



Domino connector is an efficient tool to improve lumbar lordosis correction angle after pedicle subtraction osteotomy for adult spinal deformity

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Abstract

Purpose To compare the radiological outcomes and complications of adult spinal deformity patients who underwent a pedicle subtraction osteotomy (PSO) below L2 but categorized according to their construct where either a domino connector was applied for osteotomy correction or not.

Methods Retrospective review of a prospective, multicenter adult spinal deformity database (5 sites). Inclusion criteria were adult patients who underwent PSO between L3 and L5 with a minimum follow-up of 2 years. Among 1243 patients in the database, 79 met the inclusion criteria, 41 in the no-domino (ND) group and 38 in the domino (D) group. The domino technique consisted of using 2 parallel rods connected by a domino on one side of the PSO in order to achieve gradual and controlled compression at the osteotomy site. Demographic data, operative parameters, spinopelvic parameters and complications were collected.

Results Demographic data and operative parameters were globally similar between both groups, and they showed a comparable preoperative sagittal malalignment. Segmental lordosis improved by 22° and 31° ($p < 0.05$) and L1S1 lordosis improved by 23° and 32° ($p < 0.05$) in the ND and D group, respectively. The use of multiple rods was similar between the groups (58% vs. 57%). Also, mechanical complications rate was globally similar between both groups with no statistically significant difference (22% vs. 28.9%).

Conclusion Domino connector is a safe, powerful and efficient tool for pedicle subtraction osteotomy site closure. It improved the lumbar lordosis correction angle with an acceptable rate of complications.

Keywords Domino connector · Pedicle subtraction osteotomy · Sagittal alignment · Lumbar lordosis · Adult spinal deformity

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Introduction

Pedicle subtraction osteotomy (PSO) technique is a three-column osteotomy that is commonly used for the management of severe spinal deformities. It is a posteriorly closing osteotomy that requires specific methods or tools to properly close the posterior wedge at the anterior and middle columns in order to achieve the best correction possible.

Different techniques have been described in the literature to close the pedicle subtraction osteotomy site for correction of sagittal malalignment including external maneuvers such as bending of the table [1, 2] and internal maneuvers with application of forces through the pedicle screws [3, 4]; however, good reduction may be difficult in case of vertebral body sclerosis or osteoporosis with risk of implant

failure when high modulus forces are applied on single pedicle screws. Therefore, other techniques that would mitigate such risks are preferable. The use of a side to side domino connector as a correction tool for PSO has not been previously studied.

The objective of the current study was to compare the radiological outcomes and complications between 2 groups of adult spinal deformity patients who underwent a lumbar PSO and categorized according to the use or not of a domino connector for the reduction of the osteotomy.

Our hypothesis is that lumbar lordosis correction angle would be improved with domino connector for PSO closure.

Materials and method

This is a retrospective review of a prospective adult spinal deformity database collected from 5 centers. Data from consecutive cases involving patients who underwent lumbar PSO with a minimum follow-up of 2 years were obtained, and all patients were enrolled into an institutional review board-approved protocol by the respective sites. Inclusion criteria are: age of at least 18 years, presence of a spinal deformity defined by at least one of the following parameters: Cobb angle $\geq 20^\circ$, pelvic tilt (PT) $\geq 25^\circ$, sagittal vertical axis (SVA) ≥ 5 cm, or thoracic kyphosis $\geq 60^\circ$.

The domino technique consisted of using 2 parallel rods connected by a parallel domino (with either 2 or 4 setscrews) on one side of the PSO in order to achieve gradual and controlled compression at the osteotomy site (Fig. 1, black arrow), while the other side was completed with either a single rod or a multiple rods construct. Demographic data, operative parameters, spinopelvic parameters and complications were collected.

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 lordosis (angle between the inferior and superior endplates of the osteotomized vertebra), segmental lordosis (angle between the inferior endplate of the vertebra below the osteotomized vertebra and the superior endplate of vertebra above the osteotomized vertebra), Lumbar Lordosis (LL), Thoracic Kyphosis (TK) and the coronal C7 plumb line (in relation to the center sacral vertical line (CSVL)). Angles were considered negative if lordotic and positive if kyphotic.



