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CLINICAL RESEARCH

Convex Instrumented Hemiepiphysiodesis with Concave Distraction

A Preliminary Report

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Abstract
Background The convex growth arrest (CGA) procedure has been well accepted for treatment of congenital scoliosis as it is a simpler procedure with successful results. However, unpredictability of curve behavior, slow and usually inadequate correction, and necessity of anterior surgery for completeness of the epiphysiodesis are its shortcomings.
Questions/purposes In a preliminary study we asked whether a modification of the CGA procedure using convex instrumented hemiepiphysiodesis with concave distraction would correct the coronal plane Cobb angles and would correct or maintain sagittal plane local and global kyphosis angles. We also identified complications.
Patients and Methods We retrospectively reviewed five female patients who underwent the modified procedure. Their mean age at the index operation was 40 months (range, 17–55 months). The patients underwent concave distractions every 6 months. The magnitude of the convex instrumented and concave distracted curves and sagittal plane parameters were determined on the preoperative and most recent followup radiographs. Minimum followup was 26 months (mean, 34 months; range, 26–40 months).
Results In the coronal plane, the preoperative magnitude of the convex instrumented congenital curve averaged 48°. It was corrected to 36° (25%) postoperatively and was further improved to 27° (44%) at the latest followup. For the distracted segment, the mean preoperative curve was 35°, corrected to 16° postoperatively and to 8° at the latest followup, for an average correction of 77%. Sagittal plane alignment was minimally affected from the procedure. In four of the five patients we identified partial pullout of screws for the concave distraction; these were revised at the time of planned lengthening.
Conclusions This procedure may obviate the need for multiple osteotomies and long thoracic fusions in young children with long sweeping thoracic deformities involving multiple anomalous vertebrae. Implant-related complications on the concave side may be avoided using paired pedicle screws at the proximal and distal anchor sites.
Level of Evidence Level IV, therapeutic study. See the guidelines online for a complete description of level of evidence.

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Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.
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Introduction

Congenital spinal deformities result from anomalous vertebrae that produce deformities in the coronal and sagittal planes as a result of growth imbalances. These deformities in young children continue to be one of the challenging entities of spinal surgery. In the past, the aim of surgical treatment of congenital curves was to stop the increase of the curve magnitude that accompanies the growth of the child; however, currently vertebral column resections and fusion are considered the preferred method for surgical correction of these deformities [15]. However, early fusion becomes a problem when the anomaly involves a long segment and the child is left with a short spine when he or she grows into adulthood.

Modulation of vertebral growth on either the convex or concave side of the curve (growth arrest or growth enhancement, respectively) theoretically can be an early and effective treatment alternative for the growing spine. The CGA procedure [19] has been a well-accepted approach because it reportedly is a simpler procedure when compared with other surgical alternatives and it provides successful results [14, 16–22]. Several studies have documented an epiphysiodesis effect in the majority of patients with control of the deformity [11, 18], whereas the correction effect is observed less frequently [1, 2, 7, 10, 14, 16, 20–22]. Problems with CGA include unpredictability of curve behavior, slow or inadequate correction, necessity of anterior surgery for completeness of the epiphysiodesis, poor control of the deformity in long sweeping curves greater than 50°, and inability to control trunk balance immediately until some spontaneous correction occurs years after the index procedure [19]. The CGA technique was modified by one of the senior authors (AA) to obviate the need for anterior surgery, to increase the correction effect and correction rate by stimulating growth at the concave side, and to provide immediate trunk balance.

We asked whether the modified CGA procedure involving a multilevel pedicle screw convex growth arrest combined with a single concave growing rod would correct the coronal plane Cobb angles and sagittal plane local and global Cobb angles. We also identified the complications related to the procedure.

Patients and Methods

Five female patients with congenital spinal deformities underwent the procedure. Their mean age at the index operation was 40 months (range, 17–55 months). The indications for surgery were congenital thoracic scoliosis with multiple anomalous vertebrae in patients younger than 5 years. Data obtained from medical records and radiographs were studied retrospectively. Minimum followup was 26 months (mean, 34 months; range, 26–40 months). The mean age of the patients at final followup was 74 months (Table 1).

