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The Impact of Robotic Assistance for Lumbar Fusion Surgery on 90-Day Surgical Outcomes and 1-Year Revisions

Jeremy Heard
Thomas Jefferson University

Yunsoo Lee
Thomas Jefferson University

Nicholas D D'Antonio
Thomas Jefferson University

Rajkishen Narayanan
Thomas Jefferson University

Mark Lambrechts
Thomas Jefferson University

See next page for additional authors

Authors

Jeremy Heard, Yunsoo Lee, Nicholas D D'Antonio, Rajkishen Narayanan, Mark Lambrechts, John Bodnar, Caroline Purtill, Joshua Pezzulo, Dominic Farronato, Pat Fitzgerald, Jose Canseco, Ian Kaye, Alan Hilibrand, Alex Vaccaro, Christopher Kepler, and Gregory Schroeder

Original Article

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ABSTRACT

Objectives: To evaluate the (1) 90-day surgical outcomes and (2) 1-year revision rate of robotic versus nonrobotic lumbar fusion surgery.

Methods: Patients >18 years of age who underwent primary lumbar fusion surgery at our institution were identified and propensity-matched in a 1:1 fashion based on robotic assistance during surgery. Patient demographics, surgical characteristics, and surgical outcomes, including 90-day surgical complications and 1-year revisions, were collected. Multivariable regression analysis was performed. Significance was set to $P < 0.05$.

Results: Four hundred and fifteen patients were identified as having robotic lumbar fusion and were matched to a control group. Bivariant analysis revealed no significant difference in total 90-day surgical complications ($P = 0.193$) or 1-year revisions ($P = 0.178$). The operative duration was longer in robotic surgery (287 + 123 vs. 205 + 88.3, P 0.001). Multivariable analysis revealed that robotic fusion was not a significant predictor of 90-day surgical complications (odds ratio [OR] = 0.76 [0.32–1.67], $P = 0.499$) or 1-year revisions (OR = 0.58 [0.28–1.18], $P = 0.142$). Other variables identified as the positive predictors of 1-year revisions included levels fused (OR = 1.26 [1.08–1.48], $P = 0.004$) and current smokers (OR = 3.51 [1.46–8.15], $P = 0.004$).

Conclusion: Our study suggests that robotic-assisted and nonrobotic-assisted lumbar fusions are associated with a similar risk of 90-day surgical complications and 1-year revision rates; however, robotic surgery does increase time under anesthesia.

Keywords: Complications, lumbar vertebrae, outcomes, robot-assisted surgery, robotic surgery

INTRODUCTION

Robot-assisted surgery has become an increasingly popular option for spinal fusion and instrumentation procedures since the first spine robot, the SpineAssist (Mazor Robotics Ltd., Caesarea, Israel), gained Food and Drug Administration approval in 2004.[1,2] Robotic technology is touted as a less invasive and higher precision alternative to traditional freehand techniques.[1,3] In addition, recent literature suggests that robot-assisted pedicle screw placement significantly reduces intraoperative radiation exposure compared to minimally invasive surgery.[4]

Several recent studies have compared the outcomes of robot-assisted and freehand procedures with variable findings.[5-16] Several studies show similar surgical outcomes between robot-guided and freehand fluoroscopic-guided surgeries.[10,15] Recent systematic reviews have identified

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Department of Orthopaedic Surgery, Rothman Orthopaedic Institute, Thomas Jefferson University Hospital, Philadelphia, PA, USA

Address for correspondence: Dr. Yunsoo A. Lee, Department of Orthopaedic Surgery, Rothman Orthopaedic Institute, Thomas Jefferson University, 925 Chestnut St, 5th Floor, Philadelphia, PA 19107, USA.
E-mail: yunsoo.lee@rothmanortho.com

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some benefits of robot-assisted spine surgery, including a shorter hospital stay, fewer complications, lower revision rates, and lower intraoperative radiation dose.[17,18] Although these studies show potential benefits to incorporating robots during spinal fusion, hesitancy around its widespread adoption still exists. Pitfalls to the routine use of robots during spinal fusion include high costs, a steep learning curve, longer operative times, and limited clinical differences over freehand screw placement.[18-22] Since there is no consensus on whether freehand or robot-assisted spinal fusion is superior, additional literature is needed to compare the surgical outcomes.[2] Therefore, the purpose of this study was to evaluate the (1) 90-day surgical complications and (2) 1-year revision rate of robotic versus nonrobotic lumbar fusion.

