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Assessment of Curve Flexibility in Adolescent Idiopathic Scoliosis

Azmi Hamzaoglu, MD,* Ufuk Talu, MD,† Mehmet Tezer, MD,* Cuneyt Mirzanlı, MD,‡
Unsal Domanic, MD,† and S. Bora Goksan, MD†

Study Design. A prospective comparative evaluation of the commonly accepted or described radiologic techniques to determine curve flexibility in adolescent idiopathic scoliosis (AIS), comparison of the results to those obtained by supine traction radiographs taken with the patient under general anesthesia (UGA) just before surgery and correlation of all findings to surgical correction.

Objective. To determine if supine traction radiographs taken with the patient UGA help provide better assessment of curve flexibility and better predicting surgical correction.

Summary of Background Data. Supine lateral bending radiographs are the standard methods of evaluating curve flexibility before surgery in idiopathic scoliosis. Supine traction radiographs have also been used at the authors' institution in addition to the supine lateral bending radiographs before surgery, believing that it is usually more helpful to analyze the response of the main and compensatory curves to corrective forces.

Methods. A total of 34 consecutive patients with AIS who had surgical treatment were studied. Preoperative radiologic evaluation consisted of standing anteroposterior and lateral, supine lateral bending and traction, fulcrum bending radiographs, and also supine traction radiographs taken with the patient UGA just before surgery. All structural curves were measured, and the flexibility ratio was determined on each radiograph. The amount of correction obtained by all radiographic methods was compared with the amount of surgical correction by evaluating the differences from surgery as absolute values. Mean absolute differences from surgery were used to determine the confidence intervals. Statistical differences were calculated with the comparison of the exact 95% confidence intervals for the mean.

Results. Curves were accepted to be moderate if between 40° and 65° (29 patients) and severe if >65° (5 patients). In these 29 patients, average frontal Cobb angle of the thoracic and lumbar curves were 49.7° (range 40°−60°) and 39.4° (range 22°−58°), respectively. For the moderate thoracic curves, fulcrum radiographs provided the best amount of flexibility, with no significant difference from traction with the patient UGA but with significant difference from bending radiographs. For the moderate lumbar curves, flexibility obtained by fulcrum and bending radiographs were significantly better than traction radiographs with the patient UGA. For the lumbar and thoracic curves more than 65°, traction radiographs with the patient UGA provided clearly better flexibility compared to bending and fulcrum radiographs, however, the number of patients is not enough to determine whether the differences are statistically significant. Better flexibility in traction radiographs with the patient UGA helped us eliminate the need for anterior release in all 5 patients who had severe and rigid curves more than 65°, which did not bend to less than 40° and were planned to have anterior release.

Conclusion. Fulcrum higher than bending higher than traction with the patient UGA is the order of radiographs for better predicting flexibility and correction in curves between 40° and 65°. Flexibility obtained at traction radiographs with the patient UGA is clearly better in numerical values, and closer to the amount of surgical correction than the amount of flexibility at fulcrum and side-bending radiographs for curves larger than 65°, although not statistically significant as a result of the small number of patients in this group. However, pedicle screw instrumentation provides even more correction than the traction radiographs with the patient UGA. Thus, traction radiographs with the patient UGA may show much better flexibility, especially in more than 65° and rigid curves.

Key words: idiopathic scoliosis, assessment, flexibility, bending radiograph, traction radiograph, fulcrum bending radiograph. **Spine 2005;30:1637–1642**

Optimal balance over pelvis and the least number of fused segments have always been the major goal of surgical treatment for scoliosis.[1,2] To achieve this goal, and, especially after the introduction and use of the Harrington rod, analysis and differentiation of various curve types and their response to corrective forces have been a source of concern to spine surgeons.[3–13] Thus, curve flexibility has become a crucial component of curve analysis and surgical decision making. The improved design of new generation implants and capacity to obtain more and more correction led spine surgeons to search and develop new methods for assessing curve flexibility.[2,3,13]

