Assessment of two novel surgical positions for the reduction of scoliotic deformities: lateral leg displacement and hip torsion

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Abstract Cobb angles and apical vertebral rotations (AVR) are two of the main scoliosis deformity parameters which spinal instrumentation and fusion techniques aim to reduce. Despite this importance, current surgical positioning techniques do not allow the reduction of these parameters. Two new surgical frame accessory prototypes have been developed: (1) a lateral leg displacer (LLD) allows lateral bending of a patient's legs up to 75° in either direction and (2) a pelvic torsion device (PTD) which allows transverse plane twisting of a patient's pelvis at 30° in either direction while raising the thoracic cushion, opposite to the raised side of the pelvis, by 5 cm. The objective of this study was to evaluate the ability of the LLD and PTD to reduce Cobb angles and AVR. Experimental testing was performed pre-operatively on 12 surgical scoliosis patients prone on an experimental surgical frame. Postero-anterior radiographs of their spines were taken in the neutral prone position on a surgical frame, and then again for 6 with their legs bent towards the convexity of their lowest structural curve, 4 with their pelvis raised on the convex side of their lowest structural curve and one each in opposite LLD and PTD intended use. Use of the LLD allowed for an average supplementary reduction of 16° (39%) for Cobb angle and 9° (33%) for AVR in the lowest structural curve. Use of the PTD allowed for an

average supplementary reduction of 9° (19%) for Cobb angle and 17° (48%) for AVR in the lowest structural curve. Both devices were most efficient on thoraco-lumbar/lumbar curves. Opposite of intended use resulted in an increase in both Cobb angle and AVR. The LLD and PTD provide interesting novel methods to reduce Cobb angles and AVR through surgical positioning which can be used to facilitate instrumentation procedures by offering an improved intra-operative geometry of the spine.

Keywords Spine · Surgical positioning · Scoliosis · Cobb · Vertebral rotation

Introduction

Patient positioning is a required and important step of spinal instrumentation procedures. Among other things, it has an impact on spinal geometry, which can be exploited to reduce pathologic deformities such as scoliosis. Studies [1–3] have shown that Cobb angles are reduced on average between 25 and 37% due to prone positioning, anesthesia, and surgical opening. While one of the primary objectives of scoliosis instrumentation procedures is reduction of the coronal plane deformation, and more recently on the transverse plane rotation [4], current spinal operating frames such as the Jackson, Relton-Hall, Wilson or Andrews do not allow any additional 3D corrections to be made.

One method to obtain additional correction of the coronal curves, which is sometimes used for patients with severe and rigid deformities, is pre- and intra-operative traction [5]. It allows for a safe and effective longitudinal elongation of the spine but requires a dedicated device, must be done several weeks before the procedure and has

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an uncertain impact on post-operative results [6]. An alternate method to achieve further Cobb reduction through patient positioning has been proposed by Duke et al. [7] and involves the application of lateral forces (up to 150 N) to the trunk at the curve apex using adjustable thoracic cushions. Experimental evaluation of this method on 12 patients showed significant increases in spine height and decreases in both rib and trunk torsional deformity. A drawback of this method was increased patient–cushion interface pressures.

A multi-functional positioning frame (MFPF) has been developed which holds patients in the prone position with two thoracic cushions, two pelvic cushions, and a lower limb support which can all be adjusted in order to manipulate spinal geometry intra-operatively [8]. Two novel accessories, proof of concept prototypes, were added to the frame to allow specific manipulation of scoliotic deformities: a lateral leg displacer (LLD) and the pelvic torsion device (PTD) (Fig. 1).

The LLD installed over the MFPF lower limb support allows the patient's leg to be laterally pulled and maintained either direction up to an angle of 75° via a harness placed over the patient's ankles. Also included is a lateral support cushion, whose longitudinal position on the frame is adjustable and which can prevent lateral movement of the pelvis or thorax. The LLD provides a similar position to the lateral bending test frequently used to evaluate spinal flexibility and known to reduce Cobb angles.

