Robotic versus nonrobotic sacroiliac joint fusion

John H. Lee, BS, Mark M. Zaki, MD, MBA, Rushikesh S. Joshi, MD, Joseph R. Linzey, MD, MS, Rakesh D. Patel, MD, Paul Park, MD, and Yamaan S. Saadeh, MD

1University of Michigan Medical School, Ann Arbor, Michigan; Departments of 1Neurosurgery and 2Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan; and 3Department of Neurosurgery, University of Tennessee, Semmes-Murphey Clinic, Memphis, Tennessee

OBJECTIVE Robot-assisted pedicle screw placement in spinal fusion has been well studied. However, few studies have evaluated robot-assisted sacroiliac joint (SIJ) fusion. The aim of this study was to compare surgical characteristics, accuracy, and complications between robot-assisted and fluoroscopically guided SIJ fusion.

METHODS A retrospective review of 110 patients with 121 SIJ fusions done at a single academic institution was conducted from 2014 to 2023. Inclusion criteria included adult age and a robot- or fluoroscopically guided approach to SIJ fusion. Patients were excluded if the SIJ fusion was part of a longer fusion construct, not minimally invasive, and/or had missing data. Demographics, approach type (robotic vs fluoroscopic), operative time, estimated blood loss (EBL), number of screws, intraoperative complications, 30-day complications, number of intraoperative fluoroscopic images (as a surrogate for radiation exposure), implant placement accuracy, and pain status at the first follow-up were recorded. Primary endpoints were SIJ screw placement accuracy and complications. Secondary endpoints were operative time, radiation exposure, and pain status at the first follow-up.

RESULTS Ninety patients were included who underwent a total of 101 SIJ fusions, of which 78 were robotic and 23 were fluoroscopic. The mean age of the cohort at the time of surgery was 55.9 ± 13.8 years; 46 patients were females (51.1%). No difference was found in screw placement accuracy between robotic and fluoroscopic fusion (1.3% vs 8.7%, p = 0.06). Chi-square analysis of robotic versus fluoroscopic fusion found no difference in the presence of 30-day complications (p = 0.62). Mann-Whitney U-test analysis found that robotic fusion had a significantly longer operative time than fluoroscopic fusion (72.0 vs 61.0 minutes, p = 0.01); however, robot-assisted fusions involved significantly lower radiation exposure (26.7 vs 187.4 fluoroscopic images, p < 0.001). No difference in EBL was noted (p = 0.17). No intraoperative complications were present in this cohort. Subgroup analysis comparing the 23 most recent robotic cases against the 23 fluoroscopic cases found that robotic fusion still was associated with significantly longer operative times than fluoroscopic fusions (74.0 ± 26.4 vs 61.0 ± 14.9 minutes, respectively; p = 0.047).

CONCLUSIONS SIJ screw placement accuracy did not significantly differ between robot-assisted and fluoroscopic SIJ fusion. Complications overall were low and similar between the two groups. The operative time was longer with robotic assistance, but there was markedly less radiation exposure to the surgeon and staff.

https://thejns.org/doi/abs/10.3171/2023.4.FOCUS23146

KEYWORDS sacroiliac joint fusion; spinal fusion; robot-assisted surgery; pedicle screw; fluoroscopic fusion; complications; minimally invasive surgery

Sacroiliac joint (SIJ) dysfunction is an increasingly recognized pain generator for patients presenting with low-back pain.¹,² The SIJ is a synovial fluid-filled fibrous capsule between the sacrum and ilium with limited mobility that primarily functions to maintain balance and minimize translation of the pelvis from the sacrum during bodily movement.³

Common patient history factors that may suggest SIJ dysfunction include history of trauma such as fall or motor vehicle collision, pain with sitting or changes in position, prior lumbar spine surgery, or pregnancy.³,⁴ Several physical examination maneuvers have also been validated in their diagnostic ability to assess for SIJ pain.²,³ Imaging features are not typically diagnostic for SIJ pain, although imaging often helps evaluate for other causes of low-back pain that may alter management.¹,⁶,⁸ Targeted angesic injections of the SIJ that significantly relieve the patient’s pain are the current gold-standard approach to

ABBREVIATIONS AP = anteroposterior; EBL = estimated blood loss; SIJ = sacroiliac joint.


INCLUDE WHEN CITING DOI: 10.3171/2023.4.FOCUS23146.

