients with post-laminectomy kyphosis. The 7 patients were treated with Ponte osteotomy, pedicle subtraction osteotomy, or disc bone osteotomy. None had vertebrectomy.

Type III

This was the largest group, with 58 patients having deficiency of both columns. Thirteen patients had Type IIIA (kyphosis of ≤60°), with 5 posttraumatic, 6 congenital, and 2 post-tubercular deformities. Five patients underwent disc bone osteotomy, 7 patients had single vertebrectomy, and 1 patient with post-tubercular kyphosis underwent multiple vertebrectomies at 3 levels. Type IIIB (kyphosis of >60°) was observed in 35 patients, with 20 congenital deformities, 13 post-tubercular deformities, 1 neuromuscular deformity, and 1 case of osteogenesis imperfecta. The mean kyphosis was 75.9° in the congenital deformity group and 84.6° in the post-tubercular group. Twenty patients were treated with single-level and 15 were treated with multiple-level vertebrectomy. Ten patients had Type IIIC (buckling collapse), with 5 congenital deformities and 5 neurofibromatosis-associated deformities. Two of these patients were treated with primary multiple vertebrectomies. Five were treated with preoperative halo gravity traction for a period of 4 to 6 weeks and then with multiple vertebrectomies. Three patients with severe deformity were treated with anterior in situ strut fusion using a fibular strut graft.

Modifier Results

Twenty-four patients had a C+ coronal modifier. Sixteen of them had a congenital kyphoscoliotic deformity (IIIA in 3, IIIB in 9,

TABLE I Distribution of Sagittal Modifiers

	Type I (N = 11)	Type II (N = 7)	Type III (N = 58)
M− (sagittal balance)	1 (A)	5 (4 A, 1 B)	37 (11 A, 22 B, 4 C)
M+ (sagittal imbalance)	10 (5 A, 5 B)	2 (1 A, 1 B)	21 (2 A, 13 B, 6 C)

TABLE II Correlation of Deformity Type with Nature of Surgical Procedure Performed

Deformity Type	Ponte Osteotomy	Pedicle Subtraction Osteotomy	Disc Bone Osteotomy	Single Vertebrectomy	Multilevel Vertebrectomy	Anterior in Situ Strut Fusion	Halo + Multilevel Vertebrectomy	Total
IA	6							6
IB		5						5
IIA	3		2					5
IIB		1	1					2
IIIA			5	7	1			13
IIIB				20	15			35
IIIC					2	3	5	10
Total	9	6	8	27	18	3	5	76

and IIIC in 4), 1 had a neuromuscular deformity, 1 had a post-tubercular deformity, 1 had post-laminectomy kyphosis, and 5 had a neurofibromatosis-associated deformity. The distribution of the sagittal modifiers is shown in Table I.

Four surgeons classifying 76 deformities had a high agreement rate (kappa = 0.83). The agreement rate was highest in the Type-IA and IB groups followed by Type IIIB and was the lowest for Types IIA and IIIA. The intraobserver agreement rate between assessments performed 6 weeks apart was also high (kappa = 0.76 to 0.84).

The types of osteotomy performed and the correlation with the classification are shown in Table II. There was a clear

