European Spine Journal
https://doi.org/10.1007/s00586-019-06285-7

ORIGINAL ARTICLE

Useful and innovative methods for the treatment of postoperative coronal malalignment in adult scoliosis: the "kickstand rod" and "tie rod" procedures

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Received: 2 July 2019 / Revised: 21 November 2019 / Accepted: 31 December 2019

Abstract

Study design Surgical technique description and case series.

Objective To describe the use of two techniques for the correction of postoperative coronal imbalance after surgical treatment for adult spine deformity (ASD).

Summary of background data Sagittal and coronal spinal malalignments are often present in patients with ASD or in patients who have undergone spine surgery. Surgical correction of coronal imbalance is insufficiently investigated, and the literature provides a limited spectrum of surgical options when compared to sagittal imbalance. Nevertheless, this deformity can compromise the surgical outcome and can increase the risk of hardware failure.

Methods The kickstand (KR) and tie rod (TR) techniques utilize an accessory rod, linking the previous instrumentation to an independent iliac screw. After a proper release of the lumbar spine with anterior release or posterior osteotomies, the KR technique pushes with distraction on the concave side, whereas the TR technique pulls with compression on the convex side. Four patients (mean age, 64 years; SD 5.7) affected by severe postoperative coronal imbalance were treated. C7-PL ranges from 39 to 76 mm. The mean preoperative ODI was 70/100 (range from 55 to 82). All patients had previous spinopelvic fixation as a consequence of corrective surgery for adult spine deformity. The patients were surgically treated with the addition of supplementary rods connected to the ilium. The rods were used in the concavity or convexity of the deformity functioning as "kickstand" or "tie" or a combination of both.

Results The mean surgical correction of C7-PL was 35 mm (range from 20 to 52 mm). In particular, the mean correction for kickstand rod technique was 26 mm and for tie rod technique was 43 mm. All of the patients improved their preoperative disability, and mean ODI was 30/100 (range from 10 to 60) at median 19-month follow-up. All postoperative imaging showed implants were in proper position without hardware failure. All of the patients treated demonstrated an immediate

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-06285-7) contains supplementary material, which is available to authorized users.

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Published online: 06 January 2020

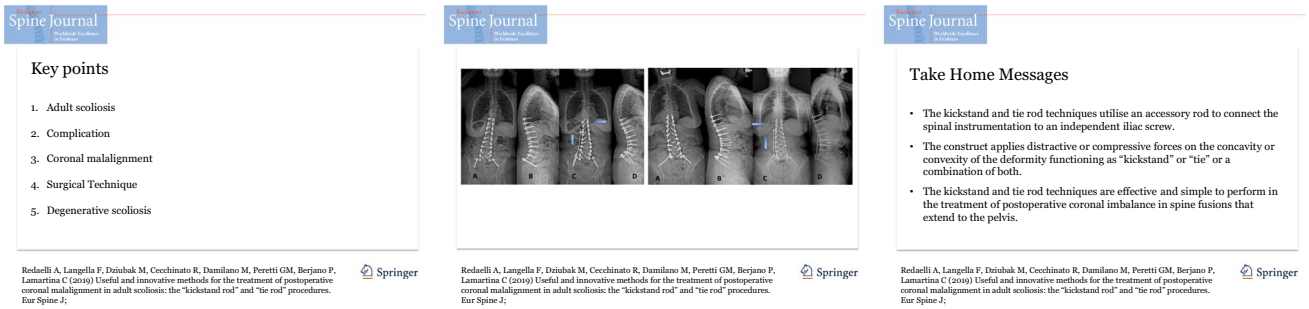
postoperative improvement in terms of coronal displacement of the spine. No complications were observed. At 1-year follow-up, all of the patients remained satisfactory in terms of clinical outcomes.

Conclusion The kickstand and tie rod techniques are effective in the treatment of postoperative coronal malalignment. Further studies are needed to confirm these findings.

Level of evidence V: Case report.

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.