METHODS

Inclusion criteria

Upon obtaining Institutional Review Board approval, all patients older than or equal to 18 who underwent lumbar fusion surgery at a single tertiary academic institution between 2016 and 2021 were retrospectively identified. The following Current procedural terminology (CPT) codes were utilized for an inclusive list of patients undergoing fusion surgery at our institution: 22612, 22630, 22633, 22840, and 22842. Physician preference determined whether surgery was done with or without a robot. Patients were excluded if the lumbar fusion was indicated in the setting of trauma, infection, or neoplastic disease.

Data extraction

Patient demographics, surgical characteristics, and surgical outcomes were collected through structured query language search and manual chart review of the electronic medical records. Operations for which a robot was used were identified by reviewing the operative notes. Those that specifically referenced robot use during surgery were classified as robotic surgeries. A 1:1 propensity match, controlling for patient age, sex, body mass index (BMI), smoking status (nonsmoker, current smoker, and former smoker), diabetic status, and Charlson Comorbidity Index (CCI) was then performed to match patients with documented robotic surgery to patients from an internal database of lumbar fusions without documented robotic surgery. Surgical characteristics included procedure type (including posterior lumbar decompression and fusion [PLDF], transforaminal lumbar interbody fusion, anterior and PLDF), indication for surgery (spondylolisthesis, spinal stenosis, intervertebral disc herniation, degenerative disk disease, or scoliosis), revision procedures, levels fused, operative duration, percutaneous screw placement, and intraoperative durotomy. Surgical outcomes included 90-day surgical complications (including cerebrospinal fluid (CSF) leak, incision, and drainage (I and D) for surgical site infection and hematoma/seroma, pseudarthrosis/hardware failure, reoperation for same-level pathology, adjacent segment disease [ASD], and hardware failure) and revision surgeries within 1 year (revisions for same level pathology, ASD, and hardware failure).

Statistical analysis

Descriptive statistics, including mean and standard deviation, were used to report patient demographics, surgical characteristics, and surgical outcomes. A Shapiro–Wilk test was used to analyze the normality of each continuous variable. Parametric data were analyzed with independent *t*-test, while nonparametric data were analyzed with Mann–Whitney *U*-tests. Categorical variables were analyzed with Pearson's Chi-square tests. For the multivariant analysis, predictors of 90-day surgical complications and 1-year revisions were assessed. First, a bivariant logistic regression was performed. Second, a stepwise regression was developed with any $P < 0.250$ removed to determine the most significant independent predictors. Third, a multivariable logistic regression model including these predictors and robotic surgery was performed. For 90-day complications, the model identified circumferential approach, preoperative diagnosis, use of percutaneous screws, and CCI were the most significant predictors. For 1-year revisions, the model identified smoking status, fused levels, and preoperative diagnosis as the most significant predictors. R software, version 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria), was used for all data analysis. Statistical significance was set at a $P < 0.05$.

RESULTS

Patient demographics

Of 830 patients included in the analysis, 415 patients (50.0%) had a robotic-assisted lumbar fusion. All demographic variables, including age ($P = 0.952$), sex ($P = 0.725$), BMI ($P = 0.701$), CCI ($P = 0.390$), a history of diabetes ($P = 0.141$), and smoking status ($P = 0.972$) were not significantly different between the two groups [Table 1].

