



One-stage multiple posterior column osteotomies and fusion and pre-op halo-gravity traction may result in a comparative and safer correction of complex spine deformity than vertebral column resection

Cristina Sacramento-Domínguez¹ · Nguyen Cynthia² · Kwadwo Poku Yankey³ · Henry Osei Tutu⁴ · Irene Wulff⁵ · Harry Akoto⁶ · Oheneba Boachie-Adjei³ · FOCOS SPINE RESEARCH GROUP³

Received: 14 December 2019 / Accepted: 4 January 2021 / Published online: 18 February 2021
© Scoliosis Research Society 2021

Abstract

Study design A retrospective review of prospectively collected from patients recruited at a single center.

Purpose To test whether safe and optimal correction can be obtained with preoperative halo-gravity traction and posterior spinal fusion with adjunctive procedures but without VCR.

Summary and background Posterior vertebral column resection(VCR) is gaining popularity for correction of severe spinal deformity. However, it is a highly technically demanding procedure with potential risk for complications and neurological injury.

Methods In total, 72 patients with severe spinal deformity (Cobb angle > 100°) who underwent HGT followed by definitive PSF with PCO, with or without concave rib osteotomy and thoracoplasty. Demographic and surgical data were collected. Conventional coronal and sagittal radiographic measurements were obtained pre-traction, post-traction, post-op and at follow-up to determine the final deformity correction. Postoperative neurological and major complications were reviewed. We used Chi-square to compare proportion between groups and t test to compare groups in quantitative/ordinal variables.

Results There were 72 patients (35 females, 37 males). The etiology was congenital (21), idiopathic (45), neurofibromatosis (2) and neuromuscular (4). The mean was: age 18 ± 4.6 years; duration of HGT 103 ± 35 days; coronal Cobb angle before traction $131.5 \pm 21.4^\circ$ vs $92. \pm 15.9^\circ$ after HGT (30% correction) and $72.8 \pm 12.7^\circ$ after fusion (47% correction); kyphosis angle before traction $134.7 \pm 32.3^\circ$ vs $97.1 \pm 22.4^\circ$ after HGT and $73.7 \pm 21.3^\circ$ post-fusion. Number of fusion levels 14 ± 1 ; EBL 1730 ± 744 cc; number of PCOs done 5 ± 2 ; number of concave rib osteotomies (2 ± 2). There were 16 patients with postoperative complications (22.2%), 10 medical, one wound infection, 2 implant related and 3 post-op neuro-deficits (all of whom recovered at follow-up). There was one death (cardiac arrest).

Conclusion HGT and one-stage posterior fusion with PCO, with or without concave rib resection and thoracoplasty, without VCR, achieved satisfactory correction of rigid complex spine deformity with minimal neurological complications. The results compare favorably with previous reports of similar deformities treated with VCR.

Level of Evidence III.

Keywords Severe spinal deformity · Posterior column osteotomy · PVCR · Halo-gravity traction · Neurological complications

✉ Cristina Sacramento-Domínguez
cristisacra@yahoo.es; csacramento@unav.es

¹ Spine Unit, Orthopaedic Department, Clínica Universidad de Navarra-Madrid, C/Marquesado de Santa Marta, 1, 28027 Madrid, Spain

² Orthopaedic Surgery, Shriners for Children Medical Center-Pasadena, Pasadena, USA

³ FOCOS Orthopedic Hospital, Accra, Ghana

⁴ Research Department, FOCOS Orthopedic Hospital, Accra, Ghana

⁵ Department of Anesthesiology, FOCOS Orthopedic Hospital, Accra, Ghana

⁶ Korle-Bu Teaching Hospital, Accra, Ghana

Introduction

The surgical management of severe spinal deformity is complex due to the inflexibility of the curves, changes in the normal anatomy of the spine and adjacent structures and their impact on lung and neurological function.

In many cases, the past decade, correcting severe spinal deformities required a combined anterior and posterior approach to the spine. MacLennan in 1922 [1] was the first to report about vertebrectomy. Later, Bradford and Boachie-Adjei [2] in 1987 described the combined anterior and posterior VCR (vertebral column resection) for the treatment of severe rigid spinal deformity. Suk [3] in 2002 was the first to promote the posterior vertebral column resection (PVCR) osteotomy. In recent years, after Lenke et al. [4–6] published their experience using PVCR osteotomy for severe deformity correction, it has become popular as an alternative procedure to the combined approach because it allows for biplanar correction through a single posterior approach which thereby decreases comorbidities associated with the combined approach. A very effective correction of severe kyphosis or scoliosis, averaging 50% to 60%, has been reported in several different series [4, 5, 10–13]. However, PVCR is a surgical procedure that requires great technical skill and is associated with a high percentage of intraoperative neuro-monitoring alerts and postoperative neurological complications. The reported prevalence of overall complications ranges from 40 to 65% [4, 6, 10, 12, 14, 15].

