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CASE SERIES

The use of three rods in correcting severe scoliosis

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Abstract

Purpose The three-rod technique, utilising a short apical concavity rod is an option to achieve controlled correction in severe scoliosis. We describe this technique, the complications encountered, and the long-term outcomes.

Method All paediatric patients who had at least 2 years follow-up after undergoing corrective surgery for scoliosis ≥ 100° using 3 parallel rods were included. Radiographs were assessed to evaluate the correction and clinical records examined for any loss of correction, complications, revision procedures or neuromonitoring events.

Results Twenty-five patients met the inclusion criteria. Four underwent prior anterior fusion to prevent crankshaft phenomenon. The mean angle of the deformity was 112.0° (range 100.3–137.1). Mean maximal kyphosis was 48.8° (range 11.4–78.8°) and mean curve flexibility 4.4% (range 0–37.0%). Intraoperative traction achieved an average of 70.4% (95% CI 56.6–84.1%). Nine patients (39%) showed a reduction in MEPs during definitive surgery. All returned to within 75% of baseline by the end of surgery. All patients had normal postoperative neurology. One patient underwent removal of hardware for late infection. The mean overall Cobb correction was 55.7° (95% CI 50.2–61.2°), equating to 50.2% (95% CI 44.9–55.4%) of the mean initial deformity. Thoracic kyphosis reduced by a mean of 18.2° (95% CI 12.8–23.6°).

Conclusion Our series suggests that three-rod constructs are able to safely and effectively achieve 50% correction of severe scoliosis.

Keywords Scoliosis · Deformity correction · Paediatric scoliosis · Instrumentation

Introduction

Posterior instrumented fusion is the most common technique used to correct paediatric spinal deformity. We are now able to tackle larger, stiffer curves with an increasing confidence, however, treating stiff curves greater than 100° carries significant risk and methods that can safely correct severe deformities are a necessary tool [1–5].

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The strategies employed to manage stiff, severe spinal deformities include preoperative traction and osteotomy, which can be either posterior based or involve all three columns, however, these are not without significant risk. Preoperative traction should be considered as an adjunct, rather than a definitive treatment, and so is not directly comparable to osteotomy or posterior instrumented fusion. A metanalysis of 292 patients from Yang et al. showed that although preoperative traction can achieve a 24.2% correction in coronal deformity, it comes at a cost of a 22% incidence of complication including neurological injury and pin site complications [6]. The literature regarding osteotomy is more extensive. It has been established that osteotomies expose the spinal cord to a risk of injury through direct trauma, elongation of the spinal column or buckling of the ligamentum flavum during correction [7–13]. As a result of these vulnerabilities, Boachie-Adejei showed an odds ratio of 1.7 of sustaining a major complication with correction of paediatric deformity with osteotomy or resection procedures compared with posterior fusion alone [14]. Similarly, a study of 147 paediatric

patients treated with 3 column osteotomy by Lenke et al. showed a complication rate of 59%, with 27% showing an intraoperative neurological event, though it is noted that no patient showed permanent neurological deficit [15].

The gradual correction of the spine using a stiff construct would avoid some of the risks of these alternative strategies, with the advantage that each increment of the correction can be undone in response to changes in motor evoked potentials (MEPs) [16]. The three-rod construct described by Cotrel and Dubousset is such a technique, whereby the use of a short apical concave rod avoids excessive bending of the long concave rod during correction, which in turn prevents ligamentous buckling, allows close control of the correction and may ultimately reduce the risk of non-union [17–20]. In this article, we describe our method for correcting severe scoliosis using three rods and the complications and outcomes observed. We hypothesise that correcting severe scoliosis with a three-rod technique is safe and associated with a low incidence of complications, revision surgery and neurological deficits.

Method

All patients who underwent corrective surgery for scoliosis using 3 parallel rods were identified using departmental records. Using electronic tools (Centricity Enterprise Web V3.0, GE Medical Systems, Arlington Heights USA) the radiographs of each patient were reviewed by 3 independent surgeons to identify those with an angular coronal deformity exceeding 100°. Patients were excluded from the analysis if their deformity was less than 100° or were followed up for less than 24 months. The flexibility of the curve was assessed with standing full-length bending films. The intraoperative radiographs were measured to establish the correction achieved by intraoperative traction. Post-operative radiographs were assessed to evaluate the correction achieved. The most recent radiograph was evaluated for loss of correction during follow-up. Clinical documentation was examined for any evidence of intraoperative neuromonitoring changes, complications and revision procedures.