To analyze better curve flexibility and minimize radiographic technique or patient-related factors, we have started using supine traction radiographs taken with the patient under general anesthesia (UGA) just before surgery. The purpose of this prospective study was to use and evaluate the commonly accepted or described radiologic techniques or methods, like supine lateral bending, supine traction, and fulcrum bending radiographs, to de-

From the *Istanbul Spine Center, Florence Nightingale Hospital, †Department of Orthopaedics and Traumatology, Istanbul University, and ‡ Department of Orthopaedics and Traumatology, Vakıf Guraba Social Security Hospital, Istanbul, Turkey.
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Address correspondence and reprint requests to Ufuk Talu, MD, Department of Orthopaedics and Traumatology, Istanbul University, Istanbul Medical Faculty, 34390, Capa, Topkapı, Istanbul, Turkey; E-mail: gutalu@superonline.com

termine flexibility and compare the results to those obtained by supine traction radiographs with the patient UGA just before surgery and correlate all findings to surgical correction.

Materials and Methods

Of 37 consecutive adolescent patients with idiopathic scoliosis (AIS) who had surgical treatment, 34 were studied. Three initial patients in the series were excluded from the study because traction radiographs obtained in the operating room with the patient UGA did not have good image quality, and clear anatomic landmarks for making proper and consistent measurements. A total of 25 patients were female and 9 were male, with an average age of 15.7 years (range 12–19). Preoperative radiologic evaluation consisted of standing anteroposterior and lateral, supine lateral bending and traction, fulcrum bending radiographs, and also supine traction radiographs with the patient UGA just before surgery. Verbal consent for these radiographs was obtained from the patient and his or her parents. Fulcrum bending radiographs were taken as described by Cheung and Luk.[3] Accordingly, fulcrum bending radiograph was made with the patient lying on his or her side over a large, radiolucent plastic cylinder. It was placed directly under the apex of a lumbar curve or under the rib corresponding to the apex of a thoracic curve. All radiographs were obtained at the radiology department of the same institution, with the same radiology technician who was well trained and also given all instructions.

The supine traction radiographs were obtained with the surgeon pulling on the head and neck, while countertraction was applied to the lower extremities by one of the orthopedic fellows. A maximum effort was applied. Curves were identified as thoracic or lumbar, depending on the location of the apex of the deformity. In patients with double curves, both curves were analyzed. All structural curves were measured using the Cobb method, and flexibility ratio was determined on each radiograph. These radiographs were compared with the postoperative radiograph, which was made with the patient standing approximately 6 weeks postoperatively. The most experienced surgeon (A.H.) measured the radiographs twice. Intra-reader reliability was assessed using the scale reliability analysis using SPSS software (version 7.5, SPSS Inc., Chicago, IL) for Windows (Microsoft Corp., Redmond, WA). Average alpha value was 0.99 (alpha >0.90 is considered very good). The amount of correction obtained by all radiographic methods was compared with the amount of surgical correction by evaluating the differences from surgery as absolute values. Surgery was performed by the senior author (A.H.) using only polyaxial pedicle screws in a segmental fashion for posterior spinal arthrodesis and instrumentation (either Moss-Miami or CD-Horizon systems), and translation by cantilever technique for correction.

Results

Curves were considered moderate if they were between 40° and 65° (29 patients) and severe if they were more than 65° (5 patients). In these 29 patients, average frontal Cobb angle of the thoracic and lumbar curves were 49.7° (range 40°–60°) and 39.4° (range 22°–58°), respectively. Average thoracic curve flexibility was 66% (range 25% to 82%) on lateral bending, 49% (range 23% to 64%) at traction, 74% (range 50% to 87%) at fulcrum bending, and 79% (range 30% to 88%) at traction radiographs with the patient UGA. Average surgical correction of the thoracic curve was 76% (range 52% to 95%).

