Active Apex Correction With Guided Growth Technique for Controlling Spinal Deformity in Growing Children: A Modified SHILLA Technique

Aakash Agarwal, PhD[1] ⓘ, Loai Aker, MD[2],
and Alaaeldin Azmi Ahmad, MD[2] ⓘ

Abstract

Study Design: A retrospective study.

Objective: To determine if active remodulation in the apex of the curve is possible in scoliosis and kyphoscoliosis patients, using a modified SHILLA; active apex correction (APC) technique for guided growth.

Method: Twenty patients with either scoliosis or kyphoscoliosis underwent a modified SHILLA approach, where instead of apical fusion, APC was applied. In this modified technique, the most wedged vertebra was selected followed by insertion of pedicle screws in the convex side of the vertebrae above and below the wedged one. The convex and concave heights of the wedged and control vertebrae were recorded at the time of the surgery and at follow-up duration, both using computed tomography.

Results: The wedged vertebra demonstrated in average a 17% ($P = .00014$) increase in the proportion of concave to convex heights ratio, whereas the control vertebra did not show any relative change in the wedged vertebra heights at the follow-ups.

Conclusion: APC, instead of apical fusion in SHILLA remodulates the apex vertebra, which may in turn help mitigate loss of correction on long term due to crankshafting and adding-on.

Keywords

modified SHILLA technique, vertebral remodulation, wedged vertebra, crankshafting, adding-on, distal migration, apex of the curve, scoliosis, active apex correction, APC

Introduction

Growth guidance technique using SHILLA is 1 of the 2 most widely used posterior-based growth friendly techniques for curve correction and halting the progression of deformity in children with scoliosis or kyphoscoliosis.[1,2] SHILLA has the advantage of being one-time surgery and is technologically less demanding compared with MAGEC rods.[3-6] However, there are still 2 major disadvantages of using SHILLA: loss of correction and need for osteotomies, that has made its use in par with distraction-based system. To elaborate, substantial percentage of patients undergoing SHILLA technique experience loss of correction via crankshafting or adding-on (eg, distal migration).[7-9] In addition, the need for osteotomies on the concave side has the potential of severe complications. Therefore, any modified SHILLA technique that could eliminate the loss of correction and complications related to the need of osteotomies on the concave side is very desirable.

Based on previous studies using staples and anterior tethering, exemplifying the well-known phenomenon of Hueter Volkmann principle, we too hypothesize that the wedging of the deformed vertebra in immature scoliosis can be corrected through apex compression (using pedicle screws as levers) on the convex side to reverse the progressive asymmetric growth

[1] University of Toledo, Toledo, OH, USA
[2] Annajah Medical School, Nablus, Palestine

Corresponding Author:
Alaaeldin Azmi Ahmad, Department of Orthopedics, Annajah Medical School, Nablus, West Bank, Palestine.
Email: alaaahmad@hotmail.com

Table 1. Diagnoses, Age at Surgery, Gender, Follow-up Duration, and Spinal Parameters Quantifying the Extent of Deformity.

