



Domino connector for thoracic pedicle subtraction osteotomy reduction: surgical technique and patient series

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Abstract

Purpose Different techniques have been previously described to close the pedicle subtraction osteotomy (PSO) site for correction of sagittal malalignment; the use of a side-to-side domino connector as a correction tool in the thoracic spine has not been specifically studied.

Methods Twenty adult patients who underwent single-level thoracic PSO from T1 to T12 were included and retrospectively reviewed (two centers). Preoperative and postoperative full-body X-rays, perioperative data, clinical data and complications were recorded with a minimum 2 years of follow-up. Surgical technique and the nuances in using the domino connector were described in detail.

Results Patients had a mean age of 40y; 40% were female. Two different techniques involving the domino were applied for closure of the PSO site depending on the type of kyphosis (smooth vs. angular deformity). Both techniques provided significant correction of the local kyphosis (from 48° to 18°) with reciprocal reduction of compensatory cervical lordosis (from 37.6° to 18.6°, $p < 0.01$) in upper thoracic PSO or lumbar lordosis (from 74.5° to 46.6°, $p < 0.01$) in lower thoracic PSO. Four patients presented postoperative complications that resolved (hemothorax, GI bleeding), and two patients presented transient neurological deficit. Oswestry Disability Index score improved in the majority of the patients (from 32.7 to 22.5, $p < 0.05$). There were no pseudarthroses, symptomatic instrumentation breakage, or surgical site infection.

Conclusion Use of a side-to-side domino connector in combination with two different rod cantilever techniques is effective for the reduction of thoracic pedicle subtraction osteotomy achieving satisfactory radiological and clinical outcome.

Keywords Domino connector · Pedicle subtraction osteotomy · Sagittal alignment · Thoracic kyphosis · Adult spinal deformity

Introduction

Pedicle subtraction osteotomy (PSO) or three-column osteotomy has been commonly used during the past two decades as an efficient technique for the management of severe spinal deformities including ankylosing spondylitis, posttraumatic kyphosis and postoperative flatback [1, 2]. It was initially described for the lumbar spine [3], but progressively was applied to all vertebral levels in the thoracic spine and lower cervical area, gradually replacing the classical combined

approach where the association of an anterior release and a posterior instrumented fusion may lead up to a 32% perioperative complications rate [4–6]. Closing the posterior osteotomy wedge is a key step during surgery in order to achieve the best correction possible and avoid non-union and mechanical complications. Different techniques have been described in the literature to close the PSO site [7–9]; however, none of them focused specifically on thoracic osteotomies where the area is well known for its higher risks of complications given the presence of the spinal cord [10, 11]. In fact, any cord buckling or kinking during the reduction maneuvers may cause neurological damage; therefore, closure of the PSO site should be as smooth and progressive as possible.

The side-to-side domino connector is frequently used in spine surgery, mainly in revision cases, such as adjacent syndromes, in order to avoid removing previously inserted

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constructs and connect new rods to old ones, thus limiting the invasiveness of the procedure; or it can be used in adult spinal deformities when a multiple rods construct is applied. However, the use of a side-to-side domino connector as a correction tool for thoracic PSO has not been previously studied.

The objective of the current study was to report the surgical specificities and assess the clinical and radiological outcomes of using the domino connector for thoracic pedicle subtraction osteotomy reduction and site closure.

Our hypothesis is that the use of a side-to-side domino connector in different ways would improve thoracic PSO closure, deformity correction and spinopelvic compensatory mechanisms.

Materials and methods

Study design: This is a retrospective review of a prospective adult spinal deformity database collected from two centers. Data from consecutive cases involving patients who underwent thoracic PSO with a minimum follow-up of 2 years were obtained. Patients who presented with a severe and rigid thoracic or thoracolumbar hyperkyphosis were included in the study. All of them presented intractable back pain related to the deformity or to its compensatory mechanisms at the level of the neck or lower back, where conservative treatment including analgesia and physiotherapy failed. Thoracic PSO was carried out when posterior column osteotomies were not feasible from the lack of curve flexibility. Surgical technique and the nuances in using the domino connector were described in detail.

