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Apical vertebral modulation with active apex correction technique for congenital early-onset scoliosis: a retrospective study

Bhavuk Garg[1], Ahmad M Hammad[2], Arpit Sahu[1], Mahmoud Hammad[2], Alaaeldin A. Ahmad[3]

[1]Department of Orthopaedics, All India Institute of Medical Sciences, New Delhi, India
[2]Department of Orthopaedics, American University of Beirut, Beirut, Lebanon
[3]Department of Orthopaedics, Palestine Polytechnic University, Hebron, Palestine

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Corresponding author: Alaaeldin Ahmad
Palestine Polytechnic Institute, Wadi Alharieh, Hebron, West Bank, Palestine
Tel: +970-599409983, **Fax:** +970-2971818, **E-mail:** alaaahmad@hotmail.com

Study Design: Retrospective, single-center study.

Purpose: This study aimed to evaluate whether active apex correction (APC) enables effective modulation of the apical vertebrae in congenital early-onset scoliosis (EOS).

Overview of Literature: APC is a posterior tethering technique that incorporates guided growth principles for the treatment of EOS. The procedure involves the strategic placement of tethering pedicle screws on the convex side of the apical region to achieve controlled modulation of vertebral growth.

Methods: This retrospective study included 10 patients with congenital EOS who underwent APC as the primary surgical procedure. Preoperative and final follow-up assessments were performed using EOS imaging to measure concave and convex vertebral heights at the apical region and evaluate growth modulation. Patients were excluded if follow-up was <2 years, if apex modulation data were incomplete, or if APC was not the index procedure.

Results: The mean age at surgery was 8.2±2.39 years, and the mean postoperative follow-up was 2.3±0.48 years. The concave-to-convex vertebral height ratio at the apical region showed significant changes. At proximal apical vertebrae (A1), the ratio increased from 0.75 preoperatively to 0.84 at final follow-up ($p<0.05$). At the middle vertebrae (A2), the ratio improved from 0.71 to 0.78 ($p<0.05$). At the distal vertebrae (A3), the ratio increased from 0.77 to 0.81, although this change was not statistically significant ($p>0.05$). In contrast, untethered control vertebrae demonstrated a stable mean concave-to-convex height ratio.

Conclusions: APC appears effective in EOS, enabling targeted modulation of the three apical vertebrae through guided growth principles. This technique enables controlled correction of the spinal apex and represents a promising growth-preserving alternative for apical deformity management.

Keywords: Scoliosis; Congenital; Early-onset scoliosis; Growth modulation; Pedicle screws; Vertebral body

Introduction

Early-onset scoliosis (EOS) is a spinal deformity that develops before age 10 [1,2]. Regardless of etiology, progressive spinal curvature leads to chest wall rotation, reduced thoracic volume, and impaired pulmonary development. The primary goals of congenital EOS treatment are to halt curve progression, correct the deformity, preserve spinal growth, and maximize thoracic volume to support cardiopulmonary development and prevent long-term respiratory and cardiac complications [1-3]. Initial management typically involves bracing and/or corrective casting to delay or avoid surgery. However, in rapidly progressive curves, these methods are often insufficient, necessitating the use of surgical, growth-friendly corrective techniques [1,4-6].

Apical curvature deformity is a complex three-dimensional (3D) phenomenon characterized by spinal rotation, coronal deviation, and passive anterior column lengthening [7,8]. The optimal magnitude and approach for achieving the required convex–concave and anterior–posterior length adjustments to restore physiological spinal morphology remain unclear. In principle, 3D correction should involve concave lengthening, convex shortening, axial plane derotation, and medial translation of the apex toward the midline in the coronal plane [9-11].

Several surgical techniques have been developed to preserve spinal growth and thoracic development while minimizing complications. A central principle in EOS management is achieving control of the apex of the spinal curve, which is essential for deformity correction without compromising growth potential.

The SHILLA technique, an early posterior approach, aimed to control the apex by fusing the apical region while allowing the rods to glide proximally and distally. Although SHILLA preserved some spinal growth, it was associated with a high incidence of crankshafting. This occurred due to continued anterior apical growth despite posterior fusion, resulting in progressive rotational deformity.