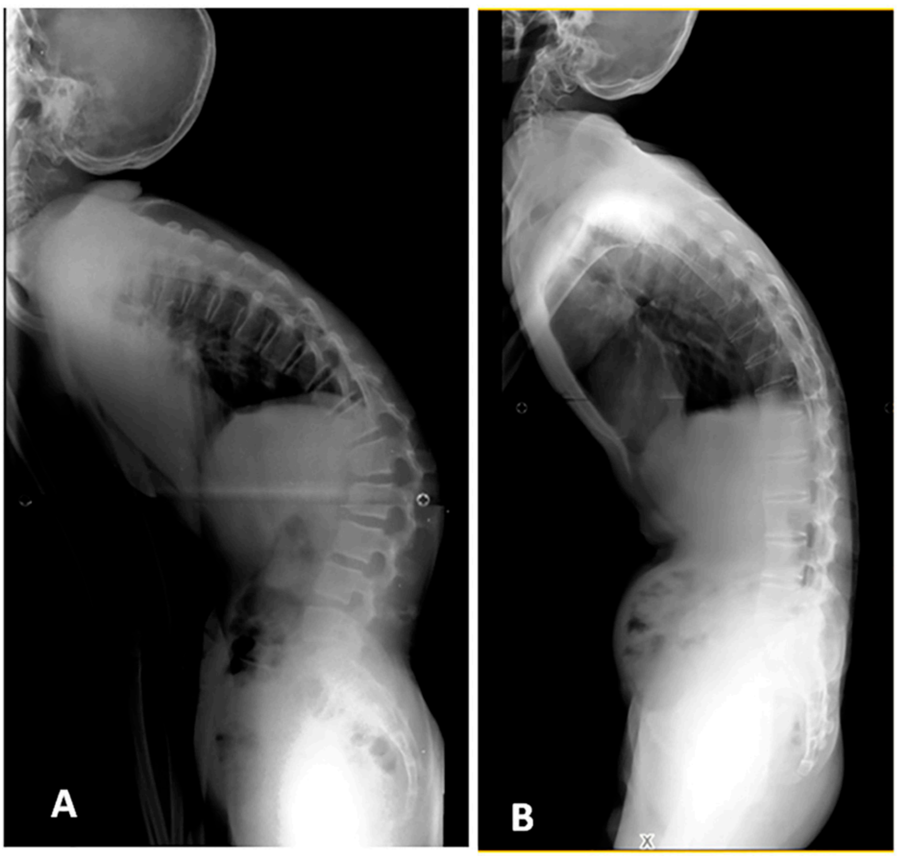

Fig. 4

Fig. 4-A Standing lateral radiograph of a patient with Type-IA kyphosis. The disc spaces are mobile with no column deficiency. **Fig. 4-B** Standing lateral radiograph of a patient with Type-IB kyphosis. The disc spaces are calcified and immobile with no column deficiency. Type-I deformities affect multiple levels and result in a substantial positive deviation of the SVA as illustrated by both radiographs.

trend toward simpler osteotomies such Ponte and pedicle subtraction osteotomies for Type-I and Type-II kyphoses and vertebrectomies for Type-III kyphosis.

Discussion

Kyphotic deformities have a wide variety of causes[1-9], and numerous procedures and techniques have been reported for the treatment of such deformities[18-23]. Unlike scoliosis, kyphosis is often associated with deficiencies of the anterior and/or posterior column, and this differs according to pathology. These structural peculiarities determine the pattern and progress of kyphosis. It is logical that a classification based primarily on column integrity will accurately reflect the clinical status and the pattern of progress of the deformity.

The King[10] and Lenke[11] classifications for scoliosis have successfully resulted in uniformity in description, treatment