Full-spine standing anteroposterior and lateral radiographs were made, and the different radiological parameters that were assessed preoperatively, at 6 months and at the last follow-up after the index surgery included sagittal vertical axis (SVA: distance between the C7-plumb line and posterior superior margin of S1), global tilt (GT: angle formed by the intersection of two lines: the first line is drawn from the center of C7 to the center of the sacral endplate and the second line is drawn from the center of the femoral heads to the center of the sacral endplate), pelvic incidence (PI), pelvic tilt (PT), local kyphosis (angle between the inferior endplate of the osteotomized vertebra and the superior endplate of vertebra above the osteotomized vertebra), lumbar lordosis (LL), thoracic kyphosis (TK) and cervical lordosis (C2C7). Angles were considered negative if lordotic and positive if kyphotic. Supine lateral X-rays with the patient positioned over a bolster were performed for all patients to assess the rigidity of the kyphosis. Oswestry Disability Index (ODI) scores were collected at baseline and 2 years of follow-up.

Surgical technique

Installation: for upper thoracic PSO, the patient was placed in a prone position with the head fixed in a Mayfield frame (Integra LifeSciences™, Plainsboro, New Jersey). Because of the upper kyphosis, the thoracic bolster is placed slightly more distally to accommodate the shape of the proximal thoracic spine. In addition, the head position will most likely lie below the level of the chest so adequate space beyond the head and below the face is important, which may be helped by a slight reverse Trendelenburg position.

For lower thoracic PSO, the installation remains classical with no need for a Mayfield frame.

Multimodal intraoperative neuromonitoring was used during the whole procedure. After posterior approach was done, midline paravertebral exposure and facetectomies were performed. Pedicle screws were mostly inserted using the free-hand technique; however, for upper thoracic PSO, navigation was used for screws insertion in the proximal thoracic and cervical pedicles given their difficult configuration related to the severe kyphosis. Posterior aspect of the ribs at the level of the osteotomized vertebra was exposed as to remove 5 cm of the rib (including the rib-head) on each side. This allows good visualization of the vertebral body's lateral walls which are exposed with a sharp Cobb dissector, and a cellulose mesh (Surgicel™) was applied to the segmental vessels. Two complete foraminotomies both cephalad and caudad to the pedicles on both sides were made; this enabled surrounding of the pedicles. Both pedicles were then removed exposing the posterior wall of the vertebra, and the nerve roots above and below were identified. After retraction of the lower nerve root, two osteotomes were placed above and below each pedicle, the distal cut is made immediately below the pedicle directed toward the upper endplate slightly anterior to its midline in the posterior–anterior plane, and the proximal cut is just above the inferior endplate of the cephalad vertebra, therefore including the disk above the osteotomy level (grade 4c osteotomy [12]). Cancellous bone was removed in a wedge fashion from posterior to anterior on both sides, and the posterior wall was removed with an up angled pituitary rongeur.

For the correction technique, and depending on the severity of the deformity, two techniques using the domino connector could be applied:

- **Single-block cantilever and compression:** two precontoured cobalt chrome rods connected by a domino in a single construct are fixed in the proximal screws with firm tightening of the setscrews, and then, cantilevering of the spine is performed by pushing the distal part of the construct inside the distal screws which can be done by applying direct downward pressure on the rod with a rod holder or sequentially with reduction towers (Fig. 1a, b). Once the rod is inserted distally, setscrews are tightened. Further closure of the osteotomy by compression with

the use of the domino is then applied, where one side of the domino is loosened and compression is performed between the edge of the domino and the closest screw belonging to the rod that was released inside the domino (Fig. 1c). This enables progressive telescoping of the latter rod inside the domino leading to a simultaneous compression between the two rods through the domino where each one is strongly connected to its screws; therefore, the maneuver is equivalent to applying a simultaneous