To overcome these limitations, the active apex correction (APC) technique was developed as a modification that incorporates principles of guided growth and posterior tethering. Unlike SHILLA, APC uses a non-fusion strategy for apical correction, focusing on growth guidance through targeted modulation. APC entails the application of controlled compression or distraction, medial translation, and axial derotation to the convex side of the apical vertebrae. This method addresses the primary drivers of curve progression, including vertebral wedging, lateral shift, and axial rotation, and helps reverse unfavorable growth patterns without fusion. By tethering only the convex side, APC allows dynamic modulation of the apical vertebrae, increases the concave-to-convex vertebral height ratio, and gradually reduces vertebral wedging [12,13].

Anterior vertebral body tethering (VBT) is another well-established technique for apical control. VBT is a non-fusion procedure that corrects the spinal curve by tethering the vertebrae with screws connected by a flexible cord. This construct maintains curve correction and facilitates modulation of the tethered vertebrae. However, VBT is primarily used in growing patients with adolescent idiopathic scoliosis and has not been widely adopted for EOS or for nonidiopathic deformities [14].

The objective of this study was to assess whether APC enables modulation of the three apical vertebrae within the tethered segment during correction of congenital EOS.

Materials and Methods

This retrospective, single-center study evaluated 10 skeletally immature patients diagnosed with scoliosis or kyphoscoliosis. All patients demonstrated radiographic evidence of vertebral wedging at the apex of the curve. Each patient underwent APC as the index surgical procedure intended for deformity correction. Inclusion criteria were as follows: (1) onset before 10 years of age, consistent with EOS; (2) a major Cobb angle greater than 40°; (3) skeletal immaturity at the time of surgery; and (4) congenital scoliosis as the underlying diagnosis. Patients were excluded if the scoliosis was noncongenital, if APC was performed as revision surgery, if follow-up was less than 24 months, or if apex modulation data were unavailable. Demographic and perioperative characteristics of the study cohort are summarized in Table 1.

Surgical technique

APC is a modified adaptation of the traditional SHILLA technique (Fig. 1). All procedures were performed with the patient in the prone position under intraoperative neuromonitoring and C-arm fluoroscopic guidance. Proximal and distal anchor fixation was achieved using pedicle screws or hooks, typically placed across two consecutive vertebrae.

At the apex, an extra periosteal dissection was performed using the Wiltse approach to insert pedicle screws on the convex side. Screws were positioned one level above (A1) and one level below (A3) the most wedged apical vertebra (A2), with care taken to avoid fusion (Fig. 2A). A 5.5 mm titanium or 4.75 mm cobalt-chrome tethering rod was then used to connect the convex screws to either the proximal or distal anchor rods, directly or via domino connectors (Fig. 2B).

Three correctional maneuvers were applied simultaneously at the tethered levels: (1) compression, (2) medial translation, and (3) axial derotation (Fig. 2C). The domino connectors were locked at the tethered rod level, while the contralateral rod was left unlocked with a minimum of 4 cm of gliding capacity to allow approximately 4 years of longitudinal growth (Fig. 2D). On the concave side, the rod connected to proximal and distal anchors was coupled to an unlocked domino with one hole reserved for guided self-gliding. Distraction was applied, and a proximal mechanical barrier was used to prevent reverse gliding. The wound was closed after irrigation, and no surgical drains were used. Postoperatively, none of the patients required casting or bracing.

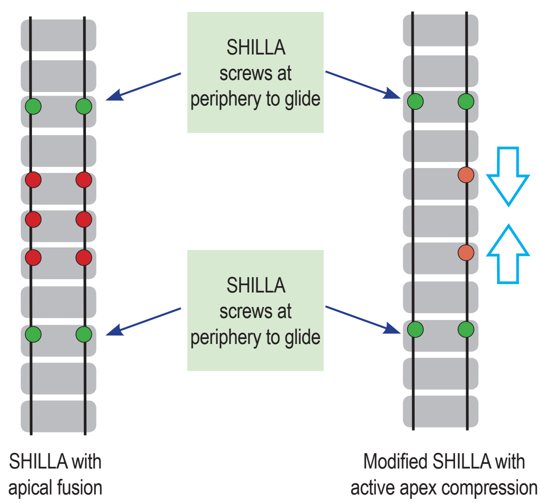

Fig. 1. Active apex correction as a modified version of the traditional SHILLA technique.

Radiographic evaluation

Radiographic evaluation was performed using EOS imaging technology (EOS Imaging, Paris, France), which provides low-dose, biplanar, full-body images in the standing position. EOS enables 3D spinal reconstruction with radiation exposure that is approximately 5 to 7 times lower than conventional computed tomography (CT) and allows accurate assessment of vertebral morphology, alignment, Cobb angle, kyphosis, and axial rotation [15,16].