Data were recorded using Microsoft Excel v 16.32 (Microsoft, Redmont, USA) and analysed using Stata v14 (StataCorp, College Station, USA). Descriptive statistics were employed to define the radiographic outcomes of surgery and two-tailed paired t tests to analyse continuous data.

Surgical technique

After recording baseline MEPs and somatosensory evoked potentials (SSEPs), perioperative skeletal traction (typically 26 lbs distally and 13 lbs proximally) is applied through transfemoral pins and Gardener-Wells tongs. Evoked potentials are recorded again immediately after application of the traction weights and closely monitored during exposure.

Following exposure, anchors for the short rod are placed at the concave apex of the curve. The small size of the pedicles at the apex of the curve in severe spinal deformities often does not allow the safe use of pedicle screws and so hooks may be used. These are usually a distal supralaminar hook, apical supralaminar hook and proximal pedicle hook. The supralaminar hooks must be inserted carefully as the lamina is short and thickened on the concavity which reduces the space available for the blade. The short apical rod is then first fixed to the proximal and distal anchors before bringing it to the apical anchor creating a corrective translation which can be further improved through a rod rolling manoeuvre if curve flexibility allows. Progressive distraction and in situ contouring to create further translation can be helpful.

The long concave rod is then inserted. The implant closest to the distal end of the short rod should be a polyaxial pedicle screw to allow the screw head to toggle laterally and avoid any impingement between the short and long concave rod. In situ contouring of the long rod allows further correction of the scoliosis through translation of the distal and proximal segments towards the central sacral line. These manoeuvres can unload the proximal pedicle hook of the short apical rod and render this fixation unstable, and so its contact with the pedicle should be confirmed as this hook can slide into the canal and cause cord injury [21]. Additional anchors can be added to improve construct stability. Finally, a convex rod is fixed to the spine to stabilise the construct. Any additional cantilever manoeuvre with the convex rod should be performed with caution as further elongation of the spinal cord can lead to a abrupt loss of neuromonitoring signals, which requires the immediate reversal of the correction. A delayed loss of signals after the fixation of all three rods can be managed with the complete release of the skeletal traction (alongside correction of anaesthetic parameters) to reduce the stretch applied to the cord at the uninstrumented cervical and lumbosacral spine.

One proximal and one distal crosslink connecting the two long rods and one short apical crosslink connecting the short apical rod to the concave rod are then applied prior to closing the wound. Contrary to the technique initially described by Cotrel, no transverse traction is applied with the intention to pull the short apical rod towards the long concave rod which in the senior authors' experience caused deformation of the long rod without additional correction [19].

Table 1 The demographics of each of the patient subgroups and the severity of the deformity

Diagnosis	Number of patients	Mean age at surgery in years (range)	Mean FVC as % of normal (range) (*n*)	Median number of levels fused (IQR)	Mean preop coronal thoracic deformity in ° (95% CI)	Mean PI in ° (95% CI)	Mean pre op LL in ° (95% CI)	Mean pre op TK in ° (95% CI)	Mean pre op pelvic tilt in ° (95% CI)	Mean pre op SS in ° (95% CI)
IS	14	13.8 (11.6–17.3)	50.9 (33.0–67.0) (8)	14.5 (14–15)	111.2 (105.4–117.0)	55.4 (49.9–60.8)	56.1 (44.2–68.0)	54.3 (45.5–62.9)	10.8 (6.8–14.8)	45.6 (41.7–49.6)
CS	2	10.5 (9.0–11.9)	51 (47–55)	14	102.7 (72.2–133.2)	45 (5.6–84.4)	31 (-97.3–159.3)	31.1 (-110.6–172.7)	10.2 (-47.6–67.7)	35.1 (33.8–36.4)
NMS	4	15.1 (13.1–16.4)	44.7 (19–66)	17.5 (16–18)	115.8 (114.1–117.5)	63.1*	4.9 (-72.9–82.7)	49.5 (-2.8–101.8)	13.5*	48.8*
SS	5	14.3 (12.2–15.6)	22.3 (9–32)	15 (15–16)	113 (101.8–124.4)	60.2 (45.7–74.7)	51.9 (33.9–70.1)	40.2 (15.2–65.2)	18.1 (9.4–26.7)	43.8 (29.8–57.9)

Only a single radiographs was readable for pelvic parameters in this cohort.