Several previously published studies done at our site [7, 8] have documented the benefits of using halo-gravity traction preoperatively for rigid spinal deformities to improve the curve flexibility and reduce complications. The gradual stretching of the spine through sustained spine traction with a halo-gravity device allows a gradual modification of the spatial arrangement of the vertebral bodies in both the coronal and the sagittal planes. The sustained traction also allows progressive stretching of the neuro-vascular structures and minimizes the risk of acute ischemic injury during surgery. There is also gradual elongation of the neurological structures, which from our point of view is “training of the neurological structures” to reduce the risk of spinal cord injury during the definitive surgical correction. We hypothesized that by using preoperative HGT, we could still obtain good correction while avoiding the high complication rates of PVCR. The aim of our study was to determine whether preoperative HGT, applied properly [7] in severe and rigid spinal deformities, followed by a single posterior instrumented fusion with adjunctive procedures such as posterior column osteotomies (PCO) and rib osteotomies, will obtain final curve corrections comparable to previously reported series of PVCR. The goal is

to demonstrate an effective way of attaining adequate correction in patients with rigid deformity while decreasing the potential risk of neurological and other complications.

Materials and methods

Clinical and radiographic parameters

Clinical and radiographic data of 72 patients who were treated at a single center between November 2012 and March 2015 were reviewed. These data had been prospectively collected as part of a hospital registry of spine deformity patients. The morphometric variables reviewed included: age, sex, weight, height and body mass index (BMI). Risser sign and triradiate cartilage were collected as indirect measures of skeletal maturity. Other variables evaluated were: etiology of spine deformity, American Society of Anesthesiologists (ASA) classification, FOCOS level score classification [9] pre-traction and post-traction, forced vital capacity (FVC) and neurological status during pre-traction, post-traction and post-op period, length in halo-gravity traction and operating room (OR) time, estimated blood loss (EBL), number of levels fused, type and number of posterior column osteotomies and rib resections and complications. Transcranial motor evoked potential (TcMEP) and somatosensory evoked potentials (SSEP) were performed on all patients, and intraoperative neuromonitoring (IONM) alerts were noted for each patient.

Radiographic measurements were taken from 36 inch, standing anteroposterior and lateral radiographs and were reviewed pre-traction, immediate post-traction, post-op and at final follow-up to assess the deformity correction and complications. The radiological parameters evaluated were: Cobb angle of major and minor coronal curves and kyphosis angle, % correction of major, minor coronal curves and kyphosis post-traction and after surgery, the Harrington Factor (HF) or DAR (Cobb/n vertebra in the curve) at the pre-traction and post-traction period of the major, minor and kyphosis curves and the HF/DAR change.

All patients had MRI and a 3D CT scans performed as part of the preoperative planning.

SRS 22 questionnaire was used at baseline and at 2-year follow-up as patient-report outcome measure.

Halo-gravity traction technique

The patients were placed in halo-gravity traction for an average of three months preoperatively (Figs. 1 and 2). Before halo application, the patients had their hair washed with disinfectant soap and shaved around their pin sites. The four pins were placed, and a torque wrench was used to tighten them to 6 to 8 inch-pounds. The two posterior pins were