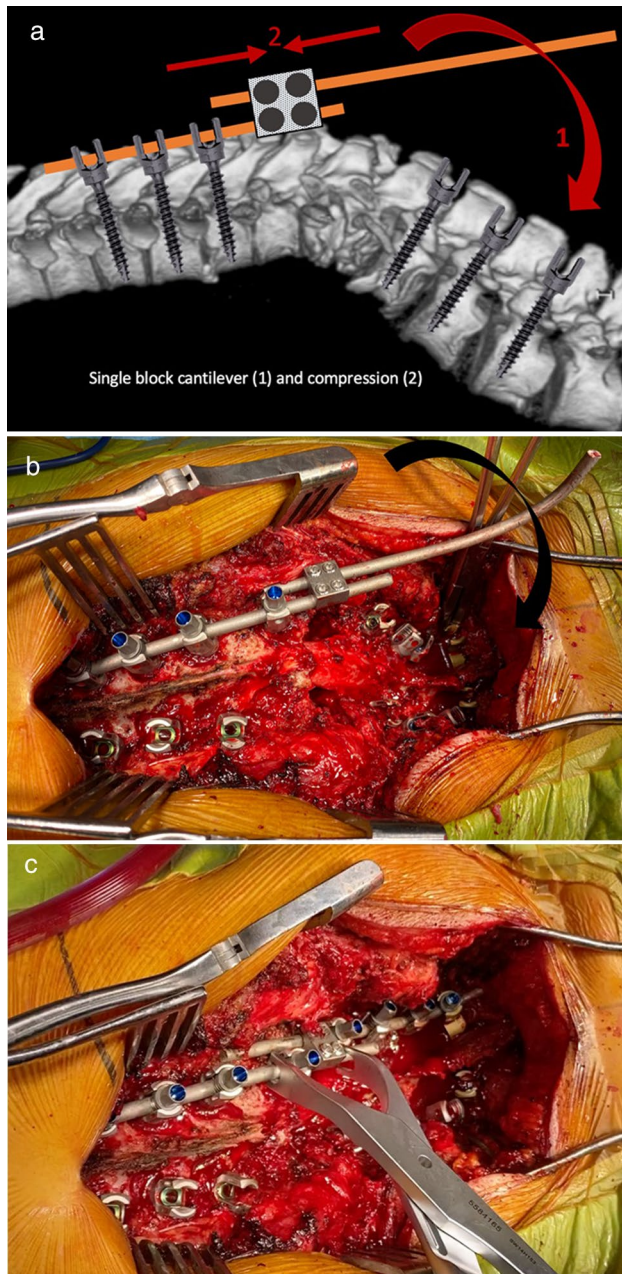


Fig. 1 Schematic illustration of the single-rod cantilever and compression technique (a). Intraoperative images showing the technique (b) with compression through the domino (c)

compression between all the proximal screws and all the distal screws at the same time but without overstressing them or compromising their stability inside the pedicles. The same compression maneuver can be repeated on the other side of the domino with the same principles. The domino is then completely locked. Intraoperative lateral fluoroscopic images demonstrating the closure of the osteotomy site after compression through the domino are illustrated in Fig. 2a, b. Immediate postoperative CT scan confirming the latter finding is shown in Fig. 2c.

- Double-block cantilever and compression, for more severe deformities: two precontoured cobalt chrome rods are applied separately across the PSO site, each one on one side of the osteotomy with the domino connector being on the extremity of one of the rods. After firm tightening of the setscrews on each rod, cantilevering of the two spinal blocks is applied by downward pressure on the two rods with the rod holders in order to make them meet at the domino level and insert the free rod in the free side of the domino (Fig. 3a). This gesture may be difficult in case of severe kyphosis and could be facilitated by progressive bending of the rod with in situ benders to enable progressive rod insertion inside the domino (Fig. 3b). Once the domino is connected to both rods, further compression may be applied with the same principles mentioned in the previous paragraph (Fig. 3c).

In case of upper thoracic osteotomy, reduction is associated to a simultaneous external maneuver where an experienced operator outside the surgical field maintains the Mayfield frame as it is progressively loosened from the table attachments. He then extends the head and neck to create closure of the osteotomy, while the rods are being applied at the osteotomy site. Combined external and internal maneuvers lead to a smooth correction avoiding spinal cord trauma and neurological impairment. Once correction is achieved, the Mayfield frame is fixed in place.

The bone-on-bone contact at the osteotomized level was checked, and the spinal cord was carefully controlled as kinking could occur in case of important reduction, which should warrant great attention to any neuromonitoring signal change that would guide the surgeon for eventual correction release. This was followed by classical decortication and wound closure.

Compression on the convex side of a coronal deformity may allow for an asymmetrical closure leading to simultaneous correction of both sagittal and also coronal planes (Fig. 4).

Postoperatively, in case of upper thoracic PSO, a Philadelphia cervical collar was worn for 3 months, whereas in