Data collected included demographic information, curve parameters (Cobb angle, apical vertebral translation [AVT]) (Fig. 3), and spinal lengths (T1–T12 and T1–L5). Measurements were obtained preoperatively, immediately after surgery, and at final follow-up.

Using EOS 3D reconstructions, concave and convex vertebral heights were measured for the three apical vertebrae (A1, A2, A3) preoperatively and at final follow-up. The concave-to-convex height ratio was calculated to assess changes in vertebral morphology consistent with apical modulation. These values were compared with an untethered control vertebra to account for physiological growth. Vertebral wedging, considered a key initiating factor in scoliotic deformity,

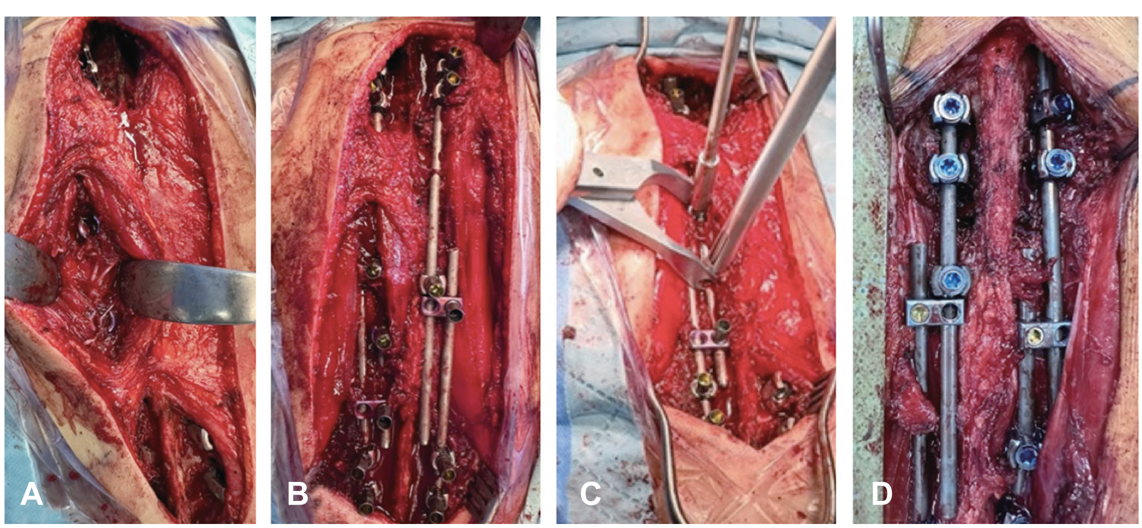

Fig. 2. Intraoperative image showing **(A)** extra periosteal dissection through Wiltse technique inserting screws on the convex side above and below the most wedged vertebrae; **(B)** tethered rod connecting the tethered screw with the proximal or distal anchors rods through dominos; **(C)** three procedures at the level of tethered screws are done at the same time: compression, medial translation, and de-rotation; and **(D)** dominos locked at the tethered rod level at least 4 cm to have a potential of 4 years self-gliding.

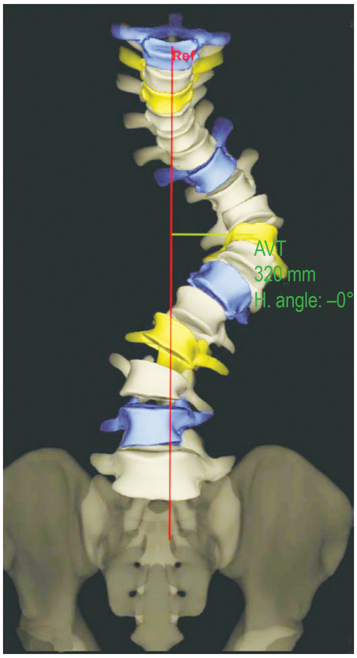

Fig. 3. Apical vertebral translation (AVT) measurement.

was also quantified and monitored over time.

Ethical considerations and statistical analysis

The study was approved by the Institutional Review Board (IRB) of All India Institute of Medical Sciences, New Delhi (IRB no., AIIMSA2927/06.12.2024). Written informed consents were obtained from the patients/parents of minors. Statistical analysis was conducted using Microsoft Excel (Microsoft Corp., Redmond, WA, USA) and IBM SPSS Statistics ver. 29.0.2.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean±standard deviation, and categorical variables as frequency (percentage). Paired *t*-tests were used to compare preoperative and postoperative measurements. A *p*-value <0.05 was considered statistically significant.

