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Clinical Research

Are the Choice of Frame and Intraoperative Patient Positioning Associated With Radiologic and Clinical Outcomes in Long-instrumented Lumbar Fusion for Adult Spinal Deformity?

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Abstract

Background Previous studies of patient positioning during spinal surgery evaluated intraoperative or immediate postoperative outcomes after short-instrumented lumbar fusion. However, patient positioning during long-instrumented fusion for an adult spinal deformity (ASD) might be associated with differences in intraoperative parameters such as blood loss and longer-term outcomes such as spine alignment, and comparing types of surgical tables in the context of these larger procedures and evaluating longer-term outcome scores seem important.

Questions/purposes (1) Do blood loss and the number of transfusions differ between patients who underwent multi-level spinal fusion with a Wilson frame and those with a four-poster frame? (2) Does restoration of lumbar lordosis and the sagittal vertical axis differ between patients who underwent surgery with the use of one frame or the other? (3) Do clinical outcomes as determined by Numeric Rating Scale and Oswestry Disability Index scores differ between the two groups of patients? (4) Are there differences in postoperative complications between the two groups?

Methods Among 651 patients undergoing thoracolumbar instrumented fusion between 2015 and 2018, 129 patients treated with more than four levels of initial fusion for an ASD were identified. A total of 48% (62 of 129) were

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eligible; 44% (57 of 129) were excluded because of a history of fusion, three-column osteotomy, or surgical indications other than degenerative deformity, and another 8% (10 of 129) were lost before the minimum 2-year follow-up period. Before January 2017, one surgeon in this study used only a Wilson frame; starting in January 2017, the same surgeon consistently used a four-poster frame. Forty patients had spinal fusion using the Wilson frame; 85% (34 of 40) of these had follow-up at least 2 years postoperatively (mean 44 ± 13 months). Thirty-two patients underwent surgery using the four-poster frame; 88% (28 of 32) of these were available for follow-up at least 2 years later (mean 34 ± 6 months). The groups did not differ in terms of age, gender, BMI, type of deformity, or number of fused levels. Surgical parameters such as blood loss and the total amount of blood transfused were compared between the two groups. Estimated blood loss was measured by the amount of suction drainage and the amount of blood that soaked gauze. The decision to transfuse blood was based on intraoperative hemoglobin values, a protocol that was applied equally to both groups. Radiologic outcomes including sagittal parameters and clinical outcomes such as the Numerical Rating Scale score for back pain (range 0-10; minimal clinically important difference [MCID] 2.9) and leg pain (range 0-10; MCID 2.9) as well as the Oswestry Disability Index score (range 0-100; MCID 15.4) were also assessed through a longitudinally maintained database by two spine surgeons who participated in this study. Repeated-measures analysis of variance was used to compare selected radiologic outcomes between the two groups over time.

Results Blood loss and the total amount of transfused blood were greater in the Wilson frame group than in the four-poster frame group (2019 ± 1213 mL versus 1171 ± 875 mL; mean difference 848 [95% CI 297 to 1399]; p = 0.003 for blood loss; 1706 ± 1003 mL versus 911 ± 651 mL; mean difference 795 [95% CI 353 to 1237]; p = 0.001 for transfusion). Lumbar lordosis and the sagittal vertical axis were less restored in the Wilson frame group than in the four-poster frame group (7° ± 10° versus 18° ± 14°; mean difference -11° [95% -17° to -5°]; p < 0.001 for lumbar lordosis; -22 ± 31 mm versus -43 ± 27 mm; mean difference 21 [95% CI 5 to 36]; p = 0.009 for the sagittal vertical axis). Such differences persisted at 2 years of follow-up. The proportion of patients with the desired correction was also greater in the four-poster frame group than in the Wilson frame group immediately postoperatively and at 2 years of follow-up (50% versus 21%, respectively; odds ratio 3.9 [95% CI 1.3 to 11.7]; p = 0.02; 43% versus 12%, respectively; odds ratio 5.6 [95% CI 1.6 to 20.3]; p = 0.005). We found no clinically important differences in postoperative patient-reported outcomes including Numeric Rating Scale and Oswestry Disability Index scores, and there were no differences in postoperative complications at 2 years of follow-up.

Conclusion The ideal patient position during surgery for an ASD should decrease intra-abdominal pressure and induce lordosis as the abdomen hangs freely and hip flexion is decreased. The four-poster frame appears advantageous for long-segment fusions for spinal deformities. Future studies are needed to extend our analyses to different types of spinal deformities and validate radiologic and clinical outcomes with follow-up for more than 2 years.

Level of Evidence Level III, therapeutic study.

