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Effect of Prone Positional Apparatus on the Occurrence of Acute Kidney Injury After Spine Surgery

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■ BACKGROUND AND OBJECTIVE: **Increased intra-abdominal pressure with prone positioning for spinal surgery is associated with intraoperative hemodynamic alterations and the potential for postoperative complications. This study investigated the incidence of postoperative acute kidney injury (AKI) in patients undergoing spine surgery on a Jackson spinal table or a Wilson frame.**

■ METHODS: **A total of 1374 patients who underwent spine surgery were divided into 2 groups: Jackson spinal table (n = 598) and Wilson frame group (n = 776). After 1:1 propensity score matching, a final analysis was performed on 970 patients. The primary endpoint was a comparison of the incidence of AKI in the 2 groups.**

■ RESULTS: **After propensity score matching analysis, the mean ± standard deviations of spine surgery invasiveness index were 4.7 ± 3.5 and 2.1 ± 1.4 in patients with the Jackson spinal table and the Wilson frame, respectively ($P < 0.001$). Considering the differences in surgical invasiveness, operative time, estimated blood loss, and administration of packed red blood cells were higher in the Jackson spinal table group than in the Wilson frame group ($P < 0.001$). However, the incidence of AKI was less with the Jackson spinal table than with the Wilson frame (1.7% vs. 3.7%, 2.25 [0.978—5.175], $P = 0.056$), not reaching statistical significance.**

■ CONCLUSION: **This analysis showed that postoperative AKI in patients undergoing spine surgery in the prone position was not different with the Wilson frame than in the Jackson spinal table despite higher surgical severity, longer operative times, and more blood loss in the latter group. In spine surgery, the appropriate selection of prone positioning apparatus can potentially be an important consideration in reducing the risk of AKI.**

INTRODUCTION

Patients undergoing spine surgery in the prone position are at risk of position-associated complications, including perioperative visual loss, peripheral nerve injuries, pressure ulcers, and compartment syndromes.[1-4] Furthermore, in the prone position, thoracoabdominal compression results in a significant increase in intra-abdominal pressure (IAP).[5-7] Inasmuch as the Wilson frame is more likely to cause higher IAP than is the Jackson spinal table, significant hemodynamic alterations and pulmonary deterioration may occur with the Wilson frame compared to the Jackson spinal table.[5,8,9] These hemodynamic alterations can be potentially detrimental, especially in patients with greater intraoperative blood loss, with the increased IAP exacerbating the hypoperfusion of multiple visceral organs.[10-12]

Key words
- Acute kidney injury
- Intra-abdominal pressure
- Jackson spinal table
- Prone position
- Propensity score-matching
- Wilson frame

Abbreviations and Acronyms
AKI: Acute kidney injury
AKIN: Acute Kidney Injury Network
ASA: American Society of Anesthesiologists
IAP: Intra-abdominal pressure

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Table 1. Patient Characteristics and Preoperative Laboratory Values