The PTD installed at the level of the pelvis consists of a support cushion that is slanted 30° and is reversible such that either side can be raised. When the PTD is installed, the thoracic cushion on the opposite side of the raised portion of the pelvis is raised by 5 cm using a spacer.

The objective of this study is to experimentally evaluate the ability of the LLD and PTD to modulate scoliotic Cobb angles and apical vertebral rotation (AVR). It is hypothesized that relative to the neutral prone position on the MFPF, these systems can be used to significantly reduce the structural curves and the AVR.

Methods

Experimental testing was performed pre-operatively on 12 surgical adolescent idiopathic or neuromuscular scoliotic patients, 5 males and 7 females aged 11–18, at our University Hospital Center with approval obtained from the ethics committee (Table 1). Standard standing postero-anterior (PA) and lateral radiographs, in combination with standing left and right side bending radiographs were acquired and utilized to identify curve types and structurality according to the Lenke method [9]. Reductions in Cobb angles during the lateral bending tests averaged 46% (−82 to 12%; $\pm 27\%$) for MT curves and 62% (−91 to −22%; $\pm 21\%$) for TL/L curves (Table 1). Subjects were weighed, their heights recorded, and then placed in the neutral prone position on the MFPF where a 36-in. (91.4 cm) PA radiograph of their spine was acquired. At this point, subjects were placed and maintained in one of two possible positions where a second PA radiograph of their spines was acquired. Subjects #1 to #6 had their lower limbs pulled towards the convexity of their lowest structural curve. Subjects #7 to #10 had their pelvis raised on the concave side of their lowest structural curve and opposite thoracic cushion spacer inserted (Fig. 2). Two additional patients were tested in positions opposite of the LLD and PTD design intentions: #11 had his lower limbs pulled towards the concavity of his lowest structural curve, and #12 had her pelvis raised on the convex side of her lowest structural curve.

Here and throughout the lowest structural curve refers to the most caudal coronal plane scoliotic curve (MT or TL/L), which is determined to be structural using the Lenke method [9]. It is the curve whose deformity the LLD and PTD directly aim to reduce. The secondary curve refers to the other scoliotic curves: a non-structural TL/L or a MT, which can either be structural or non-structural.

Patients #1 to #6 and #11 had their lower limbs laterally bent at an angle between 50° and 60° based on a position that was considered at least mildly comfortable. While laterally displacing the legs, their thoracic cage was

Fig. 1 **a** Lateral leg displacer (LLD) with subject; **b, c** pelvic torsion device (PTD) with and without subject