On the convex side, only the anomalous vertebrae forming the congenital curve were instrumented by unilateral pedicle screws and a single rod connecting them. Convex fusion was performed by decortication and resection of the facet joints on this side. After the instrumentation, as much correction as possible was achieved by derotation and particularly by compression through the resected facet joints. On the concave side, submuscular exposure was accomplished without dissecting the periosteum and pedicle screws were placed at the most proximal and most distal nonanomalous vertebrae contributing to the deformity as one at each end. Originally, no fusion was applied around the pedicle screws (Fig. 1). However, after observing migration of several single screws at both ends of the concave growing rod construct during the periodic lengthening, we began using double pedicle screws below and above (Fig. 2). Neutral vertebrae (without rotation on AP radiographs) at the upper and lower ends of the curve were selected to be the upper and lower instrumented vertebrae at the concave side. In this way, fusion was applied only at the apical anomalous segments at the convex side. Patients underwent concave distraction every 6 months (Fig. 1). The mean number of distractions was five.

The patients were mobilized immediately after the surgery. They did not use braces postoperatively or during the followup period. The concave rods were lengthened every 6 months.

Table 1. Demographic data for the five patients

Patient number	Age at index (months)	Gender	Age at last followup (months)	Followup (months)	Number of lengthenings
1	58	F	98	40	6
2	29	F	55	26	4
3	40	F	78	38	6
4	55	F	90	35	6
5	17	F	47	30	5

F = female.