Surgical characteristics

The preoperative diagnosis for patients who had a robotic-assisted fusion was significantly more likely to be disc herniation/degenerative disc disease (11.10% vs. 2.14%, $P < 0.001$) and less likely to be degenerative scoliosis (3.61% vs. 9.64%, $P < 0.001$). Cases with the robot were less likely to be revisions (5.54% vs. 17.1%, $P < 0.001$), more likely to have a longer operative duration (287 vs. 205 min, $P < 0.001$), and more likely to utilize percutaneous screws (30.6% vs. 3.13%, $P < 0.001$). There were no significant differences in the number of levels fused ($P = 0.183$) or the surgical approach used ($P = 0.320$). However, intraoperative durotomies were less common in cases where the robot was used (3.37% vs. 14.9%, $P < 0.001$) [Table 1]. The total number of vertebral levels fused was 743 for robotic surgery and 759 for nonrobotic surgery.

Surgical outcomes

Compared to the cases where the robot was not used, robotic surgeries did not significantly differ in 90-day surgical complications (2.65% vs. 4.58%, $P = 0.193$). Further, there were no significant differences between the groups when comparing the etiology for surgical complications, including reoperation for CSF leak ($P = 0.373$), I and D for surgical site infection ($P = 0.233$) and hematoma/seroma ($P = 0.499$), hardware failure ($P = 0.123$), and same level pathology ($P = 1.000$). There were no differences between the groups concerning revision surgeries within 1 year (5.54% vs. 3.37%, $P = 0.178$). There were no differences between etiology for revision, including hardware failure/pseudarthrosis ($P = 0.449$), same-level pathology (0.178), and ASD ($P = 1.000$). In the nonrobotic surgery group, two people had hardware failure/pseudarthrosis and same-level disease, while one person had same-level disease and ASD [Table 2].

Table 1: Demographics and surgical characteristics of patients undergoing nonrobotic versus robotic surgery

	Nonrobotic surgery (*n*=415)	Robotic surgery (*n*=415)	P^a
Age (years)	63.8 (11.6)	63.5 (12.6)	0.952
Sex			
Female	236 (56.9)	242 (58.3)	0.725
Male	179 (43.1)	173 (41.7)	
BMI (kg/m^2)	30.8 (6.31)	30.7 (6.54)	0.701
CCI	0.67 (0.99)	0.70 (0.96)	0.390
Diabetes			
No	352 (84.8)	335 (80.7)	0.141
Yes	63 (15.2)	80 (19.3)	
Smoking status			
Nonsmoker	249 (60.0)	252 (60.7)	0.972
Current smoker	59 (14.2)	57 (13.7)	
Former smoker	107 (25.8)	106 (25.5)	
Surgical approach			
PLDF	359 (86.5)	359 (86.5)	0.320
TLIF	45 (10.8)	38 (9.16)	
A/PLDF	11 (2.65)	18 (4.34)	
Preoperative diagnosis			
Spondylolisthesis	273 (65.8)	262 (63.1)	<0.001*
Central stenosis	92 (22.2)	92 (22.2)	
DH/DDD	10 (2.41)	46 (11.1)	
Degenerative scoliosis	40 (9.64)	15 (3.61)	
Revision procedures	71 (17.1)	23 (5.54)	<0.001*
Levels fused	1.83 (1.70)	1.79 (1.50)	0.183
Operative duration (min)	205 (88.3)	287 (123)	<0.001*
Intraoperative durotomy	62 (14.9)	14 (3.37)	<0.001*
Percutaneous screws	13 (3.13)	127 (30.6)	<0.001*

*Statistical significance (P<0.05), [a]Independent *t*-test, Mann–Whitney *U*-test, or Pearson's Chi-square test. PLDF - Posterior lumbar decompression and fusion; TLIF - Transforaminal lumbar interbody fusion; A/PLIF - Combined anterior and posterior lumbar interbody fusion; DH - Disk herniation; DDD - Degenerative disk disease; BMI - Body mass index; CCI - Charlson comorbidity index

Multivariate analysis: 90-day surgical complications

For 90-day surgical complications, a bivariant logistic regression followed by a stepwise regression identified circumferential approach, preoperative diagnosis, use of percutaneous screws, and CCI as the most significant independent predictors. A multivariable logistic regression model including these variables and robotic surgery identified a circumferential approach (OR = 10.76 [3.12–33.00], $P < 0.001$) and diagnosis of degenerative scoliosis (OR = 4.04 [1.32–10.98], $P < 0.009$) as positive predictors of 90-day surgical complications. However, robotic fusion was not a significant positive predictor of 90-day surgical complications (OR = 0.76 [0.32–1.67], $P = 0.499$). Percutaneous screw placement and CCI did not significantly influence 90-day surgical complications [Table 3].