	All Patients (N = 1374)				PS-Matched Patients (n = 970)			
Characteristic	Jackson Spinal Table (n = 598)	Wilson Frame (n = 776)	Standardized Difference	*P* Value	Jackson Spinal Table (n = 485)	Wilson Frame (n = 485)	Standardized Difference	*P* Value
Sex (female/male)	344 (57.5%)/254 (42.5%)	342 (44.1%)/434 (55.9%)	0.272	<0.001	259 (53.4%)/226 (46.6%)	255 (52.6%) /230 (47.4%)	0/0.017	0.781
ASA class (I/II/III)	44 (7.4%)/533 (89.1%)/21 (3.5%)	96 (12.4%)/663 (85.4)/17 (2.2%)	0/0.119/ 0.072	0.004	41 (8.5%)/435 (89.7%)/9 (1.9%)	40 (8.3%)/439 (90.5)/6 (1.2%)	0/0.026/ 0.034	0.733
Age (years)	61.8 ± 12.8	58.4 ± 16.2	0.260	<0.001	61.7 ± 13.3	61.4 ± 13.8	0.027	0.661
Weight (kg)	64.1 ± 11.7	66.5 ± 12.0	0.207	<0.001	64.8 ± 11.7	65.2 ± 11.7	0.035	0.571
Height (cm)	160.3 ± 9.5	163.4 ± 9.6	0.335	<0.001	161.2 ± 9.4	161.5 ± 9.4	0.037	0.520
Diabetes mellitus	30 (5.0%)	35 (4.5%)	0.023	0.661	26 (5.4%)	24 (5.0%)	0.019	0.768
Hypertension	264 (44.2%)	306 (39.4%)	0.095	0.079	211 (43.5%)	213 (43.9%)	0.008	0.899
Hemoglobin (g/dL)	13.4 ± 1.6	13.8 ± 1.5	0.243	<0.001	13.5 ± 1.5	13.5 ± 1.5	0.015	0.799
Platelet ($\times 10^3/\mu L$)	249.2 ± 65.7	242.7 ± 61.6	0.099	0.059	246.6 ± 61.4	248.5 ± 60.2	0.029	0.624
Albumin (g/dL)	3.9 ± 0.4	4.0 ± 0.4	0.357	<0.001	3.9 ± 0.4	4.0 ± 0.4	0.058	0.270
BUN (mg/dL)	15.9 ± 5.2	15.2 ± 5.0	0.121	0.023	15.4 ± 4.8	15.5 ± 4.8	0.001	0.983
Creatinine (mg/dL)	0.81 ± 0.33	0.83 ± 0.27	0.061	0.209	0.81 ± 0.33	0.80 ± 0.21	0.022	0.677
Prothrombin time (INR)	0.97 ± 0.10	0.96 ± 0.06	0.076	0.074	0.96 ± 0.06	0.96 ± 0.05	0.015	0.686

Data are presented as the mean ± standard deviation or number as appropriate.
PS, propensity score; ASA, American Society of Anesthesiologist; BUN, blood urea nitrogen; INR, international normalized ratio.

Given that increased IAP decreases renal microvascular and macrovascular blood flow in a pressure-dependent manner,[13] these increases in IAP may cause renal dysfunction.[14] Furthermore, even a mild increase in IAP during surgery can cause acute renal dysfunction.[15-17] However, there is limited information on the effects of the methods of prone positioning on perioperative renal dysfunction. Therefore, we compared the incidence of postoperative acute kidney injury (AKI) in groups undergoing spine surgery on a Jackson spinal table and a Wilson frame. The 2 groups were matched by propensity scoring. We hypothesized that patients undergoing spine surgery with the Jackson table would have a lower incidence of AKI than those positioned on the Wilson frame.

MATERIALS AND METHODS

Patient Characteristics and Anesthesia

The protocol was approved by the our institutional review board, and patient consent was waived because of the retrospective nature of study. This report follows the applicable Equator guidelines. Patients who underwent spine surgery in the prone position between January 2011 and February 2016 were included in this retrospective study. Exclusion criteria included inability to identify the positional apparatus, incomplete laboratory data, and cervical spine surgery. No patients were premedicated for surgery. After the application of routine monitoring systems, including electrocardiography, pulse oximetry, invasive blood pressure or noninvasive blood pressure monitoring, and train-of-4 monitoring, general anesthesia was induced with a bolus intravenous injection of 2 mg/kg propofol and 0.6 mg/kg rocuronium, and maintained by use of a volatile anesthetic with sevoflurane or total intravenous anesthesia with propofol and remifentanil. Patients were mechanically ventilated at a constant tidal volume of 6—8 mL/kg. Ventilation rate was adjusted to maintain the end-tidal carbon dioxide partial pressure between 30 and 35 mm Hg during the operation. After anesthesia induction was complete, patients were positioned prone on either the Jackson spinal surgery table (model 5803, OSI, Union City, California, USA) or the Wilson frame (model 5319G, OSI). The choice of positioning device was based on the type of surgery, with the Wilson frame being used more commonly for less invasive procedures, including discectomy or laminectomy. All patients received intravenous fluids with 0.9% normal saline or Plasmalyte. The hemoglobin level was maintained above 8.0 g/dL. When the hemoglobin level decreased to <8 g/dL, transfusion of packed red blood cells was performed. All operations were performed by 3 experienced spine