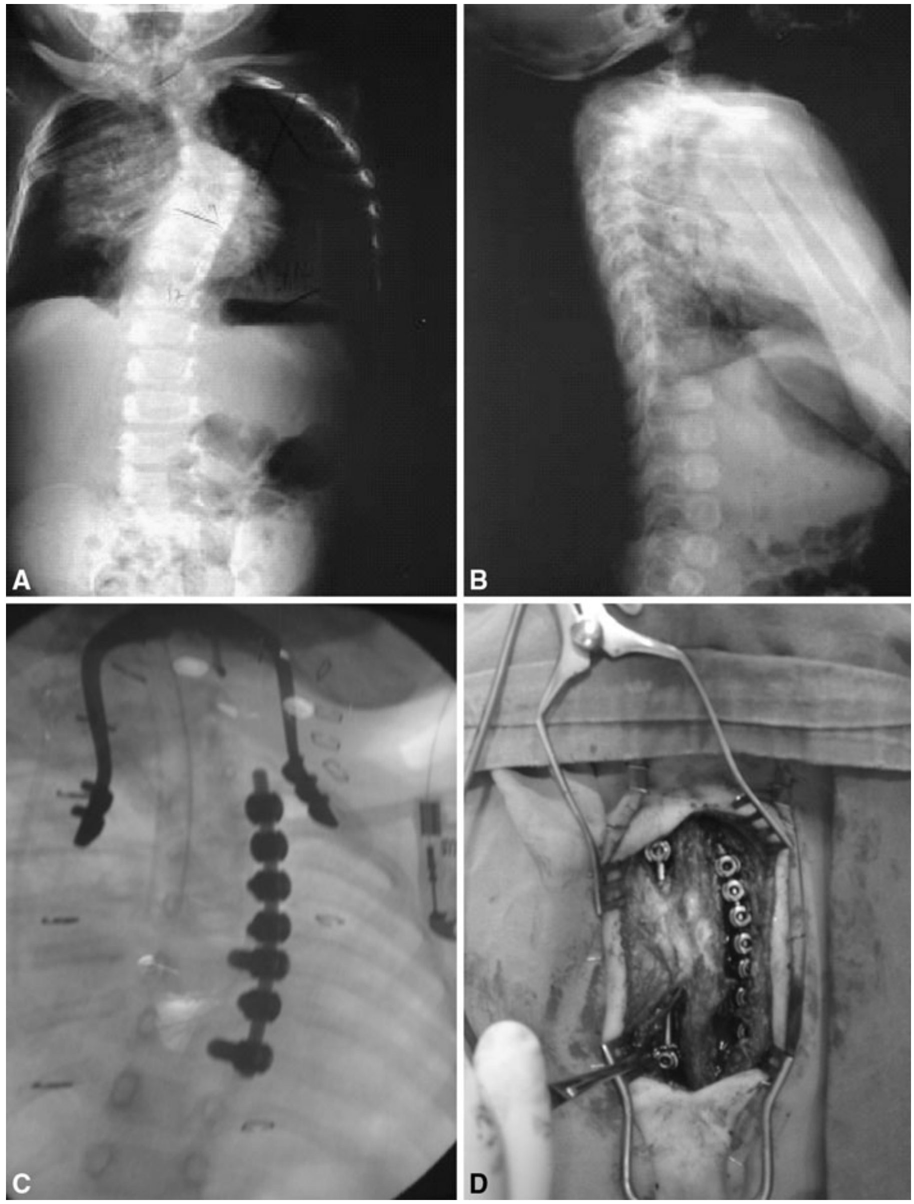

Fig. 1A–D A 1½-year old female patient had a left thoracic scoliosis, seen on these (**A**) AP and (**B**) lateral views obtained before treatment. (**C**) An intraoperative radiograph was obtained immediately after convex instrumentation with compression. (**D**) This intraoperative photograph was obtained before wound closure. Intermediate segments of the concavity are not exposed subperiosteally.

The patients were seen every 3 months and had AP and lateral 35-inch scoliosis radiographs at every followup. The hospital charts were examined for any complications that the patients might have experienced. We defined major complications as screw pull-out, rod breakage, infection, and pulmonary problems, whereas we considered wound dehiscence a minor complication [8, 11, 16–19, 23]. To avoid confusion, we called the hemiepiphysiodesed congenital curve the 'convex instrumented curve', and the longer sweeping curve that was instrumented with a conventional growing rod system, the 'concave distracted curve'.

The anomalous segments that were instrumented and fused at the convex side and the longer sweeping curve (including the proximal and distal nonanomalous adjacent segments), distracted by the growing rod without fusion, were measured preoperatively, immediately postoperatively, and at the final followup. Segmental kyphosis was measured for the same segments. Global thoracic kyphosis and lumbar lordosis were measured and compared with the normative data reported by Cil et al. [6].

All measurements were made by one observer (OD) not involved with the surgery. For the coronal plane, the mean magnitude of the preoperative convex instrumented congenital curve was 48° (Table 2). For the distracted segment, the mean preoperative curve was 35°. The preoperative global thoracic kyphosis was 28.2° and the global lumbar lordosis was 39°. Segmental kyphosis was measured for the instrumented segments (Table 3).