Introduction

Relton and Hall [28] introduced the four-poster frame to decrease intraoperative blood loss by reducing pressure on the abdomen and vena cava during scoliosis surgery. The Jackson surgical table was developed with a four-poster frame, similar to the Relton-Hall frame, and is also widely used. These four-poster frames have clear advantages in terms of reducing blood loss and restoring lordosis during correction of a spinal deformity. A recent randomized controlled study [21] reported that the four-poster frame can decrease blood loss during short-segment fusion compared with a Wilson frame. Another study reported that restoration of lumbar lordosis was greater when surgeons used a four-poster frame than when they used an Andrews-type table [11].

However, intraoperative patient positioning might be even more important in spinal surgery for an adult spinal deformity (ASD) because long-segment fusion is usually performed, which can result in increased bleeding. This is even more problematic because many patients undergoing surgery for an ASD involving long-segment fusions may be older, and they may have more medical comorbidities; as such, they are at greater risk of complications after surgery for an ASD [4, 9]. Investigating steps to mitigate these problems in long-segment ASD surgery seems important. In addition, restoring and maintaining sagittal alignment is also important during surgery; previous studies have reported that sagittal malalignment is related to increased pain and lower quality of life in patients with an ASD [7, 8, 14, 18]. Different surgical tables might not achieve these goals with similar effectiveness, and to our knowledge, this question has not been explored in a well-matched series of patients undergoing long-segment spinal fusion for an ASD. Although the four-poster frame and Jackson surgical table have been used in deformity surgery because of their clear benefits, the long-term clinical and radiologic outcomes of intraoperative patient positioning in surgery for an ASD have not been evaluated.

Therefore, the purpose of this study was to evaluate radiologic and clinical parameters associated with patient positioning during surgery for an ASD by comparing two different surgical positions. We asked: (1) Do blood loss and the number of transfusions differ between patients who underwent multilevel spinal fusion with a Wilson frame and those with a four-poster frame? (2) Does restoration of lumbar lordosis and the sagittal vertical axis differ between patients who underwent surgery with the use of one frame or the other? (3) Do clinical outcomes as determined by Numeric Rating Scale (NRS) and Oswestry Disability Index (ODI) scores differ between the two groups of patients? (4) Are there differences in postoperative complications between the two groups?

Patients and Methods

Study Design and Setting

This was a retrospective study from a longitudinally maintained database from 2015 to 2018 at an urban, academic, tertiary spine care center, which included patients who were cared for by two surgeons.

Participants

We included patients who underwent surgery for an ASD who had sagittal imbalance (sagittal vertical axis ≥ 5 cm) and clinical symptoms such as intractable radiculopathy and low back pain with a minimum follow-up period of 2 years [14, 20]. Among 651 patients who underwent thoracolumbar instrumented fusion between 2015 and 2018, 129 patients treated with more than four levels for an ASD were identified. We excluded 15% (20 of 129) of the patients; these were treated with three-column osteotomy for a fixed sagittal deformity. Twenty-one percent of the patients (27 of 129) underwent revision surgery for previous fusions, and these patients were also excluded in order to evaluate radiologic and clinical outcomes by intraoperative positioning alone. Eight percent (10 of 129) undergoing procedures for congenital scoliosis or adolescent idiopathic scoliosis were also excluded. Another 8% (10 of 129) were lost before 24 months. Thus, 48% (62 of 129) were clinically and radiologically eligible for inclusion in this study (Fig. 1).

Between January 2015 and December 2016, the surgeon in this study (KYH) used only a Wilson frame; between January 2017 and June 2018, the same surgeon consistently used the four-poster frame (Fig. 2). Forty patients underwent surgery for a deformity using a Wilson frame before January 2017; 85% (34 of 40) of those who had follow-up at least 2 years after surgery (mean 44 ± 13 months of follow-up) were included in the Wilson frame group (Fig. 3). Thirty-two patients underwent surgery using a four-poster frame starting in January 2017; 88% (28 of 32) of those who had follow-up at least 2 years later (mean 34 ± 6 months of follow-up) were included in the four-poster frame group (Fig. 4). With the numbers available, there was no difference in loss to follow-up between these groups. An Allen surgical table (Hillrom) connected to an operating room table was used in this study as a four-poster frame instead of a Jackson surgical table (Mizuho OSI).

Patient Demographics and Baseline Parameters

The two groups of patients did not differ in age, gender, BMI, bone mineral density, smoking status, American Society of Anesthesiologists grade, and type of deformity (Table 1.).