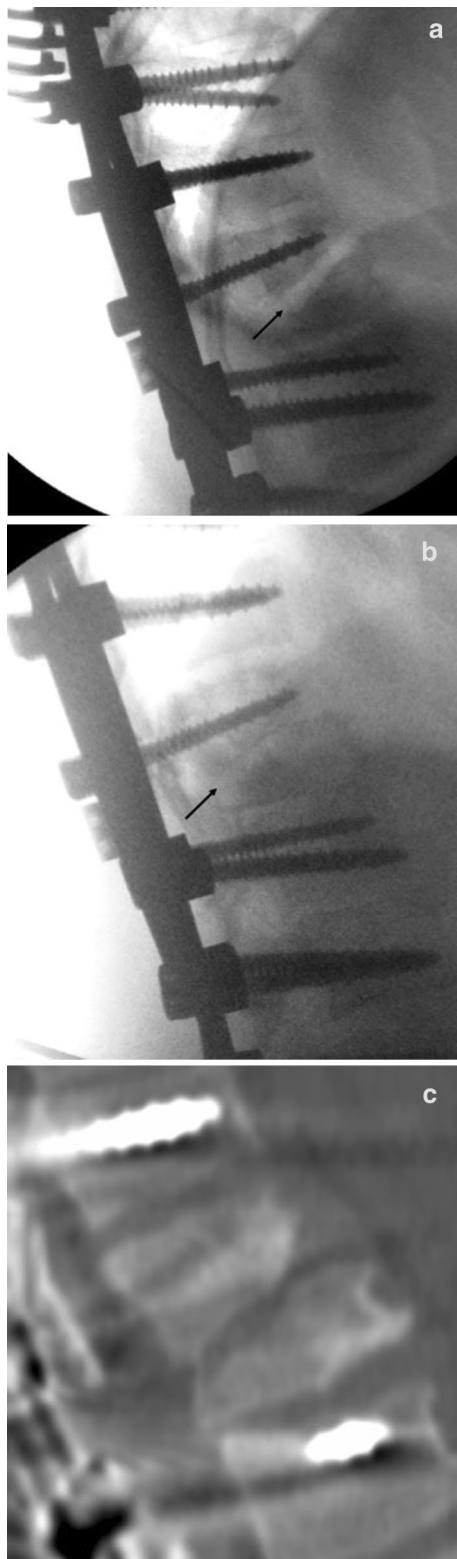


Fig. 2 Intraoperative lateral fluoroscopic images demonstrating the closure of the osteotomy site after compression through the domino (a and b, arrow). Postoperative lateral CT scan confirming the osteotomy closure (c)

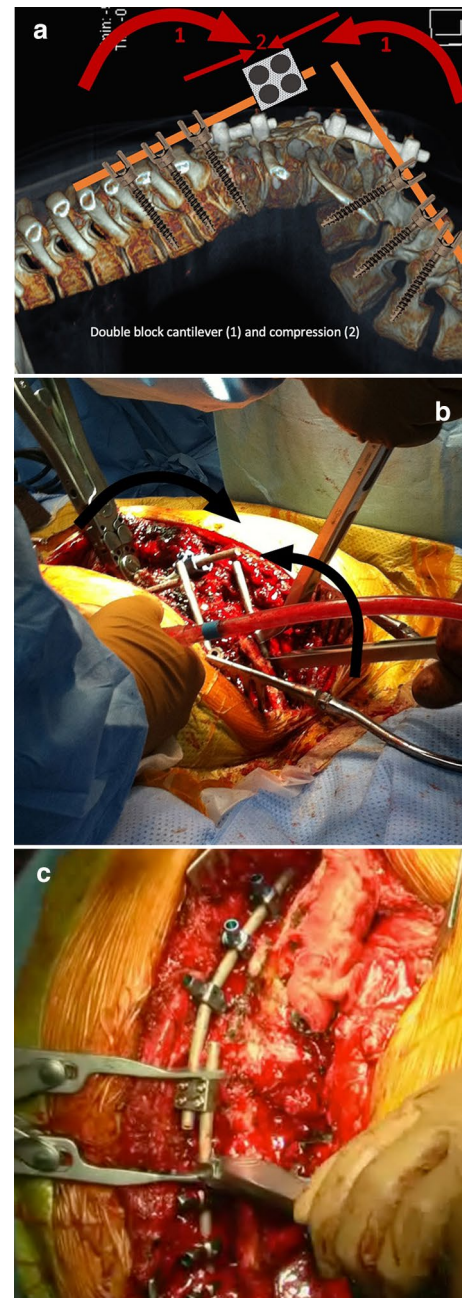


Fig. 3 Schematic illustration of the double-rod cantilever and compression technique (a). Intraoperative images showing the technique (b) with compression through the domino (c)

case of lower thoracic PSO, a thoracic lumbar orthosis was kept for 3 months.