Fig. 1 X-ray depicting the domino technique which consists of using 2 parallel rods connected by a domino on one side (black arrow)

Univariate and multivariate analysis was performed on the relationship between the different rod constructs (with or without domino) and the radiological parameters using SPSS software (IBM SPSS statistics, version 25.0). Student's t-test and the Mann–Whitney U test were used to compare continuous variables. Chi-square and Fisher exact tests were performed for categorical variables. Continuous variables are expressed as mean \pm standard deviation, and frequency data are expressed as counts and percentages. All *p*-values were 2-tailed, and *p* < 0.05 was considered statistically significant.

Results

Among 1243 patients in the database, 79 met the inclusion criteria and were categorized into 2 groups: the no-domino (ND) group with 41 patients and the domino (D) group with 38 patients.

Demographic data and operative parameters were globally similar between both groups and are presented in Table 1.

The 2 groups showed a comparable preoperative sagittal malalignment with a Global Tilt of 43° and 49° in the ND and D group respectively (*p* = 0.08), segmental lordosis improved

Table 1 Demographic and surgical data of the 2 groups. ND is for No Domino group and D is for Domino group

Parameter	Value		
	ND	D	<i>P</i>
Patients (N)	41	38	0.546
Age (years)	58.9 ± 13	60.8 ± 11	0.708
Female sex (%)	30 (73)	32 (84)	0.609
Body mass index (kg/m ²)	25.4 ± 4	27.1 ± 4	0.398
Smoking history (%)	22 (53.6)	18 (47)	0.236
Prior lumbar fusion (%)	27 (65)	28 (73)	0.896
Level of PSO (%)			0.209
L3	8 (19.5)	7 (18.4)	
L4	26 (63.4)	25 (65.8)	
L5	7 (17.1)	6 (15.8)	
No. of instrumented vertebra	10.3 ± 3.1	9.1 ± 3.8	0.543
Estimated blood loss in L	1.9 ± 1.3	2.1 ± 1.1	0.698
Op duration in minutes	318 ± 52	329 ± 74	0.532
Follow-up period in months	29 ± 7	32 ± 8	0.639

by 22° and 31° ($p < 0.05$) and L1S1 lordosis improved by 23° and 32° ($p < 0.05$). The aforementioned data are summarized in detail in Tables 2 and 3.

Mechanical complications rate was globally similar between both groups with no statistically significant difference (22% vs. 28.9%, $p = 0.400$), and in terms of pseudarthrosis/rod breakage the rate was numerically lower in the ND group when compared to the D group; however, the difference was not statistically significant (9.8% vs. 15.7%, $p = 0.095$, Table 4). In addition, the use of multiple rods was similar between the 2 groups (58% vs. 57%), and when sub-dividing each group according to the use or not of multiple rods, no significant difference was found in term of mechanical complications inside the sub-groups (Tables 5, 6, 7 and 8), the rate of pseudarthrosis/rod breakage inside the domino group was lower if multiple rods were used, meaning a protective effect of the multiple rods technique, when compared to the no use of multiple rods in this category; however, the difference did not reach statistical significance.

There was no difference between the ND and D groups in terms of other complications such as epidural hematoma, surgical site infection, motor or sensory radiculopathy, and in terms of revised patients after complications (11 vs. 10).

Figure 2 illustrates a case showing L5 PSO with use of the domino for simultaneous correction in both planes and multiple rods construct.

Table 2 Preoperative and postoperative radiological data of total population. ND is for No Domino group and D is for Domino group

Parameters	Domino	<i>N</i>	Average	SD	<i>P</i>
Preoperative GT	ND	41	42.70	13.69	0.083
	D	38	48.97	17.65	
2y post-operative GT	ND	41	26.30	6.35	0.47
	D	38	28.48	13.51	
Preoperative PI	ND	41	60.71	14.14	0.97
	D	38	61.56	18.86	
2y post-operative PI	ND	41	59.90	15.32	0.577
	D	38	60.58	13.18	
Preoperative PT	ND	41	31.61	7.27	0.321
	D	38	33.88	6.75	
2y post-operative PT	ND	41	21.29	11.12	0.561
	D	38	22.17	10.75	
Preoperative TK	ND	41	29.50	15.55	0.224
	D	38	27.21	19.62	
2y post-operative TK	ND	40	44.64	16.19	0.668
	D	37	46.34	12.16	
Preoperative SVA in mm	ND	41	113.80	47.98	0.242
	D	38	119.92	56.85	
2y post-operative SVA in mm	ND	41	44.98	30.62	0.734
	D	38	46.61	32.65	
Preoperative C7-CSVL in mm	ND	41	34.61	9.74	0.652
	D	38	32.23	35.21	
2y post-operative C7-CSVL in mm	ND	41	18.55	14	0.531
	D	38	17.63	15.95	