Average lumbar curve flexibility was 81% (range 61% to 100%) on lateral bending, 56% (range 35% to 73%) at traction, 83% (range 66% to 100%) at fulcrum bending, and 59% (range 39% to 72%) at traction radiographs with the patient UGA. Average surgical correction of the lumbar curve was 74% (range 44% to 100%).

In the other group of 5 patients, average frontal Cobb angle of the thoracic and lumbar curves were 79° (range 47°–110°) and 67° (range 38°–90°), respectively. With the same order of aforementioned radiographs, average thoracic curve correction was 43% (range 35% to 55%), 35% (range 29% to 38%), 45% (range 41% to 50%), and 52% (range 49% to 58%) (Figure 1). Also average lumbar curve correction was 51% (range 40% to 65%), 40% (range 32% to 50%), 53% (range 38% to 69%), and 60% (range 45% to 79%). Average surgical correction of the thoracic and lumbar curve in this group were 68% (range 64% to 72%) and 63% (range 42% to 79%), respectively (Table 1).

Mean absolute differences (χ) from surgery were used to determine the 95% confidence interval (CI) using the formulas for the: 29 patient group =

$$\chi \pm \textit{standard deviation}/\sqrt{29}(2.048)$$

and 5 patient group =

$$\chi \pm \textit{standard deviation}/\sqrt{5}(2.776)$$

Statistical differences were calculated with the comparison of the exact 95% CI for the mean. Results were considered significant when upper and lower limits did not overlap. Statistical data were analyzed using SPSS software for Windows (version 7.5, SPSS Inc.) (Table 2).

Accordingly, for the moderate thoracic curves between 40° and 65°, flexibility obtained by traction radiographs with the patient UGA was slightly inferior to the flexibility obtained at fulcrum radiographs and slightly better than the flexibility at bending radiographs. There was no statistically significant difference. However, fulcrum radiographs provided significantly better flexibility compared to bending radiographs in this group. For the moderate lumbar curves between 40° and 65°, flexibility obtained by fulcrum and bending radiographs were close, but not better, to the amount of surgical correction, and both were significantly better than traction radiographs with the patient UGA.

For the lumbar curves more than 65°, traction radiographs with the patient UGA gives clearly better flexibility compared to bending and fulcrum radiographs. However, the number of patients is not enough to determine whether this difference is statistically significant. For the thoracic curves more than 65°, again the traction radiographs with the patient UGA gives close but better flex-