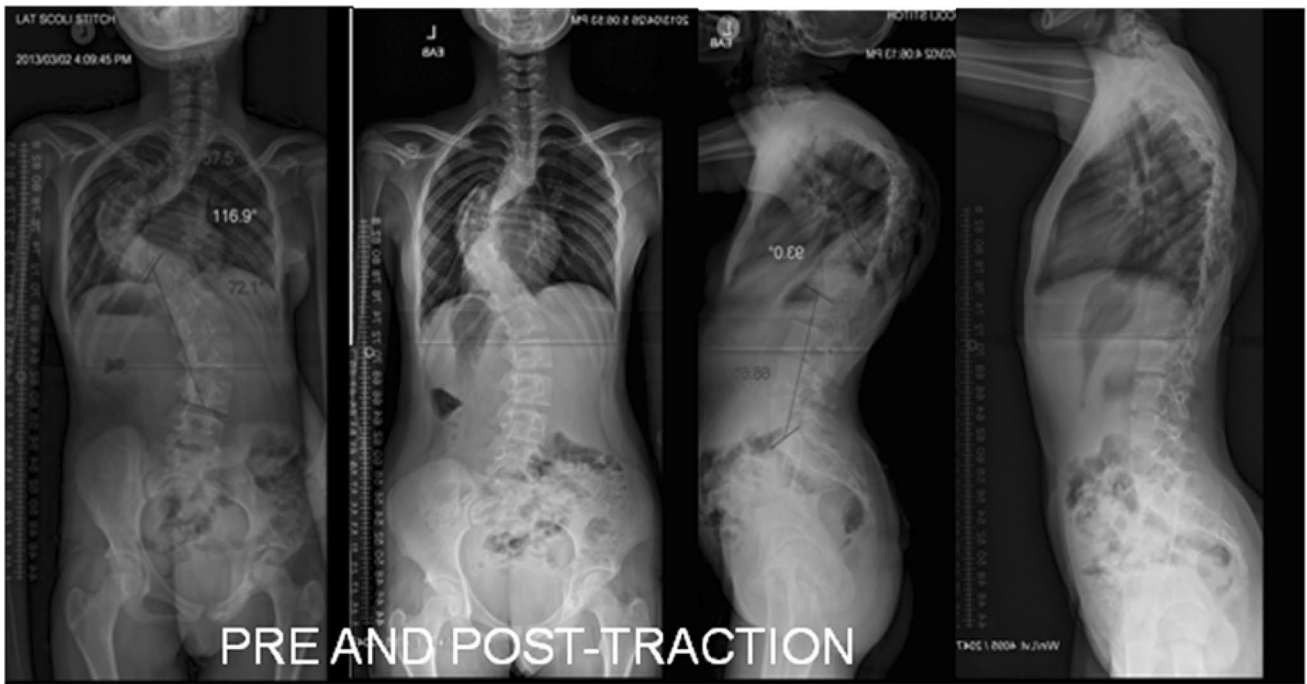


Fig. 1 AP and lateral X-rays pre-traction and at final HGT period

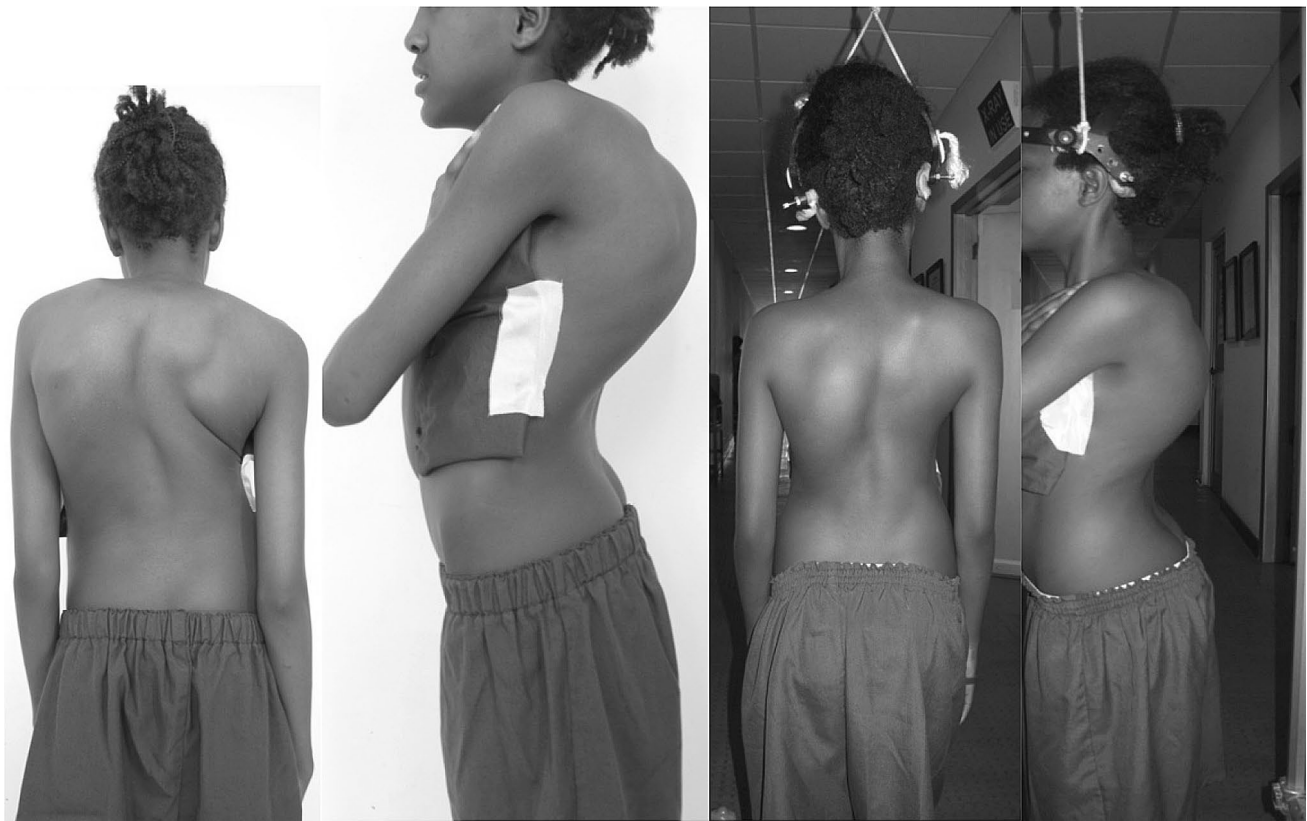


Fig. 2 AP and lateral view pre-traction and at final HGT period

placed one centimeter above the pinna of the ears, to avoid injuring the temporalis muscle or the temporal artery. The HGT was started at 20% of body weight and increased by 10% per week until 50% of body weight was reached at the 4th week and maintained thereafter. Patients unable to tolerate this target remained with less traction weight until a comfortable threshold was reached and advanced to the 50% body weight target as they became more comfortable. Traction was maintained full time using a mobile wheelchair apparatus, walking frame or bed device except during meals and personal hygiene. Halo monitoring with pin site cleaning was performed daily to detect or prevent possible complications, and pins were torqued weekly by the surgical team.

Control X-rays are performed every 4 weeks to assess the degree of correction. A maximum partial correction of about 30–40% can be achieved with HGT, but we often use 30% correction as our target. About 20% correction is typically achieved at 4 weeks and approximately 30% correction by 8 or 12 weeks in HGT. If from the first control at 4 weeks, 30% correction is reached, traction may be stopped at that time. In cases where 20% correction is attained at 4 weeks HGT with no additional correction at 8 weeks, it is also considered to have plateaued and traction is discontinued. In some cases, traction is prolonged after correction has plateaued due to other reasons such as nutritional or pulmonary function optimization. This is especially the case for malnourished patients who present with severe deformities and poor pulmonary function.

Surgical technique

The patient was brought into the operating room and placed under general anesthesia. Pre- and post-positioning baseline IONM using TcMEP and SSEP was obtained.

IONM recordings were also obtained before and after intraoperative traction was applied.