Table 1 Patient and lateral bending data

Subject #	1	2	3	4	5	6	7	8	9	10	11	12
Sex M/F	F	M	M	F	F	F	F	M	M	F	M	F
Weight (kg)	64	45	48	39	46	36	64	58	32	41	50	33
Height (cm)	165	163	166	152	152	155	157	175	147	160	171	154
T12–L5 Lordosis	45°	42°	53°	47°	58°	18°	62°	38°	42°	56°	53°	40°
T4–T12 Kyphosis	32°	24°	52°	14°	40°	14°	33°	23°	58°	46°	32°	10°
Lenke type	5C	3B	1B	5C	1B	5C	5C	1B	1A	6C	5C	1A
Scoliosis type	AIS	AIS	Neuro	AIS	Neuro	AIS	AIS	AIS	AIS	AIS	AIS	Neuro
MT Cobb	22°	69°	90°	30°	79°	15°	31°	62°	70°	34°	29°	79°
MT AVR	T5–T10	T6–T12	T6–L2	T1–T9	T7–L2	T1–T9	T5–T11	T7–L2	T5–L3	T6–T10	T6–T11	T5–T12
TL/L Cobb	<10°	32°	48°	<10°	34°	<10°	<10°	33°	42°	13°	<10°	36°
TL/L AVR	44°	52°	30°	44°	46°	49°	56°	22°	19°	58°	57°	32°
Left Bend MT	T10–L2	T12–L4	L2–L5	T9–L2	L2–L5	T9–L2	T11–L4	L2–L5	L3–L5	T10–L4	T11–L4	T12–L5
Left Bend TL/L	28°	24°	<10°	34°	<10°	27°	53°	<10°	<10°	34°	43°	<10°
Right Bend MT	34° +55%	78° +13%	105° +17%	12°	83° +5%	31° +107%	37° +19%	70° +13%	97° +39%	40° +18%	32° +10%	80° +1%
Right Bend TL/L	7°	25°	3°	63° +43%	19°	38°	23°	2°	11°	25°	22°	5°
Right Bend MT	–84%	–52%	–90%	33° +10%	–59%	–22%	–59%	–91%	–42%	–57%	–61%	–84%
Right Bend TL/L	4°	27°	71°	24°	69°	4°	16°	31°	46°	38° +12%	9°	39°
	–82%	–61%	–21%	–45%	–13%	–73%	–48%	–50%	–34%	75° +29%	–69%	–51%
	50° +14%	58° +12%	40° +33%	24°	39°	65° +33%	66° +18%	30° +36%	37° +95%	32° +10%	62° +9%	38° +19%

Fig. 2 Direction of lower limb lateral displacement and pelvic torsion/thoracic cushion vertical displacement depending on location of lowest structural scoliotic curve

Table 2 Impact of lateral leg displacement

#	Neutral prone on MFPP					Laterally displaced legs					
	MT		TL/L		Pelvic Obliquity	Direction of leg pull	MT		TL/L		Pelvic obliquity (°)
	Cobb (°)	AVR (°)	Cobb (°)	AVR (°)			Cobb	AVR	Cobb	AVR	
1	21	<10	35	30	−1°	CV TL/L	12° (−43%)	<10°	14° (−60%)	19° (−37%)	21
2	56	28	33	17	1°	CV TL/L	52° (−7%)	36° (+29%)	10° (−70%)	9° (−47%)	20
3	74	41	25	<10	3°	CV MT	65° (−12%)	38° (−7%)	34° (+36%)	<10°	15
4	23	<10	38	30	2°	CV TL/L	19° (−17%)	<10°	23° (−39%)	26° (−13%)	14
5	63	29	25	<10	−1	CV MT	54° (−14%)	20° (−31%)	35° (+40%)	<10°	24
6	10	<10	47	27	0°	CV TL/L	5° (−50%)	<10°	30° (−36%)	10° (−63%)	22
11	23	<10	42	33	−4°	CC TL/L	24° (+4%)	<10°	52° (+24%)	33° (±0%)	−17

CV convexity, CC concavity

observed to ensure that it was maintained in place by the MFPP thoracic cushions. A consistent transverse plane pelvic torsion of 30° was obtained for subjects #7 to #10 and #12 by ensuring that both anterior portions of their iliac crests were in contact with the PTD cushion.

Patients were verbally questioned about their level of comfort in the second position of radiograph acquisition and asked to choose one of four levels; comfortable, mildly comfortable, mildly uncomfortable or uncomfortable. In addition, the time taken to switch between positions was recorded.

Each radiograph was analyzed using Synapse image analysis software (Fujifilm Medical Systems, USA) and the following indices were measured. For all patients, scoliotic Cobb angles and AVR using the Nash-Moe method [10]. For patients #1 to #6 and #12, pelvic obliquity, or coronal plane rotation, defined as the angle between the bi-tangent line linking the two proximal apices of the iliac crest and a reference horizontal taken as positive when the left crest is proximal relative to the right one. Vertebral rotations inferior to 10° were not considered in average results due to accuracy issues for small rotations [11].