Keywords Adult spinal deformity · Adult scoliosis · Complication · Coronal imbalance · Coronal malalignment · Surgical technique

Introduction

In adult spinal deformity (ASD), the occurrence of coronal and sagittal imbalance has been comprehensively investigated in past decades. Both kinds of deformity influence the preoperative and postoperative clinical outcomes [1, 2]. Coronal malalignment (CM) is defined as the lateral displacement of the C7-PL (C7 minus plumbline) more than 4 cm from the central sacral vertebral line (CSVL) [3–5]. It can be the result of infection, tumor, trauma or neurological disease. CM can even be caused by extraspinal conditions, such as anatomical limb length discrepancy. Patients with preoperative convex CM have been found to have a higher risk of postoperative persistence or worsening of the CM [6]. Ploumis et al. [3] found that while sagittal malalignment was consistently reduced in patients after long segment fusions for ASD, CM did not change from preoperative to early postoperative period for 60% of patients. 9% of patients without preoperative CM even showed new onset CM postoperatively.

CM often presents with adjacent segment disease and hardware failure in multiple revision cases [7]. It is related to unsatisfactory results, back pain, poor functional outcome and alteration of self image, even when its correlation with quality of life has not been as well investigated as for sagittal deformity [8, 9]. In patients undergoing surgery for ASD, Koller et al. [10] found that postoperative CM was associated with worse clinical outcomes. CM that is moderately severe is poorly tolerated by many patients, especially when the spine is fused or is associated with sagittal malalignment [11].

The treatment of CM of the spine depends on its etiology. Pisa syndrome caused by Parkinson's disease and other atypical neurodegenerative disorders present as a flexible and reversible alteration in the coronal alignment of the spine that often improves with proper pharmacological treatment [12, 13]. Conversely, CM due to spinal diseases or following previous surgeries is a stiff deformity that alters the spine in both standing and laying position. Recently, Obeid et al. [11] proposed a treatment-oriented classification depending on the pattern of CM, concave or convex, to help the surgeon optimize the therapeutic strategy in ASD patients.

The surgical treatment of CM is often challenging when the spine has associated sagittal imbalance. In a vast majority of cases, it represents a complication of a previous failed surgery. Asymmetrical osteotomy is a valuable option for the correction of coronal imbalance but is associated with considerable complications, especially in revision surgery [5, 14]. Another option is the implant of interbody cages to realign the foundation of the fusion [15, 16]. However, in case of a long fusion that includes the sacrum or the pelvis with coronal imbalance, these two techniques have been shown to have disadvantages. Asymmetrical osteotomies, the gold standard, are often applied on previous fusion mass or severe deformity. This procedure becomes technically demanding and often related to the risk of pseudarthrosis, dural tear, neurological impairment and hardware failure [17]. Otherwise, the correction with cages relies on intervertebral disks opening up asymmetrically to restore normal coronal

alignment. The optimal correction is difficult to achieve with interbody cages distally to a long fusion mass due to a disadvantageous lever arm. Part of the energy of correction is dissipated along the spinal curve. In 2018, Makhni et al. [18] described the use of a kickstand rod in one adult case report to aid in correcting coronal deformity, demonstrating the feasibility of the technique.

We analyze the results of the kickstand technique in a small group of patients and describe a variation of this (the tie rod technique) for the correction of coronal malalignment in patients with previous spinopelvic fusion. Furthermore, we present a consecutive case series of patients that have undergone revision surgery for post-surgical coronal malalignment with a combination of these methods.