For 1-year revisions, a bivariant logistic regression model identified smoking status, levels fused, and diagnosis as significant independent predictors. A multivariable logistic regression model including these variables and robotic surgery identified levels fused as a positive predictor of 1-year revisions (OR = 1.26 [1.08–1.48], $P = 0.004$). Current smokers also had a significantly higher 1-year revision rate (OR = 3.51 [1.46–8.15], $P = 0.004$). Robotic fusion was not a significant predictor of 1-year revisions (OR = 0.58 [0.28–1.18], $P = 0.142$). Similarly, the preoperative diagnosis did not significantly influence 1-year revisions [Table 4].

Table 2: Outcomes patients undergoing nonrobotic versus robotic surger

	Nonrobotic surgery (*n*=415), *n* (%)	Robotic surgery (*n*=415), *n* (%)	P^{a*}
90-day surgical complications	19 (4.58)	11 (2.65)	0.193
Etiology for surgical complications			
CSF leak	4 (0.96)	1 (0.24)	0.373
I and D for surgical site infection	12 (2.89)	6 (1.45)	0.233
I and D for hematoma/seroma	0	2 (0.48)	0.499
Hardware failure	6 (1.45)	1 (0.24)	0.123
Same level disease	1 (0.24)	2 (0.48)	1.000
Revision within 1 year	23 (5.54)	14 (3.37)	0.178
Indication for revision			
Hardware failure/pseudarthrosis	10 (2.41)	6 (1.45)	0.449
Same level disease	10 (2.41)	4 (0.96)	0.178
Adjacent segment disease	4 (0.96)	4 (0.96)	1.000

*Statistical significance (P<0.05), [a]Pearson's Chi-square test. I and D - Irrigation and debridement; CSF - Cerebrospinal fluid

Table 3: Multivariable logistic regression: 90-day surgical complications

	Estimate	*P*	OR	Lower 95	Upper 95
Robotic surgery	−0.28	0.499	0.76	0.32	1.67
Circumferential approach	2.38	<0.001*	10.76	3.12	33.00
Combined diagnosis					
Spondylolisthesis	Reference				
Stenosis	0.44	0.338	1.54	0.60	3.70
Degenerative disc disease	−0.09	0.936	0.92	0.05	5.02
Degenerative scoliosis	1.40	0.009*	4.04	1.32	10.98
Nonpercutaneous screws	1.25	0.127	3.48	0.86	24.18
Charlson comorbidity index	0.21	0.192	1.23	0.88	1.64

*Statistical significance ($P<0.05$). OR - Odds ratio

Table 4: Multivariable logistic regression: 1-year revisions

	Estimate	*P*	OR	Lower 95	Upper 95
Robotic surgery	−0.54	0.142	0.58	0.28	1.18
Smoking					
No	Reference				
Current	1.26	0.004*	3.51	1.46	8.15
Former	0.55	0.187	1.73	0.75	3.87
Levels fused	0.23	0.004*	1.26	1.08	1.48
Combined diagnosis					
Spondylolisthesis	Reference				
Stenosis	0.35	0.420	1.42	0.58	3.29
Degenerative disc disease	0.92	0.171	2.50	0.55	8.29
Degenerative scoliosis	0.75	0.229	2.12	0.58	6.84

*Statistical significance ($P<0.05$). OR - Odds ratio

DISCUSSION

As robotic-assisted lumbar fusion techniques rapidly evolve, there is a lack of consensus regarding their efficacy and safety.[19,20] Previous studies have compared robot-assisted surgeries to nonrobotic surgery with differing outcomes, including complication rates; thus, authors have discussed the need for additional evidence on the benefits of robotic spine fusion.[5-16,20] Some limiting factors to the widespread adoption of robotic surgery include the high cost and steep learning curve.[21-23] When starting to perform robotic surgery, one study suggests that supervision from a spine surgeon skilled in robotic surgery may be needed during a surgeon's first 25 surgeries to minimize robot-assisted pedicle screw inaccuracies.[22]