Staged operations were performedin most patients in both groups; lateral lumbar interbody fusion at levels above the lumbosacral joint was conducted as the first procedure, followed by posterior spinal fusion with posterior lumbar interbody fusion, usually at the lumbosacral joint, at a 5-day to 7-day interval [17]. Anterior column release and hyperlordotic cages were not used in either group. The total number of fusion levels and distribution of upper and lower instrumented vertebrae in both groups were not different, with the numbers available. The numbers of patients undergoing lateral lumbar interbody fusion and posterior lumbar interbody fusion, as well as the average number of fused levels, did not differ between the two groups (Table 2.).

Primary and Secondary Study Outcomes

Our primary study goals were to determine intraoperative surgical and postoperative radiologic outcomes. Intraoperative surgical outcomes included estimated blood loss, the amount of blood transfused, and admission to the intensive care unit (ICU). Estimated blood loss was measured as the amount of suction drainage and amount of blood that soaked gauze [35].Transfusion of packed red blood cells was recommended when the intraoperative hemoglobin level dropped within 8.0 g/dL to 9.0 g/dL, a protocol that was applied in both groups [27]. Blood loss and the amount of blood transfused were measured and recorded in the operation record by the anesthesiologist who participated in each surgery. Admission to the ICU was determined by intraoperative hemodynamic instability, including blood loss and total transfusion, after agreement between the anesthesiologist and spine surgeon.

Postoperative radiologic outcomes were correction of radiologic parameters including lumbar lordosis and the sagittal vertical axis, and the achievement of desired

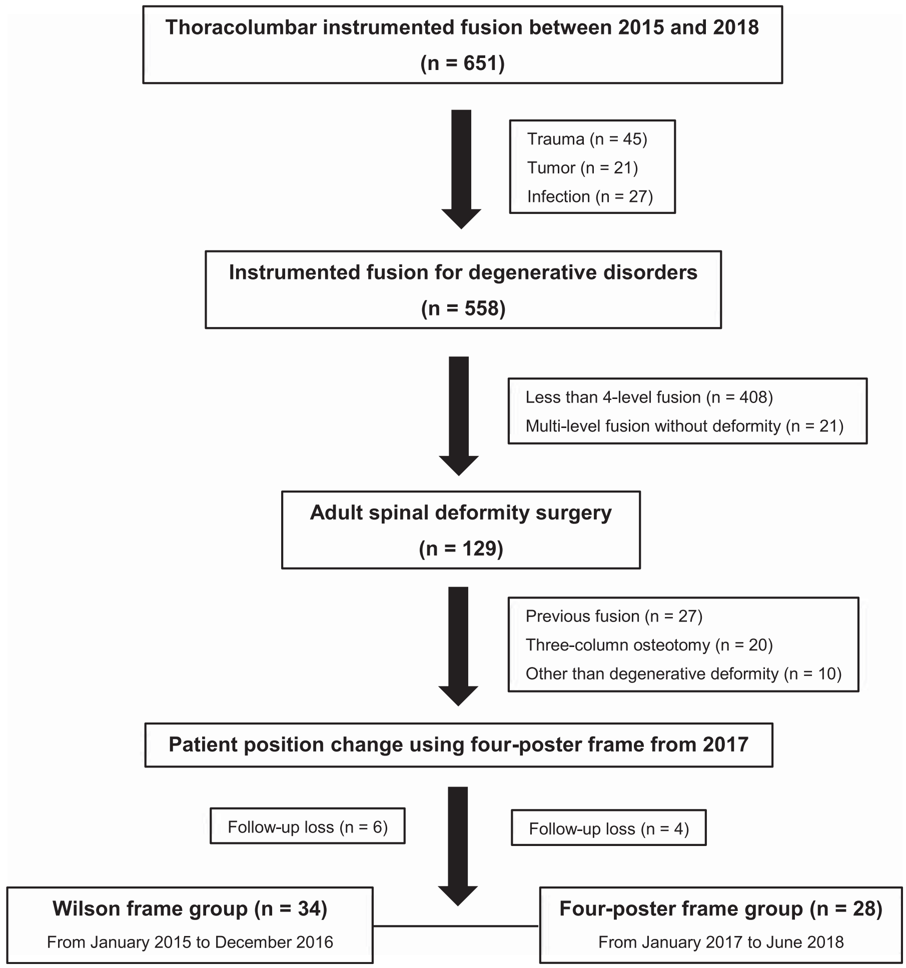

Fig. 1. This flowchart shows the inclusion and exclusion criteria for patient selection in this study.

correction. Two spine surgeons who participated in this study (DGC and SIK) measured radiologic parameters according to a reported method [12, 16, 24, 30] using a longitudinally maintained database preoperatively and again at 3 months and 2 years postoperatively. For this study, the desired correction was defined as a sagittal vertical axis less than 50 mm, pelvic tilt less than 20°, and pelvic incidence minus lumbar lordosis less than ± 9° [31].