©AANS 2023, except where prohibited by US copyright law
TABLE 1. A comparison of basic characteristics and primary endpoints between the robotic and fluoroscopic groups

<table>
<thead>
<tr>
<th></th>
<th>Robotic</th>
<th>Fluoroscopic</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of procedures</td>
<td>78</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Age, yrs</td>
<td>56.9 ± 13.5</td>
<td>52.5 ± 14.7</td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>40 (51.3%)</td>
<td>13 (66.5%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>38 (48.7%)</td>
<td>10 (43.5%)</td>
<td></td>
</tr>
<tr>
<td>Sidedness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right</td>
<td>39 (50%)</td>
<td>14 (60.9%)</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>39 (50%)</td>
<td>9 (39.1%)</td>
<td></td>
</tr>
<tr>
<td>No. of screws</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>59 (75.6%)</td>
<td>15 (65.2%)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>19 (24.4%)</td>
<td>8 (34.8%)</td>
<td></td>
</tr>
<tr>
<td>30-day complications</td>
<td>9 (11.5%)</td>
<td>2 (8.7%)</td>
<td>0.62</td>
</tr>
<tr>
<td>Op time</td>
<td>72.0 ± 21.3</td>
<td>61.0 ± 14.9</td>
<td>0.01</td>
</tr>
<tr>
<td>Fluoroscopic images</td>
<td>26.7 ± 17.2</td>
<td>187.4 ± 70.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>EBL, mL</td>
<td>14.3 ± 15.5</td>
<td>19.1 ± 21.5</td>
<td>0.17</td>
</tr>
<tr>
<td>No. of procedures w/ inaccurate implant position</td>
<td>1 (1.3%)</td>
<td>2 (8.7%)</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Values are presented as the number of procedures (%) or mean ± SD unless stated otherwise. Boldface type indicates statistical significance.

diagnose SIJ dysfunction that may improve with surgical fixation.5,9

Historically, open SIJ fusion, including posterior, lateral transiliac, and anterior approaches, have had higher morbidity compared with modern minimally invasive approaches, which previously limited widespread adoption.10 Recent studies have also shown that minimally invasive approaches have been more effective than conservative management in controlling pain and improving quality of life.11 Traditionally, minimally invasive SIJ fusions have been performed with fluoroscopic guidance using true lateral, pelvic inlet, and pelvic outlet views.12 Spinal robots are an enabling technology that have been shown to be safe and provide significant accuracy with pedicle screw placement. Recently, robotic assistance has been developed for SIJ fusion.13 However, few studies have compared fluoroscopic and robot-assisted SIJ fusion. This investigation analyzes perioperative characteristics, SIJ screw placement accuracy, and complications in patients undergoing fluoroscopic versus robot-assisted SIJ fusion.

Methods

A retrospective review of 110 patients with 121 SIJ fusions performed at a single academic institution was conducted from October 2014 to January 2023. The study was approved by the University of Michigan Institutional Review Board. Demographics, intraoperative navigation type, operative time (incision time to dressing completion), operative estimated blood loss (EBL), number of screws placed, intraoperative complications, 30-day complications, and number of intraoperative fluoroscopic images (as a surrogate for radiation exposure) were extracted. Pain status, dichotomized as improved and not improved at the first postoperative follow-up was also recorded. An event was considered a complication if it was an unanticipated event that prolonged the postoperative hospital stay, required further specialized consultation, or changed the anticipated course of postoperative recovery. Patients were included if they had SIJ fusion using either fluoroscopic or robotic navigation. The robotic navigation was CT based. Patients were excluded if their SIJ fusions were part of a longer construct or operation, were open SIJ fusions, were performed without fluoroscopic or robotic assistance, or if documentation was unavailable. Primary endpoints were screw placement accuracy and complication occurrence, while secondary endpoints included operative time and radiation exposure. Complications were defined as any adverse event related to the procedure intraoperatively or within 30 days of the procedure.

SIJ fusions were also evaluated for accuracy of screw implantation based on postoperative anteroposterior (AP) and lateral radiographs. These were true AP and lateral postoperative radiographs, as opposed to Ferguson views, which would have allowed more direct visualization of the SIJ implants. As there is no accepted classification system for screw placement accuracy with SIJ fusion, we used a simple binary grading system. A screw was considered to be accurately placed when it was found to be positioned within the sacral body on both lateral and AP radiographs without extraosseous breach of the screw. A screw was considered to be inaccurately placed when any portion of the screw had extension ventral or dorsal to the sacral body margins on lateral radiography or pelvis sacral foramina on AP radiography.

Given the more recent integration of robotic navigation in SIJ fusion when compared with fluoroscopic navigation, the robot-assisted operative times were also trended to evaluate for changes in operative time based on familiarity with the technology. Toward that end, a subgroup comparison of operative times between the 23 most recent robotic cases against the 23 fluoroscopic cases was also conducted.