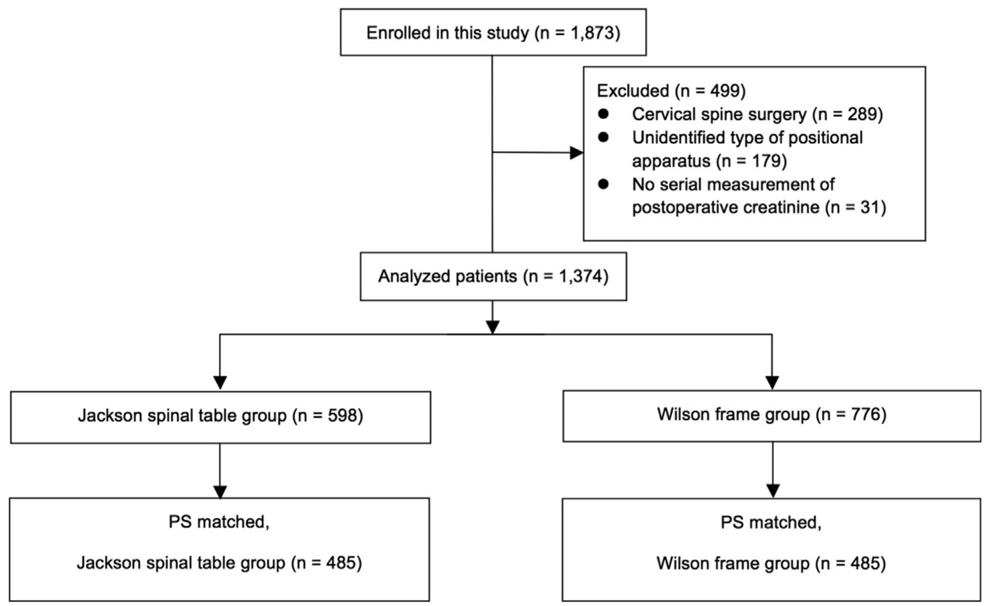

Figure 1. Study flow chart. PS, propensity score.

surgeons (R.S.W., R.S.C., and J.S.R.), who have at least 10 years of experience performing spine surgery.

Clinical Data Collection

Demographics, preoperative laboratory values, intraoperative variables, spine level and spine surgery invasiveness index,[18] and type of position apparatus were obtained or calculated from the electronic medical record system. Demographics included sex, age, weight, height, the American Society of Anesthesiologists (ASA) physical status classification, and history of diabetes mellitus and hypertension. Preoperative laboratory values included hemoglobin, platelets, prothrombin time, serum creatinine, blood urea nitrogen, and albumin. Intraoperative variables included the hourly amount of each type of fluid (crystalloid and colloid), urine output, total estimated blood loss, total packed red blood cell use, and operation time. The spinal surgery invasiveness index was used to quantify the extent of surgery and was defined as the sum of procedural elements applied to each vertebra. The 6 constituent procedural elements included anterior decompression, anterior fusion, anterior instrumentation, posterior decompression, posterior fusion, and posterior instrumentation.[18]

Definition of Primary Endpoint

In this study, the primary endpoint was a comparison of the incidence of AKI, defined by the Acute Kidney Injury Network (AKIN) criteria,[19] in the Jackson spinal table group and the Wilson frame group. AKI was defined by an increase in absolute serum creatinine of at least 0.3 mg/dL or by an increase to ≥1.5-fold over the baseline serum creatinine value within 48 hours.[19] AKI was staged for severity: stage 1, 1.5- to 1.9-fold increase or ≥0.3 mg/dL increase over baseline serum creatinine value; stage 2, 2.0- to 3.0-fold increase over baseline serum creatinine value; stage 3, 3-fold increase over baseline serum creatinine value or increase to ≥4.0 mg/dL in the serum creatinine value or initiation of renal replacement therapy.[19]