Table 2 Changes in MEPS, the actions taken and the post-operative neurology

No	Coronal correction (°)	Action taken	MEPs at closure	Post-operative neurology
1	54.0	B, F, G	> 90% of baseline	Normal
4	58.2	A, C, E, H	> 90% of baseline	Normal
5	49.0	C, H	> 90% of baseline	Normal
14	61.4	D, F, G,	Normal	Normal
16	57.5	A, F, G	> 75% of baseline	Normal
17	52.6	E, F, G,	Normal	Normal
19	72.3	A, C, F, H	Normal	Normal
20	45.9	C, F	Normal	Normal
23	62.5	A, F, H	Normal	Normal

A Traction reduced, *B* screw position changed, *C* short rod released, *D* long concave rod released, *E* Convex rod released, *F* Mean Arterial Pressure elevated, *G* Traction removed, *H* Correction reduced

Results

Twenty-five patients had a minimum of 2 years follow-up after undergoing corrective surgery for scoliosis using a three-rod construct between August 2006 and August 2017. The demographics of each of the patient subgroups and the severity of deformity are seen in table 1. Within the patients with syndromic deformity, 1 showed chromosome 5 abnormality, 1 7q33 abnormality, 1 Prader Willi syndrome and 1 Coffin-Lowry syndrome, and within the 4 patients with neuromuscular deformity, 2 were diagnosed with cerebral palsy and 2 with spinal muscular atrophy.

The cohort showed a mean follow-up of 44.1 months (range 24–119 months), with a mean age at surgery of 13.9 years (range 9.0–17.3 years). The mean angle of the thoracic deformity was 112.0° (range 100.3–137.1) with a mean kyphosis of 48.8° (range 11.4–78.8°) and mean curve flexibility 4.4% (range 0–37.0%). Sixteen patients underwent preoperative assessment of forced vital capacity (FVC) with a mean value of 44.4% of age-matched normal (95% CI 35.2–53.6%).

Four patients underwent anterior spinal fusion prior to posterior surgery to reduce the risk of later decompensation due to continued anterior column growth. Patients who underwent anterior spinal fusion prior to posterior instrumented fusion showed no significant difference in the correction achieved with intraoperative traction when compared to those who did not ($p > 0.1$), and so were included in the analysis.

Intraoperative traction achieved an average of 70.4% (95% CI 56.6–84.1%) of the final angular correction, with the remaining 29.6% due to posterior release and instrumentation. The median number of levels fused was 15 [interquartile range (IQR) 14–15]. One patient sustained a durotomy

which was primarily repaired. Nine patients (39%) showed a reduction in MEPs during surgery. Of these, 5 had returned to 100%, 3–90% and 1–75% of baseline signals by the conclusion of the procedure. The strategies employed to manage MEP changes are detailed in Table 2.

The mean overall Cobb correction was 55.7° (95% CI 50.2–61.2°), equating to 50.2% (95% CI 44.9–55.4%) of the initial deformity. Pelvic tilt, lumbar lordosis and sacral slope did not change significantly with surgery. Thoracic kyphosis reduced by a mean of 18.2° (95% CI 12.8–23.6°, $p < 0.001$) (Table 3).

All patients showed normal postoperative neurological examination (Table 2). One patient was diagnosed with a urinary tract and clostridium difficile infection during their inpatient stay, and another was readmitted with superior mesenteric artery syndrome which was managed conservatively. Coronal correction was maintained at final follow-up ($p = 0.2$). One patient suffered a late hardware infection at 2 years requiring subsequent debridement and removal of instrumentation without loss of correction at last follow-up. No other patients underwent revision surgery during the study period. (Table 4).

Discussion

Our series shows that the three-rod technique is capable of safely and effectively achieving a 50% correction in skeletally immature patients with previously unfused severe spinal deformities (Fig. 1).

We chose a lower deformity limit of 100° for inclusion in our study. In the senior author's experience, curves above this limit are stiffer than lesser deformities where a two-rod construct can often achieve a satisfactory result. Posterior instrumentation without osteotomy has been discussed as a solution for stiff, severe deformity, however, each report has been without the benefit of three rods and seldom in relation to paediatric patients. Di Silvestre et al. analysed a similar cohort to ours, investigating 27 paediatric patients treated for severe idiopathic curves with pedicle screws and two-rod constructs [22]. The mean major curve measured 88°, showed 25.62% flexibility and a correctability to 40°. The team achieved a mean correction of 52.4%, though importantly, these curves were smaller and more flexible than those in our cohort.