|	Diagnosis	Age (Years)	Gender	Follow-up (Months)	Coronal Cobb Angle (Degrees)		AVT (mm)		Sagittal Cobb Angle/ Kyphosis (Degrees)		Sagittal Balance (mm)		Spine Length (mm)		Coronal Balance (mm)	
					Pre	Follow-up	Pre	Follow-up	Pre	Follow-up	Pre	Follow-up	Pre	Follow-up	Pre	Follow-up
1	Syndromic scoliosis	7	M	24	57	59	34	69	N/A				281	299	5	20
2	Congenital scoliosis	5	F	15	69	53	38	18					281	293	6	24
3	Syndromic scoliosis	3	M	20	40	52	13	29					260	244	2	2
4	Syndromic scoliosis	6	M	24	69	33	56	23					244	292	10	25
5	Congenital scoliosis	4	F	24	61	46	25	25					233	258	6	3
6	Congenital scoliosis	3	F	24	47	32	26	30					231	238	37	3
7	Congenital scoliosis	3	F	16	40	32	34	38					273	296	13	8
8	Syndromic scoliosis	6	F	8	48	51	32	26					343	396	4	17
9	Neurofibromatosis	7	F	15	63	60	39	34					299	292	11	18
10	Syndromic scoliosis, Noonan syndrome	5	F	14	92	55	56	44					211	245	23	19
11	Neurofibromatosis with scoliosis	5	M	12	82	79	57	57					284	317	48	22
12	Congenital scoliosis	3	F	12	62	60	46	52					229	253	2	3
13	Achondroplasia with kyphoscoliosis	3	M	97	53	30	26	24	54	62	24	14	240	251	8	14
14	Congenital kyphoscoliosis	4	M	74	42	38	29	27	32	10	40	57	282	322	57	3
15	Muscular dystrophy kyphoscoliosis	4	F	72	50	34	19	9	40	12	23	65	218	264	2	1
16	Syndromic kyphoscoliosis	6	M	42	55	41	47	14	55	38	28	26	251	278	42	3
17	Congenital kyphoscoliosis	4.5	F	85	20	21	17	8	45	25	22	8	262	313	21	23
18	Mucopolysaccharidosis kyphoscoliosis	5	F	32	27	14	28	9	55	16	124	51	174	216	15	16
19	Achondroplasia with kyphoscoliosis	5	M	12	45	48	42	38	100	23	34	20	274	280	6	12
20	Congenital Kyphoscoliosis	3	F	24	55	39	8	7	76	24	23	8	227	270	4	3
	P value (2-tailed)				.002		.2		.01		.5		.00001 (1-tailed)		.3	
	Average	5		32	54	44	34	29	57	26	40	31	255	281	16	12
	Standard deviation	1		27	17	15	14	17	22	17	35	23	37	39	17	9
	Maximum	7		97	92	79	57	69	100	62	124	65	343	396	57	25
	Minimum	3		8	20	14	8	7	32	10	22	8	174	216	2	1

Abbreviations: AVT, apical vertebral translation; M, male; F, female; N/A, not applicable.

of that vertebra, and thereby actively reducing the wedge angle.[10-12] This nonfusion SHILLA procedure, active apex correction (APC), is performed by placing pedicle screws on the convex side, above and below the wedged vertebrae. The pedicle screws are then compressed before final tightening, to artificially create a compensatory pressure on the vertebral body by thus gradually allow its remodulation (reverse modulation) and reduction in the wedging over time. In contrast to the regular SHILLA approach, the addition of APC could mitigate or reduce future loss of correction, and also eliminates the complications related to the need of osteotomies (no screw is required at the concave side of the apex) as a procedural byproduct.

Method

Institutional review board approved this study. The study consisted of 20 patients with either scoliosis or kyphoscoliosis undergoing an index surgery or revision surgery and demonstrating a clear radiographic evidence of vertebral wedging at the apex. In the subgroup of congenital scoliosis, these patients had both malformation and malsegmentation with unilateral bony bar. All patients were younger than 8 years with Risser less than or equal to 2, and the major Cobb's angle more than 40°. Refer to Table 1 for further patient details at surgery and during follow-up.