Our secondary study goal was to determine clinical outcomes, including 10-point NRS scores for back and leg pain, ODI scores, and postoperative complications. Two spine surgeons who participated in this study (DGC and SIK) assessed clinical outcomes through a longitudinally maintained database preoperatively and again at 3 months and 2 years postoperatively. Regarding the NRS, patients were asked to rate their pain on a scale from 0 (no pain) to 10 (worst pain possible). The minimum clinically important difference (MCID) using the anchor-based method for patients undergoing lumbar surgery was 2.9 points for the NRS back score, 2.9 points for the NRS leg score, and 15.4 points for the ODI score [3]. Reoperation within 2 years was assessed in both groups. Complications related to the patient's position, including pressure skin lesions, were also compared between the two groups. Pressure-related skin injury was divided into five grades: I, nonblanching skin erythema; II, blister; III, peeling of the epidermis; IV, peeling of the full-skin thickness; and V, exposure of the underlying muscle [2].

Ethical Approval

This study was approved by our institutional review board (approval number KC21RISI0002).

Statistical Analyses

Perioperative continuous variables are presented as means and SDs. These variables were compared between the two

Fig. 2 A-B. These photographs show (**A**) the patient position with the use of a Wilson frame and (**B**) patient position using a four-poster frame. A color image accompanies the online version of this article.

groups using a t-test. Categorical variables were compared using Pearson chi-square or Fisher exact tests. Repeated-measure analysis of variance was used to compare selected radiologic outcomes between the two groups over time. Statistical analyses were conducted using SPSS software (IBM SPSS Statistics, version 24.0), with the significance level set at $p < 0.05$.

Results

Blood Loss and Transfusions

Although the total surgical time did not differ between the two groups, estimated blood loss and the amount of blood transfused were greater in the Wilson frame group than in the four-poster frame group (2019 ± 1213 mL versus 1171 ± 875 mL, respectively; mean difference 848 [95% CI 297 to 1399]; p = 0.003 for estimated blood loss; 1706 ± 1003 mL versus 911 ± 651 mL, respectively; mean difference 795 [95% CI 353 to 1237]; p = 0.001 for transfusion). The Wilson frame group had more admissions to the ICU after the procedure than the four-poster group did (56% [19 of 34] versus 18% [five of 28], odds ratio 5.8 [95% CI 1.8 to 19]; p = 0.002). In both groups, the 24 patients who were admitted to the ICU had greater estimated blood loss and amount of total transfusion than the 38 patients who were not admitted to the ICU (2181 ± 1416 mL versus 1272 ± 755 mL, respectively; mean difference 908 [95% CI 350 to 1465]; p = 0.003 for estimated blood loss; 1856 ± 1081 mL versus 1007 ± 662 mL, respectively; mean difference 849 [95% CI 403 to 1295]; p = 0.002 for transfusion).

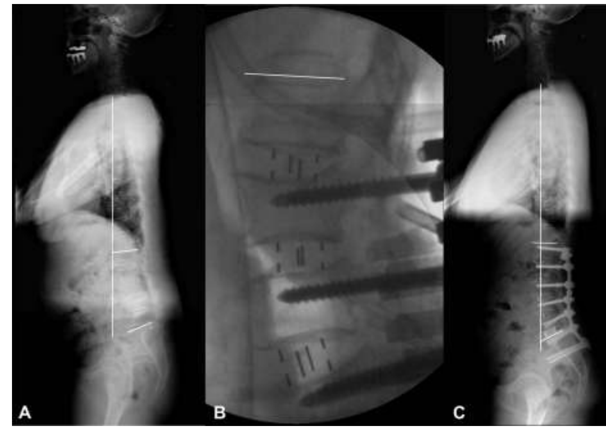

Fig. 3 A-C (**A**) A preoperative whole-spine radiograph shows sagittal imbalance in a patient in the Wilson frame group. (**B**) An intraoperative image was taken with the patient in the prone position. (**C**) This postoperative whole-spine radiograph shows undercorrection.