Surgical technique

The preoperative planning is mandatory to have an accurate assessment of the deformity in coronal and sagittal plane [19, 20]. The PI-LL mismatch (pelvic incidence minus lumbar lordosis) was used to establish the absence of sagittal malalignment [21]. In case of primary surgery as well as revisions, the surgeon can decide to address the deformity with anterior or posterior techniques in order to achieve the correct alignment. In cases with insufficient lumbar lordosis, we performed the tie rod (TR) technique. On the contrary, in cases with excess of lumbar lordosis, we performed the kickstand rod technique (KR). Under general anesthesia, with the patient in prone position, a midline longitudinal incision is made to expose the previous fusion area. The iliac crest is then exposed for insertion of a screw, and a single open domino connector is placed at the level of thoracolumbar junction. A rod is then placed in between without being locked. The connector applied near the thoracolumbar junction is used to perform the corrective maneuvers by distraction or compression of the accessory rod on it, due to the advantageous lever arm of the connector in this position. The set screws are released in the lower part of the previous fixation. If necessary, facet joint arthrectomies, posterior column osteotomies (PCOs) or three column osteotomy (3CO) can be performed during this phase in order to achieve the sufficient spinal release to correct the deformity [5, 22, 23]. Then, the accessory rod is distally locked. Distractive (kickstand) or compressive (tie) maneuvers are applied on the accessory rod and locked. Under radiographic control, the coronal correction is checked. This final procedure is performed with the help of a 90° cross-shaped tool placed on the superior border of the iliac crests and centered on S1. The cranial portion of this tool allows the surgeon to evaluate the coronal displacement of the C7 spinous process. Once the ideal correction is reached, all of the set screws are locked. Closure of the muscle, subcutaneous tissue and skin are performed in usual manner. No postoperative brace was used, and the patients were encouraged to stand and walk in first or second postoperative day.

Demographics, preoperative clinical and radiographic data are summarized in Table 1. Immediate postoperative radiographic results and amount of surgical correction are described in Table 2. Furthermore, clinical outcome and occurrence of complications were collected at a minimum of 12-month follow-up.

Case examples 1 and 2: tie rod technique

Case 1

Patient

A 68-year-old female (159 cm, 75 kg) with a history of multiple spine surgeries for adult spine deformity. When the patient was admitted, she was suffering from severe back pain limiting the quality of life. The preoperative radiographic examination showed a severe coronal imbalance on the convex side (76 mm) associated with pseudarthrosis and hardware failure (rod breakage). Radiographs are shown in Fig. 1. The coronal deformity was classified as Type 2 according to Obeid et al. [11].

Previous surgeries

In 2012, the patient had undergone T2-L5 fusion. Postoperatively she suffered from surgical site infection and proximal junctional kyphosis. In 2013, a revision was performed with extension to T1 and ilium. In 2014, interbody fusion was performed at levels L1–L5 and two supplementary rods were inserted. In 2015, cranial extension to C7 was performed for proximal junctional kyphosis.

Surgery

In November 2016, the patient underwent surgical revision for coronal imbalance and C7-ilium arthrodesis with L5-S1 ALIF (anterior lumbar interbody fusion) and simultaneous kickstand and tie rods. In this case, both the methods provided a complementary action on coronal correction.

Follow-up

The patient was discharged after 9 days without surgical or general complications. The immediate postoperative radiographs showed restoration of both coronal and sagittal alignment. At 25-month follow-up, no sign of implant failure or loss of correction was observed and the clinical outcome was improved.

Table 1 Baseline demographics, preoperative radiographic and clinical outcome parameters

Patient #	Gender	Age	Previous procedures[a]	Fusion area	C7-PL (mm)	CM pattern	ODI pre-op	VAS back Pre-op	ODI 1 year FU	VAS back 1 year FU	Surgery duration (min)	Estimated blood loss (ml)
1	F	68	4	C7-ilium	76	Type 2	75	5	60	3	500	1500
2	F	64	2	T10-ilium	40	Type 1	71	10	20	3	60	70
3	F	56	4	T5-ilium	55	Type 1	55	6	10	2	160	250
4	F	68	4	T10-ilium	44	Type 2	82	3	12	1	80	100

[a]Number of previous surgical spine procedures in the patient's history; C7-PL: C7-plumbline; CM pattern: type of coronal malalignment according to Obeid et al. classification, Type 1 (concave CM) and Type 2 (convex CM); ODI: Oswestry Disability Index; VAS back: Visual Analog Scale back pre-op and at 1-year follow-up, surgery duration and estimated blood loss at the index procedure

Case 2

Patient

A 64-year-old female (160 cm, 58 kg) with a history of previous surgery for disk degenerative disease. The patient was admitted with severe low back pain and coronal and sagittal imbalance. On preoperative radiographic evaluation, she demonstrated a sagittal (> 150 mm) and coronal (40 mm) malalignment on the convex side with Type 1 CM (Fig. 2).