Several authors have proposed vertebral column resections for severe scoliosis and although early reports were optimistic in terms of correction and low neurological risks, more recent articles show that correction varies from 58.6% to 61.6% [15, 23–25]. A recent systematic review of posterior vertebral column resection demonstrated a neurologic complication rate of 8% and a risk of spinal cord injury of

Table 3 The observed radiological outcomes through the course of treatment

	Mean pre op in ° (95% CI)	Intraoperative traction in ° (95% CI)	Post-operative in ° (95% CI)	Final follow up in ° (95% CI)
Coronal deformity	112.0 (108.2–115.8)	75.6 (69.9–81.2)	56.3 (49.1–63.4)	59.3 (52.9–65.7) ($p = 0.1$)
Pelvic tilt	12.3 (9.2–15.4)	–	14.2 (11.0–17.5)	10.2 (6.4–13.9) ($p = 0.05$)
Sacral slope	44.4 (41.1–47.7)	–	45.6 (40.4–51.0)	46.7 (42.0–51.5) ($p = 0.67$)
Lumbar lordosis	46.7 (35.7–57.8)	–	38.8 (32.5–45.0)	44.1 (37.0–51.3) ($p = 0.02$)
Thoracic kyphosis	48.8 (41.4–56.3)	–	30.9 (24.9–36.8)	32.1 (25.5–38.6) ($p < 0.001$)

Table 4 The characteristics of the deformities treated and the incidence of complications seen in each technique described for managing stiff, severe scoliosis in the paediatric population

Technique	Number of patients (*n*)	Incidence of neurological complication (%)	Incidence of any complication (%)	Magnitude of coronal deformity (°)	Reported preoperative curve flexibility (%)	Postoperative Correction (%)
3CO [15]	147	8	59	104	21.8	58.6–61.6
Pre operative HGT prior to fusion [6]	351	1	16–22	101.1	12.9	24.2–46
2 posterior rods [22]	52	0	44	88	25.62	52.4
three rods	25	0	9	111.4	5.9	50.3

Data from studies reported by Yang et al. [6], Lenke et al. [15] and Di Silvestre et al. [22]

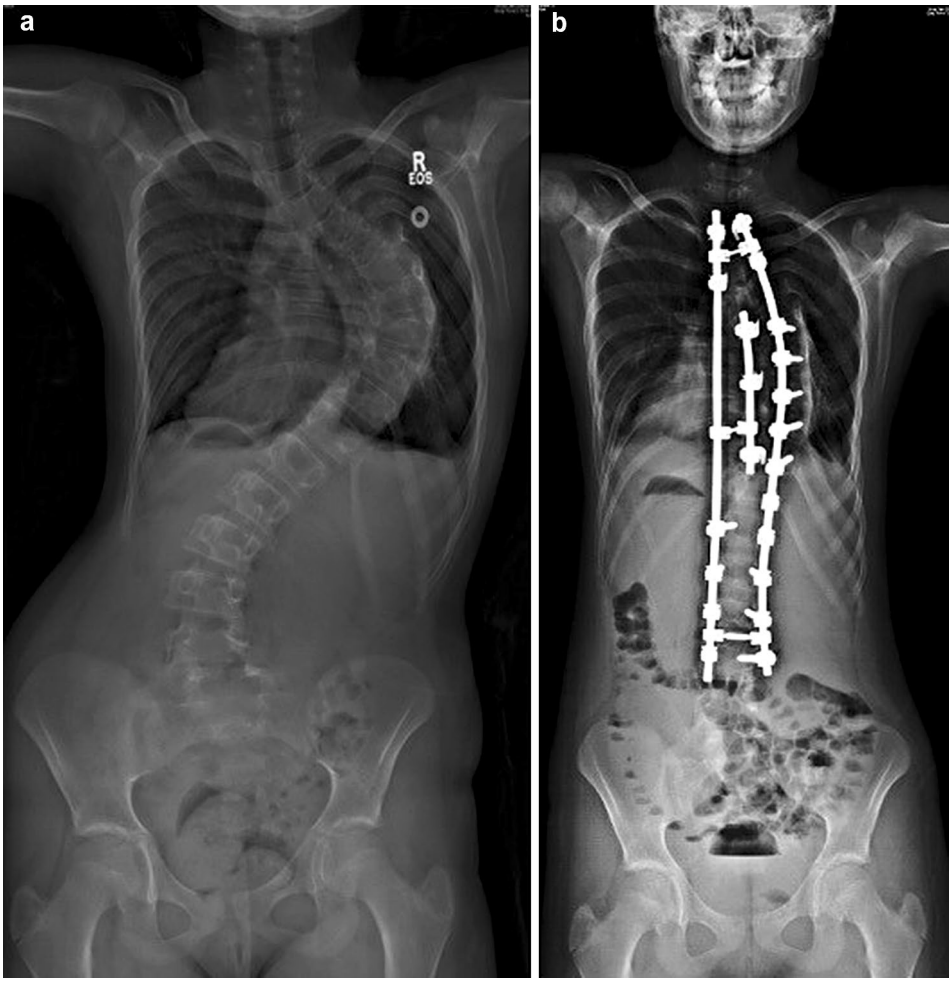

Fig. 1 The a pre operative anteroposterior and b post operative operative radiographs of a patient treated with the three-rod technique showing a thoriac curve of 110°