The surgical procedure involved was a modified version of to SHILLA (Figures 1 and 2), either using rod to screw
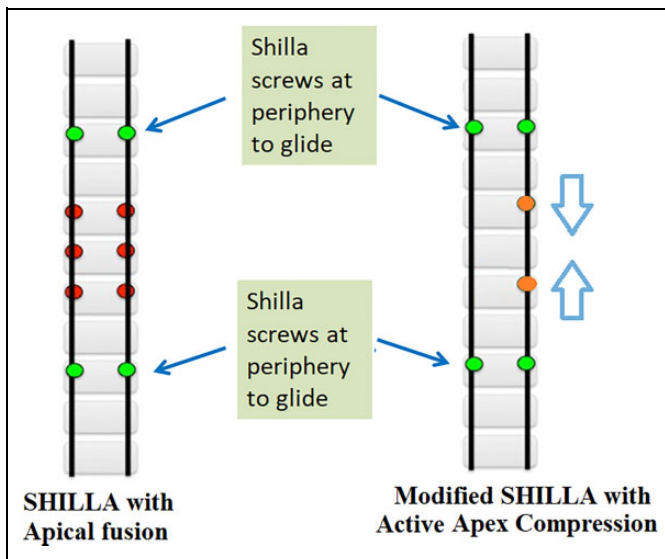
Figure 1. Schematic showing key differences in established SHILLA procedure and the modified SHILLA approach used in this study.
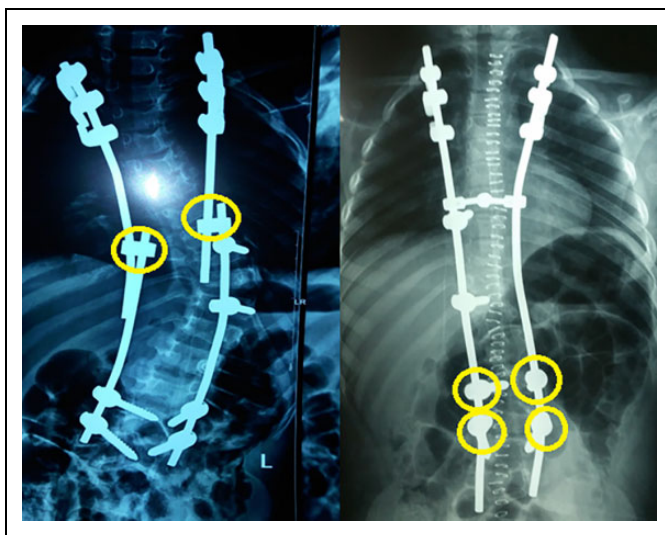
Figure 2. Radiographs of 2 patients exemplifying the 2 types of, but analogous, modified SHILLA procedure. (Left) The modified SHILLA approach using dominos (4.5-mm rod in 5.5-mm domino hole) for sliding with growth. (Right) The modified SHILLA approach using pedicle screw-rod clearance for sliding with growth. Yellow circles identify the sliding units of this SHILLA construct for sustenance of overall longitudinal growth of the spine until puberty.

(SHILLA screws from Medtronics) sliding mechanism or the analogous rod to domino (4.5-mm rod in 5.5-mm domino) sliding mechanism. In this modified technique, the most wedged vertebra was selected followed by insertion of pedicle screws in the convex side of the vertebrae above and below the wedged one. No screws were put on the concave side of the apex. All surgeries were performed under intraoperative neuromonitor and C-arm. Additionally, no cast or brace were used for these patients postoperatively. The technique was

extraperiosteal except for the convex side of the apical (and wedged) vertebrae, where we put screws for compression. The rods and domino remained subfacial, to avoid prominence. The patients were followed for a period of at least 8 months. The convex and concave heights of the wedged vertebra were recorded at the time of the surgery and at follow-up, both using computed tomography. For comparison, a control vertebra was chosen, whose physical dimensions were in par with the wedged vertebra to record the normal growth rate of the particular duration of follow-up and age. The main difference between a wedged vertebra and the control vertebra was the compression forces being applied at the convex end (including congenital subgroup) for the wedged vertebra, with the expectations of reducing local longitudinal growth rate. In the control group no such forces were applied.

Results

The wedged vertebra under apex compression demonstrated an average increase of 17% ($P = .00014$) in the proportion of concave to convex heights ratio. However, as expected, the control vertebra did not show any lateral deviance in the height at the follow ups. Table 2 presents data array on the wedged vertebra, concave and convex vertebral heights, and their ratio at surgery and during follow-up. The concave end of wedged vertebra increased by an average of 36%, whereas the convex side showed an increase of 16%. Table 3 presents data array on the control vertebra, convex and concave vertebral heights, and their ratio during surgery and at follow-up. Both the concave and convex ends of the control vertebra increased by an average of 17%.