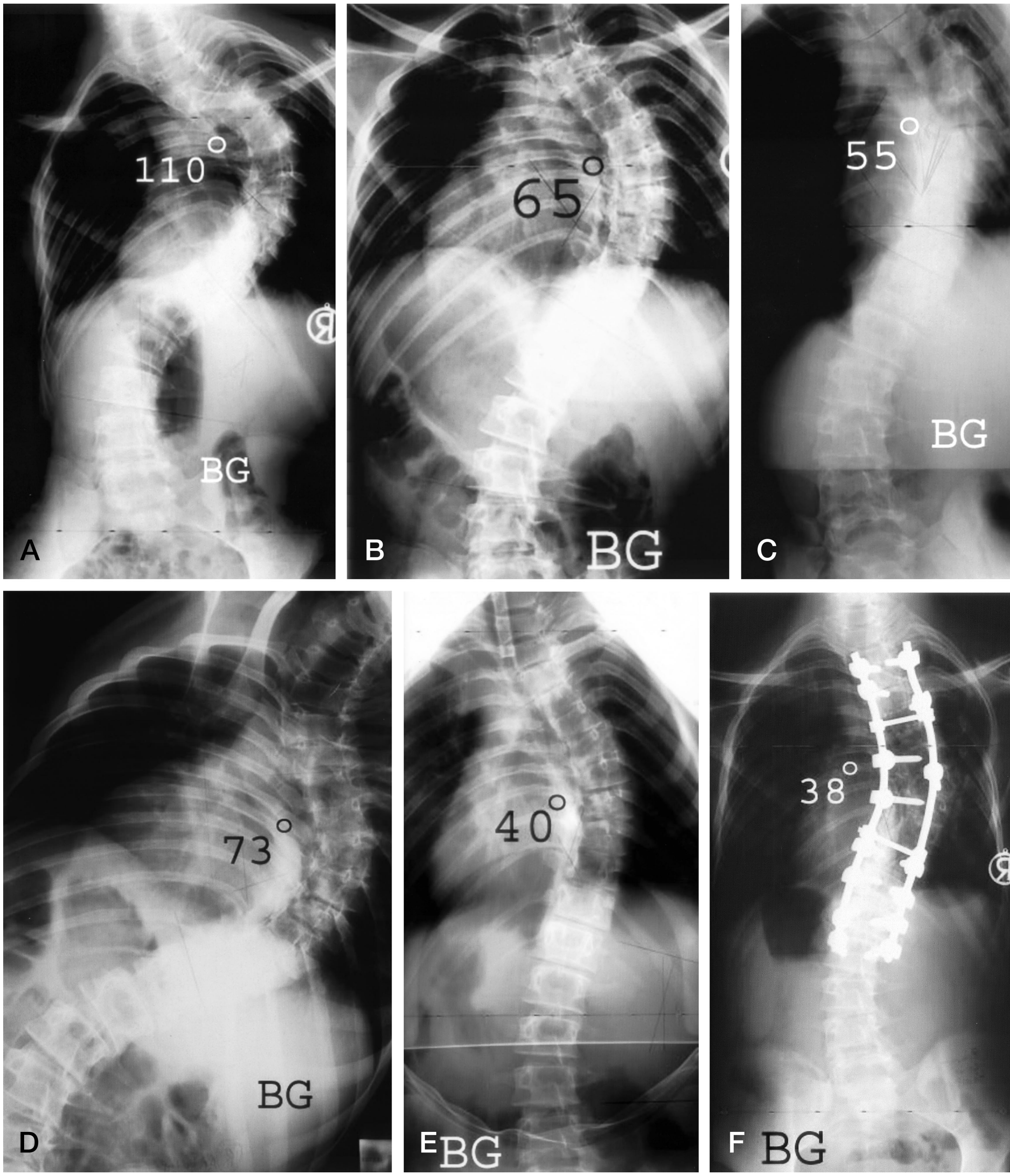

Figure 1. **A**, Standing anteroposterior radiograph of a patient with 110° severe thoracic curve. **B**, Curve is decreased to 65° in supine traction radiograph. **C**, Fulcrum radiograph shows correction of the curve to 55°. **D**, Curve is quite rigid and decreased to 73° on maximal lateral bending, which made us think that anterior release should be performed as an initial procedure. **E**, Traction with the patient UGA just before surgery showed much better flexibility, which made us proceed with posterior surgery. **F**, Only posterior surgery using segmental pedicle screws provided even more correction.

ibility compared to fulcrum and bending radiographs. The number of patients again is not enough to determine whether this difference is statistically significant. However, it seems that the difference in favor of traction radiographs with the patient UGA might well be significant if the group of patients was larger. For all patients and groups, normal traction radiographs showed significantly less flexibility when compared to other radiographic methods. Overall flexibility obtained at traction radiographs with the patient UGA is clearly better in numerical values, and closer to the amount of surgical correction than the amount of flexibility at fulcrum and side-bending radiographs for curves larger than 65°, although not statistically significant as a result of the small number of patients.