To determine the amount of traction used intraoperatively, the traction achieved preoperatively was equally divided for the head and the lower extremities.

A conventional posterior midline approach to the spine was done. Often, the severity of vertebral rotation and deformation of the ribcage and costovertebral joints on the convexity made the convex exposure difficult. In such circumstances a thoracoplasty was performed to facilitate the exposure of the convexity of the curvature. Following the exposure, multilevel pedicle screws were placed except on the more prominent periapical vertebrae. Posterior column osteotomies were done at the more rigid periapical region of the main curves utilizing Smith–Petersen or Ponte osteotomy techniques. Additionally, concave rib osteotomies were done in cases where there was autofusion of the costovertebral joints. Once the spine became more flexible, correction

maneuvers were applied using cantilever, compression over the convex side and distraction on the concave side and/or posterolateral translation of the spine using sublaminar bands or wires. In most cases three- or four-rod constructs were used to achieve desired balanced correction (Fig. 3).

Statistical analysis

We used the Chi-square test to compare proportions between groups.

We used Students t tests to compare groups in quantitative/ordinal variables. A *P* value < 0.05 was considered to indicate statistical significance. Statistical analyses were carried out with STATISTICA v. 7.0 (StatSoft, OK).

Results

Morphometric variables

There were 35 female patients and 37 male patients. The etiology of spine deformity was idiopathic in 45 patients, congenital in 21 patients, neuromuscular in 4 patients, and 2 patients had neurofibromatosis. The averages of morphometric variables were: age 18 ± 4.6 years, ASA score 3.3 ± 0.7 , weight 37.8 ± 9.2 kgs, height 143.7 ± 10 cm, body mass index (BMI) 18 ± 3 kg/m². Using the FOCOS risk stratification score⁹, the average FOCOS level pre-HGT was 4.1 ± 0.4 and FOCOS level post-HGT was 3.8 ± 0.4 . The average time spent in halo was 103 ± 35 days, and forced vital capacity (FVC) pre-HGT was $55.9 \pm 31.7\%$ (Table 1).