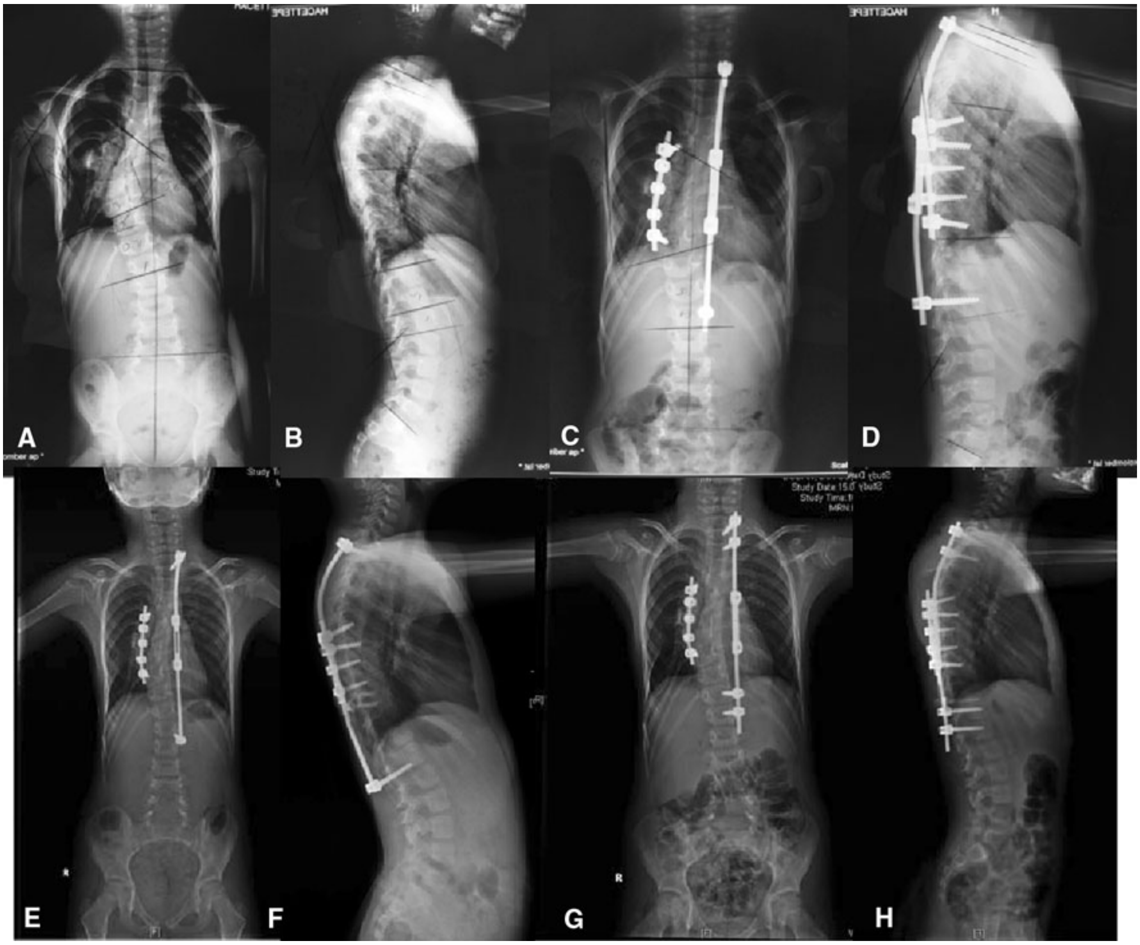

Fig. 2A–H Preoperative (**A**) AP and (**B**) lateral radiographs show a left thoracic scoliosis in a 55-month-old female patient. (**C**) AP and (**D**) lateral radiographs were obtained immediately after surgery. At the 27-month followup, (**E**) AP and (**F**) lateral radiographs show partial pull-out of the proximal and distal pedicle screws on the concave side. The patient underwent revision of the proximal and distal anchor points, as can be seen on these (**G**) AP and (**H**) lateral views, with replacement of the loose pedicle screws and addition of an additional pedicle screw to the adjacent level of the proximal and distal ends.

Table 2. Coronal deformity for concave distracted and convex hemiepiphysiodesis segments*

Curve	Preoperatively	Immediate postoperatively	Amount of correction	Latest followup	Amount of correction
Concave distracted	35	16	19 (54%)	8	27 (77%)
Convex instrumented	48	36	12 (25%)	27	21 (44%)

* In degrees.

Results

The coronal plane (Table 2) convex curve was corrected to a mean of 36° postoperatively and was 27° at final followup. Average correction at the final followup was 21° (44% correction). For the distracted segment, the preoperative curve was corrected by 54% to 16° postoperatively and to 8° at final followup, with an average correction of 27° (77% correction). The global thoracic kyphosis increased to 28.8° immediately postoperatively and to 32.4° at final followup. All patients had improvement in their curve size postoperatively followed by further improvement by the final followup (Table 4). Global lumbar lordosis decreased to 37.8° immediately after the operation and to 44.4° at final followup. For all patients, the preoperative sagittal alignment at distracted segments was hypokyphotic when compared with the normative data. Hypokyphosis between T4-T10 was normalized to 30° in

Table 3. Segmental sagittal deformity for concave distracted and convex hemiepiphysiodesis segments†

Curve	Normative data*	Preoperative	Immediate postoperative	Latest followup
Concave distracted curve				
T1-8	30	25	23	30
T1-L1	44	31	30	32
T1-L1	44	38	30	46
T1-10	37	19	20	20
T4-10	28	16	30	30
Convex instrumented curve				
T1-6	20	23	26	30
T6-10	17	18	19	15
T6-10	17	13	12	15
T4-8	21	15	14	13
T5-9	20	14	28	28

* Segmental kyphoses are low compared with the normative data by Cil et al. [5] for the same age group; distraction causes an increase in segmental kyphoses, especially for the concave instrumented segment; †in degrees.