A prospective comparative study of 485 patients by Good *et al*. evaluated Mazor robotic guidance compared to fluoroscopic guidance (FG). They determined that robotic guidance showed 5.8 times lower risk of 1-year surgical complications and 11 times lower risk for revision surgery than FG spinal fusions. More specifically, at 90 days postoperative, 73% of FG patients were complication-free compared to 97% in the robot group. The authors suggest that this decrease in complication rate is due to the detailed three-dimensional planning required before robotic-assisted surgery. However, in a subgroup analysis of single-level surgery, robotic surgery only trended toward decreasing complications.[5] In a separate retrospective analysis of 224 patients undergoing robotic versus nonrobotic TLIF, Lin *et al*. suggested similar rates of surgical complications (1.3% in both groups).[9] In contrast, in a retrospective study by Passias *et al*., robot-assisted surgery was associated with significantly higher postoperative complication rates. However, the same study found no differences in revision rates between all groups.[24] Meanwhile, Lieber *et al*. analyzed 520 patients in a retrospective analysis and determined that when accounting for other risk factors, robotic fusion was not an independent predictor of complications (OR = 0.834, [0.214–3.251]).[16]

The present study supports the findings made by Leiber *et al*. and Lin *et al.* by demonstrating that robotic surgeries are not associated with increased 90-day surgical complications.[9,16] We found on multivariant analysis that circumferential fusions were significant positive predictors of 90-day surgical complications but not the use of robotic assistance. At the same time, having more levels fused was a significant positive predictor of 1-year revisions. Prior literature has mirrored our results, finding that a circumferential approach is associated with a longer length of stay and more perioperative complications, which may contribute to our higher rates of surgical complications.[25]

Many studies have shown that robotic lumbar fusions have longer operative durations than nonrobot-assisted fusions.[5,26] The present study also found a significantly longer operative time associated with robotic surgery (total time of 287 min, 82 min longer than open surgery) comparable to other literature (total time of 323 min, 87 min longer than open surgery).[24] This is likely due to the machine's calibration and physical setup before each case when using the robot. This lost time contributes to the high monetary cost of robotic surgery, which literature has estimated to be 30% greater than minimally invasive and open spine surgery. However, studies suggest that cost-benefit analysis may soon favor using robots once surgeons and operating room staff become more familiar with robot-assisted surgery, reducing time-related and training costs.[24] Importantly, all surgeons in this study are experienced with robots and at high-volume spine centers; despite this, the robot still increased the surgical time, indicating that this is a factual finding and will not improve with time.

This study has limitations, including those inherent to retrospective analysis. In addition, because this was not a randomized cohort, procedure selection and outcomes cannot fully be unlinked. A surgeon's choice of procedure may have been influenced by individual patient factors that impacted procedure outcomes. In addition, we could not evaluate screw placement directly as computed tomography scans are not routinely ordered at our institution. Therefore, we cannot comment on screw accuracy. Although our cohort was matched by age, sex, BMI, CCI, and levels fused, other factors (such as history of revision, preoperative diagnosis, and intraoperative durotomy) were not matched and thus could have confounded our analysis. However, our statistical strategy aimed to reduce the impact of these factors. By performing bivariant logistic regression analysis before building our multivariant logistic regression model, we could independently assess each variable and its impact on the outcome of interest. By reporting on the multivariable regression model developed from this list of variables, we were able to assess the impact of robots and variables of interest on our outcomes in the most accurate way possible through retrospective analysis.

CONCLUSION

Our study suggests that robotic-assisted and nonrobotic lumbar fusions are associated with a similar risk of 90-day surgical complications and 1-year revision surgery. Robotic surgery leads to increased time under anesthesia but does not affect overall complications or revisions. In summary, we offer a large cohort study demonstrating comparable 90-day surgical outcomes and 1-year revision rates showing that robotic surgery is comparably safe to nonrobotic surgery.

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Conflicts of interest

There are no conflicts of interest.

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