Discussion

Preoperative assessment of spine flexibility in a patient who has scoliosis is important to determine the levels to be included in the arthrodesis and the expected postop-

Table 1. Data Summarizing Results

Curve	Flexibility	Surgical Correction (%)
Moderate thoracic	Tr UGA (79%) > fulcrum (74%) > SB (66%) > Tr (49%)	76
Moderate lumbar	Fulcrum (83%) > SB (81%) > Tr UGA (59%) > Tr (56%)	74
Severe thoracic	Tr UGA (52%) > fulcrum (45%) > SB (43%) > Tr (35%)	68
Severe lumbar	Tr UGA (60%) > fulcrum (53%) > SB (51%) > Tr (40%)	63

SB = side-bending film; Tr = supine traction film; Tr UGA = traction film with patient under general anesthesia.

erative correction. However, ideally it also should help in determining the effect of this correction on the curves above and below the level of fusion, and on the overall spinopelvic balance.

Supine side-bending films have been used widely to help in the preoperative evaluation, especially for selection of the fusion area. However, despite the issues of safety of correction or coronal decompensation, current segmental spinal instrumentation systems, especially segmental pedicle screw constructs, have achieved more correction than would be expected from evaluation of traditional side-bending radiographs made with the patient supine.[14]

Although less frequently used than side-bending films, traction films are also being used by some surgeons and centers for predicting the amount of postoperative correction. Traditionally, traction films have also been obtained, especially in patients who are less able to perform the side-bending (*i.e.,* in patients with neuromuscular scoliosis or mental retardation).[1] Winter and Lonstein[15] found that a traction view is more accurate for determining flexibility in curves more than 60°. A recent clinical study performed by Polly and Sturm[1] suggested that traction shows the highest flexibility in thoracic curves more than 60°. Whether traction shows higher flexibility in scoliotic curves is unknown or debatable, but we believe that it is usually much more helpful to analyze the response of the main and compensatory curves to corrective forces. This is why we use supine traction films in addition to the supine side-bending films before surgery in all patients with scoliosis, regardless of the etiology since 1990.

However, the variability of results can be caused by both technique or patient-related factors as well as measurement errors. To analyze better curve flexibility and obtain consistent results, different radiologic methods or techniques are developed and used. Transfeldt and Winter[16] compared correction in supine *versus* standing side-bending radiographs and reported that the highest flexibility was achieved in the supine side-bending films. Vaughan *et al*[17] conducted a study to evaluate the use of voluntary supine side-bending radiographs and Risser

Table 2. Descriptive Statistical Data with Mean and Median Representing Differences of the Methods to Surgical Correction, and Statistical Analysis Comparing the Exact 95% CI for the Mean*

Group	No.	Method Compared to Surgery	Mean ± SE , 95% CI	Median, Min−Max	Statistical Analysis
Curves between 40° and 65° lumbar	29	Fulcrum	9.14 ± 1.09, 6.91−11.37	9, 0−22	Fulcrum−bending (Nonsig)
		Bending	9.07 ± 1.03, 6.96−11.18	8, 0−22	Fulcrum−traction (Sig)
		Traction	18.0 ± 1.38, 15.17−20.83	18, 1−32	Fulcrum−traction UGA (Sig)
		TractionUGA	15.0 ± 1.36, 12.21−17.79	14, 5−34	Bending−traction (Sig)
					Bending−traction UGA (Sig)
					Traction−traction UGA (Nonsig)
Curves between 40° and 65° thoracic		Fulcrum	5.24 ± 1.05, 3.09−7.39	3, 0−21	Fulcrum−bending (Sig)
		Bending	12.48 ± 2.25, 7.87−17.09	9, 0−45	Fulcrum−traction (Sig)
		Traction	27.0 ± 1.48, 23.97−30.03	27, 5−46	Fulcrum−traction UGA (Nonsig)
		TractionUGA	6.93 ± 1.25, 4.37−9.49	5, 0−30	Bending−traction (Sig)
					Bending−traction UGA (Nonsig)
					Traction−traction UGA (Sig)
Curves >65° lumbar	5	Fulcrum	10.0 ± 1.90, 4.73−15.27	10, 4−16	Fulcrum−bending (Nonsig)
		Bending	12.0 ± 2.90, 3.95−20.05	12, 2−20	Fulcrum−traction (Nonsig)
		Traction	23.0 ± 3.56, 13.12−32.88	23, 10−30	Fulcrum−traction UGA (Nonsig)
		TractionUGA	4.20 ± 2.03, (−1.44)−9.84	3, 0−12	Bending−traction (Nonsig)
					Bending−traction UGA (Nonsig)
					Traction−traction UGA (Sig)
Curves >65° thoracic		Fulcrum	23.0 ± 0.32, 22.11−23.89	23, 22−24	Fulcrum−bending (Nonsig)
		Bending	25.0 ± 2.10, 19.17−30.83	27, 17−29	Fulcrum−traction (Sig)
		Traction	33.0 ± 0.71, 31.03−34.97	33, 31−35	Fulcrum−traction UGA (Nonsig)
		TractionUGA	16.0 ± 0.71, 14.03−17.97	6, 14−18	Bending−traction (Sig)
					Bending−traction UGA (Nonsig)
					Traction−traction UGA (Sig)