Discussion

Fixed sagittal or coronal malalignment often requires complex spinal procedures involving the use of 3-column osteotomies such as pedicle subtraction osteotomy [5, 6]. PSO technique enables satisfactory correction but only when closure of the osteotomy site is performed properly to achieve the best outcome possible. Different maneuvers or techniques have been previously described in the literature to close the PSO site such as patient positioning, rod cantilevering, extending the fixation points and compression through pedicle fixation points. However, most of the aforementioned techniques place added stress on the pedicle screws which may lead to screw loosening and eventual failure. In order to palliate such drawbacks, specific techniques or tools have been reported.

A central hook-rod construct [7], which places fixation points (hooks) in fusion masses above and below the

Table 3 Preoperative and postoperative radiological data (lordosis) of total population. Δ means the difference between preoperative and postoperative values. ND is for No Domino group and D is for Domino group

Parameters	Domino	N	Average	SD	P
Preoperative local lordosis	ND	41	0.11	6.35	0.47
	D	38	0.96	3.51	
Preoperative segmental lordosis	ND	41	-11.71	14.14	0.059
	D	38	-4.56	18.86	
Preoperative lumbar lordosis (LL)	ND	41	-26.90	15.32	0.477
	D	38	-24.58	13.18	
3 m post- operative local lordosis	ND	41	-17.61	7.27	0.425
	D	38	-18.88	6.75	
3 m post-operative segmental lordosis	ND	41	-31.29	13.12	0.098
	D	38	-36.17	12.75	
3 m post-operative LL	ND	41	-50.50	15.55	0.062
	D	38	-56.21	9.62	
2y post-operative LL	ND	40	-48.64	16.19	0.040
	D	37	-55.34	10.16	
Δ preop-postop local lordosis	ND	41	17.80	7.98	0.942
	D	38	17.92	6.85	
Δ preop-postop segmental lordosis	ND	41	21.98	10.62	0.000
	D	38	31.61	12.65	
Δ preop-postop LL	ND	41	23.61	9.74	0.001
	D	38	31.63	11.95	

Italic results indicate statistical significance ($p < 0.05$)

Table 4 Complications of the series (ND=no domino, D=domino)

		No complications	Complications		Total
			Pseudarthrosis/rod breakage	Junctional complication	
ND	N	32	4	5	41
	%	78.0%	9.8%	12.2%	100.0%
D	N	27	6	5	38
	%	71.1%	15.7%	13.2%	100.0%
Total	N	59	10	10	79
	%	74.8%	12.6%	12.6%	100.0%
P		0.400	0.095	0.850	

Table 6 Detailed results of the pseudarthrosis complication in the Domino group subdivided according to the use or not of multirods

		N	Pseudarthrosis/rod breakage		Total
			No	Yes	
Multirods	No	N	13	3	16
	%		81.2%	18.8%	100.0%
	Yes	N	19	3	22
	%		86.4%	13.6%	100.0%
Total	N		32	6	38
	%		84.2%	15.8%	100.0%
P			0.701	0.571	

Table 5 Detailed results of the junctional complication in the Domino group subdivided according to the use or not of multirods

		N	Junctional complication		Total
			No	Yes	
Multirods	No	N	13	3	16
	%		81.2%	18.8%	100.0%
	Yes	N	20	2	22
	%		90.9%	9.1%	100.0%
Total	N		33	5	38
	%		86.8%	13.2%	100.0%
P			0.632	0.384	

Table 7 Detailed results of the junctional complication in the No Domino group subdivided according to the use or not of multirods

		N	Junctional complication		Total
			No	Yes	
Multirods	No	N	15	2	17
	%		88.2%	11.8%	100.0%
	Yes	N	21	3	24
	%		87.5%	12.5%	100.0%
Total	N		36	5	41
	%		87.8%	12.2%	100.0%
P			0.679	0.646	

Table 8 Detailed results of the junctional complication in the No Domino group subdivided according to the use or not of multirods