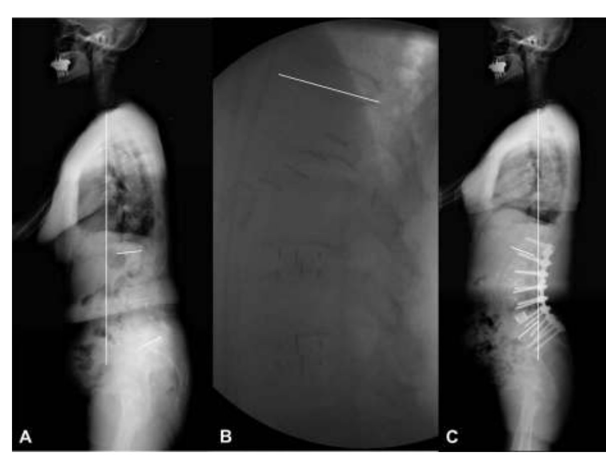

Fig. 4 A-B. (**A**) A preoperative whole-spine radiograph shows sagittal imbalance in a patient in the group with a four-poster frame. (**B**) An intraoperative image was taken in the prone position in patients with a four-poster frame. (**C**) This post-operative whole-spine radiograph shows that sagittal balance has been restored.

Table 1. Patient demographics in both groups

Variable	Wilson frame group (n = 34 patients)	Four-poster frame group (n = 28 patients)	p value
Age in years, mean ± SD	70 ± 6	70 ± 7	0.60
Women, % (n)	77 (28)	71 (20)	0.65
BMI in kg/m^2, mean ± SD	26 ± 4	26 ± 4	0.43
BMD T-score, mean ± SD	-2.7 ± 1.1	-2.4 ± 0.8	0.26
Smoking status, % (n)	9 (3)	11 (3)	> 0.99
ASA class (1:2:3 + 4)	4:29:1	5:23:0	0.54
Type of deformity, % (n)			
DLK	50 (17)	57 (16)	0.58
DLKS	50 (17)	43 (12)	

BMD = bone mineral density; ASA = American Society of Anesthesiologists; DLK = degenerative lumbar kyphosis; DLKS = degenerative lumbar kyphoscoliosis.

Restoration of Lumbar Lordosis and the Sagittal Vertical Axis

Restoration of lumbar lordosis and the sagittal vertical axis was less effective in the Wilson frame group than in the four-poster frame group (7° ± 10° versus 18° ± 14°; mean difference -11° [95% CI -17° to -5°]; p < 0.001 for lumbar lordosis; -22 ± 31 mm versus -43 ± 27 mm; mean difference 21 [95% CI 5 to 36]; p = 0.009 for the sagittal vertical axis) (Table 3). The proportion of patients who achieved the desired correction was also greater in the four-poster frame group than in the Wilson frame group (50% [14 of 28] versus 21% [seven of 34], respectively; odds ratio 3.9 [95% CI 1.3 to 11.7]; p = 0.02).

Lumbar lordosis and the sagittal vertical axis were lower and greater in the Wilson frame group, respectively, at 2 years postoperatively (28° ± 9° versus 45° ± 12°; mean difference -16° [95% CI -22° to -10°]; p < 0.001 for lumbar lordosis; 45 ± 35 mm versus 24 ± 35 mm; mean difference 20 [95% CI 0.8 to 40]; p = 0.04 for the sagittal vertical axis) (Fig. 5). A higher portion of patients achieved the desired correction in the four-poster frame group than in the Wilson frame group

Table 2. Surgical factors and clinical parameters in the two groups

Variable	Wilson frame group (n = 34 patients)	Four-poster frame group (n = 28 patients)	p value
Number of fusion levels, mean ± SD	4.6 ± 0.7	4.7 ± 0.7	0.54
Upper-instrumented vertebrae, % (n)			
Above T12	12 (4)	14 (4)	0.61
L1	50 (17)	54 (15)	
L2	38 (13)	32 (9)	
Lower-instrumented vertebrae, % (n)			
L5	15 (5)	14 (4)	0.60
S1	65 (22)	57 (16)	
Iliac screws	20 (7)	29 (8)	
Patients undergoing LLIF, % (n)	91 (31)	96 (27)	0.62
Number of LLIF levels, mean ± SD	2.2 ± 1.1	2.2 ± 0.5	0.84
Patients undergoing PLIF, % (n)	88 (30)	89 (25)	> 0.99
Number of PLIF levels, mean ± SD	1.2 ± 0.6	1.1 ± 0.6	0.85
Total operating time in minutes, mean ± SD	290 ± 55	309 ± 36	0.13
Estimated blood loss in mL, mean ± SD	2019 ± 1213	1171 ± 875	0.003
Transfusion in mL, mean ± SD	1706 ± 1003	911 ± 651	0.001
ICU care, % (n)	56 (19)	18 (5)	0.002

LLIF = lateral lumbar interbody fusion; PLIF = posterior lumbar interbody fusion.