Radiographic measures

The average Risser score was (3.9 ± 1.7). The triradiate cartilage was open in 6 patients, closed in 62 patients and not available in 4 patients. The averages of the variables measured at pre-traction versus post-traction period were: major Cobb angle $131 \pm 21.4^\circ$ degrees vs $92.4 \pm 15.9^\circ$, minor Cobb angle $69.9 \pm 17.6^\circ$ vs $50.3 \pm 16.7^\circ$, kyphosis Cobb angle $134.7 \pm 32.3^\circ$ vs $97.1 \pm 22.4^\circ$, HF/DAR major Cobb angle 17.7 ± 3.1 vs 12.2 ± 2.5 , HF/DAR minor Cobb angle $12.5 \pm 3.8^\circ$ vs $9.1 \pm 3.2^\circ$ and HF/DAR kyphosis Cobb angle 17.7 ± 5.8 vs $12.6 \pm 4.6^\circ$. The mean time on traction in our series was 102.5 (42–173) days. The percentage of Cobb angle correction after traction was: major curve $30 \pm 11.5\%$, minor curve $28.2 \pm 17.1\%$ and kyphosis $32.0 \pm 14.9\%$. The percentage of correction of the curve magnitude after surgery was: major curve $47.5 \pm 14\%$, minor curve $39.66 \pm 16.2\%$ and kyphosis $51.2 \pm 18.8\%$ (Table 2 and 3).



Fig. 3 AP and lateral X-rays and AP and lateral views after surgery

Table 1 Demographic and clinical characteristics

Age (years)	18 ± 4.6
Risser	3.9 ± 1.7
ASA	3.3 ± 0.7
FOCOS level pre-HGT	4.1 ± 0.4
FOCOS level post-HGT	3.8 ± 0.4
Weight (kg)	37.8 ± 9.2
Height (cm)	143.7 ± 10
BMI (kg/m ²)	18 ± 3
Length in halo (days)	103 ± 35
% FVC pre-HGT	55.9 ± 31.7

Surgical parameters

The average length of surgical procedure was 292 ± 87.8 min, and the mean number of fusion levels was (14 ± 1 levels). The mean number of SPO/Ponte osteotomies was 5 ± 2, the mean number of concave rib osteotomies was 2 ± 2, and the mean number of convex rib resections was (4 ± 1). The average estimated blood loss was 1730 ± 744 ml, and post-op FVC average was 50 ± 2% (Table 4).

Table 2 Major, minor and kyphosis Cobb angle measures, pre- and post-traction

	Traction		%Correction post-traction	<i>p</i>
	Pre	Post		
Major Cobb angle	131.5 ± 21.4 <i>n</i> = 72	92.4 ± 15.9 <i>n</i> = 59	30.0 ± 11.5	< 0.001
Minor Cobb angle	69.9 ± 17.6 <i>n</i> = 71	50.3 ± 16.6 <i>n</i> = 58	28.2 ± 17.1	< 0.001
Kyphosis Cobb angle	134.7 ± 32.3 <i>n</i> = 72	97.1 ± 22.4 <i>n</i> = 58	32.0 ± 14.9	< 0.001

The total number of patients with complications was 16 (22.2%)—8 pts had pulmonary complications (6 pts had a pleural tear, and 2 pts had respiratory failure), 1 patient had a wound infection, 2 pts had complications related to implants, and 2 pts had a cardiac complication (1 pt with tachycardia and 1 pt had cardiac arrest who eventually died). In total, 40 pts (55.6%) had IONM alerts during surgery and 3 (4.1%) of those woke up with neurological deficit, but all had completely recovered at the latest follow-up. No permanent neurological deficit occurred in our series (Table 5).

Table 3 Major, minor and kyphosis Cobb angle measures pre- and post-surgery

	PRE-traction	Post-op 1st follow-up	(%)Correction post-op 1st follow-up	<i>p</i>
Major Cobb angle	131.5 ± 21.4 <i>n</i> = 72	72.8 ± 12.7 <i>n</i> = 69	47.5 ± 14.0	< 0.001
Minor Cobb angle	69.9 ± 17.6 <i>n</i> = 71	41.8 ± 14.9 <i>n</i> = 68	39.66 ± 16.2	< 0.001
Kyphosis Cobb angle	134.7 ± 32.3 <i>n</i> = 72	73.7 ± 21.3 <i>n</i> = 68	51.2 ± 18.8	< 0.001

Table 4 Surgical characteristics

Length of Surgery (Minutes)	292 ± 87.8
Estimated Blood Loss (EBL)(cc)	1730 ± 744
EBL%	67 ± 30
Levels of Fusion	14 ± 1
Smith–Peterson Osteotomy	5 ± 2
Concave Rib Osteotomy	2 ± 2
Convex Rib Osteotomy	4 ± 1
FVC Post-op%	50 ± 16

Table 5 Description of the complications

Pulmonary— <i>n</i>	Pleural Tear	6	8
	Respiratory Failure	2	
Infectious— <i>n</i>	Wound infection	1	2
	Broken rod (2 y post-op)	1	
Related to implants— <i>n</i>	Prominent implant (under observation)	1	2
	Tachycardia	1	
Cardiac— <i>n</i>	Cardiac Arrest	1	2
	Intraop Cord injury	3	
Neurological— <i>n</i>	Total post-op recovery	3	3
Total Complications— <i>n</i> (%)	16 (22.2%)		
IOM Changes— <i>n</i>	40(55.5%)		

n = number of patients

Table 6 Comparisons within the group between the baseline and the follow-up period, including percentage change from baseline (%Δ)