Previous surgeries

In 2014, the patient had undergone L2-L5 fusion for disk degenerative disease. In July 2017, the patient had been treated with T10-ilium arthrodesis with L5-S1 ALIF and L4-L5 XLIF for sagittal correction.

Surgery

In July 2017, with the evidence of residual CM, the patient underwent a revision. One supplementary rod was placed on the convex side, working in compression, utilizing the tie rod technique.

Follow-up

The patient was discharged after 10 days. No intraoperative and perioperative complications occurred. The immediate postoperative radiographs showed that the implant was in proper position with reduction of coronal malalignment. At 17-month follow-up, no surgical complication or implant displacement occurred.

Case examples 3 and 4: kickstand rod technique

Case 3

Patient

A 56-year-old female (167 cm, 60 kg) with a history of three previous spine surgeries for idiopathic scoliosis, persistent low back pain and coronal and sagittal imbalance. At the time of hospital admission, the radiographic examination showed 55 mm of coronal imbalance on the concave side, Type 1 CM (Fig. 3).

Previous surgeries

In 2002, spinal arthrodesis was performed from T4 to L4. In 2007, hardware was removed, resulting in progressive

Table 2 Preoperative and postoperative radiographic parameters

Patient #	PI (°)	C7-PL (mm)		LL (°)		SVA (mm)		PI-LL (°)	
		Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op	Pre-op	Post-op
1	49	76	24	38	55	− 26	− 100	11	− 6
2	54	40	6	54	63	52	10	0	− 9
3	52	55	35	66	62	12	− 11	− 14	− 10
4	50	44	12	58	55	22	30	− 2	− 9

PI pelvic incidence; *C7-PL* C7-plumbline; *LL* lumbar lordosis; *SVA* sagittal vertical axis; *PI-LL* mismatch between pelvic incidence and lumbar lordosis