Table 3. Radiologic outcomes of the two groups

Variable	Wilson frame group (n = 34 patients)	Four-poster frame group (n = 28 patients)	p value
Preoperative			
PI in degrees	51 ± 13	50 ± 10	0.71
LL in degrees	25 ± 2	30 ± 11	0.18
SVA in mm	62 ± 17	64 ± 20	0.70
3 months postoperatively			
LL in degrees	32 ± 10	47 ± 12	< 0.001
SVA in mm	40 ± 32	21 ± 32	0.03
Targeted correction, % (n)	21 (7)	50 (14)	0.02
Postoperative changes			
LL in degrees	7 ± 10	18 ± 14	< 0.001
SVA in mm	-22 ± 31	-43 ± 27	0.009
2 years postoperatively			
LL in degrees	28 ± 9	45 ± 12	< 0.001
SVA in mm	45 ± 35	24 ± 35	0.04
Targeted correction, % (n)	12 (4)	43 (12)	0.005
PJK, % (n)	15 (5)	7 (2)	0.44

Data are presented as the mean ± SD, unless indicated otherwise. PI = pelvic incidence; LL = lumbar lordosis; SVA = sagittal vertical axis; PJK = proximal junctional kyphosis.

(43% versus 12%, respectively; odds ratio 5.6 [95% CI 1.6 to 20.3]; p = 0.005). With the numbers available, we found no difference in proximal junctional kyphosis between the two groups (15% [five of 34] versus 7% [two of 28], respectively; odds ratio 2.2 [95% CI 0.4 to 13]; p = 0.44) [10].

Clinical Outcomes (NRS and ODI Scores)

There were no important baseline between-group differences, and no clinically important differences [3] were observed 2 years after surgery (Table 4).

Complications

A single patient in the Wilson frame group underwent reoperation for wound infection, whereas three patients in the four-poster frame group underwent revision surgery for an early proximal junctional vertebral fracture, wound infection, and interbody cage migration. Regarding complications related to the patient's position, we found no differences in Grade I or II pressure skin lesions between the Wilson and four-poster frame groups (15% [five of 34 patients] versus 11% [three of 28 patients], respectively; p = 0.64). In addition, pressure skin lesions with a grade of more than

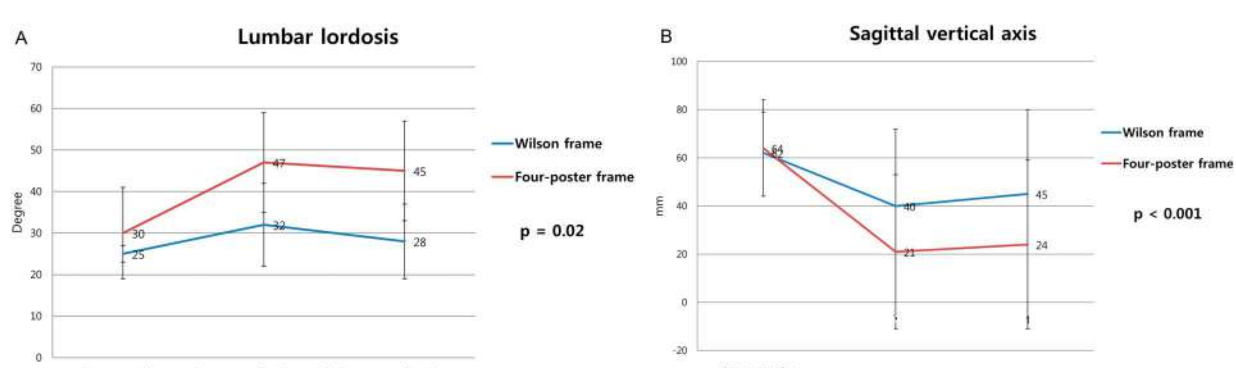

Fig. 5 A-B. (**A**) This graph shows lumbar lordosis preoperatively, 3 months postoperatively, and 2 years postoperatively. (**B**) This graph shows the sagittal vertical axis preoperatively, 3 months postoperatively, and 2 years postoperatively (p value at repeated-measures analysis of variance).