Table 4. Initial deformity and correction magnitudes for each patient*

Patient number	Convex instrumented			Concave distracted		
	Preoperative	İmmediate postoperative	Last followup	Preoperative	İmmediate postoperative	Last followup
1	40	36	22	47	31	12
2	50	42	33	23	10	8
3	60	46	34	28	3	0
4	32	28	24	28	17	12
5	60	28	23	50	21	10

* In degrees.

one patient. The same pattern was seen for the kyphosis at the convex instrumented segments where all but one patient had minimal changes in segmental kyphosis.

In four of the five patients, partial pullout of the proximal, distal, or both pedicle screws of the concave distraction was observed (Fig. 2). These pedicle screws were revised during planned lengthening procedures. Revision consisted of replacing the loose pedicle screw with or without addition of one more pedicle screw to the adjacent level. Perioperatively or during postoperative followup, there were no pulmonary, neurologic, or wound complications.

Discussion

Because congenital scoliosis may present a major challenge to the orthopaedic surgeon, many options for treatment are available, including the CGA procedure. However, CGA [19] requires an anterior surgery for completeness of the hemiepiphysiodesis and minor correction at the time of surgery, and therefore, unpredictability of the curve behavior has been observed. By modifying the procedure to include pedicle screw fixation of the anomalous convex levels and concave distraction of the entire curve, we aimed to eliminate these shortcomings. We therefore asked whether the modified CGA procedure involving a multilevel pedicle screw convex growth arrest combined with a single growing rod would correct the coronal Cobb angles and sagittal local and global kyphotic angles with a low number of complications.

However, there were certain limitations of this study. First, we had a small number of patients. We intended this as a preliminary review to determine whether the procedure was worth pursuing. Second, we had a relatively short final followup of a minimum of 26 months and mean of 24 months. We cannot ensure the corrections will be maintained although we will continue to follow these patients. Third, we did not include any length/growth measurements of the anomalous segments. The radiographs were not scaled; therefore, any length measurement made on these films would not reflect the actual lengths. However, we do believe the progressive angular correction seen on serial radiographic measurements indicated the epiphysiodesis effect was present and spine growth was enabled. Fourth, we had only one observer measure the curves at followup. These measurements are prone to interobserver variability and small differences cannot be reliably judged. Finally, we have no pulmonary functional data to report and therefore cannot comment on the effect of this technique for improvement of pulmonary functions.

Compared with the conventional (uninstrumented) CGA, the technique we describe uses an instrumented convex hemiepiphysiodesis of the anomalous segment along with fusionless distraction of the whole curve. The potential advantages of this modification are that instrumentation on the convex side provides a complete hemiepiphysiodesis at the anterior and posterior convex sides, obviating the need for anterior surgery and enabling compression-rotation maneuvers for initial acute correction. The fact that our patients have not experienced any symptomatic pseudarthrosis and correction loss in addition to no substantial change in the sagittal plane of the instrumented levels during the 2-year followup may indicate posterior pedicle screws might control growth of the anterior column. However, additional followup and imaging studies are needed to confirm whether pedicle screws will control anterior growth or provide anterior convex growth arrest. The immediate correction rates were better and the final followup Cobb angles and kyphosis angles compared favorably with those reported in other series of conventional CGA [15, 16, 18, 20–22]. The end result of uninstrumented CGA reportedly controls the coronal curve (stabilization effect), improvement in curve size (correction effect), and increase in curve size (progression) [2, 7, 9, 10–12, 15, 16, 18, 20–22]. Numerous clinical studies have compared the current technique in terms of possible end results of the CGA procedure [1, 10, 11, 18, 19, 22] (Table 5). The current technique seems to be more effective than the uninstrumented CGA, as there was no progression in the curve size but there was correction in all patients. Control of the whole curve by the concave growing rod also helped obtain immediate correction of coronal plane balance problems when compared with uninstrumented CGA.