		<i>N</i>	Pseudarthrosis/rod breakage		Total
			No	Yes	
Muitirods	No	<i>N</i>	16	1	17
		%	94.1%	5.9%	100.0%
	Yes	<i>N</i>	21	3	24
		%	87.5%	12.5%	100.0%
Total		<i>N</i>	37	4	41
		%	90.2%	9.8%	100.0%
<i>P</i>			0.629	0.482	

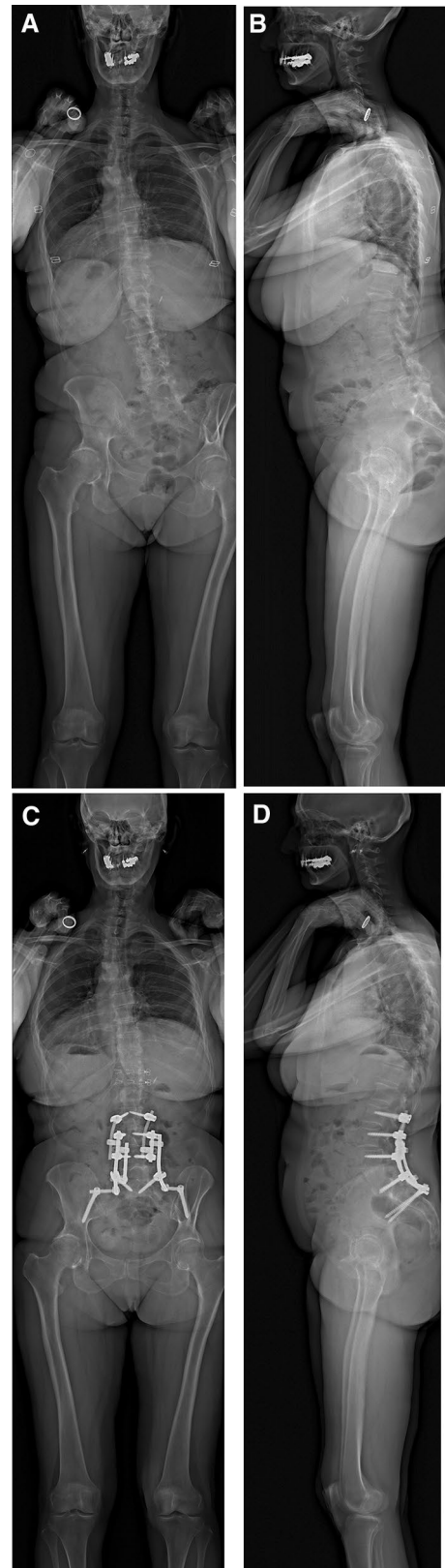
osteotomy sites and centrally attached to a short rod, has been described. It enabled a safe and controlled closure of the osteotomy site with an average increase in lumbar lordosis of 31°, which is similar to the correction rate of the current study, and satisfying long-term results [8]; however, it was mainly used in revision cases with previous fusion masses and was not reported for primary cases.

Another technique reported the use of sublaminar bands to assist PSO closure [9], it consists of tensioning sublaminar bands under L2 lamina connected to clamps placed between the S1 and the iliac screws, this facilitates osteotomy closure and reduces the load supported by the rod. However, it was only described on a case report and not generalized to a series of patient.

Gupta described the outrigger technique to close the osteotomy gap where an additional rod is used bilaterally at the peri-osteotomy levels directly attached to the pedicle screws but with offset connectors allowing rods to be placed lateral to the screws [3, 10]. Combination of compression between the pedicle screws and table hyperextension allow progressive closure, and the construct is completed by 2 long rods bypassing the osteotomy levels. Such technique avoids the use of temporary rods, nevertheless the osteotomy closure relies only on 2 screws on each side which may overstress them and increase the chances of loosening and failure.

Closing of the osteotomy may be carried out using the in situ bending technique as it was described by Chiffolot [11]. This technique relies on bending the rods bilaterally inside the patient in the sagittal plane between the 2 screws above and below the osteotomy, this increases the lordosis through compression at the osteotomy site and ligamentotaxis mechanism. Nonetheless, in case of vertebral body sclerosis or osteoporosis, such manipulation may overload the hardware and lead to mechanical failure.