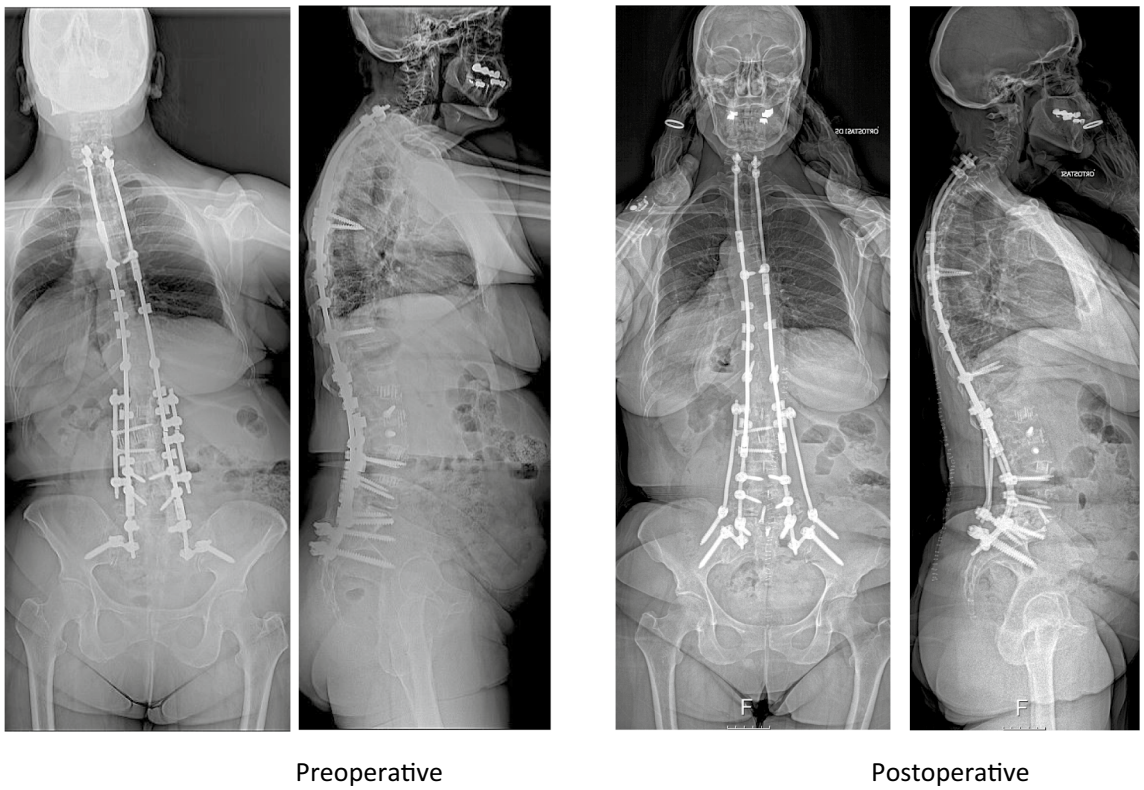


Fig. 1 Case #1. This is a case of Type 2 CM. Simultaneous kickstand rod (on the concavity) and tie rod (on the convexity) techniques have been performed. Both the methods provided a complementary action on coronal correction. C7-PL and lumbar lordosis were improved preoperatively to postoperatively from 76 to 24 mm and 38° to 55°, respectively

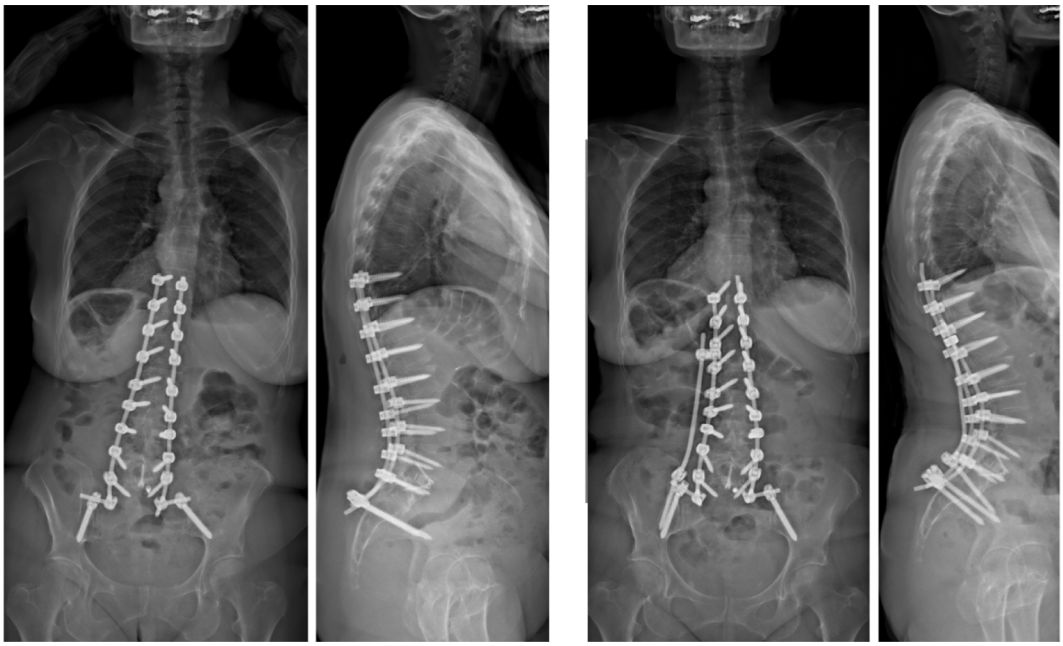
sagittal and coronal imbalance. In November 2016, two-stage surgery with L3-ilium percutaneous fixation and L5-S1 ALIF was performed, but insufficient sagittal correction was achieved. In 2017, L4 pedicle subtraction osteotomy (PSO) plus cranial extension to T5 was performed and two satellite lumbar rods inserted. Full correction of sagittal malalignment was achieved, but new coronal imbalance presented.