Discussion

Crankshaft phenomena has been well described by Dubousset as a major complication in growing spine management.[7,8] The long-term goals of selecting this procedure is to assess if active remodulation of the apex is possible, and if so, whether it would avoid crankshaft effect or distal migration. The study presents preliminary data on apex vertebral growth remodulation post modified SHILLA procedure. Instead of apical fusion, apex compression was applied at the wedged vertebra. This in addition to allowing a foundation for fixation at the apex, traditionally sought for controlling the curve, also seeks to dynamically modify the peak of the curve. The immediate benefits of the procedure alone are avoidance of risky osteotomies required to insert screws at the concave end of the apex, and more economical surgery (putting 2 screws instead of 6 at the apex of the curve) for underprivileged patients globally with no added risk over SHILLA.[13,14] Furthermore, in presence of more than one curve, this procedure is still applicable, whereas the SHILLA technique may not be as practical. Biomechanical complications included dislodgment of iliac screws (1), proximal hook dislodgment (1), iliac screw and rod loosening (1), rod fracture (1) and proximal junctional kyphosis (1). The subject of this study was to estimate the reverse modulation as a result of this

Table 2. The Data on the Wedged Vertebra, Convex and Concave Vertebral Heights, and Their Ratio at Surgery and During Follow-up.

	Wedged Vertebra	Concave (mm)		Convex (mm)		Ratio	
		Pre	Follow-up	Pre	Follow-up	Pre	Follow-up
1	T9	9.20	11.20	12.40	13.80	0.74	0.81
2	T8	6.25	9.77	10.40	14.50	0.60	0.67
3	T11	7.70	8.70	10.40	12.10	0.74	0.72
4	T11	9.53	10.90	12.70	14.20	0.75	0.77
5	T6	6.40	8.70	13.60	14.00	0.47	0.62
6	Fused T12-L1	8.20	9.90	22.90	23.40	0.36	0.42
7	L3	7.60	9.60	13.90	14.70	0.55	0.65
8	T7	11.90	12.60	19.20	19.40	0.62	0.65
9	T4	8.60	8.70	13.50	14.20	0.64	0.61
10	T10	8.80	9.90	10.80	11.70	0.81	0.85
11	T12	14.20	15.10	18.70	19.60	0.76	0.77
12	T12	7.46	8.99	10.90	11.80	0.68	0.76
13	T12	4.28	11.00	8.92	13.40	0.48	0.82
14	L2	10.07	16.60	14.54	20.70	0.69	0.80
15	L1	10.32	14.21	14.88	16.71	0.69	0.85
16	T12	6.35	14.50	12.96	19.50	0.49	0.74
17	L1	7.64	16.00	13.19	18.30	0.58	0.87
18	T12	4.40	5.40	7.90	8.13	0.56	0.66
19	L1	5.33	8.25	11.50	14.00	0.46	0.59
20	Fused T9-T10	8.60	12.10	18.80	21.20	0.46	0.57
P value (1-tailed)		.00002		.00006		.00014 (2-tailed)	
Average		8.14	11.11	13.60	15.77	0.61	0.71
Standard Deviation		2.42	2.94	3.77	3.90	0.13	0.11
Maximum		14.20	16.60	22.90	23.40	0.81	0.87
Minimum		4.28	5.40	7.90	8.13	0.36	0.42
Percentage increase		36%		16%		17%	

Table 3. The Data on the Control Vertebra, Convex and Concave Vertebral Heights, and Their Ratio at Surgery and During Follow-up.