SRS-22 scores and radiographic measurements at minimum 2-yr follow-up (<i>N</i> = 43)	Baseline	At 2 years of follow-up	Δ	<i>P</i> value
SRS Domains				
Function	3.5 ± 0.7	4.2 ± 0.6	0.7	< 0.001
Pain	4.0 ± 0.7	4.2 ± 0.7	0.2	0.1178
Image	2.4 ± 0.6	4.2 ± 0.5	1.8	< 0.001
Mental	3.7 ± 0.8	4.1 ± 0.8	0.4	0.0235
Satisfaction	2.4 ± 2.1	4.6 ± 0.6	2.2	< 0.001
Total	3.4 ± 0.5	4.2 ± 0.4	0.8	< 0.001
Radiographic Measurements				
Major Coronal Cobb (deg)	128.8 ± 21.7	70.3 ± 13.1		< 0.001
Major Sagittal Cobb (deg)	133.2 ± 28.5	61.3 ± 19.7		< 0.001

Patient report outcome measures

There was statistically significant improvement in baseline SRS total scores at 2-year follow-up ($p < 0.05$). There was statically significant improvement in SRS scores under function, image, mental and satisfaction domains ($p < 0.05$) (Table 6).

No significant differences were observed in the baseline patient characteristics between those followed and those lost in the follow-up (Table 7 and 8).

Discussion

The surgical management of severe spinal deformity is a challenge, with considerable technical difficulties especially in undeveloped countries where the availability of resources limited. Extreme care must be taken to avoid any eventual complication, and one needs to be aware of the different surgical alternatives with fewer risk factors in order to achieve optimal deformity correction with the fewest possible complications. The PVCR osteotomy has been widely used in the past decade because it provides a reasonable amount of correction in severe and rigid deformities; however, it is technically demanding and has a high percentage of neurological complications.

Several studies have shown a very good percentage of correction obtained after PVCR. Suk et al. in 2005 [10] reported their results in a series of patients with severe rigid

Table 7 Comparison in the baseline patients characteristics between those followed and those lost in the follow-up

Mean and SD	Incomplete follow-up	2-year follow-up	<i>p</i>
Age	19.9 ± 5.6	15.9 ± 2.7	0.01
BMI	19.01 ± 3.0	17.45 ± 2.9	0.9
FVC pre-traction	1.7 ± 0.7	1.6 ± 0.7	0.4
% FVC pre-traction	48.1 ± 20.5	61.5 ± 38.1	0.2
Major Cobb angle	134.1 ± 21.6	129.6 ± 21.3	0.8
Kyphosis Angle	134.6 ± 32.1	134.8 ± 32.8	0.9

scoliosis with a preoperative major curve of 109.0° ± 19.8° which decreased to 45.6° ± 14.8° after surgery, showing a 59% of scoliosis correction. Their patients had an average minor curve of 59.3° ± 15.2° which decreased to 29.2° ± 11.3° (51% of correction) and a preoperative thoracic kyphosis of 30.7° ± 40.0° which corrected to 34.4° ± 12.4°. Lenke et al. [4] in 2009 reported their results based on 5 diagnosis categories: the kyphoscoliosis group (*n* = 8) had an average preoperative major curve of 87° and a kyphosis Cobb angle of 103° and had 54% correction with a PVCR and the severe scoliosis group (*n* = 2) which had a preoperative major curve of 115° corrected to 61° (51% correction). Later in 2010, the same group [5] reported the results of a series of 43 patients with similar results—the severe scoliosis cases obtained a correction rate of 69%, and the kyphoscoliosis cases (*n* = 14) had 56% of correction. Ozturk et al. [11] in 2012 reported their results also based on several categories: the scoliosis group (*n* = 24) had a mean major curve of 103° which corrected to 39.8° (61.3% of correction) and the kyphoscoliosis group (*n* = 15) had a preoperative major Cobb of 110.8° which corrected to 43.9° (60.3% of

correction) and a thoracic kyphosis of 88° which corrected to 36.6° (59% of correction).

Xie et al. [12] in 2012 reported a mean correction rate of 54 ± 12.2% of the major Cobb angle in a series of 46 patients with severe scoliosis and kyphoscoliosis with an average preoperative major Cobb angle of 110.1° ± 18.1° which decreased to 51° ± 17.3° post-op. Recently, in 2015 [13], the same researchers published their results in a series of 105 patients with a mean preoperative major Cobb of 108.9° ± 25.5° which decreased to 37.2° ± 16.8° post-op and segmental kyphosis of 89.8 ± 31.1 which decreased to 30.4° ± 15.3°.