A radio-opaque beam of the surgical frame was used as a reference horizontal as well as to scale the radiographic distance measurements to account for perspective projection. Changes in spinal geometrical parameters between positions were statistically analyzed using paired *t* tests performed with STATISTICA V7 software (StatSoft Inc). Correlations between Cobb angle reductions obtained with the lateral bending tests and LLD/PTD positioning as well as the correlations between Cobb and AVR changes were tested using the Pearson method. Proximal thoracic curves were not analyzed as part of this study as they were not always visible on the radiographs and the LLD and PTD are not designed to impact them. No patient in the study had structural proximal thoracic curves.

Results

Patients experienced a decrease in Cobb angles and AVR while going from the standing to neutral prone position on the MFPP averaging 10° (1° to 26°; ±8°) or 19% for MT Cobb, 10° (2° to 21°; ±7°) or 21% for TL/L Cobb, 3° (5° to

Fig. 3 Radiographs of patients 1–6 and 11 in the neutral prone (*top row*) and laterally bent leg (*bottom row*) positions. Arrow direction of lower limb displacement

Table 3 Impact of pelvic torsion

#	Neutral prone on MFPF				Twisted pelvis				
	MT		TL/L		Side raised	MT		TL/L	
	Cobb (°)	AVR (°)	Cobb (°)	AVR (°)		Cobb	AVR	Cobb	AVR
7	30	<10	48	34	CC TL/L	29° (−3%)	<10°	34° (−29%)	9° (−74%)
8	52	32	14	<10	CC MT	44° (−15%)	23° (−28%)	17° (+21%)	17°
9	44	40	21	<10	CC MT	41° (−7%)	35° (−13%)	23° (+10%)	13°
10	31	18	38	37	CC TL/L	26° (−16%)	<10°	29° (−24%)	8° (−78%)
12	59	30	26	<10	CV MT	61° (+3%)	35° (+17%)	28° (+8%)	16°

7°; $\pm 4^\circ$) or 4% for MT AVR, and 5° (+3° to 19°; $\pm 8^\circ$) or 12% for TL/L AVR.

Lateral displacement of patients' legs from the neutral prone position towards the convexity of their lowest structural curve (2 MT cases and 4 TL/L cases) resulted in a 16° (9° to 23°; $\pm 6^\circ$) or 39% supplementary reduction in Cobb and 9° (3° to 17°; std: 5°) or 33% supplementary reduction in AVR. Statistical analysis showed that both these reductions were significant with respective *p* values of 0.0013 and 0.0124. When considering only TL/L structural curves average Cobb reduction was 19° or 51%. The impact of lateral leg displacement on the secondary curves depended on their location. The MT secondary curves (*n* = 4) decreased 6° (4° to 9°; $\pm 2^\circ$) or 29%. The TL/L secondary curves (*n* = 2) increased 9° and 10°.

Secondary curve AVRs were small and minimally impacted. Pelvic obliquity in the laterally displaced position averaged 19° $\pm 4^\circ$ (14° to 24°). The detailed results for each patient are outlined in Table 2 and can be observed on the radiographs in Fig. 3.

The correlation between the lowest structural curve percentage Cobb angle reduction experienced during the lateral bending tests and with the LLD was 0.81 with similar respective average values 40 and 39%. The correlation between reduction in Cobb and AVR in the lowest structural curves was poor at 0.38.

Placing the pelvis in torsion by raising it on the side of the concavity of the lowest structural curve (2 MT cases and 2 TL/L cases) resulted in a 9° (3° to 14°; $\pm 5^\circ$) or 19% supplementary reduction in Cobb angle and 17° (4° to 30°;

Fig. 4 Radiographs of patients 7–10 and 12 in the neutral prone (1st and 2nd row) and twisted pelvis positions (3rd and 4th row). Arrow direction of pelvic torsion

$\pm 12^\circ$) or 48% supplementary reduction in AVR. When considering only TL/L structural curves AVR reduction was the most effective with values of 25° (74%) and 30° (79%) achieved. The impact of pelvic torsion on the secondary curves also depended on their location. The MT secondary curves ($n = 2$) decreased 1° and 5° . The TL/L secondary curves ($n = 2$) increased 2° and 3° . It also resulted in an increase in secondary TL/L AVR going from $<10^\circ$ to 13° and 17° . The detailed results for each patient are outlined in Table 3 and can be observed on the radiographs in Fig. 4.