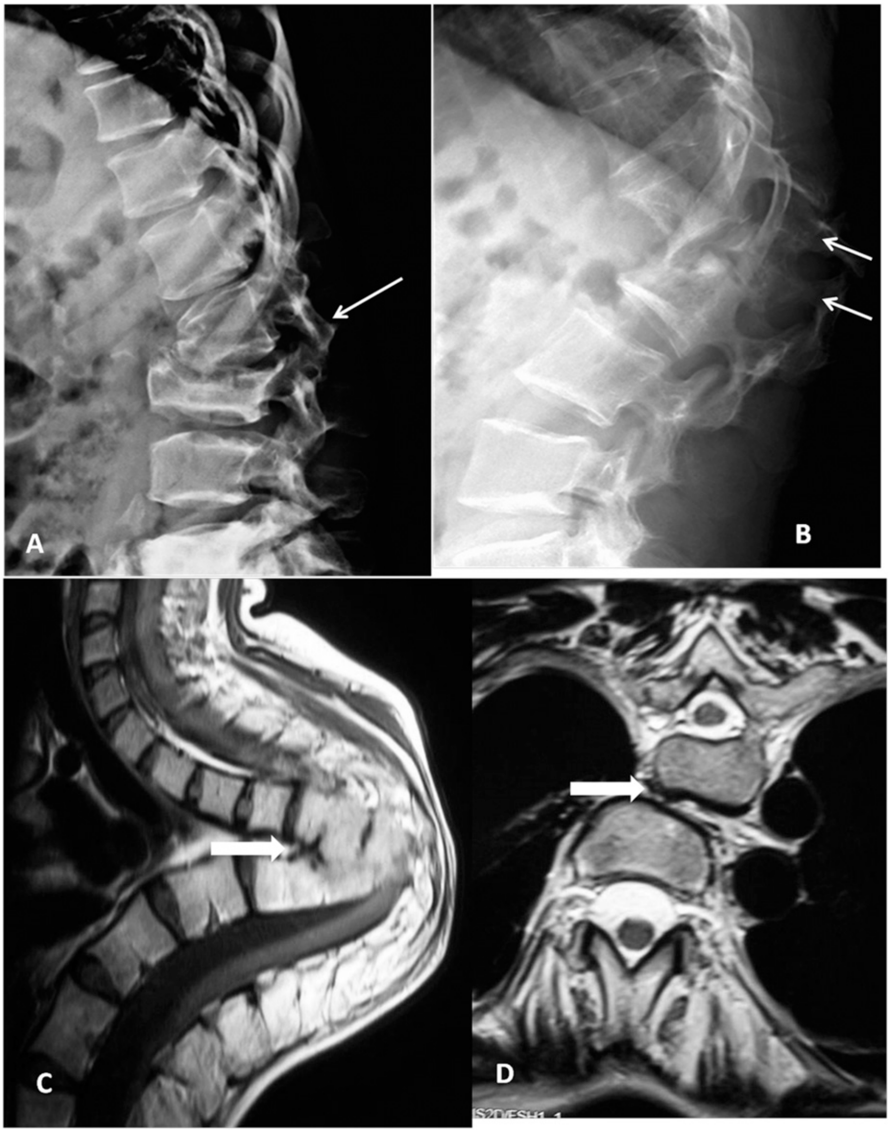

Fig. 5

Fig. 5-A Lateral radiograph of a patient with Type-IIIA kyphosis. There is an anterior column deficiency due to a posttraumatic kyphosis and a posterior column deficiency due to facet subluxation (arrow). **Fig. 5-B** Lateral radiograph of a patient with Type-IIIB kyphosis. There is an anterior deficiency due to post-tubercular vertebral body destruction and a posterior column deficiency secondary to posterior facet subluxation. The arrows mark the pedicles of 2 vertebral bodies that have been eroded by the infective disease process. **Fig. 5-C** T1-weighted MRI sagittal section of the thoracolumbar spine of a patient with a Type-IIIC kyphosis (buckling collapse) showing horizontalization of the peri-apical vertebrae (arrow). **Fig. 5-D** T2-weighted MRI coronal section over the apex of the deformity showing the proximal and distal parts of the spinal canal in cross-sectional view with the spinal cord in the peri-apical region. There is an approximation of the anterior vertebral cortex over the region of buckling collapse (arrow).

selection, and comparison of results[10,11]. A similar classification system is not available for kyphotic deformities[12-16]. We propose a classification that includes the anatomical and physiological characteristics of the deformity, the severity of the deformity, and surgical decisions.

Basis of the Classification

Kyphosis, irrespective of its etiology, can be grouped on the basis of the integrity of the anterior and posterior columns. Kyphosis may occur with both anterior and posterior columns being intact (Type I), with deficiency of either the anterior (Type IIA) or posterior (Type IIB) column, or with deficiency of both columns (Type III). Each subgroup is unique with regard to the characteristics of the kyphotic morphology, the propensity for the deformity to progress, and the type of surgical treatment required.

Type I

Kyphosis can occur without substantial loss of either bone or disc, as it does in ankylosing spondylitis. The deformity is usually diffuse, multisegmental, or even panspinal[1,6,7]. Neurological deficits, instability, and pain are usually not factors, and surgery is dictated by the need to restore sagittal balance. The mobility of the disc spaces is an important consideration in planning the osteotomy. When the disc spaces are mobile (Type IA), the correction is achieved with Ponte osteotomy. Immobile disc spaces usually require a pedicle subtraction or disc bone osteotomy (Fig. 4). Vertebrectomy is generally not performed, and full correction can be obtained.

In our study, all 11 patients with Type I were successfully treated with Ponte or pedicle subtraction osteotomy; none required vertebrectomy. Irrespective of the etiology of the kyphosis, the 6 patients with flexible disc spaces were treated with Ponte osteotomy and the 5 patients with an ankylosed spine underwent pedicle subtraction osteotomy.