Results

A total of 10 patients with congenital EOS underwent APC as their index surgical intervention. The mean age at surgery was 8.2±2.39 years. Demographic data and curve characteristics are summarized in Tables 1–3. Among this cohort, seven patients had a wedge vertebra, and three had a fully segmented hemivertebra. None of the patients demonstrated an intervertebral bar.

Illustrative case example

Fig. 4 presents a representative case of a 5-year-old male

Table 1. Cohort demographic and spinal parameters at surgery and at 2 years follow-up quantifying the extent of deformity and subsequent correction

Patient	Diagnosis	Age (mo)	Gender	FU (mo)	Congenital anomaly	Apex level	Cobbs angle (°)		AVT (cm)		SL T1–T12 (cm)		SL T1–L5 (cm)	
							Preop	FU	Preop	FU	Preop	FU	Preop	FU
1	Congenital scoliosis	108	M	36	Hemi vertebrae T7 & T9	T8	56	42	6.2	4.9	15.6	16.5	27	29
2	Congenital scoliosis	48	F	36	T10 wedge	T10	47	42	3.2	2.6	16	17.2	30	34
3	Congenital scoliosis	132	M	36	Hemi vertebrae L1	L1	48	36	5.6	4.3	17	18	33	30
4	Congenital scoliosis	72	F	24	T9 wedge	T11	58	49	4.6	3.6	16	16.6	30	33
5	Congenital scoliosis	96	F	24	T9 wedge	T9	48	43	4.9	4	14	16	29.6	33.2
6	Congenital scoliosis	120	M	24	T10 wedge	T10	49	42	4.7	4	15	16	28.9	32
7	Congenital scoliosis	84	M	24	Hemi vertebrae L1	L1	52	40	3.6	2.9	16.3	17.2	33.4	36
8	Congenital scoliosis	72	M	24	T11 wedge	T11	57	45	5.2	3.9	15.5	16.3	32	34.2
9	Congenital scoliosis	120	M	24	T11 wedge	T11	47	39	4.2	3.6	16	17	32	34.5
10	Congenital scoliosis	132	M	24	T9 wedge	T9	45	38	3.2	2.8	16.2	16.7	33.5	36.2
Mean±SD		98.4±28.73		27.6±5.80			50.7±4.72	41.6±3.69	4.5±1.00	3.7±0.72	15.8±0.81	16.8±0.62	30.9±2.17	33.2±2.35
p-value							<0.001*		<0.001*		<0.001*		<0.002*	

FU, follow-up; AVT, apical vertebral translation; SL, spinal length; Preop, preoperative; M, male; F, female; SD, standard deviation.
*$p<0.05$ (statistically significant).

Table 2. Cohort spinal parameters at surgery, at immediate and at final follow-up quantifying and comparing the extent of deformity and subsequent correction

Variable	Patient										*p*-value	Mean±SD
	1	2	3	4	5	6	7	8	9	10		
Preoperative vs. immediate FU												
Cobbs angle (°)											<0.01*	
Preoperative	56	47	48	58	48	49	52	57	47	45		50.7±4.72
Immediate FU	49	46	45	52	46	45	46	49	45	40		46.3±3.20
AVT (cm)											<0.01*	
Preoperative	6.2	3.2	5.6	4.6	4.9	4.7	3.6	5.2	4.2	3.2		4.5±1.00
Immediate FU	5.7	3	5.2	4.2	4.6	4.5	3	4.2	4	3		4.1±0.93
SL T1–T12 (cm)											<0.01*	
Preoperative	15.6	16	17	16	14	15	16.3	15.5	16	16.2		15.8±0.81
Immediate FU	16	16.9	17.5	16.2	15	15.2	17	16	16.5	16.3		16.3±0.77
SL T1–L5 (cm)												>0.05
Preoperative	27	30	33	30	29.6	28.9	33.4	32	32	33.5		30.9±2.17
Immediate FU	29	32	29	31	30	30	35	34	34	35		31.8±2.46
Immediate vs. final FU												
Cobbs angle (°)											<0.01*	
Immediate FU	49	46	45	52	46	45	46	49	45	40		46.3±3.20
Final FU	42	42	36	49	43	42	40	45	39	38		41.6±3.69
AVT (cm)											<0.01*	
Immediate FU	5.7	3	5.2	4.2	4.6	4.5	3	4.2	4	3		4.1±0.93
Final FU	4.9	2.6	4.3	3.6	4	4	2.9	3.9	3.6	2.8		3.7±0.72
SL T1–T12 (cm)											<0.01*	
Immediate FU	16	16.9	17.5	16.2	15	15.2	17	16	16.5	16.3		16.3±0.77
Final FU	16.5	17.2	18	16.6	16	16	17.2	16.3	17	16.7		16.8±0.62
SL T1–L5 (cm)											<0.01*	
Immediate FU	28.5	32	29	31	30	30	35	33.6	34	35		31.8±2.46
Final FU	29	34	30	33	33	32	36	34	35	36		33.2±2.35