Demographics, surgical and radiological data were evaluated using descriptive statistics of means and standard deviations (SD). No patient was lost for follow-up. Frequency analysis was used to report the incidence of complications. Pre- and postoperative parameters were compared using the Student’s paired t test for continuous variables. In addition, correlation analyses between the parameters were evaluated

Fig. 4 Full-spine anteroposterior and lateral X-rays of a 43-y-old patient with congenital thoracolumbar kyphoscoliosis (**a** and **b**). Post-operative full-spine X-rays after T12 pedicle subtraction osteotomy and the use of the single-rod cantilever and compression technique on the right side with satisfactory correction in both planes (**c** and **d**)

using the Pearson coefficient. $p < 0.05$ was considered statistically significant.

Results

Twenty patients were finally included with a minimum follow-up of 2 years. The average age was 40 (range, 17–69), and 8 out of 20 (40%) had previously undergone surgery at a directly related level. Thoracic or thoracolumbar kyphosis was secondary to various pathologies including proximal and distal junctional kyphosis (PJK and DJK), neurofibromatosis, post-traumatic kyphosis, postlaminectomy kyphosis, postinfection kyphosis and congenital kyphosis. Patients' characteristics are summarized in Table 1.

On average, surgical time was 288 min (range, 210–360) and total blood loss was 1520 mL (range, 800–3200). Two patients presented transient neurological deficit, and one patient had an asymptomatic rod breakage that did not require revision. No pseudarthrosis or wound infections were recorded. Operative data and complications are detailed in Table 2.

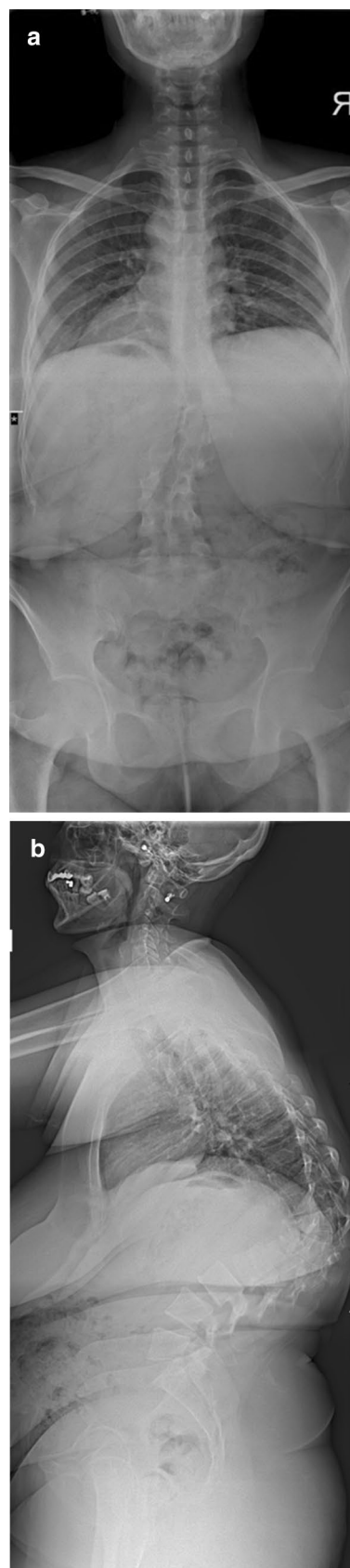
The mean correction angle at the PSO site was 30.1° with a significant difference between correction in the upper thoracic spine with 26.6° and lower thoracic spine with 33.5° ($p = 0.036$, Table 3). In the sagittal plane, significant reciprocal reduction of compensatory cervical lordosis (from 37.6° to 18.6° , $p < 0.01$) in upper thoracic PSO or lumbar lordosis (from 74.5° to 46.6° , $p < 0.01$) in lower thoracic PSO was noted. In fact, there was a significant and positive correlation between the reduction of upper thoracic kyphosis and the reduction of cervical lordosis ($R = 0.840$, $P = 0.002$) and between the reduction of lower thoracic kyphosis and the reduction of lumbar lordosis ($R = 0.890$, $P = 0.001$). Previous data are summarized in Table 4.

Pre- and postoperative ODI scores showed a significant improvement in the majority of the patients (Table 5).

Figures 4 and 5 illustrate two cases of lower thoracic (T12) and upper thoracic (T4) PSO using the domino technique.