Surgery

In July 2017, 2 weeks after the three column osteotomy, the patient underwent revision with one supplementary distraction rod (kickstand rod) implanted on the concave side. Complete correction of coronal imbalance was not performed in order to avoid worsening of shoulder imbalance.

Follow-up

The patient was discharged after 6 days. The immediate postoperative radiographs showed the reduction of the coronal malalignment with modest right shoulder elevation. The final alignment was acceptable to the patient. At 17-month follow-up, the patient had a significant improvement of the clinical outcome and no further revision was necessary.



Preoperative Postoperative

Preoperative Postoperative

◂**Fig. 2** Case #2. This is a case of Type 1 CM. Tie rod technique has been performed on the convexity. C7-PL was improved from 40 mm preoperatively to 6 mm postoperatively. Lumbar lordosis was increased from 54° to 63° due to compression on the convexity

Case 4

Patient

A 68-year-old female (165 cm, 73 kg) with a history of four previous surgeries. She presented with low back pain, bilateral lower limb pain and coronal imbalance. She was only able to mobilize with the aid of two crutches. The preoperative radiographs showed a coronal imbalance of 44 mm on the convex side and were classified as Type 2 CM (Fig. 4).

Previous surgeries

In 2007, the patient had undergone L4-L5 arthrodesis for de novo scoliosis. In 2011, a cranial extension to L3 was performed for adjacent segment disease. In 2015, a lateral interbody fusion at L2-L3 and a L1–L4 posterior fusion were performed. In 2017, cranial and caudal extensions of the arthrodesis were carried out from T10 to ilium with L5-S1 ALIF for sagittal imbalance.

Surgery

In July 2017, the patient underwent T10-ilium revision with one supplementary rod on the convex side, working in distraction (kickstand rod). At the same time, right L5 screw was removed because it caused a symptomatic radiculopathy.

Follow-up

The patient was discharged after 10 days without complications. The immediate postoperative radiographs showed excellent coronal balance at 11 mm. At 17-month follow-up, the patient had improvement in back pain and was able to walk without any aids. She did not need further surgical revision.

Discussion

We describe and discuss the efficacy of a combination of techniques for the correction of postoperative coronal malalignment. The "kickstand" or "tie" rod correction techniques were used in revision cases for fixed coronal malalignment. The surgical procedures were able to improve and maintain the coronal deformity in all cases.

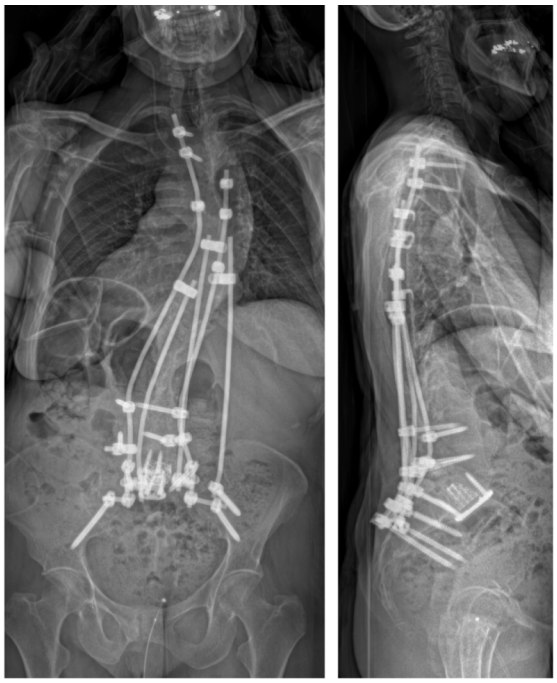
The KR and TR techniques share some principles with Harrington instrumentation system that relied on distraction of the spine with hooks attached to rod [24]. Moreover, the inclusion of the ilium in the instrumentation to achieve major stability and correction power relies on the Galveston technique popularized by Allen and Ferguson in the 1980s [25]. Their intuition has allowed us to address the issue of lumbosacral fusion and paved the way for modern instrumentation techniques.