Data analysis was done using RStudio (RStudio Team, https://posit.co) and Excel (Microsoft Corp.). Normality was determined by the Shapiro-Wilk test, and chi-square tests and Mann-Whitney U-tests were used where appropriate to determine significance between the robotic and fluoroscopic groups regarding operative time, radiation exposure, EBL, complication rate, and optimal implant placement.

Results

Of the 110 patients with 121 SIJ fusions, 12 were excluded as they were part of larger, more complex spine operations. Another 7 fusions were excluded for using only StealthStation-guided navigation (Medtronic), and 1 was excluded as it was a bilateral fusion. The resulting cohort of 90 patients included a total of 101 SIJ fusions, of which 78 were robotic and 23 were fluoroscopic (Table 1). The mean (± SD) age of the total cohort at the time of surgery was 55.9 ± 13.8 years; 46 patients were female (51.1%) and 44 patients were male (48.9%). Of the 101 SIJ fusions included, 94 were done by the same two surgeons, and their
distributions of robotic and fluoroscopic fusions were not significantly different ($p = 0.86$); as such, surgeon identity was not considered to be a confounder, as intrasurgeon differences should affect both types of fusions similarly.

Of the 78 robotic fusions, 40 (51.3%) were performed in females and 38 (48.7%) were performed in males. The average age of the robotic cohort was 56.9 ± 13.5 years. Fusions were performed on the right and left sides in 39 cases each. Nineteen of the fusions were done with 3 screws and 59 were done with 2 screws. No intraoperative complications were noted in this group. Fifty-one of the 78 robotic fusions had postimplant intraoperative CT scans available, and none of these intraoperative CT scans resulted in intraoperative revision. Within 30 days postoperatively, 9 complications (11.5%) were reported. These included new significant pain ($n = 3$), postoperative urinary retention ($n = 2$), poor wound healing ($n = 2$), surgical site infection ($n = 1$), and immediate postoperative pulmonary edema ($n = 1$). All 3 cases in which new pain was reported were evaluated with pelvic CT and/or lumbar MRI and were determined to not have a structural etiology and resolved following the perioperative period.

Of the 23 fluoroscopic fusions, 13 (56.5%) were performed in females and 10 (43.5%) were performed in males. The mean age of the fluoroscopic cohort was 52.5 ± 14.7 years. Fourteen of the fusions were on the right side and 9 were on the left side. Eight of the fusions were done with 3 screws and 15 were done with 2 screws. No intraoperative complications were noted in this group. Two postoperative complications were noted within 30 days (8.7% complication rate). In one case, there was poor wound healing around the surgical incision site, and the other case involved postoperative urinary retention, which resolved during the patient’s inpatient stay following SIJ fusion. Chi-square analysis of robotic versus fluoroscopic groups found no difference in the presence of 30-day complications ($p = 0.62$).

Assessment of SIJ screw placement accuracy found that inaccurate screw placement was present in 1 (1.3%) of 78 the robotic fusions and in 2 (8.7%) of the 23 fluoroscopic fusions. None of the inaccurate screw placements required revision surgery, and the patients in all 3 cases reported improvement in their SIJ pain at both the first and second follow-ups with no adverse clinical sequelae noted. This difference was not considered to be significant on chi-square analysis ($p = 0.06$). See Fig. 1 for examples of accurate and inaccurate screw placement on postoperative imaging.

The Mann-Whitney U-test found that robotic fusion was associated with a significantly longer operative time than fluoroscopic fusion (72.0 ± 21.3 vs 61.0 ± 14.9 minutes, $p = 0.01$). Robot-assisted operative times did not trend considerably either up or down from the first case done on February 8, 2018, to the most recent case captured by this study on January 6, 2023 (Fig. 2). Subgroup analysis comparing the 23 most recent robotic cases against the
23 fluoroscopic cases found that robotic fusion remained significantly longer in operative time than fluoroscopic fusion (74.0 ± 26.4 vs 61.0 ± 14.9 minutes, p = 0.047).

Radiation exposure during robotic and fluoroscopic fusions was determined using the number of fluoroscopic images obtained during the operation as a surrogate for radiation exposure. The Mann-Whitney U-test found that robotic fusion involved significantly less radiation exposure compared with fluoroscopic fusion (26.7 ± 17.2 vs 187.4 ± 70.7 images, p < 0.001). EBL between the robotic and fluoroscopic fusions did not differ significantly (14.3 ± 15.5 vs 19.1 ± 21.5 mL, p = 0.17).