Discussion

Sagittal alignment has been well studied in the past decade, and its principles have been well established [13, 14]. It taught the spine community that in case of a fixed kyphotic deformity, a lordotic compensation should occur in order to re-establish the balance of the patient, and that



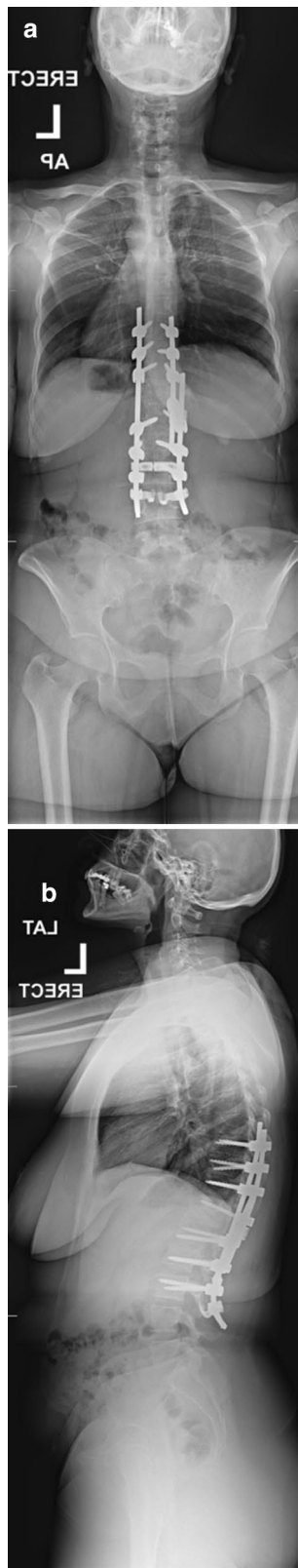


Fig. 4 (continued)

Table 1 Patients characteristics

Mean age (years)	40 (17–69)
Males/females	12/8
Prior spinal fusion	40%
<i>Etiology of deformity</i>	
Proximal junctional kyphosis	3
Distal junctional kyphosis	1
Neurofibromatosis	4
Posttraumatic kyphosis	8
Postlaminectomy kyphosis	1
Postinfection kyphosis	1
Congenital kyphosis	2
<i>Thoracic PSO level</i>	
T1–T6	10
T7–T12	10
Mean follow-up (months)	34 (24–48)

Table 2 Operative data and complications

Surgical time (min)	288 (210–360)
Instrumented levels	10.8 (7–15)
Total blood loss (mL)	1520 (800–3200)
Hospitalization days	9 (7–14)
<i>Complications</i>	
Transient neurological deficit	2
Rod breakage	1
Painful crosslink (removed)	1
Hemothorax	2
Paralytic ileus	1
GI bleeding	2

Table 3 Mean correction angle at PSO site

Overall local correction (°)		<i>P</i>
All patients	30.1	0.036
T1–T6	26.6 (18–34)	
T7–T12	33.5 (24–38)	

Significance set as $p < 0.05$

would be at the nearest mobile curve from the deformity apex. Therefore, an upper thoracic kyphosis would be compensated by a cervical hyperlordosis and a lower thoracic kyphosis would be compensated by a lumbar hyperlordosis, and correction of the main deformity would lead to an automatic correction of the adjacent compensating levels. This could be typically seen in the current series where the surgical correction of the upper thoracic kyphotic deformity lead to an automatic correction of the exaggerated cervical lordosis and the surgical correction

Table 4 Preoperative and postoperative radiological data of total population

Parameters	Preoperative (Mean ± SD)	2 years postoperative (Mean ± SD)	Change (Mean ± SD)	P value preop/postop
Local kyphosis (°)	48.4 ± 20.7	18.3 ± 22.2	30.1 ± 6.3	< 0.001
TK (°)				
All patients	51.7 ± 8.9	43.9 ± 5.8	7.8 ± 4.1	0.170
T1–T6 group	83.1 ± 18.0	53.6 ± 15.0	29.5 ± 8.9	< 0.001
T7–T12 group	20.3 ± 8.9	34.2 ± 5.8	13.9 ± 4.8	< 0.001
C2C7 (°)				
All patients	−25.7 ± 13.9	−15.1 ± 4.7	10.6 ± 7.2	0.010
T1–T6 group	−37.6 ± 32.2	−18.6 ± 25	19.0 ± 15.6	< 0.001
T7–T12 group	−13.8 ± 9	−11.6 ± 4.3	2.2 ± 2.8	0.578
LL (°)				
All patients	−66.9 ± 6.6	−52.9 ± 8.1	14.0 ± 3.9	< 0.05
T1–T6 group	−59.2 ± 13.7	−59.2 ± 17.7	0.0 ± 7	0.979
T7–T12 group	−74.5 ± 6.6	−46.6 ± 8.1	27.9 ± 5.6	< 0.001
PI (°)	53.5 ± 7.3	53.1 ± 6.8	0.4 ± 4.8	0.276
PT (°)	16.6 ± 4.2	15.9 ± 4.1	0.7 ± 4.3	0.316
GT (°)	17.8 ± 6.1	16.5 ± 6.3	1.3 ± 5.2	0.426
SVA (mm)	−5.4 ± 16	2.1 ± 15	7.5 ± 12	0.102