The KR technique has been previously described [18], but the description was based on a single case. In this paper, we confirm with a small case series of four patients the efficacy of the KR technique. At the same time, we present a useful variation, calling it the TR technique. Furthermore, we discuss the relative advantages of each and suggest in which specific scenarios the surgeon might prefer one or another (or their combination). All the patients obtained substantial correction of the coronal malalignment and had no complications at last follow-up. There were no mechanical failures.

Both the KR and TR techniques, once the release of the spine is achieved, are relatively easy to perform, requiring minimal extra instrumentation and time. Though we used these techniques for the early correction of postoperative coronal malalignment, there is no reason to prevent surgeons from using them in primary surgery or in late correction of postoperative coronal malalignment. In case of early postoperative coronal malalignment, it is quite easy to correct the deformity with kickstand or tie rod since the spine is still mobile and additional release is likely not required. In the second case (late corrections, stiff primary deformity or even insufficient mobility in early postoperative cases), the surgeon must ensure that at least one part in the lumbar spine is mobile in order for the correction to occur. This can be obtained by posterior column releases such as arthrectomies (in case of persistence of a mobile disk at the level of the correction), by posterior column osteotomies (PCOs) or by more aggressive three column osteotomies (3CO). More technical details on releases have been provided in previous publications [11].

While KR and TR techniques are conceptually similar, their effect on lumbar sagittal alignment differs. The axis of the supplementary rod is posterior to the axis of the spine. Thus, distraction on the supplementary rod (KR technique) causes decrease in the lumbar lordosis, whereas compression (TR technique) causes increase in the lumbar lordosis. This information can be used by the surgeon in order to fine-tune the lumbar lordosis when coronal correction is needed. Patients with coronal malalignment who need an increase in lumbar lordosis would be better corrected with compression (TR technique), while those with overcorrection of positive sagittal malalignment in the lumbar spine would benefit from the application of distraction (KR technique). When the combination of the two techniques is applied, the surgeon can perform greater compression if an increase in lordosis is needed (in this case the compressive maneuver would be

Preoperative



Postoperative

Preoperative

Postoperative

◂**Fig. 3** Case #3. This is a case of Type 1 CM. The kickstand rod placed in the concave side of the lumbar coronal deformity acts in distraction. Due to the presence of complete fusion of the whole thoracic spine, complete correction of the coronal imbalance in the lumbar spine would have caused severe shoulder imbalance. Thus, the surgeon chose a partial correction of coronal imbalance which provided the patient with both acceptable coronal and shoulder balance. As a result of the concave distraction technique, C7-PL was improved from 55 to 35 mm and lumbar lordosis was decreased from 66° to 62°

applied first) and vice versa if the patient presents with coronal malalignment and excessive lordosis in the lumbar spine. In case of coronal malalignment without any sagittal malalignment, the surgeon must take care to not alter the correct amount of lumbar lordosis: the simultaneous use of KR and TR provides a complimentary action on coronal correction, while the effect of distraction and compression on sagittal alignment is reciprocally neutralized. Moreover, when the correction of coronal alignment has modified the normal sagittal profile, the surgeon can adjust it by acting with compression/distraction at the osteotomy level and between set screws previously released. The two techniques can also provide additional stability, with previous literature supporting the use of multi-rod constructs in enhancing the stability of the spine, preventing implant failure and pseudarthrosis [26, 27]. They can potentially be performed on patients of different ages. Our findings confirm the expectations of previous authors with the use of the technique [18].

Coronal imbalance due to limb length discrepancy needs special consideration: functional limb length discrepancy due to spinal deformity is improved by correction of the primary spinal deformity [28]. In most cases of coronal spinal malalignment with anatomical limb length discrepancy, the treatment of choice is correction of the spinal coronal is made to bring the spine orthogonal to the pelvis, followed by correction of the limb length discrepancy at the limbs (with a heel rise or foot orthosis, or in selected cases by surgery on the limbs). In some cases (where the discrepancy is anatomical and correction at the limbs is not possible or accepted), the spinal coronal alignment may be brought to a sacral vertical line in standing position (not perpendicular to the bi-iliac line).