Pain status of the SIJ between the robotic and fluoroscopic fusions was dichotomized into improved and not improved. For robotic fusion, patients in 62 of 76 cases with follow-up data available at the time of data collection reported improvement in their SIJ pain at the first follow-up, with a mean duration to first follow-up of 22.0 ± 9.5 days. For fluoroscopic fusion, patients in 19 of 23 cases reported improvement at the first follow-up, with a mean duration to first follow-up of 23.8 ± 15.9 days. Chi-square analysis found no difference between these groups (p = 0.91).

Discussion

SIJ dysfunction is an increasingly recognized pain generator for patients presenting with low-back pain. Traditional open sacroiliac fusion was associated with significant exposure-related morbidity. In recent years, minimally invasive approaches have become more popular. The efficacy of minimally invasive SIJ fusion compared with conservative management in controlling pain and improving quality of life has also been shown. Fluoroscopic guidance has been the primary method to perform SIJ fusion. Numerous studies have shown robot-assisted pedicle screw implantation to be highly accurate and safe. However, there are limited data regarding the accuracy and safety of robot-assisted SIJ screw implantation. In this study, screw placement accuracy was high and similar with robot-assisted and fluoroscopic guidance. This comparison, however, was limited by a relatively small sample size. It is possible that in a larger study, robot-assisted screw placement will be found to be more accurate, as the accuracy rate was higher, although not statistically significant in this study. Similar to screw placement accuracy, the complication rate for robot-assisted fusion was similar to that for fluoroscopic fusion.

On average, the length of robotic surgery was about 10–15 minutes longer than fluoroscopy-only surgery, even after accounting for a potential learning curve with the implementation of new technology. This increased time may be related to the use of intraoperative image acquisition and requirement for screw planning during the operation. Alternatively, preoperative CT and screw planning can be performed, which would result in decreased operative time.

Robotic surgery was associated with significantly less radiation exposure for the surgeon and operating room team compared with fluoroscopy-only surgery, due to significantly fewer fluoroscopic images obtained during robotic surgery compared with fluoroscopy-only surgery. Radiation exposure is a known risk to spine surgeons and operating room personnel, and efforts should be made to minimize exposure while still optimizing patient care. Excessive amounts of radiation can cause complications such as cataract formation, skin erythema, leukemia, thyroid cancer, and other malignancies. In this study, we found that complications were not significantly different between the two groups; however, the surgeons and operating room teams that performed fluoroscopy-only fusions were exposed to more than 6 times the number of fluoroscopic radiographs compared with robotic surgeries. Over the course of a surgeon’s lifetime, this can be a major difference in exposure to potentially harmful radiation. There are many safeguards in place to minimize surgeons’ risks of radiation exposure, including personal lead shields and maintaining appropriate distance from radiography, fluoroscopy, and CT imaging machines. In addition to these daily safeguards, emphasis should be placed on continuing to improve surgical techniques that minimize harmful radiation to surgeons and operating room staff.

Limitations

This study is a retrospective review, so there may be bias in the gathering and interpretation of data that would not be present in a prospective analysis. The data were obtained from a single academic institution, which may limit generalizability; however, we have included data from multiple different neurosurgeons and orthopedic surgeons, which we hope will allow for greater generalizability. Furthermore, the postoperative radiographs used to visualize screw accuracy were true AP and lateral views, which is not as ideal as having Ferguson views available for evaluation of the implants.

Conclusions

The accuracy of robot-assisted screw placement was high and similar to that for fluoroscopic guidance. The overall complication rate was low and did not differ significantly, suggesting that robot-assisted SIJ fusion is safe. Notably, robot-assisted SIJ fusion had longer operative times but markedly reduced radiation exposure.

References


Disclosures
Dr. Patel reported being a consultant for Globus and Bioventus and royalties from Globus outside the submitted work. Dr. Park reported personal fees from Globus, NuVasive, DePuy Synthes, Accelus, and Medtronic; grants from Cerapedics, SI Bone, ISSG, and DePuy Synthes; and royalties from Globus outside the submitted work.

Author Contributions
Conception and design: Saadeh, Patel. Acquisition of data: Lee, Joshi. Analysis and interpretation of data: Saadeh, Lee, Zaki, Joshi, Linzey, Park. Drafting the article: Saadeh, Lee, Zaki, Linzey. Critically revising the article: Saadeh, Zaki, Joshi, Linzey, Pattel, Park. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Saadeh. Statistical analysis: Lee. Administrative/technical/material support: Saadeh. Study supervision: Saadeh.

Correspondence
Yamaan S. Saadeh: University of Michigan, Ann Arbor, MI. yamaans@med.umich.edu.