Table 4. Clinical outcomes of the two groups

Parameter	Wilson frame group (n = 34 patients)	Four-poster frame group (n = 28 patients)	p value
Preoperative			
NRS score (back)	7 ± 3	7 ± 2	0.79
NRS score (leg)	7 ± 3	7 ± 2	0.83
ODI score	60 ± 19	54 ± 18	0.22
3 months postoperatively			
NRS score (back)	4 ± 3	4 ± 3	0.61
NRS score (leg)	5 ± 4	4 ± 3	0.26
ODI score	47 ± 22	44 ± 20	0.52
2 years postoperatively			
NRS score (back)	4 ± 3	3 ± 3	0.048
NRS score (leg)	5 ± 3	4 ± 3	0.28
ODI score	48 ± 24	36 ± 17	0.04
Reoperation			
% of patients (n)	3 (1)	11 (3)	0.32
Cause of reoperation	Wound infection	Proximal junctional vertebral fracture, wound infection, cage migration	

Data are presented as the mean ± SD, unless indicated otherwise. The minimal clinically important difference was 2.9 points for the NRS back score, 2.9 points for the NRS leg score, and 15.4 points for the ODI score, based on a previous report [3].

III, meralgia paresthetica, visual impairment, and pulmonary complications were not noted in either group.

Discussion

Previous studies have reported that a four-poster frame can decrease intra-abdominal pressure and blood loss during short-instrumented lumbar fusion [5, 21, 25]. Patient positioning is also associated with intraoperative or immediate postoperative regional lordosis [11, 23, 32]. The purpose of the present study was to ascertain whether the hemodynamic advantages of a four-poster frame observed during short fusions would also be observed in older patients undergoing long-instrumented fusion for an ASD. Radiologic outcomes at 2 years of follow-up, including global sagittal alignment, were also evaluated. We found that the four-poster frame was more effective in decreasing blood loss, the total amount of blood transfused, and ICU admissions than the Wilson frame. Postoperatively, restoration of global sagittal alignment and regional lordosis was also greater in the four-poster frame group than in the Wilson frame group. Such restoration was maintained at 2 years of follow-up. We found no clinically important differences in outcomes scores.

Limitations

This study has several important limitations. First, the passage of time might influence our findings. Improvements in surgeon skill could result in a difference between the two groups. The indications for blood transfusions and admission to the ICU have changed over time. However, we believe that most of these differences could be attributed to the surgical frame because all operations were performed by one experienced surgeon who had performed 5496 spinal fusions before the first patient in this series underwent surgery, and the criteria for transfusion and ICU admission were unchanged at our institution between 2015 and 2018. Second, transfusions were performed at the surgeon's discretion, and measurement of blood loss could be inaccurate. However, we believe that transfusion and blood loss measurements were reliable without bias because the decision to transfuse blood was mainly based on intraoperative hemoglobin levels < 9 g/dL. In addition, intraoperative blood loss was measured and recorded by an anesthesiologist. Third, transfer bias (loss to follow-up) could have played a role; however, there was no difference in loss to follow-up between the groups, and a high proportion of patients were accounted for in both groups. On the other hand, radiologic and clinical outcomes were assessed by two spine surgeons who did not perform the surgery.

Blood Loss and Transfusions

Blood loss and transfusion were greater and the frequency of admission to the ICU was higher in the Wilson frame group than in the four-poster group. The reduction in blood loss, which might have contributed to decreased use of ICU services, is likely to be associated with decreased intra-abdominal pressure. Ni et al. [25] demonstrated that lumbar surgery using a Jackson surgical table can reduce intra-abdominal pressure and peak airway pressure compared with a general surgical table. Dharmavaram et al. [5] reported that the Jackson table compared with the Wilson frame has a positive effect on cardiac function measured by transesophageal echocardiography. Those findings are important because the prone position can reduce the cardiac index by 24%, resulting in decreased blood pressure and hemodynamic instability [6]. Similar to our study, in a randomized study, Malhotra et al. [21] reported that a four-poster frame can decrease intra-abdominal pressure and mean airway pressure, resulting in less blood loss than the Wilson frame. We extended their findings to long-instrumented fusions in older patients with comorbidities (they excluded patients with cardiac disorders in that report, and the average ages of patients in their study groups were 38 and 40 years). We believe that the prone position with the use of a four-poster frame is associated with less morbidity because of decreased intra-abdominal pressure and improved hemodynamic function, especially in older patients undergoing long-instrumented fusion for an ASD.

Restoration of Lumbar Lordosis and the Sagittal Vertical Axis

Better restoration of lumbar lordosis and the sagittal vertical axis was achieved in patients treated with the four-poster frame (7° versus 18°, respectively; -22 versus -43 mm, respectively). Postoperatively and at 2 years of follow-up, the desired correction was also achieved more frequently in patients treated with the four-poster frame (50% versus 21%, respectively; 43% versus 12%, respectively). These findings were consistent with those of previous studies revealing that intraoperative patient positioning affected radiologic parameters [11, 23, 32]. Guanciale et al. [11] reported greater restoration of lumbar lordosis in the four-poster frame group than in the Andrews-type table group (48° versus 33°). Tribus et al. [32] demonstrated that intraoperative kneeling can induce loss of lumbar lordosis compared with preoperative values (37° versus 51°), suggesting the need for caution in long-instrumented lumbar fusion. Previous studies have evaluated regional lordosis according to patient positioning intraoperatively and immediately postoperatively [11, 23, 32]. However, our study revealed that regional lordosis induced by patient positioning during long-instrumented fusion for an ASD might have a positive effect on global sagittal alignment postoperatively and at 2 years of follow-up.