Significance set as $p < 0.05$ **Table 5** Baseline and 2-year postoperative Oswestry Disability Index (ODI) scores for all patients

Preop ODI	Postop ODI	P
32.7 (2–56)	22.5 (2–42)	0.014

of the lower thoracic kyphotic deformity lead to an automatic correction of the exaggerated lumbar lordosis.

Three-column osteotomy is a closing wedge osteotomy that has been widely used in the past decades for the treatment of sagittal malalignment [3]. It involves an anterior apex and a posterior base; thus, reduction should be done in compression, which grants an increased bone-on-bone contact, directly promoting fusion. Previous studies reported the use of direct compression between hooks or screws at the levels immediately above and below the osteotomy site to achieve reduction [15]; in addition, a specific reduction plier has been described to increase technical safety and angular reduction efficiency for PSOs [16]. The main disadvantage of the previously mentioned techniques is that they apply reduction forces directly on the two pedicle screws adjacent to the PSO which may increase the risks of loosening and failure. Using a hinge-powered remotely controlled OR table has been described for osteotomy gentle and safe closure [8]; however, it was mainly used for lumbar osteotomies performed for adult degenerative deformities and may show limitations in severe deformities especially in the thoracic area.

PSO is believed to be more technically challenging when performed in the thoracic spine because of spinal cord vulnerability and structural rigidity of the rib cage that may potentially limit its correction ability [17]. Ideal reduction technique would therefore require to be smooth and progressive to avoid neurological impairment but also strong to overcome the aforementioned rigidity.

The only paper that previously mentioned the use of a domino connector for PSO reduction was described specifically for the lumbar spine [18]. Authors demonstrated that it is a safe, powerful tool for pedicle subtraction osteotomy site closure, improving significantly the lumbar lordosis correction angle, when compared to a regular reduction technique without use of the domino, and with an acceptable rate of complications.

The use of a side-to-side domino connector is the only technique that enables osteotomy closure by involving directly and simultaneously the pedicle screws above and below the osteotomy but without applying a direct compression or rotation on them which significantly decreases the risks of loosening or failure. In fact, no pseudarthrosis or mechanical complication requiring surgical revision occurred in the current study. Using two versions of reduction according to the severity of the deformity enabled satisfactory radiological results and also good clinical outcomes as demonstrated by the significant improvement of the ODI score with no neurological long-term complications. In relatively moderate kyphotic deformities, the single-block cantilevering technique enables smooth reduction through

Fig. 5 Full-spine anteroposterior and lateral X-rays of a 17-year-old patient with cervicothoracic kyphoscoliosis in the context of neurofibromatosis (**a** and **b**). Postoperative full-spine X-rays after T4 pedicle subtraction osteotomy and the use of the double-rod cantilever and compression technique on the left side with satisfactory correction in both planes (**c** and **d**)

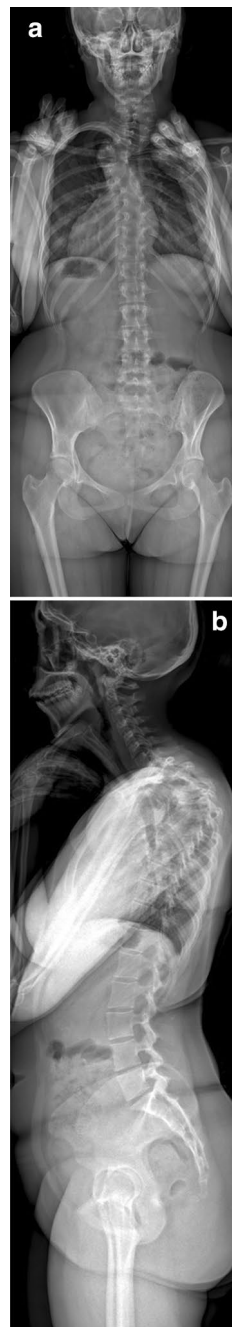
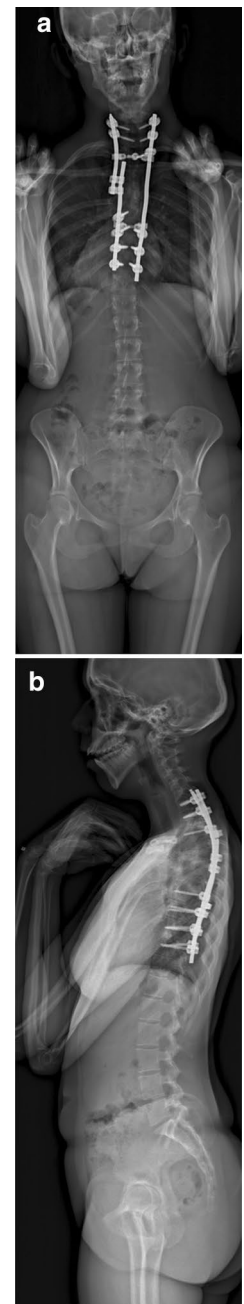