SD, standard deviation; FU, follow-up; AVT, apical vertebral translation; SL, spinal length.
*$p<0.05$ (statistically significant).

with congenital scoliosis treated with APC. Postoperative imaging demonstrated clear medial translation of the apical vertebra.

Curve characteristics

At final follow-up, statistically significant improvements were observed across multiple parameters compared with preoperative values. Cobbs angle, AVT, T1–T12 spinal length, and T1–L5 spinal length all showed significant improvements ($p<0.01$) (Table 1).

Immediate postoperative comparisons also demonstrated significant improvements in Cobb angle, AVT, and T1–T12 length ($p<0.01$), whereas the change in T1–L5 length was not statistically significant ($p>0.05$) (Table 2).

When final follow-up measurements were compared with immediate postoperative values, further significant gains were noted in Cobb angle, AVT, T1–T12 length, and T1–L5 length ($p<0.05$) (Table 2, Fig. 3).

At the 2-year follow-up, both concave and convex vertebral heights increased significantly at all evaluated vertebral levels (A1, A2, A3, and the untethered control) ($p<0.01$) (Table 3).

Apical modulation, assessed using concave-to-convex height ratios, increased significantly from preoperative to final follow-up at A1 ($p<0.03$) and A2 ($p<0.05$). A3 also demonstrated an increase in the ratio, although this change was not statistically significant ($p>0.05$). In contrast, the untethered vertebra showed no change in

Table 3. Curve parameters at surgery and at 2-year follow-up quantifying the concave and convex heights of the deformity and subsequent correction

Variable	Patient										*p*-value	Mean±SD
	1	2	3	4	5	6	7	8	9	10		
A1												
Concave (cm)											<0.01*	
Preoperative	0.7	1.2	1	1.1	0.7	1.1	1.2	1.1	0.8	0.9		0.98±0.19
FU	1	1.4	1.2	1.3	1.2	1.6	1.8	1.3	1.7	1		1.35±0.28
Convex (cm)											<0.01*	
Preoperative	1.1	1.4	1.5	1.4	1.1	1.6	1.4	1.2	1.6	1.2		1.35±0.19
FU	1.3	1.6	1.6	1.5	1.3	1.8	2	1.5	1.9	1.6		1.61±0.23
Concave/convex ratio											<0.03*	
Preoperative	0.64	0.86	0.67	0.79	0.64	0.69	0.86	0. 0.8792	0.5	0.75		0.73±0.13
FU	0.77	0.88	0.75	0.87	0.92	0.89	0.9		0.89	0.63		0.84±0.09
A2												
Concave (cm)											<0.01*	
Preoperative	0.9	0.9	0.9	1	1	1	0.6	0.9	0.8	1.1		0.91±0.14
FU	1	1.1	1	1.2	1.2	1.2	0.9	1	1.4	1.1		1.11±0.14
Convex (cm)											<0.01*	
Preoperative	1.2	1.2	1.3	1.2	1.3	1.3	1.3	1.1	1.6	1.4		1.29±0.14
FU	1.3	1.3	1.4	1.6	1.5	1.4	1.4	1.1	1.7	1.5		1.42±0.17
Concave/convex ratio											<0.04*	
Preoperative	0.75	0.75	0.69	0.83	0.77	0.77	0.46	0.82	0.5	0.79		0.71±0.13
FU	0.77	0.85	0.71	0.75	0.80	0.86	0.64	0.91	0.82	0.73		0.78±0.08
A3												
Concave (cm)											<0.01*	
Preoperative	0.7	1.1	1.1	1.1	1.2	1.5	1.1	1.3	1	1.2		1.13±0.21
FU	1.1	1.5	1.5	1.3	1.6	1.6	1.6	1.4	1.3	1.3		1.42±0.17
Convex (cm)											<0.01*	
Preoperative	1.2	1.6	1.7	1.4	1.4	1.8	1.4	1.4	1.3	1.5		1.47±0.18
FU	1.4	1.9	1.8	1.6	1.7	2.2	2.1	1.7	1.6	1.6		1.76±0.25
Concave/convex ratio											>0.05	
Preoperative	0.58	0.69	0.65	0.79	0.86	0.83	0.79	0.93	0.77	0.8		0.77±0.10
FU	0.79	0.79	0.83	0.81	0.94	0.73	0.76	0.82	0.81	0.81		0.81±0.05
Untethered vertebra												
Concave (cm)											<0.01*	
Preoperative	1.5	2	2	0.7	1.5	1.8	0.7	1.8	1.6	1.1		1.47±0.49
FU	1.8	2.2	2.4	0.7	1.7	1.9	1.1	2	1.8	1.2		1.68±0.53
Convex (cm)											<0.01*	
Preoperative	1.5	2	2	0.7	1.6	1.7	0.7	1.8	1.7	1.1		1.48±0.48
FU	1.8	2.3	2.4	0.7	1.7	1.9	1.1	2	2.3	1.3		1.75±0.56
Concave/convex ratio											>0.40	
Preoperative	1	1	0.95	1	0.94	1.06	0.88	1	0.89	1		0.97±0.06
FU	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00	0.78	0.92		0.97±0.07