2% for an average correction of 61.2% [23]. A single surgeon, single institution 5 year review of vertebral column resections in a paediatric cohort of 31 patients with an average correction of 61.6% found that 5 (9.3%) of the patients experienced postoperative neurological deficits, and 7 (13.0%) required a revision by 5 years postoperatively [25]. These authors comment that despite the high rate of complications, patients experienced significant improvement in the Scoliosis Research Society (SRS) self-image and satisfaction domains.

An alternative to osteotomy is preoperative traction. This technique provides gradual improvement of the deformity, however, it important to view it as an adjunct to treatment, rather than as a definitive correction [26]. The evidence supporting the efficacy of preoperative traction is varied, with Sponseller et al. suggesting that the technique does not add to operative correction and Rinella et al. showing a 46% improvement in 33 patients treated for severe scoliosis [27, 28]. Unfortunately, preoperative halogravity traction is not without a 1% incidence of neurological complication and 16% incidence of pin site infection and loosening [6].

The role of anterior spinal fusion prior to posterior correction in patients who are skeletally immature in this cohort was to prevent crankshaft phenomenon rather than to aid in achieving correction. Our data shows that pre-emptive anterior fusion did not improve the final correction achieved, and comparing this sub-group with the rest of the cohort did not reveal any significant difference in the correction achieved. This is supported in the existing literature. Luhmann et al. and Dobbs et al. both carried out studies comparing pedicle screw posterior instrumentation alone with anterior release and posterior instrumentation, and showed that anterior release did not lead to a greater correction than posterior pedicle screw instrumentation alone [29, 30]. The anterior approach is associated with morbidity, extended surgical time and a reduction in pulmonary function postoperatively of at least 15%, and so it's use should be carefully considered on a case by case basis [31–33] (Fig. 2).

The 2014 checklist published by Vitale et al. and subsequently endorsed by the Scoliosis Research Society, explains that the resolution of intraoperative neuromonitoring changes centres on the removal of traction and corrective forces [34, 35]. The three-rod technique facilitates these

Fig. 2 The a pre operative lateral and b post operative lateral radiographs of the same patient seen in Fig. 1 treated with the three-rod technique

responses to changes in neuromonitoring signals and consequently addresses the risks of three-column osteotomy. The most common reasons for neuromonitoring changes during instrumented fusion are stretching of neural elements or compromise of the anterior cord circulation through overly ambitious correction [34, 36]. This is in contrast to the risks of osteotomy where changes in monitoring may be due to direct trauma to the cord, where the release of corrective force may not be possible because of the intentional instability brought to the spine. This series showed no neurological complications that necessitated revision surgery and no neurological deficits.

This study is limited by its retrospective nature, the varied aetiology of the curves, the limitations of the radiology and the absence of a comparable control group. The radiological assessment of severe curves is known to be limited by the rotational component of the deformity [37, 38]. The assessment of curve stiffness remains challenging in large deformities where bending views are impractical. Identifying a more homogeneous population to evaluate this technique may theoretically yield more refined results, however, it is impossible to have a valid cohort study in severe spinal deformity in children and adolescents as the characteristics of each condition vary widely between individual patients. Similarly, matching a control group to the cohort managed with this technique would be challenging and may introduce an additional source of heterogeneity. We do not have any data regarding the cosmetic outcome of the surgery; however, we suggest that patients may have some improved self-image, potentially due to an improvement in the thoracic contour after caused by the two concave rods which act as fillers. Despite this, this series represents more than 10 years of practice in a single institution by one surgeon and as such is a useful assessment of these uncommon cases.

Conclusion

The treatment of severe scoliosis has the potential to cause serious injury regardless of the techniques used to achieve correction. Our results show that the three-rod technique avoids some of these risks and is a safe and effective option to manage these deformities through being incrementally reversible at every stage to achieve and maintain a safe correction in contrast to osteotomy and halogravity traction.

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Compliance with ethical standards

Conflicts of interest None of the authors declare any competing interests of relevance to this work.

Ethics approval Institutional ethics approval was granted for this study no 1000053025.

Availability of data and material Data is made available through direct communication with the corresponding author.

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