The correlation between the percentage reduction in Cobb angles experienced during the lateral bending tests and raising the pelvis on the side of the concavity for the lowest structural curves was 0.96 with the losses experienced due to lateral bending much larger; 50% as compared to 19%. The correlation between reduction in Cobb and AVR in the lowest structural curves was fair at 0.73.

Positioning patient #11 opposite to the LLD design intention resulted a 10° or 24% increase in TL/L Cobb with negligible impact on AVR. Positioning patient #12 opposite to the PTD design intention resulted in a 5° or 17% increase in MT AVR, increased a nil TL/L AVR to 16° , and had negligible impact on Cobb angles.

None of the patients experienced discomfort in the second position of radiograph acquisition; 7 said that they were comfortable (4 on the LLD and 3 on the PTD), 4 that they were mildly comfortable (2 on the LLD and 2 on the PTD), and 1 could not provide reliable input due to an intellectual impairment.

The time taken between LLD positions was approximately 1 min and consisted of putting the patient's ankle into the harness, pulling their legs to one side via the cable, and fixing the cable to the frame. The thorax remained stable during this process. The time taken between PTD was approximately 3 min and consisted of having the patient get off the MFPP, switching the existing pelvic support for the PTD, inserting the thoracic cushion spacer, and placing the patient back on the MFPP.

Discussion

This study is considered a proof of concept of two novel surgical positions, which allow for the effective reduction of Cobb angles and AVR in the lowest structural curves. Both devices worked best on TL/L curves but can also be effective on MT curves. The supplementary reduction of the scoliotic deformities achieved was significant. While not tested in the present study, it could be possible, with some design changes discussed below, to combine their use with the potential for even greater reduction of the scoliotic deformities.

The patient position resulting from LLD use is one known to reduce scoliotic deformities and similar effect is currently exploited during lateral bending spinal flexibility tests and with the Charleston bending brace [12]. Instead of laterally displacing the torso, the LLD moves the lower limbs. A surgical frame, which allows lateral displacement of the thoracic cushions could further reproduce the lateral bending position by displacing the torso in the same direction as the lower limbs. Despite only moving the lower limbs, the Cobb angle reductions were comparable to those of the lateral bending tests.

The two tested positioning systems were only functional prototypes; improvements need to be made to their current design in order for them to be practical in a surgical setting. The PTD can be made to incrementally slant thus permitting multiple levels of pelvic torsion, including the level position, and negating the need to switch between pelvic cushions. The LLD can be replaced by a leg harness (slightly wider than the lower limbs), which would have the ability to swivel to either side and be locked in place. This would negate the need for cable pulling/tying and allow more room for the surgical staff to maneuver around the table. Alternatively, since pelvic coronal plane rotation is the mechanism of transfer for the reductions seen with the LLD, it could be achieved directly with a pelvic cushion and harness while maintaining the legs relatively straight. A pelvic cushion and harness, which could both slant and tilt would allow for simultaneous pelvic rotation and torsion.

The LLD and PTD have many potential intra-operative applications. They could be used to improve vertebral alignment in order to facilitate pedicle screw insertion. They could be used to manipulate coronal curves in order to facilitate rod insertion and allow more flexibility with regards to the shape of initial rod contouring thus requiring less subsequent in situ adjustment. For older instrumentation techniques, they could be used in conjunction with distraction maneuvers in order to achieve more Cobb reduction and allow for rotational corrections, which would otherwise not be possible. Finally, the LLD could be used in order to correct pelvic obliquity often associated with neuromuscular scoliosis as opposed to using unilateral halo-femoral traction [13]. Patients would be returned to the neutral prone position prior to setscrew/hook tightening and fusion to ensure a level and straight pelvis. In the event that a double curve is present, it is believed that the devices could be used in a two-stage approach; 1st to facilitate primary curve instrumentation then altering the direction of pelvic rotation/torsion in order to address the secondary curves. While the LLD and PTD cannot replace the corrective forces applied by modern instrumentation techniques, they can be used in conjunction with them to facilitate the maneuvers. A randomized control trial