SD, standard deviation; FU, follow-up; A2, most wedged vertebra; A1, vertebra proximal to A2; A3, vertebra distal to A2.
*p<0.05 (statistically significant).

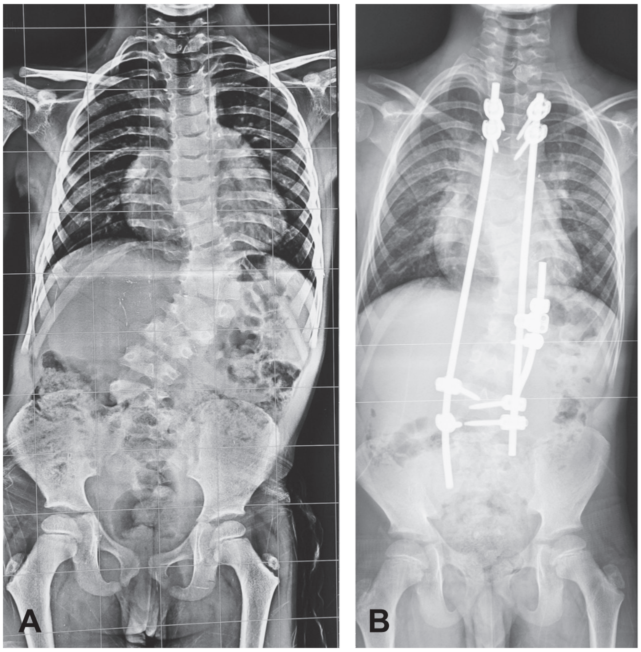

Fig. 4. Preoperative **(A)** and postoperative **(B)** X-ray showing correction of deformity with active apex correction technique.

the mean ratio (0.97 to 0.97, p>0.05) (Table 3).

These findings indicate that the tethered vertebrae, particularly A1 and A2, underwent differential growth modulation consistent with Hueter-Volkmann principles. This supports the hypothesis that APC promotes modulation of vertebral wedging across multiple apical vertebrae, rather than solely on the most wedged vertebra (Fig. 5).

Complications

During the follow-up period, two of the 10 patients (20%) developed implant-related complications. One patient experienced a rod fracture, and another had a screw pull-out. In addition, one case of intraoperative neuromonitoring signal loss necessitated a staged surgical approach. No postoperative neurological deficits were observed in any patient.