*Statistical significances were determined by whether the upper and lower limits of 95% CI overlapped or not.
Max = maximum; Min = minimum; Nonsig = nonsignificant; SE = standard error; Sig = significant; UGA = under general anesthesia.

table traction radiographs in patients with AIS undergoing posterior spinal fusion. They found that for curves less than 60°, side-bending radiographs showed higher curve correction than traction radiographs, whereas the opposite was true for curves more than 60°. Also, according to their results, the stable vertebra was 1.4 vertebral levels higher on traction radiographs than on the standing film. They suggested that when the fusion level was moved proximally because of the traction radiograph, decompensation or "adding-on" commonly occurred, and concluded that selection of fusion levels in AIS was best determined by a combination of standing posteroanterior and lateral radiographs, and the supine maximum voluntary bend films.

On the other hand, Cheung and Luk[3] found a discrepancy between the correction that was seen on the preoperative supine lateral bending radiographs and the degree of correction achieved after the operation. They discussed that if the flexibility seen on traditional lateral bending radiograph does not accurately reflect the actual flexibility of the scoliosis, a patient may have an unnecessary anterior release. Therefore, they have described "the fulcrum bending radiograph" for the assessment of spinal flexibility and compared the predictive value of the fulcrum bending radiograph with that of the supine lateral bending radiograph. They found that the fulcrum bending radiograph was most useful for patients in whom the curve was relatively stiff (*i.e.,* more than 40° on the lateral bending radiograph), but even in the patients who had a more flexible curve the difference between the angle measured on the lateral bending radiograph and that on the fulcrum bending radiograph was significant. Thus, they have reached the conclusion that the fulcrum bending radiograph was always more predictive of the final correction obtained with the use of their preferred segmental spinal instrumentation system. In their practice, the fulcrum bending radiograph has replaced the lateral bending radiograph in their routine preoperative assessment.

In search of an optimal method to analyze curve flexibility and, at the same time, the curve response to surgical correction, we have started using supine traction radiographs taken with the patient UGA just before surgery. One of the major advantages of the supine traction radiograph with the patient UGA compared to supine side-bending and fulcrum bending radiograph is that muscle spasm and related patient discomfort are avoided, and there is no need for patient or parent cooperation. Thus, it can be used in a more uniform or standardized fashion, even in patients with neuromuscular disorders and/or mental retardation, in which cases supine lateral bending radiographs are unreliable, and fulcrum bending radiographs may be difficult to obtain because of the lack of patient cooperation and effort.

There are also some disadvantages that we have noted or experienced during the study. It is sometimes difficult to obtain high-quality films in the operating room for proper evaluation and measurement. There is also an increased exposure to radiographs for both the surgeons and patients. However, these were minimized after the initial few patients as the method became more standardized.