Type II

Kyphosis due to loss of 1 column was classified as Type II. Anterior column loss (Type IIA) can be due to infection such as tuberculosis or to trauma or tumor[3-5]. Kyphosis can involve long segments with partial collapse of a few segments or complete loss of a single segment or multiple segments[24]. In the first case the kyphosis is gradual, whereas in the second there is an angular kyphosis, the severity of which depends on the extent and number of vertebrae lost. The implication of a Type-IIA kyphosis is that, in the presence of an intact posterior column, the deformity rarely progresses >60° and posterior closing osteotomies alone were usually sufficient. All 5 patients with Type-IIA kyphosis in our series had <60° of deformity and were treated with Ponte or disc bone osteotomy; no vertebrectomies were performed. Patients with a deformity of ≤30° were treated with Ponte osteotomy and those with a deformity of >30° underwent disc bone osteotomy. In the presence of an associated coronal imbalance, an asymmetrical osteotomy was performed[15].

The loss of the posterior column alone (Type IIB) can be congenital, as in patients with myelomeningocele; iatrogenic, as in those with post-laminectomy kyphosis; or, rarely, due to tumor or infection[3,5,8,25]. These situations are very common in the cervical region and in children with a progressive kyphosis after laminectomy[26,27]. The 2 Type-IIB deformities in our study were due to post-laminectomy kyphosis; 1 was corrected with pedicle subtraction osteotomy and the other, with disc bone osteotomy. Vertebrectomy was not performed.

Type III

Patients with Type-III kyphosis have loss of both columns with a poor prognosis for curve progression, instability, and buckling collapse[28]. This type requires early intervention and a surgical philosophy that is different from that for Type-I and Type-II kyphosis (Fig. 5). A cutoff of 60° was chosen to distinguish between Type IIIA and Type IIIB because our previous work had shown faster progress to buckling collapse when the deformity crossed 60°, leading to multiple facet joint dislocations[3,28]. There is also a difference in the nature of the osteotomies required in the 2 groups. Disc

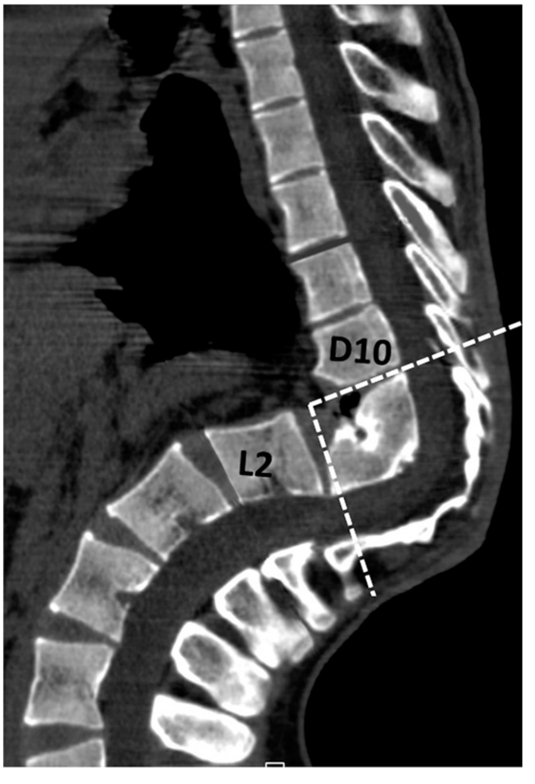

Fig. 6

Mid-sagittal section of a CT scan of a patient with a healed D11-L1 vertebral collapse due to tuberculosis. The fusion mass anteriorly is small but represents the remnants of 3 segments (D11-L1). The small wedge resected anteriorly has to be accompanied by an extensive laminectomy (dashed line) of the 3 segments. Frequently, this has to include an additional 1 or 2 laminae cranially and caudally to prevent compression after deformity correction.

bone osteotomy may be used when the deformity is ≤60°; however, vertebrectomy was always performed in patients with Type IIIB.