However, despite the excellent results of PVCR osteotomy regarding correction of severe and rigid deformities, the percentage of total complications reported is moderately high in most series and consists mainly of neurological complications during vertebral resection and correction maneuvers. The complications usually involve alteration in the vascular supply to the cord, cord impingement due to dislocation of the spinal column or over-shortening of the spinal cord during closure of the vertebrectomy gap and excessive retraction of nerve roots. Suk et al. [10] reported a 34.3% overall rate of complications and 17.1% rate of neurological complications. Lenke et al. [4] in 2009 reported a 40% overall rate of complications and 11.4% rate for neurological complications. Later, in 2013 Lenke et al. [6] reported 59% overall complications after 147 consecutive PVCR for severe pediatric deformities; 27% of these were neurological complications although none had complete permanent paraplegia. Xie et al. [12] in 2012 reported 64.3% overall complications and 17.8% neurological complications. Hamzaoglu et al. [14] reported a 7.8% overall complication rate. Zhang Tao et al. [15] reported a neurological complication rate of

Table 8 Comparison in the baseline patients characteristics between those followed and those lost in the follow-up

Percentage	Incomplete follow-up	2-year follow-up	<i>P</i>
Pre-neurostatus			
Abnormal	33.3% (2)	66.7% (4)	0.48
Normal	43.9% (29)	56.1% (37)	
Etiology			
Congenital	14.3% (3)	85.7% (18)	0.005
Idiopathic	57.8% (26)	42.2% (19)	
NF	0% (0)	100% (2)	
NM	50% (2)	50% (2)	
ASA			
3	43.5% (27)	56.5% (35)	0.6
5	40% (4)	60% (6)	
FOCOS Level pre-HGT			
3	50% (2)	50% (2)	0.9
4	41.4% (24)	58.6% (34)	
5	44.4% (4)	55.6% (5)	

13.6%. Having other surgical options which could achieve a similar correction of the deformity will allow surgeons to adopt the best decision in each specific case and also take into account the surrounding circumstances as well as the surgical skills of the surgeon and the resources available to him or her.

In our study, the rate of IONM alerts was high at 55.5% with 4% transient neurological deficits compared to the PVCR series. None of our patients had a permanent deficit. The potential factors that could explain the high rate of IONM alerts include the use of intraoperative traction, the reversal of which improved some IONM alerts, the application of posterior column osteotomies and some of the correction maneuvers used to obtain curve correction.

A slight diminution of the FVC postoperatively was found in our series despite the deformity correction. The addition of rib osteotomies increases curve flexibility and facilitates the exposure of the convexity of the curvature but could be associated with worse postoperative pulmonary function.

Our experience with the use of halo-gravity traction has allowed us an option to obtain gradual correction of deformity in patients instead of applying abrupt corrective maneuvers or performing a VCR to obtain an optimal correction. Moreover, during the preoperative traction period, some patients improve their respiratory function and even their baseline neurological state. In this series we observed two patients who had worsening of their neurological state when the traction was eliminated and therefore had to be maintained beyond the plateau period of correction (63 days) so as to reach a stable neurological status before definitive surgery [7].

Compared to other reports, in this study we report a large and homogeneous group of patients with severe kyphoscoliosis with a higher mean magnitude of the curve in both the coronal and sagittal planes. In our study the pre-op mean major Cobb was $131.5^\circ \pm 21.4^\circ$ which decreased to $72.8^\circ \pm 12.7^\circ$ at the first post-op follow-up, and the pre-op kyphosis angle was $134.7^\circ \pm 32.3^\circ$ which decreased to $73.7^\circ \pm 21.3^\circ$ at the first post-op follow-up. The final percentage of correction achieved was $47.5 \pm 14.0\%$ in the major Cobb angle and $51.2 \pm 18.8\%$ in the kyphosis Cobb angle. These results are comparable to those of VCR, implying that the judicious use of preoperative HGT, posterior column osteotomies, concave and/or convex rib osteotomies and posterior instrumented spinal fusion is a viable and safe alternative procedure for severe and rigid deformities. This is even more important for the inexperienced surgeon and in the setting of limited resource environments.

One limitation of our study is the loss to follow-up for long-term evaluation. Only 43/72 (60%) patients attained the minimum 2-year follow-up with an average follow-up being 4 yrs. The remaining have been lost to follow-up. Most of the lost to follow-up are patients from other African countries

besides Ghana. Thus, cost of air travel to Ghana for follow-up can be very challenging for some patients. We biannually visit these countries for follow-up visits, and this is what has helped us to attain follow-up in about 60% patients. However, no significant differences were observed in the baseline patients characteristics between those followed and those lost in the follow-up.