Statistical Analysis

Data are expressed as the mean ± standard deviation or number (%) as appropriate. Data variables included in this study were compared in the Jackson spinal table and Wilson frame groups by the χ^2 test or the Fisher exact test for categoric variables and the Student *t* test or the Mann-Whitney U test for continuous variables, respectively. We performed multiple logistic regression analysis to determine propensity score using the following 13 variables and interaction terms between the variables: sex, age, weight, height, American Society of Anesthesiologist (ASA) physical status classification, history of diabetes mellitus and hypertension, and preoperative laboratory values (hemoglobin, platelet count, prothrombin time/international normalized ratio, albumin, blood urea nitrogen, creatinine) (Table 1). Propensity score matching was performed by Greedy matching with a caliper of 0.2 standard deviations of the logit of the propensity score. After performance of 1:1 propensity score matching, continuous variables were compared by the paired samples *t* test or the Wilcoxon signed-rank test, as appropriate, and categoric variables were compared with the McNemar test or a marginal homogeneity test, as appropriate. Model discrimination was assessed with *c* statistics (0.703), and model calibration was assessed with Hosmer-Lemeshow statistics ($\chi^2 = 7.810$; $df = 8$; $P = 0.452$). The risks of AKI were compared with the use of conditional logistic regression model for matched data and

Table 2. Intraoperative and Postoperative Variables After Propensity Score—Matching Analysis

	PS-Matched Patients (n = 970)		
Variable	**Jackson Spinal Table (n = 485)**	**Wilson Frame (n = 485)**	***P* Value**
Level of operation			
Thoracic	50 (10.3%)	29 (6.0%)	0.019
Thoracolumbar	9 (1.9%)	6 (1.2%)	0.607
Lumbar	360 (74.2%)	379 (78.1%)	0.169
Lumbosacral	62 (12.8%)	70 (14.4%)	0.516
Sacral	4 (0.8%)	1 (0.2%)	0.375
Spine surgical invasiveness index	4.7 ± 3.5	2.1 ± 1.4	<0.001
Crystalloid use (mL/hour)	348.0 ± 191.0	284.3 ± 199.1	<0.001
Colloid use (mL/hour)	40.4 ± 61.9	14.3 ± 42.1	<0.001
Intraoperative urine output (mL/hour)	123.6 ± 139.3	86.5 ± 86.1	<0.001
Estimated blood loss (mL)	208.4 ± 429.8	55.6 ± 196.6	<0.001
Packed RBC use (units)	0.26 ± 1.06	0.05 ± 0.50	<0.001
Intraoperative vasopressor/inotropics use	26 (5.4%)	19 (3.9%)	0.349
Operation time (minutes)	303.0 ± 123.5	198.8 ± 76.1	<0.001
Immediate postoperative hemoglobin (g/dL)	12.0 ± 1.7	12.8 ± 1.6	<0.001
Postoperative ICU admission	55 (11.3%)	20 (4.1%)	<0.001
Hospital stay (days)	9.6 ± 8.7	7.3 ± 10.4	<0.001

Data are presented as the mean ± standard deviation or number (%) as appropriate.
PS, propensity score; RBC, red blood cells; ICU, intensive care unit.

logistic regression model for total data. By division of AKI into stages according to the AKIN criteria, the risks of AKI were compared by cumulative logistic regression with the use of generalized estimating equations that accounted for the clustering of matched pairs and cumulative logistic regression for total data. In all analyses, a P value <0.05 was considered statistically significant. Statistical analysis was conducted with R (version 3.3.1; R Foundation for Statistical Computing, Vienna, Austria) and SPSS 23 for Windows (version 24.0.0; IBM Corporation, Chicago, IL, USA).