The evolution of Type-III deformities needs special understanding. The loss of the anterior column is always structural, and the posterior column failure is usually secondary to a functional failure consisting of facet dislocation. The disease is often primarily anterior and starts off as a Type-IIA deformity with an intact posterior column initially. Conversion to Type III occurs by a secondary posterior column failure due to facet subluxation or dislocation (Fig. 2). Certain clinical situations with anterior column loss due to tuberculosis or a wedged hemivertebra may have a subluxated or perched facet without actual dislocation, causing confusion between Type IIA and Type IIIA. Although by strict definition, such cases would be Type IIA, the surgeon must recognize them as "impending Type IIIA" and treat them appropriately. The intent of this classification is to highlight the potential risk of progression in such cases, and it would be surgically wise to treat them on that basis. This is very common in children, and failure to recognize the onset of functional failure of the posterior column is a common cause of rapid and severe progression of deformity leading to a Type-IIIC buckling collapse[3,28,29].

Often, patients with Type-III kyphosis have disproportionately greater loss of the anterior column than of the posterior column. This has 3 important surgical implications. First, posterior closing procedures such as pedicle subtraction and disc bone osteotomies, which are sufficient for Type-I and Type-II kyphosis, are not appropriate for Type III. Pedicle subtraction or disc bone osteotomy necessitates the removal of an obtuse wedge and, when the column is closed posteriorly, leads to severe shortening or posterior herniation of the spinal cord and a subsequent deficit. Neurological deficits due to anterior spinal artery kinking, following acute shortening of the cord, have been well documented by Kawahara et al.[30]. When the posterior column is closed, an appropriate lengthening of the anterior column by the placement of a suitable graft or cage is also required. This is termed "closing-opening wedge osteotomy" and can be effectively and safely performed from a posterior approach[29,30].

The second surgical modification required for Type III is an extensive laminectomy to prevent cord compression. For example, in the patient with spinal tuberculosis in Figure 6, the wedge resection performed anteriorly was relatively small but represents 3 vertebral segments. Failure to perform adequate laminectomies corresponding to the number of anterior vertebrae lost will result in compression of the cord.

The posterior bone-to-bone contact that can be achieved with closing osteotomies in Type-I and Type-II kyphosis is not possible in Type-III deformities. Therefore, there is a need for robust anterior support with adequate bone-grafting

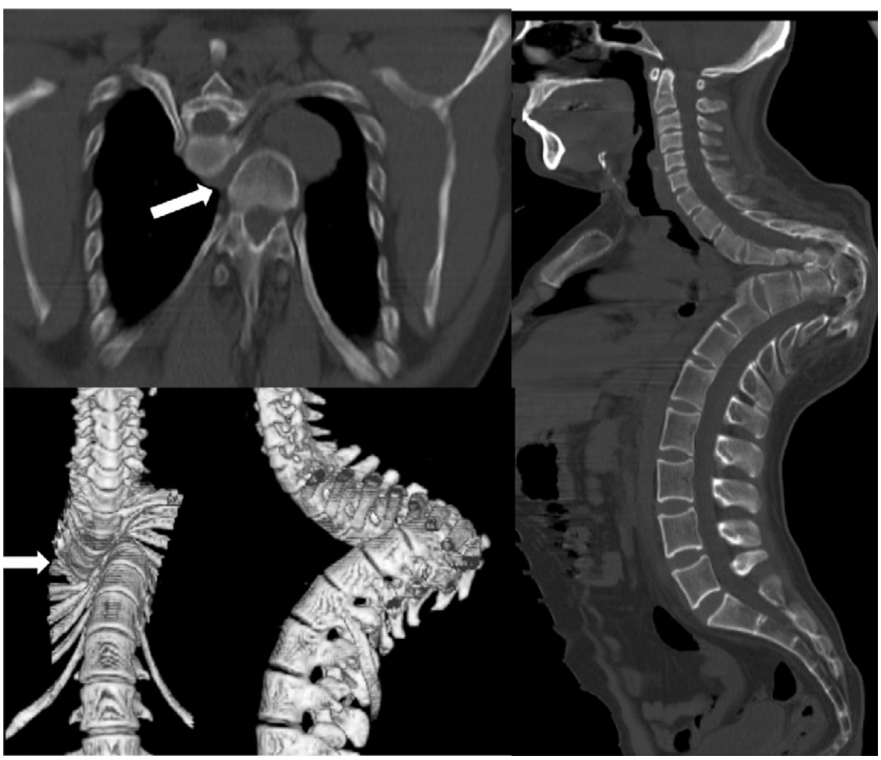

Fig. 7

CT images of a patient with buckling collapse in terminal stages. The kyphosis exceeds 180° as a translation occurs (arrows) at the apex, with the end vertebra lying inferior to the apical vertebra.