The sample size in this series includes 72 patients selected from a database of consecutively operated patients. No patient in this series was considered for PVCR. However, we consider the PVCR as the procedure of choice in deformities with pure kyphosis that had extremely rigid, sharp angular curves, in which the apex of the deformity is rigid and correction cannot be achieved with traction. Thus, patients with postinfectious kyphosis or congenital causes are relatively resistant to preoperative HGT and likely will need a 3-column osteotomy for optimal correction [16].

Conclusion

Preoperative halo-gravity traction and one-stage posterior fusion with posterior column osteotomies with or without concave rib resection and/or thoracoplasty without VCR achieved satisfactory correction of rigid complex spine deformity with minimal neurological complications. The rate of IONM alerts in the present study was high (55.5%); however, no permanent post-op neurological deficit occurred. The results compare favorably with previous reports of similar deformities treated with VCR.

Acknowledgements This study was approved by the appropriate Institutional Review Board of the Noguchi Research Institute, Ghana, and national research ethics committee and was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Funding The study was supported by grant from K2M. Reference number—K2M/FC/060216.

Compliance with ethical standards

Conflict of interest Author Oheneba Boachie-Adjei received research grant from Company K2M. The rest of the authors declare that they have no conflict of interest.

Informed consent All individual participants have individual rights that have not been infringed. All patients have given the consent for publication. We give permission to reproduce copyrighted materials or signed patient consent forms.

References

1. MacLennan A (1922) Scoliosis. *Br Med J* 2(2):864–866
2. Bradford DS (1987) Vertebral column resection. Printed abstract from the Association of Bone and Joint Surgeons Annual Meeting. *Ortho Trans* 11:502

3. Suk SI, Kim JH, Kim WJ et al (2002) Posterior vertebral column resection for severe spinal deformity. *Spine* 27:2374–2382
4. Lenke LG, O'Leary PT, Bridwell KH et al (2009) Posterior vertebral column resection for severe pediatric deformity. *Spine* 34:2213–2221
5. Lenke LG, Sides BA, Koester LA et al (2010) Vertebral column resection for the treatment of severe spinal deformity. *ClinOrthopRelat Res* 468:687–699
6. Lenke LG, Newton PO, Sucato DJ et al (2013) Complications after 147 consecutive vertebral column resections for severe pediatric spinal deformity. *Spine* 38:119–132
7. Nemani VM, Kim HJ, Bjerke-Kroll BT et al (2015) Preoperative halo-gravity traction for severe spinal deformities at an SRS-GOP Site in West Africa: protocols, complications, and results. *Spine* 40(3):153–161
8. Sacramento-Domínguez C, Pellisé F, Ayamga J et al (2016) Effectiveness of rib osteotomies in correction of severe spinal deformity treated with halo gravity traction and posterior spinal fusion (Early Onset Scoliosis Session, IMAST 2016)
9. Boachie-Adjei O, Yagi M, Sacramento-Dominguez C et al (2014) Surgical risk stratification based on preoperative risk factors in severe pediatric spinal deformity surgery. *Spine Deform* 2(5):340–349
10. Suk SI, Chung ER, Kim JH et al (2005) Posterior vertebral column resection in fixed lumbosacral deformity. *Spine* 30:1682–1687
11. Ozturk C, Alanay A, Ganiyusufoglu K, Karadereler S, Ulusoy L, Hamzaoglu A (2012) Short-term X-ray results of posterior vertebral column resection in severe congenital kyphosis, scoliosis, and kyphoscoliosis. *Spine* 37(12):1054–1057
12. Xie J, Wang Y, Zhao Z et al (2012) Posterior vertebral column resection for correction of rigid spinal deformity curves greater than 100°. *J Neurosurg Spine* 17:540–551
13. Wang Y, Xie J, Zhao Z et al (2015) Perioperative major non-neurological complications in 105 patients undergoing posterior vertebral column resection procedures for severe rigid deformities. *Spine* 40(16):1289–1296
14. Hamzaoglu A, Alanay A, Ozturk C et al (2007) Posterior vertebral column resection in severe spinal deformities: a total of 102 cases. *Spine* 36(5):340–344
15. Zhang T, Tao H, Huang J et al (2015) Neurological complications of posterior vertebral column resection for severe rigid congenital spinal deformities. *Zhonghua Wai Ke Za Zhi* 53(6):424–429
16. Sacramento-Domínguez C, Yagi M, Ayamga J et al (2015) Apex of deformity for 3column osteotomy. Does it matter in the occurrence of complications. *Spine J* 15(11):2351–2359

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.