comparing post-operative results and duration of operation with and without the use of these types of features would further allow determination of their usefulness.

The pelvic coronal and transverse plane rotation principles investigated in this study can also be applied to minimally invasive surgeries (e.g. vertebral stapling, tether, etc.) whose instrumentation does not allow for large corrective forces to be applied. This could be achieved in the lateral decubitus position by raising and lowering a patient's legs with a lower limb positioner type device [8] to achieve pelvic tilt and by tilting their pelvis to the left and right with a V-shaped pelvic support in order to achieve pelvic torsion.

Since none of the patients experienced discomfort in the laterally displaced legs or pelvic twisted positions, it is believed that additional movement could be induced intra-operatively to provide even more correction of Cobb angles and AVR than presented in this study.

The support cushion aimed at preventing lateral pelvis movement during LLD positioning was not required during this study since the existing pelvic cushions sufficiently held the patient in place. It is possible that more extreme LLD positioning would necessitate use of the support cushion; if the case then it should be placed at the level of the superior iliac crest on the side toward which the legs are being pulled.

The relatively high correlation and similar values found between lowest structural curve Cobb angle reductions obtained with the LLD and lateral bending tests suggest that the standard pre-operative lateral bending tests could be used in order to identify good candidates for LLD use. Consequently this feature, like all external forces applied to the spine, is most effective on flexible curves and less effective on more rigid ones.

The main difference between the devices presented in this study and halo traction devices is in the manner in which they reduce Cobb angles. Halo traction correction is primarily due to a longitudinal elongation of the spine (increasing disc height), LLD and PTC correction is due to coronal and transverse plane vertebrae alignment (disc angles and rotation). While disc height increase may be hard to maintain post-operatively [5] due to gravitational forces, the changes in disc angles and rotations will be maintained by the instrumentation.

The amount of AVR correction obtained for primary structural curves in the MT region are likely higher than those measured on the radiographs. Since the thoracic cushion on the convex side of the MT deformity is raised this globally rotates the thorax towards the curve concavity, which would translate to the spine and appear to increase AVR on coronal plane radiographs. Knowing the differences in height and lateral position between the two superior surface centroids of the thoracic cushions, the

global thorax rotation can be estimated at 10°. This thorax twisting is necessary in order to maximize global spinal derotation, simply torsioning the pelvis would be less efficient.

The current study is limited by the number of patients especially with regards to the opposite of intended use testing which was only done for one case for each device. While most results were statistically significant, power would increase with additional patients. This was a proof of concept study. Before the LLD and PTD can be used in an operative setting, additional testing has to be done after incorporation of the proposed design changes. One factor, which was not considered in this study, was the impact of anesthesia and surgical opening. Traditionally, these factors increased spinal flexibility, which would lead to additional corrective ability for both devices. Finally, intra-operative testing needs to be performed to see if the benefits of the LLD and PTD warrant the additional complexity of patient positioning they would require.

Conclusion

The LLD allows for a significant reduction of Cobb angle and AVR in the lowest structural curve by lateral bending of the lower limbs towards the scoliotic spine convexity. The PTD allows a significant reduction in Cobb angles and important reductions in AVR by raising the pelvis on the concave side of their lowest structural curve and opposite thoracic cushion. Greatest improvements are obtained with lumbar curves. These proofs of concept devices offer two novel ways to facilitate surgical intervention of scoliosis by allowing intra-operative manipulation of the spine.

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