RESULTS

Patient Characteristics

A total of 1873 patients who underwent spine surgery in the prone position between January 2011 and February 2016 were included in this study. We excluded patients whose positioning apparatus was not identified (n = 179), those for whom no serial measurement of postoperative creatinine was performed (n = 31), and those who underwent cervical spine surgery (n = 289). Therefore, this study selected 1374 patients who were divided into 2 groups as follows: Jackson spinal table group (n = 598) and Wilson frame group (n = 776) (Figure 1).

Results of Propensity Matching

The patient characteristics and preoperative laboratory values of all patients (n = 1374) and propensity score—matched patients (n = 970) are listed in Table 1. Sex, ASA class, age, weight, height, and preoperative laboratory values, including hemoglobin, albumin, and blood urea nitrogen, showed statistically significant differences between the Jackson spinal table group (n = 598) and the Wilson frame group (n = 776) (Table 1). After propensity score matching analysis, there were no significant differences in baseline patient demographics and preoperative laboratory values between the groups (Table 1).

The patients in the Jackson spinal table group were more likely to have a thoracic lesion ($P < 0.019$) and a higher spine surgical invasiveness index ($P < 0.001$). The Jackson spinal table group received higher hourly amounts of crystalloid ($P < 0.001$), and colloid (5% albumin, $P < 0.001$). In addition, estimated blood loss and administration of packed red blood cells were also higher in the Jackson spinal table group than in the Wilson frame group ($P < 0.001$ and $P < 0.001$, respectively) (Table 2). The operative times were substantially different between groups: 303.0 ± 123.5 minutes in the Jackson spinal table group and 198.8 ± 76.1 minutes in the Wilson frame group ($P < 0.001$). The incidence for admission to intensive care unit postoperatively was higher in the Jackson spinal table group ($P < 0.001$) (Table 2). Other intraoperative and postoperative variables after propensity score matching analysis are shown in Table 2.

Incidence of AKI

The incidence of AKI based on the AKIN criteria was lower in the Jackson spinal table group than in the Wilson frame group (1.7% vs. 3.7%, odds ratio [95% confidence interval]: 2.250 [0.978–5.175], $P = 0.056$) (Table 3); however, this was not statistically significant. The stages of AKI according to the AKIN criteria are also shown in Table 3. The odds estimate for AKI stage 3 (reference was the patients without AKI) in the Wilson frame group was about 2.307 times that of the Jackson spinal table group and was statistically significant at a significance level of 5%.

DISCUSSION

Our study showed that the incidence of AKI after spine surgery was more frequent with the Wilson frame group than in the Jackson spinal table group, although the Wilson frame was used primarily in less invasive spine surgery such as discectomy or laminectomy. Our results are similar to the overall AKI incidence of previous studies.[20] It has been reported that mild AKI was closely associated with postoperative outcomes,[21-24] and the mortality related to AKI after surgery continued even after 3 to 10 years of follow-up.[23,25] Similarly, AKI with a mild elevation of serum creatinine after major surgery was significantly associated with a long-term risk of death.[26,27] Therefore, intraoperative efforts to reduce the incidence of postoperative AKI are crucial.[28]

Table 3. Acute Kidney Injury After Propensity Score-Matching Analysis

	All Patients (N = 1374)				PS-Matched Patients (n = 970)			
AKI	Jackson Spinal Table (n = 598)	Wilson Frame (n = 776)	OR (95% CI)	*P* Value	Jackson Spinal Table (n = 485)	Wilson Frame (n = 485)	OR (95% CI)	*P* Value
AKI*								
Overall	10 (1.7%)	27 (3.5%)	2.120 (1.018−4.414)	0.045	8 (1.7%)	18 (3.7%)	2.250 (0.978−5.175)	0.056
AKI†								
Stage 1	10 (1.7%)	22 (2.8%)			8 (1.7%)	15 (3.1%)		
Stage 2	0 (0.0%)	3 (0.4%)			0 (0.0%)	2 (0.4%)		
Stage 3	0 (0.0%)	2 (0.3%)	2.128 (1.022−4.432)	0.044	0 (0.0%)	1 (0.2%)	2.307 (0.984−5.407)	0.054

Data are presented as the number (%) as appropriate.
PS, propensity score; AKI, acute kidney injury; OR, odds ratio; CI, confidence interval.
In all patients, *logistic regression model (reference = Jackson spinal table), †cumulative logistic regression model (reference = Jackson spinal table).
In PS-matched patients, *conditional logistic regression model for matched pairs (reference = Jackson spinal table), †cumulative logistic regression model with the use of generalized estimating equations that accounted for the clustering of matched pairs (reference = Jackson spinal table).