This study has limitations. The numbers are small; thus, complications might be underestimated and factors influencing the success or failure of the techniques cannot be fully explored. The demographic of the patients treated is limited, with effects of gender and age unable to be determined. It is a retrospective study, and some information might be underreported in the clinical chart, although major complications are usually well documented. The time of follow-up is modest, and mechanical complications over the mid or long term could have been missed. The techniques described require the ilium to be included in the fusion and therefore not suitable for procedures where the pelvis is spared. Finally, it is important to understand that KR and TR are two innovative

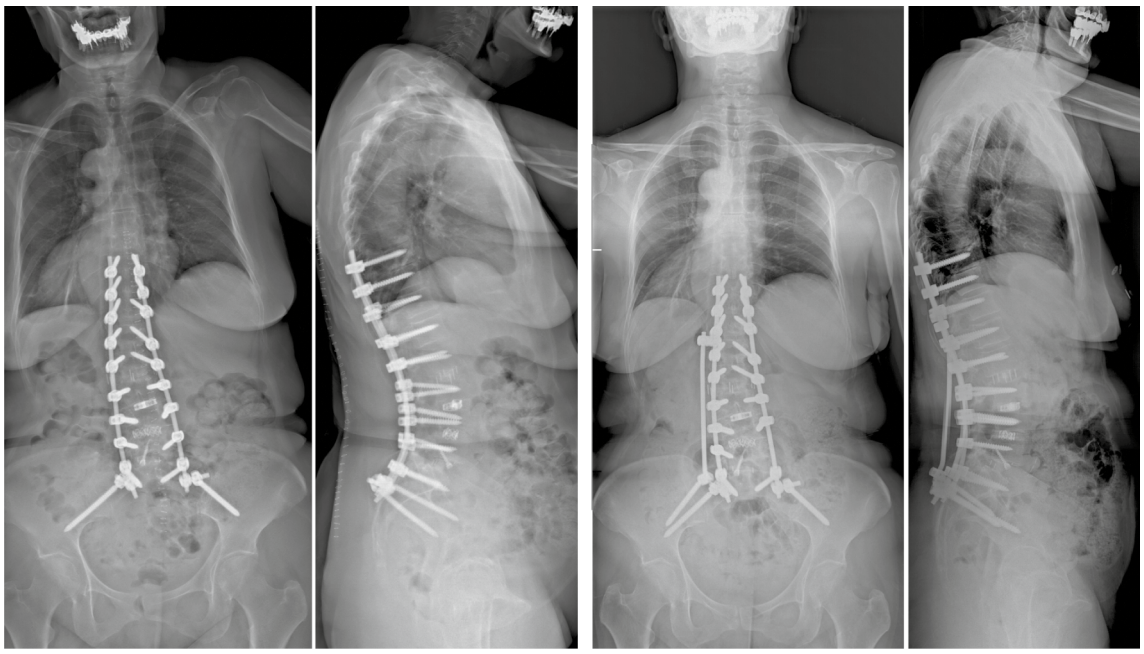


Fig. 4 Case #4. This is a case of Type 2 CM. The kickstand rod technique, working in distraction, has been performed on the concavity. Coronal alignment was improved from 44 to 12 mm (C7-PL), while the lumbar lordosis was decreased from 58° to 55° with no significant change in sagittal profile

and useful ways to correct residual coronal malalignment in adult spinal deformity. However, often, especially in severe cases, prior aggressive and complex procedures must be performed to achieve the appropriate correction.

Further studies are needed to confirm the various findings.

Conclusion

The kickstand and tie rod techniques are effective and useful to perform in the treatment of postoperative coronal imbalance in spine fusions that extend to the pelvis. The choice of the specific technique or their combination depends on surgeon's preference and on the specific targets of lumbar sagittal alignment.

Acknowledgements We thank Alvin Pun, M.D. (Austin Health, Melbourne, Australia), for his assistance in language correction of the manuscript.

Funding None.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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