Fig. 5 (continued)



progressive translation of the deformity on a pre-assembled rod–domino–rod construct, and once the two pre-connected rods are firmly tightened in the pedicle screws above and below the PSO, compression through the domino enables complete closure of the osteotomy site. By simultaneously cantilevering the two spinal blocks above and below the osteotomy in severe angular deformities, forces are spread equally on the different parts of the construct enabling a smooth and progressive correction under direct vision. The distribution of correctional forces across multiple screws

increases the power of simultaneous compression at the osteotomy site together with the adjacent levels.

O’Shaughnessy [19] presented the first study in which PSOs were performed throughout the entire thoracic spine where 15 patients were included and the local kyphotic correction achieved was $16.3^\circ \pm 9.6^\circ$ with the highest angles at the distal thoracic segments. Cacho-Rodriguez published an average correction of 41° in the lower thoracic spine and 31° in the upper thoracic spine [20], which is similar to our results. Technique refinements over the time and better understanding of the sagittal alignment may explain the significant improvement of correction between the different

series. In addition, the height and width of the thoracic vertebral body and its relation with the pedicle height increase as we get more distal, which explains the better correction in the lower thoracic area.

Compensatory changes in spinal alignment outside the fused spine that occur after surgical correction have been well described [21], and it has been shown that after a fixed sagittal deformity in the thoracic spine, the lordotic compensatory mechanisms occur at the nearest mobile segments from the apex of the deformity in order to achieve a normal global balance [20]. As previously mentioned, an upper thoracic kyphosis compensates mainly by increasing the cervical lordosis, whereas a lower thoracic kyphosis would involve an increase of lumbar lordosis for compensation. These findings were clearly observed in the current study with a reduction of 20° on average of the compensatory cervical hyperlordosis after high thoracic PSO and reduction of 30° on average of the compensatory lumbar hyperlordosis after low thoracic PSO. Lamartina [22] identified deformity patterns after combining regional deformities and compensatory mechanisms, providing a comprehensive classification that could be helpful in better interpretation of the deformity and muscle forces acting on the spine and also in surgical planning.

In addition to its advantage in the sagittal malalignment correction technique, the domino may allow asymmetrical correction when indicated, where be placed at the opposite side of coronal malalignment, thus enabling improvement of both planes simultaneously. A previously published case report described the use of the domino for correction of a thoracolumbar kyphoscoliosis after T11 butterfly vertebra resection in an adult [23]. It showed a satisfactory correction of the deformity in both planes.

Several limitations should be acknowledged in the current paper. The retrospective nature of the study with the series of patients being collected from two different centers. However, the senior surgeons performing the osteotomies were using rigorously the same technique for the different deformities. With the relative limited number of patients and the fact that no direct comparison to a control group was done, however, thoracic PSO is relatively rare when compared to lumbar PSO, thus limiting the number of patients and making a comparative study difficult to carry out. In addition, the paucity of the literature papers specifically studying thoracic PSO reduction techniques may limit the comparison to the current series technical details and deformity correction angles.

Conclusion

Domino connector is a safe and efficient tool for thoracic pedicle subtraction osteotomy deformity correction and site closure with an acceptable rate of complications. Using two

technical nuances according to the severity of the kyphotic deformity enables smooth and progressive reduction while distributing the correctional forces on all the pedicle screws simultaneously with controlled compression at the osteotomy site.

Declarations

Conflict of interest There is no conflict of interest for this article.

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