A specific reduction plier has been described to increase technical safety and angular reduction efficiency for PSOs [4]. Through its articulations, it exerts closure of the

**Fig. 2** Full spine X-rays showing L5 PSO with use of the domino for simultaneous correction in both planes and multiple rods construct

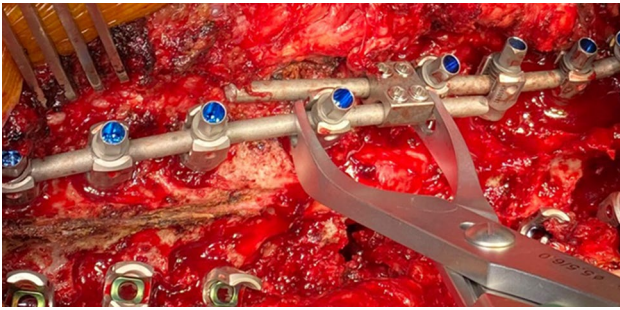


Fig. 3 Picture showing compression on the domino for further closure of the osteotomy site

osteotomy site by rotation of the pedicle screws and around the anterior vertebral wall hinge. However, the plier applies the reduction forces directly to the 2 pedicle screws above and below the PSO which, again, may increase the risks of loosening and failure.

Closure osteotomy by flexing a hinge-powered remotely controlled OR table has been specifically studied in a prospective study including 84 patients [1]. The reduction technique did not include any compressive or cantilever forces, and enabled safe, gentle closure of the osteotomy site with minimal risk of implant failure or accidental neurological injury. This technique has been mainly described for lumbar osteotomies (L3 and L4) performed in adult degenerative deformity patients, it may show limitations in severe deformities, especially in the thoracolumbar and thoracic area.

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 but without applying a direct compression or rotation on them. In fact, the PSO reduction involves 2 steps: after the 2 rods bent to the desired shape and connected by the domino are fixed on the distal implants (through the distal rod), cantilever maneuver is performed on the proximal rod to reach the proximal implants and engage closure of the PSO site. Once the proximal implants are secured, the domino is unlocked and used to perform further compression by sliding the rods inside it, either from proximal to distal for the proximal rod, or from distal to proximal for the distal rod. The compression device is actually applied between the edge of the domino on the opened side and one locked screw (connected to the other screws through the rod) on the other side (Fig. 3). Domino is finally locked once satisfactory reduction with bone on bone contact at the osteotomy site is achieved. By performing such compression, domino helps increasing the fusion rate, and also improving further sagittal correction. In addition, in case of coronal malalignment associated to sagittal malalignment, the domino may be placed at the opposite side of coronal imbalance in order to achieve an

asymmetrical closure of the PSO to correct simultaneously both planes.

A retrospective study [12] analyzed risk factors for rod fracture after posterior correction of adult spinal deformity with the use of osteotomies (3-column and posterior-column osteotomies) and found a significant association between rod fractures and the following factors: sagittal rod contour $> 60^\circ$, presence of dominos and/or parallel connectors at date of fracture, construct crossing thoracolumbar and lumbosacral junctions, pseudarthrosis at more than 1 year of follow-up. However, only 2 patients actually presented a rod fracture at or near a domino connector, and the indication for domino use was not PSO site closure but revision surgery with extension of the initial construct where manipulation and re-contouring of the end of the previous rods to match the new instrumentation could play a role in the setting of future pseudarthrosis and lead to mechanical failure. Our study did not show a significant difference for rods fracture when comparing the benefit of the domino as a compressing device for PSO between the No Domino and Domino groups.

Domino connector use at the osteotomy site significantly improves lumbar lordosis correction angle. The distribution of correctional forces across multiple screws increases the power of simultaneous compression at the osteotomy site together with the adjacent levels. Although biomechanically weaker than an intact rod, the use of multiple-rods alongside each domino compensates for this theoretical weakness leading to a similar rate of complications. The domino also allows asymmetrical correction when indicated, where be placed at the opposite side of coronal malalignment.

Some limitations of the current study should be acknowledged such as the limited number of patients, the limited number of published papers studying specifically a PSO reduction technique and establishing accurate measured angles in order to compare them to the current paper. In addition, clinical or functional evaluation with the help of patient-reported outcome measures (PROMs) was not performed as it was not the objective of the study.

Conclusion

Domino connector is a safe, powerful and efficient tool for pedicle subtraction osteotomy site closure. It improves the lumbar lordosis correction angle with an acceptable rate of complications.

Declaration

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

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