Discussion

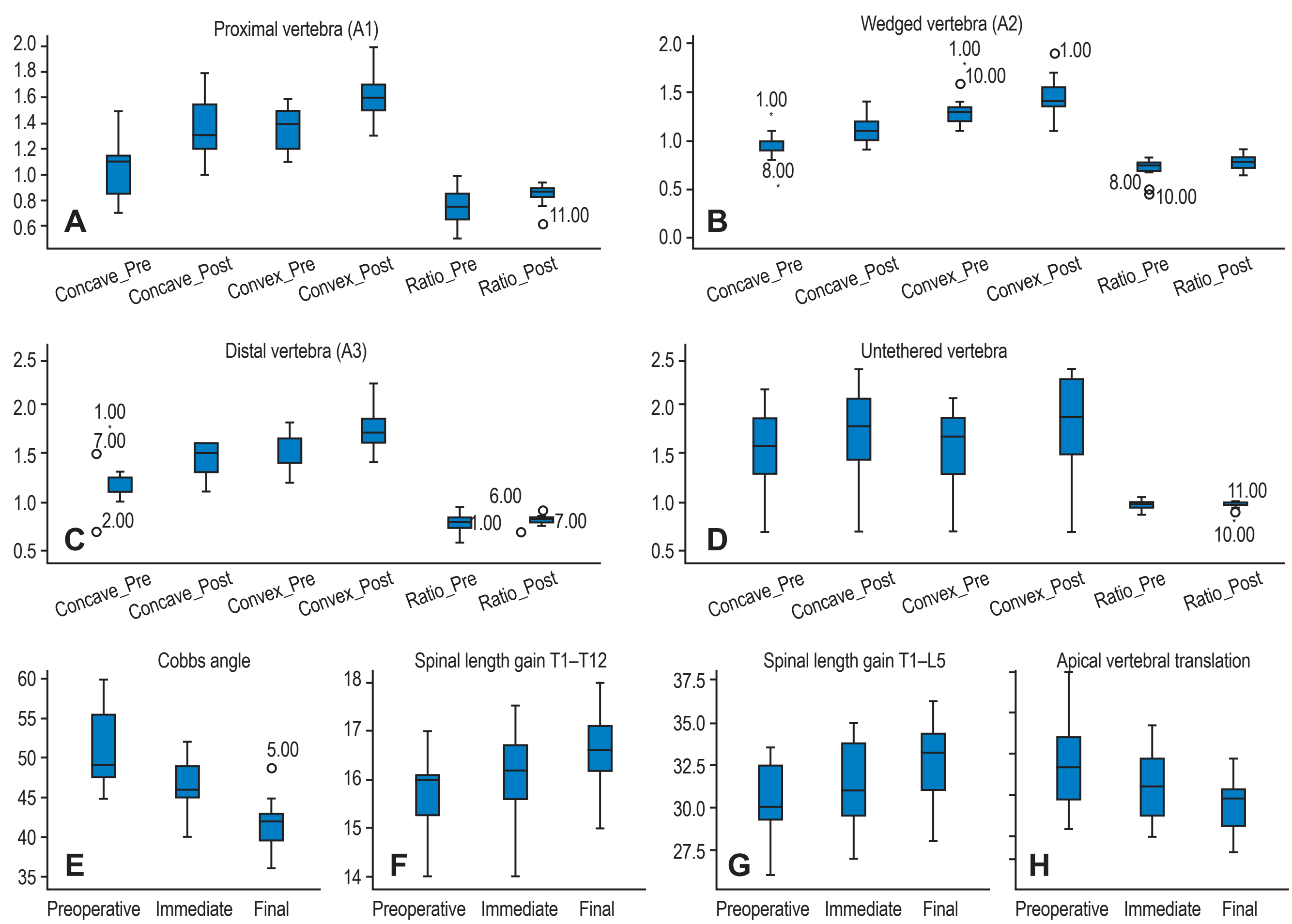

Fig. 5. Box plots comparing **(A–D)** concave height, convex height, and the concave-to-convex ratio at the proximal vertebra (A1), wedged vertebra (A2), distal vertebra (A3), and untethered vertebra between preoperative and postoperative measurements, and **(E–H)** Cobb angle, spine length gain (T1–T12 and T1–L5), and apical vertebral translation among preoperative, immediate postoperative, and final follow-up measurements.

The spine plays a fundamental role in maintaining posture, enabling movement, and supporting cardiopulmonary development. In EOS, progressive deformity alters spinal morphology and function, warranting surgical intervention when conservative methods fail [17]. Scoliotic deformity is a complex 3D anomaly characterized by coronal deviation, vertebral rotation, and apical lordosis, influenced by both vertebral and intervertebral disc mechanics [7,8,10,18,19].

Traditional methods for apical control include fusion-based techniques such as SHILLA and convex growth arrest (CGA). CGA involves epiphyseal plate fusion on the convex side with the aim of permitting continued growth on the concave side [20-22]. However, results have been inconsistent. Ginsburg et al. [22] reported that CGA halted curve progression in only seven of 10 cases and did not promote spinal growth, and Tauchi et al. [20] noted that failed hemiepiphysiodesis can compromise subsequent corrective efforts. Although posterior instrumented fusion provides structural correction, it restricts longitudinal growth and limits further modulation potential [23].