	Control Vertebra	Concave (mm)		Convex (mm)		Ratio	
		Pre	Follow-up	Pre	Follow-up	Pre	Follow-up
1	N/A						
2	L3	12.50	12.62	14.50	14.70	0.86	0.86
3	L5	9.20	10.80	9.38	11.20	0.98	0.96
4	L4	13.30	14.40	14.10	14.70	0.94	0.98
5	L3	11.60	12.30	12.30	13.30	0.94	0.92
6	N/A						
7	L1	10.80	11.50	14.40	14.60	0.75	0.79
8	L2	20.20	20.50	22.70	22.70	0.89	0.90
9	L2	15.70	15.80	15.90	16.10	0.99	0.98
10	L5	12.80	14.00	13.90	14.80	0.92	0.95
11	L5	15.60	17.10	17.10	18.30	0.91	0.93
12	L5	9.15	9.70	10.20	11.20	0.90	0.87
13	L2	5.39	15.30	9.15	20.80	0.59	0.74
14	T11	9.72	15.70	13.30	19.20	0.73	0.82
15	L4	11.34	15.22	15.49	20.02	0.73	0.76
16	L5	13.64	16.35	15.47	18.27	0.88	0.89
17	L4	11.38	15.30	13.63	19.00	0.83	0.81
18	L4	7.80	7.88	10.10	10.20	0.77	0.77
19	N/A						
20	L2	13.20	14.10	14.90	17.60	0.89	0.80
P value (1-tailed)		.002		.003		.3 (2-tailed)	
Average		11.96	14.03	13.91	16.28	0.85	0.87
Standard Deviation		3.40	3.02	3.28	3.61	0.11	0.08
Maximum		20.20	20.50	22.70	22.70	0.99	0.98
Minimum		5.39	7.88	9.15	10.20	0.59	0.74
Percentage increase		17%		17%		2%	

Abbreviation: N/A, not applicable.

intervention, that is, APC. The results did show correction in the wedging of the vertebra due to APC, in contrary to a static fusion at the apex, which have been shown to cause continued growth of deformity and thus crankshafting or adding-on. Nevertheless, a less varied cohort with equal follow up duration in patients undergoing this procedure is required to establish its efficacy in mitigating or reducing crankshafting or distal migration. Although, we do see reduction in wedging, it is still not clear if it was a result of convex-only fixation without fusion at the apex or due to apex compression of the wedged vertebra on the convex side.

There are several limitations to the current study, first and foremost being the number of patients. Given a major deviation from the established SHILLA procedure, it was a prudent measure to limit this procedure to a few and perform a close follow up. However, given these results we are confident to carry on an open enrollment of patients with scoliosis and kyphoscoliosis. The second shortcoming of the study is that we didn't quantify the amount of compression being applied, and how the magnitude of compression or lack of it altogether affects the reverse modulation in practice. We intend to quantify that in future either via direct measurement or virtual setup employing Hueter Volkmann principle where a patient-specific kinetic model could be used to determine the forces based on the height gain in a given period.[15-20]

Yet with all these shortcomings, the study demonstrates the possibility of safely and effectively reverse modulating the wedging at the apex using a modified SHILLA technique, and in theory has the potential to mitigate crankshafting or adding-on.

Conclusion

The result of this study provides clinical evidence of reverse vertebral modulation at the apex of the curve in patients with scoliosis and kyphoscoliosis, when modifying the traditional SHILLA technique with APC.

Authors' Note

ORCID iD

Aakash Agarwal, PhD https://orcid.org/0000-0002-6183-3765
Alaaeldin Azmi Ahmad, MD https://orcid.org/0000-0001-6897-3915

References

1. McCarthy RE, McCullough FL. Shilla growth guidance for early-onset scoliosis: results after a minimum of five years of follow-up. *J Bone Joint Surg Am*. 2015;97:1578-1584.

2. Bumpass DB, McCullough L, McCarthy RE. Shilla growth guidance—evolution of a new procedure: rate of complications in the first two years following implantation in the first 80 patients. *Spine J*. 2017;17(10 suppl):S106-S107.

3. Agarwal A, Goswami A, Vijayaraghavan GP, et al. Quantitative characteristics of consecutive lengthening episodes in early-onset scoliosis (EOS) patients with dual growth rods. *Spine (Phila Pa 1976)*. 2019;44:397-403.

4. Agarwal A, Jayaswal A, Goel VK, Agarwal AK. Patient-specific distraction regimen to avoid growth-rod failure. *Spine (Phila Pa 1976)*. 2018;43:E221-E226.