Several other modifications of the CGA procedure have been described [4, 9, 12]. Cheung et al. modified the CGA procedure by adding concave distraction with a single Harrington rod and hook construct [4]. They recommended this procedure for children with severe deformities and decompensation [4]. Concave distraction produced immediate improvement in coronal balance, eliminating the need to wait for uncertain growth-mediated correction in patients who undergo convex fusion only. However, they used an anterior approach to complete hemiepiphysiodesis [4]. All deformities in their series were thoracolumbar curves which included a complete hemivertebra. Mean correction after a followup of 10.8 years was 41% [4]. In contrast, all patients in our study had more complex mixed deformities in the midthoracic spine. Followup was shorter but the correction magnitude was comparable to that reported by Cheung et al. [4]. We expect further correction would occur with additional distractions.

Another alternative of limited fusion techniques for treatment of congenital scoliosis is growing rods. Growing rod treatment is an alternative method for treatment of young children with a long curve and with a relatively flexible apical deformity including congenitally deformed vertebrae [8, 23]. However, growing rods may not control the apex of congenital curves with stiff anomalous segments involving more than four vertebrae, as were the typical case samples in the current study [23]. In our series we had control of the apex by convex screws and hemiephysiodesis and still had the opportunity to control and further correct the curve via the concave growing rod.

Another option for rigid, long sweeping congenital curves may be posterior vertebral column resection (PVCR) [14]. Successful management of rigid severe curves was reported by Lenke et al. [14]. However, this technique might have caused shortening of the thoracic spine in our patients and might necessitate fusion of at least four additional thoracic levels (two above and two below) for fixation after resection of the anomalous segments, thus interfering with thoracic growth and lung development in small children. Moreover, this procedure is technically difficult and carries more neurologic risk compared with less complex procedures [4]. Therefore we believe our technique might provide advantages over PVCR, such as being an easier technique with less

Table 5. Comparison of results of uninstrumented traditional CGA and instrumented CGA with concave distraction

Study	Number of patients	Followup	Correction	Stabilization	Progression
Winter et al. [22]	10	2 years 9 months	2 (20%)	7 (70%)	1 (10%)
Andrew & Piggott [1]	13	4 years 4 months	6 (46%)	6 (46%)	1 (8%)
Keller et al. [10]	16	4 years 8 months	7 (37%)	8 (42%)	4 (21%)
Thompson et al. [18]	30	8 years 10 months	23 (77%)	5 (17%)	2 (6%)
Kieffer & Dubousset [11]	6	4 years 6 months	3 (50%)	2 (33%)	1 (17%)
Uzumcugil et al. [19]	32	3 years 4 months	13 (41%)	15 (47%)	4 (12%)
Current study	5	2 years 10 months	5 (100%)	0 (0%)	0 (0%)

major complications, shorter fusion, and it preserves the length of the spinal column while controlling and even correcting the curve in the coronal plane.

Four of our five patients experienced some complications, as observed during followup, including partial pullout of the proximal, distal, or both pedicle screws of the concave distracted curves. This type of complication would not have been seen with the traditional CGA as no screws were used. However, this type of complication has been reported in series that used growing rod techniques and has been accepted as natural history rather than a complication [8, 23]. We originally used single pedicle screws at both ends and these cases were revised with pedicle screw changes during the planned distraction surgeries (Fig. 2). Single-level fixation in fusionless instrumentation poses a substantial risk for failure; therefore, our recommendation is to put pedicle screws over two levels at the proximal and distal end vertebrae. One of the advantages of the current technique compared with uninstrumented CGA is the lack of pulmonary complications as no anterior approach was performed. Uzumcugil et al. reported pulmonary complications in six (19%) patients, all related to anterior surgery to provide anterior hemiephysiodesis [19].

Despite the limitations mentioned, we believe this modified procedure may be appropriate for certain congenital spinal deformities. The rationale for this technique is that pedicle screws control growth of the anomalous vertebral segments in the longitudinal [13] and transverse planes [5], obviating the need for an anterior fusion, while permitting spinal growth on the concave side of the anomalous segments as a result of distraction [3]. The procedure is a less invasive alternative for complex congenital curves, which otherwise may require multiple osteotomies and longer thoracic fusions. We recommend this technique for young children with multiple anomalous vertebrae and upper thoracic deformities, especially with long sweeping curves. However, care must be taken during distractions to prevent potential screw pull-out and to avoid iatrogenic kyphosis.

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