Hybrid approaches that combine convex fusion with concave distraction have attempted to balance deformity correction with continued spinal growth [24,25]. Alanay et al. [24] reported improvements in coronal alignment and concave-side growth, although these benefits were accompanied by frequent surgeries and an 80% complication rate. Similarly, Demirkiran et al. [25] demonstrated effective correction and growth preservation, but complications occurred in 72% of patients, and repeated distraction procedures were required.

More recently, techniques have shifted toward nonfusion strategies that aim to correct the deformity while preserving spinal growth and function [4]. APC, introduced 16 years ago, was developed to achieve dynamic apical modulation through posterior convex-side tethering and controlled compression. This facilitates medial translation and derotation of the apex [26]. The underlying concept is that maintaining anterior and posterior growth helps prevent the crankshaft phenomenon. Studies by Newton et al. [14] and Louer et al. [27] have demonstrated asymmetric growth modulation and vertebral remodeling through tethering, and EOS imaging has become a valuable tool for monitoring these morphological changes.

Our study is the first to evaluate 2-year outcomes of APC in congenital EOS with a specific focus on vertebral modulation assessed through EOS imaging. We observed significant improvements in Cobb angle, AVT, and spinal lengths (T1–T12 and T1–L5). Concave and convex vertebral heights increased significantly at all assessed levels, consistent with previous reports indicating that APC supports growth-friendly deformity correction [26,28].

Notably, the concave-to-convex height ratio at A1 and A2 increased significantly, indicating greater concave-side growth and demonstrating true modulation of the tethered vertebrae. In contrast, the untethered vertebrae showed no change in this ratio, highlighting the localized effect of APC-mediated modulation. Although A3 did not reach statistical significance, the observed trend suggests a clinically meaningful response that may have been constrained by the small sample size and limited follow-up duration.

Our findings also support recent observations that the apical vertebra is not always the most rotated and that adjacent vertebrae may contribute more significantly to trunk rotation [18,29]. This highlights the importance of including periapical vertebrae in the corrective strategy, which is reflected in the modulation detected at A1 and A3. In our cohort of patients with congenital scoliosis, postoperative correction was achieved in all cases using the APC technique. The posterior-only tether provides asymmetric growth by allowing distraction on the concave side, which contributes to deformity correction and helps prevent the crankshaft phenomenon.

The complication rate in our series was low (20%) with one rod breakage and one screw pull-out, notably lower than other growth-friendly techniques. None of the patients developed the crankshaft phenomenon, a major drawback of SHILLA [26]. In comparison, SHILLA and CGA-based techniques have reported complication rates of up to 80%, including implant failure and the need for revision surgery [22,24,25].

This study is limited by its small sample size and relatively short follow-up period. The degree of the applied compression force was not quantified, leaving its specific contribution to vertebral modulation uncertain. The lack of statistical significance at A3 also warrants further investigation in a larger cohort. Long-term, multicenter studies are needed to confirm the durability and growth-modulating potential of APC. Potential iatrogenic effects on the intervertebral disc and adjacent spinal segments require extended follow-up and are acknowledged as a limitation of this study.

Conclusions

Congenital EOS remains a challenging condition, yet advances in growth-preserving surgical techniques offer new therapeutic opportunities. APC is a novel method that achieves deformity correction through apical modulation without the need for fusion. This study is the first to demonstrate vertebral modulation following posterior tethering with APC, supported by short-term improvements in spinal alignment, growth parameters, and a low complication rate. These findings position APC as a promising alternative to fusion-based approaches. Long-term studies are needed to assess the durability and wider applicability of these outcomes.

Key Points

- Active apex correction (APC) is technique used to control the spinal apex in congenital scoliosis by tethering technique.
- APC demonstrated significant improvements in Cobb angle, apical vertebral translation, and spinal length over 2 years followup.
- APC represents growth preserving alternatives to fusion based surgery for deformity correction.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

ORCID

Bhavuk Garg: https://orcid.org/0000-0003-3169-6437; Ahmad M Hammad: https://orcid.org/0000-0001-7459-7856; Arpit Sahu: https://orcid.org/0009-0001-6576-6918; Mahmoud Hammad: https://orcid.org/0009-0000-3398-2360; Alaaeldin A. Ahmad: https://orcid.org/0000-0001-6897-3915

Authors Contributions

AA contributed to conception and design, did the statistical analysis. AH, MH, and AA critically wrote, read, and revised the manuscript. BG and AS gathered the data and X-ray findings. All authors gave final approval and agreed to be accountable for all aspects of work ensuring integrity and accuracy.

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