5. Beaven A, Gardner AC, Marks DS, Mehta JS, Newton-Ede M, Spilsbury JB. Magnetically controlled growing rods: the experience of mechanical failure from a single center consecutive series of 28 children with a minimum follow-up of 2 years. *Asian Spine J*. 2018;12:794-802.

6. Mak H, Redmond A, Quidwai S, Carroll P, Kiely P. The use of magnetically-controlled growth rods (MCGR) and traditional growth rods (TGR) in a paediatric population. *Spine J*. 2017;17(11 suppl):S331.

7. Dubousset J, Herring J, Shufflebarger H. The crankshaft phenomenon. *J Pediatr Orthop*. 1989;9:541-550.

8. Murphy RF, Mooney JF 3rd. The crankshaft phenomenon. *J Am Acad Orthop Surg*. 2017;25:e185-e193.

9. Wilkinson JT, Songy CE, Bumpass DB, McCullough FL, Mccarthy RE. Curve modulation and apex migration using Shilla growth guidance rods for early-onset scoliosis at 5-year follow-up [published online April 3, 2017]. *J Pediatr Orthop*. doi:10.1097/BPO.0000000000000983.

10. Betz RR, Ranade A, Samdani AF, et al. Vertebral body stapling: a fusionless treatment option for a growing child with moderate idiopathic scoliosis. *Spine (Phila Pa 1976)*. 2010;35:169-176.

11. Cebeci BO, Ergene G, Sogunmez N, Ay B, Yilgor C, Alanay A. Non-fusion growth modulation with anterior vertebral body tethering via thoracoscopic approach for adolescent idiopathic scoliosis. *Spine J*. 2017;17(10 suppl):S106.

12. Miyanji F, Parent S. Anterior vertebral body tethering (AVBT) for early-onset scoliosis. In: El-Hawary R, Eberson C, eds. *Early Onset Scoliosis*. Cham, Switzerland: Springer; 2018:117-134.

13. Collins M, Saleh A, Razi A. Evaluation of infantile and juvenile scoliosis and osteotomies in spinal deformity surgery. *Curr Orthop Pract*. 2018;29:440-444.

14. Ruf M, Jensen R, Letko L, Harms J. Hemivertebra resection and osteotomies in congenital spine deformity. *Spine (Phila Pa 1976)*. 2009;34:1791-1799.

15. Agarwal A, Agarwal AK, Jayaswal A, Goel V. Smaller interval distractions may reduce chances of growth rod breakage without impeding desired spinal growth: a finite element study. *Spine Deform*. 2014;2:430-436.

16. Agarwal A, Agarwal AK, Jayaswal A, Goel VK. Effect of distraction force on growth and biomechanics of the spine: a finite element study on normal juvenile spine with dual growth rod instrumentation. *Spine Deform*. 2014;2:260-269.

17. Agarwal A, Agarwal AK, Jayaswal A, Goel VK. Outcomes of optimal distraction forces and frequencies in growth rod surgery for different types of scoliotic curves: an in silico and in vitro study. *Spine Deform*. 2017;5:18-26.

18. Agarwal A, Jayaswal AK, Goel VK, Agarwal AK. Letter to the editor concerning "rod fracture and lengthening intervals in traditional growing rods: is there a relationship?" by P. Hosseini et al. *Eur Spine J* (2016). doi:10.1007/s00586-016-4786-8. *Eur Spine J*. 2017;26:1696-1697.

19. Agarwal A, Zakeri A, Agarwal AK, Jayaswal A, Goel VK. Distraction magnitude and frequency affects the outcome in juvenile idiopathic patients with growth rods: finite element study using a representative scoliotic spine model. *Spine J*. 2015;15:1848-1855.

20. Lemans J, Kodigudla M, Kelkar A, Kruyt M, Goel V, Agarwal A. Spring distraction system for early onset scoliosis provides continuous distraction without a potential increase in rod fractures, compared to traditional growing rods. *Spine Deform*. 2018;6:819-820.