Clinical Outcomes (NRS and ODI Scores)

We found no clinically important differences in postoperative patient-reported outcomes including NRS and ODI scores at 2 years of follow-up. Meanwhile, some studies [13, 15, 22] reported that greater correction of sagittal parameters might increase proximal junctional kyphosis. Such patients might have worse clinical outcomes after surgery [13, 33]. In this regard, further studies with follow-up of more than 2 years are needed to evaluate clinical outcomes.

Complications

We found no differences in reoperations or complications related to the patient's position between the Wilson frame and four-poster frame groups. Although meralgia paresthetica was not observed in this study, Agarwal et al. [1] reported that the four-poster frame, particularly the Relton-Hall frame, could increase the occurrence of meralgia paresthetica owing to greater pressure on the anterior superior iliac spine and increased tension on the lateral femoral cutaneous nerve. A symmetric position and sufficient padding should be considered in order to prevent position-related complications, especially in patients with diabetes mellitus and obesity [1].

Suggestions About Patient Positioning

If a four-poster frame is unavailable in a hospital, it is imperative that the surgeon ensure that the patient's abdomen hangs freely when undergoing surgery for an ASD in the prone position [29]. Park et al. [26] reported that blood loss tends to increase with an increase in intra-abdominal pressure, based on a comparison of pad distance in the Wilson frame. Pads should be far enough apart and lowered in order to decrease intra-abdominal pressure and restore lordosis. A recent study reported that a horizontal bolster could be an alternative to the four-poster frame by decreasing intra-abdominal pressure and blood loss more than the Wilson frame can [19]. Furthermore, hip extension can increase lumbar lordosis. Decreased hip flexion can result in improved global spinal alignment, including lumbar lordosis [34].

When using a four-poster frame, hip extension is also a key factor. Recently, Miyazaki et al. [23] reported that segmental lordosis is greater intraoperatively and postoperatively in patients for whom a Jackson table was used and who had hip flexion of 0° than in the four-poster frame group of patients with hip flexion of 30°. Regarding the location of pads in a four-poster frame, the top edge of the chest pads should be placed at the patient's suprasternal notch to maintain proper ventilation. Pelvic pads should be placed symmetrically and widely under the anterior superior iliac spine. Additional padding is recommended to prevent meralgia paresthetica in patients with obesity [1].

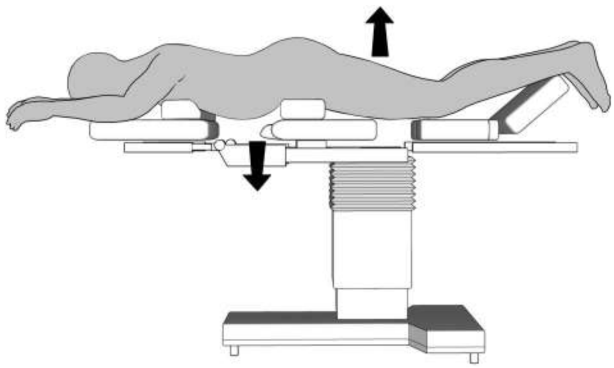

Fig. 6. This drawing shows the suggested ideal patient position during spinal surgery for an ASD. The abdomen should hang freely and the hips should be extended to decrease intra-abdominal pressure and increase lumbar lordosis.

We believe that in patients undergoing a procedure for an ASD, the abdomen should hang freely and the hips should be extended in order to decrease intra-abdominal pressure and induce lordosis (Fig. 6).

Conclusion

Patient positioning using a four-poster frame is more effective not only in decreasing blood loss, the total amount of blood transfused, and ICU admission, but also in restoring sagittal alignment of the spine than the Wilson frame during surgery for an ASD. As shown by others [5, 11, 21, 23, 25, 32], these results with the use of a four-poster frame are likely correlated with decreased intra-abdominal pressure and increased lumbar lordosis because the abdomen hangs freely and hip flexion is decreased. We found no clinically important differences in patient-reported outcomes, and differences in postoperative complications were not found between the two groups at 2 years of follow-up. Future studies are needed to extend our findings to different types of spinal deformity and validate radiologic and clinical outcomes at more than 2 years of follow-up.

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