Results obtained by this study lead to some preliminary but important deductions and conclusions. The curve flexibility in supine traction films taken with the patient UGA was more than the curve flexibility in routine supine traction films in all patients and all types of curves. Thus, there is no need before surgery to obtain a normal supine traction film for flexibility analysis. Fulcrum or side-bending films seem to be the proper method for flexibility analysis in the moderate lumbar curves because curve flexibility in supine traction films taken with the patient UGA was less in this group of patients. Curve flexibility in supine traction films taken with the patient UGA was more than but very close to the amount of curve flexibility in fulcrum and side-bending films in moderate thoracic curves. Any one of these can be used or preferred for flexibility analysis in moderate thoracic curves. In our opinion, bending films are needed in all cases and all types of curves, not for flexibility analysis, but for determining the fusion levels. In that respect, we think that these are different issues and do not agree with Cheung and Luk,[3] who have replaced the lateral bending radiograph with the fulcrum bending radiograph in their routine preoperative assessment.

More importantly, supine traction radiographs with the patient UGA showed much better flexibility compared to side-bending and fulcrum radiographs in rigid and higher curves, which are more than 65° and not bending to less than 40°. This helped us eliminate the need for anterior surgery in 5 patients who had so-called severe and rigid curves more than 65°, and were planned to have initial anterior release according to the flexibility in supine lateral bending radiographs (*i.e.,* the angle on the lateral bending radiograph is more than 40°). In these patients, supine traction radiographs with the patient UGA showed a higher flexibility compared to lateral bending and fulcrum bending radiographs, and, thus, we have proceeded with only posterior surgery and segmental pedicle screw instrumentation, which provided even more correction. Actually, more correction was obtained after surgery in all patients, other than some with moderate lumbar curves.

These results and conclusions apply to patients with AIS. Our practice in this series of patients showed that curve flexibility is usually best predicted by the supine traction radiograph obtained with the patient UGA just before surgery. The main difference between traction with the patient UGA and the other methods reported is that the former is performed with the patient completely relaxed. This will surely remove the muscle factor that affects clinical curve flexibility and show more flexibility in almost all curves of all locations (other than moderate lumbar curves). This result is especially the case for higher lumbar or thoracic curves, which gradually become stiffer as a result of facet degeneration and arthritic changes. Active forces that are more dependent on patient and muscle relaxation during bending and fulcrum radiographs may not be adequate to obtain further flexibility, which is achieved more effectively by traction radiographs with the patient UGA.

One potential limitation or problem in the clinical application is that the surgeon will not be able to give the patient a definitive plan before surgery because the decision can only be finalized after seeing the traction radiographs with the patient UGA. The patient or the parents are consented accordingly, and once the decision is made after traction radiographs are taken with the patient UGA, parents are further informed about the final decision. There are 2 shortcomings of this study. The first one is that we have used manual traction with maximum effort, which should be replaced by a more standard technique or method of traction to standardize the amount of force applied. We have recently started using a standard cervical traction halter with another but the same individual applying traction to both lower extremities. As Takahashi *et al*[18] described, the load of traction was determined as half of the patient's weight, with an upper limit of 30 kg for each patient. The second shortcoming is that the number of patients in the severe curve group is small in this study population, and it needs to be increased because the most impressive results are obtained in this group of patients. The authors of this study hope that these preliminary results obtained by supine traction radiographs taken with the patient UGA just before surgery will allow surgeons to assess better, curve flexibility and improve preoperative planning.

■ Key Points

- The main difference between traction with the patient UGA and the other methods reported is that the former is performed with the patient completely relaxed. This process will surely remove the muscle factor that affects curve flexibility and show more flexibility.
- This effect is especially true for higher lumbar or thoracic curves that gradually become stiffer as a result of arthritic changes.
- Pedicle screw instrumentation provides even more correction than the traction radiographs with the patient UGA.
- Better flexibility in traction radiographs with the patient UGA may help eliminate the need for anterior release and lead to the decision of proceeding with posterior-only surgery.

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