Multiple complications are associated with the prone position, including increased bleeding resulting from elevated abdominal pressure, abdominal compartment syndrome, nerve palsies, decubitus ulcers, thrombosis, and postoperative visual loss.[29,30] However, studies comparing the incidence of AKI secondary to the prone position are not common.

Hemorrhage and hemodynamic perturbations can potentially increase the risk for the development of AKI and are not uncommon in patients undergoing multilevel spine surgery compared with minor procedures such as discectomy or decompressions.[19,20,31] In the present study, we consistently found that the patients requiring the Jackson spinal table were more likely to have a higher spine surgery invasiveness index and increased blood transfusion requirements than were patients in the Wilson frame group. In addition, operative times were significantly longer in the Jackson table group. Hospital lengths of stay were longer and ICU admissions were more frequent in the Jackson table group. Although not statistically significant, AKI rates were slightly higher with the Wilson frame despite less surgical severity, shorter operative times, and less blood loss. These results suggest that the Jackson table may provide better visceral organ perfusion, with a consequent lower incidence of AKI.

The Wilson frame maintains a patient in the prone position with 2 pads supporting the chest and pelvis. Because these pads are longitudinally aligned and support the chest, abdomen, and pelvis, it is likely that the use of this frame will increase the intra-abdominal pressure. By contrast, on the Jackson table, the abdomen has less direct pressure because of the 3 separate pads supporting both sides of the chest and the pelvis. In a prospective observational study comparing IAP among 3 prone positional apparatuses,[5] IAP in prone position was significantly lower in patients on the Jackson spinal table than those on the Wilson frame or chest rolls. This significant increase in IAP with the Wilson frame can cause more hemodynamic alteration and pulmonary deterioration after the patient is changed from the supine to the prone position, compared with the use of the Jackson spinal table.[8,13] Moreover, increased IAP is closely correlated with decreased microvascular and macrovascular renal blood flow,[13] resulting in the development of oliguria and renal dysfunction.[14-17] Our findings suggest that patients requiring the Wilson frame may be more vulnerable to the development of AKI because of decreased renal blood flow.

The limitations of our study include the retrospective study design and difficulty in matching for surgical invasiveness owing to the choice of the positioning device for specific procedures. Additionally, it was difficult to assess the impact of intraoperative hemodynamic variables and interventions that may influence the risk of AKI. Direct measurements of IAP and renal perfusion were not performed during surgery. Given that IAP measurements during spinal surgery are not a routine practice, there are no IAP data in this retrospective study. However, previous studies have shown significant changes of IAP from supine to prone position between the Wilson frame and Jackson spinal table.[5] Therefore, similar changes are expected to be reproduced in most cases when the prone position is used except in patients who are morbidly obese.[32] Last, inasmuch as the postoperative blood urea nitrogen level was not measured in this study, it was difficult to assess the cause of AKI. Although we used AKIN criteria, in which only serum creatinine and urine output are considered to determine the occurrence of AKI, the prerenal cause of AKI in our study could have been proved if the increased ratio of blood urea nitrogen and serum creatinine level had been shown.

In summary, our propensity matching analysis showed that the postoperative occurrence of AKI in patients who underwent spine surgery was higher with use of the Wilson frame compared with the Jackson spinal table. Inasmuch as prone positioning with Wilson frames may increase the risk of AKI, meticulous monitoring of perioperative renal function and renal protective strategy are required, especially when the Wilson frame is used. A prospective controlled study on the effect of prone positioning apparatus on the risk of AKI is warranted.

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