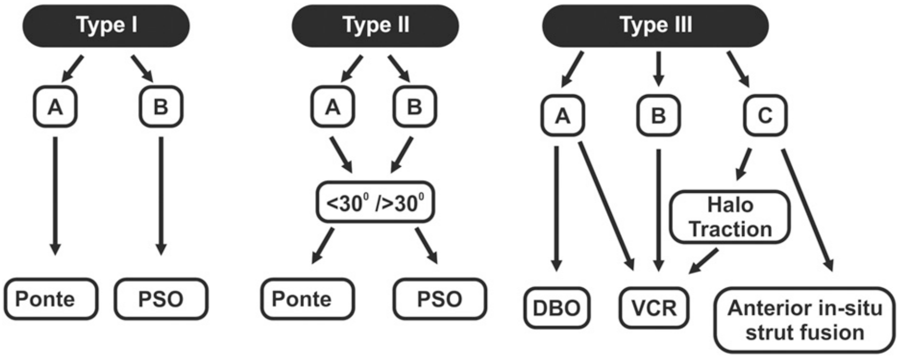

Fig. 8
A treatment algorithm to guide selection of appropriate posterior approach osteotomies based on the classification presented in the study. PSO = pedicle subtraction osteotomy, DBO = disc bone osteotomy, and VCR = vertebral column resection.

around the cage and posterolateral regions of the remaining vertebrae. In our series, 86% of the 58 Type-III deformities were treated with a single or multiple-level vertebrectomy and only 5 of the 58 patients were treated with disc bone osteotomy.

Buckling collapse (Type IIIC) represents a special scenario in which correction is difficult and dangerous. We have observed 2 patterns of collapse—1 where the 2 columns collapse on each other without translation and the other where the collapse occurs with vertebral translation. The kyphosis can reach 180° in the first scenario and can even exceed 180° when translation occurs[31] (Fig. 7).

Single-stage surgical correction of curves with Type-IIIC buckling collapse is impossible and dangerous; preoperative halo traction for 4 to 5 weeks or longer is essential to correct these curves safely. In effect, a Type-IIIC curve is gradually converted to a Type-IIIB curve, for which surgical correction is safe.

Finally, many patients seek treatment because of pain at the apex or the late onset of neurological deficits. It is often impossible to correct such deformities as the soft-tissue envelope may not tolerate instrumentation at the apex or the neurological risk is too great. Very often, in neglected cases the compensatory curves have become rigid and severe, preventing successful surgical correction. Practical difficulties due to medical or socioeconomic conditions can prevent the use of prolonged preoperative halo traction and staged surgical treatment. In such cases, a salvage anterior in situ strut fusion using fibular grafts is performed without osteotomy or vertebrectomy (Fig. 3).

Modifiers

Modifiers were included in the classification to account for SVA deviation of ≥5 cm. An SVA of ≥5 cm has been used as a parameter in the management of adult deformity correction and as a realignment objective[32,33]. Coronal deformity of ≥20° was selected as a modifier based on the use of asymmetrical pedicle subtraction osteotomy by previous authors for deformity correction[34,35] and retrospective data used in the development of the classification.

Strengths and Limitations

The study was a reliability evaluation of a novel classification for kyphotic deformities in a large sample of patients. On the basis of this classification, we suggested a preferred treatment algorithm to guide surgical strategy in kyphotic deformity management (Fig. 8). The main limitation is that the study was performed at a single institution. Further validation of the classification system and correlation with osteotomies and clinical outcomes in a multicenter study involving more surgeons is required.

In conclusion, a classification system was designed based on retrospective analysis of 180 patients and was prospectively evaluated in a group of 76 patients with kyphotic deformity of the spine. The classification had a high interobserver agreement rate and will be useful in guiding the appropriate choice of osteotomy for correction of the deformity. ■

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