Safety and accuracy of robot-assisted versus fluoroscopy-guided pedicle screw insertion for degenerative diseases of the lumbar spine: a matched cohort comparison

Clinical article

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Object. Recent years have been marked by efforts to improve the quality and safety of pedicle screw placement in spinal instrumentation. The aim of the present study is to compare the accuracy of the SpineAssist robot system with conventional fluoroscopy-guided pedicle screw placement.

Methods. Ninety-five patients suffering from degenerative disease and requiring elective lumbar instrumentation were included in the study. The robot cohort (Group I; 55 patients, 244 screws) consisted of an initial open robot-assisted subgroup (Subgroup IA; 17 patients, 83 screws) and a percutaneous cohort (Subgroup IB, 38 patients, 161 screws). In these groups, pedicle screws were placed under robotic guidance and lateral fluoroscopic control. In the fluoroscopy-guided cohort (Group II; 40 patients, 163 screws) screws were inserted using anatomical landmarks and lateral fluoroscopic guidance. The primary outcome measure was accuracy of screw placement on the Gertzbein-Robbins scale (Grade A to E and R [revised]). Secondary parameters were duration of surgery, blood loss, cumulative morphine, and length of stay.

Results. In the robot group (Group I), a perfect trajectory (A) was observed in 204 screws (83.6%). The remaining screws were graded B (n = 19 [7.8%]), C (n = 9 [3.7%]), D (n = 4 [1.6%]), E (n = 2 [0.8%]), and R (n = 6 [2.5%]). In the fluoroscopy-guided group (Group II), a completely intrapedicular course graded A was found in 79.8% (n = 130). The remaining screws were graded B (n = 12 [7.4%]), C (n = 10 [6.1%]), D (n = 6 [3.7%]), and E (n = 5 [3.1%]). The comparison of “clinically acceptable” (that is, A and B screws) was neither different between groups (I vs II [p = 0.19]) nor subgroups (Subgroup IA vs IB [p = 0.81]; Subgroup IA vs Group II [p = 0.53]; Subgroup IB vs Group II [p = 0.20]). Blood loss was lower in the robot-assisted group than in the fluoroscopy-guided group, while duration of surgery, length of stay, and cumulative morphine dose were not statistically different.

Conclusions. Robot-guided pedicle screw placement is a safe and useful tool for assisting spine surgeons in degenerative spine cases. Nonetheless, technical difficulties remain and fluoroscopy backup is advocated.

Key Words • spine instrumentation • pedicle screw • robotic surgery • spinal fusion • computer-assisted surgery • lumbar

Pedicle screw insertion is the workhorse of thoracolumbar posterior instrumentation, but it may be associated with complications such as screw malpositioning. Recent years have been marked by efforts to improve the accuracy and therefore the safety of pedicle screw placement. These developments include image guidance with navigation and intraoperative imaging. A comprehensive review of image-guided spine surgery concluded that, for the most part, these techniques had a beneficial impact particularly on the management of complex spinal cases. The common goal of most auxiliary techniques is to assist the surgeon in visualizing the mostly invisible anatomy required to place pedicle screws. In light of the experience of robotic surgery in other specialties, it appears intuitive to go a step further and exploit the rigid vertebral anatomy for robot-guided maneuvers.

Recently, a bone-mounted, miniature robotic spine surgery system, SpineAssist (Mazor), has been developed.

Abbreviations used in this paper: BMI = body mass index; LOS = length of stay; PLIF = posterior lumbar interbody fusion; TLIF = transforaminal lumbar interbody fusion.
Robot-assisted spine surgery

to increase the accuracy of pedicle screw trajectories.\textsuperscript{11,17} It is a semiactive robotic system in that it only indicates the direction of the pedicle screw trajectory. The surgeon manually performs the drilling and screw insertion.

The goal of the present study is to compare the accuracy of robot-guided screw insertion in lumbar surgery at our center with a cohort of patients who underwent fluoroscopy-guided spinal instrumentation. Secondary parameters, such as duration of surgery, blood loss, cumulative morphine, and length of stay (LOS) were also evaluated and compared between groups.

Methods

For this retrospective study, we reviewed the charts of 95 consecutive patients requiring elective lumbar spine surgery with posterior instrumentation for degenerative disease from 2007 to 2011. Patients who underwent surgery between 2007 and 2009 were included in the fluoroscopy-guided cohort, while the robot cohort comprised the patients who have undergone surgery since mid-2009 (robot acquired in June 2009). The senior author (E.T.) operated on all patients.

Surgical Technique and Cohorts

The robot cohort (Group I; 55 patients, 244 screws) consisted of an initial open robot-assisted subgroup (Subgroup IA; 17 patients, 83 screws) and a percutaneous cohort (Subgroup IB, 38 patients, 161 screws). In the fluoroscopy-guided cohort (n = 40, Group II, 163 screws), screws were inserted using anatomical landmarks and lateral fluoroscopy guidance.

In the robot-guided groups, pedicle screw trajectories were planned on the SpineAssist system image-processing unit prior to surgery. Using a modified intraoperative fluoroscope and a spinous process anchored clamp, we performed intraoperative data set matching, and the robot was attached to a specific bridge. Screws were then inserted guided by the robot arm as described elsewhere.\textsuperscript{11} We performed lateral fluoroscopy before drilling of the pedicle and during screw placement.

Open Robot-Guided Technique (Subgroup IA). In the first 17 patients undergoing robotic surgery, we used the robot after exposure of the spine via a midline incision in a standard subperiosteal manner. The anatomical landmarks for pedicle screw insertion were prepared. Screws were inserted under robotic guidance. Using this open technique, the surgeon could always check the entry point “suggested” by the robot. We consider this approach appropriate for the initial learning curve to gain trust in the system. We did not plan to alter the entry point suggested by the robot, but we were able to assess at all times whether the robot’s suggestion for pedicle screw insertion was anatomically plausible. Lateral fluoroscopic control was performed until the screw had passed the pedicle. In this technique, the edges of the wound occasionally touched the robot arm, although retraction was used to prevent pressure of the surrounding tissue on the arm. This medially directed pressure from the soft tissues on the robot arm appeared to be highest at the L5–S1 level, where a more medially directed trajectory and more lateral entry points are required. The additional posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), or decompressive procedures were done through the same incision, and the rods were connected to the screws at the end of surgery.

Percutaneous Robotic Technique (Subgroup IB). After our initial experience with an open robot-guided technique, we performed percutaneous robot-guided screw insertion in 38 patients. First, the spinous process clamp and the robot were mounted through a small midline incision. Screw insertion was performed through small paramedian stab incisions, relying on the planned robotic trajectory. Lateral fluoroscopy was regularly used to “supervise” the trajectory chosen by the robot. The rods were then inserted into the screw heads either through the midline incision (in upper lumbar levels) or through the enlarged stab incisions (in lower lumbosacral levels). Additional procedures were performed through the initial small midline incision.

Open Fluoroscopy-Guided Surgery (Group II). In patients undergoing open surgery for fluoroscopy-guided pedicle screw placement, the lumbar spine was prepared subperiosteally.\textsuperscript{16} The landmarks for the pedicle insertion were exposed (transverse process, facet joint, and isthmus), and the pedicle was breached with specific tools (such as the probe and palpator). The additional procedure was then performed, and the rods were attached to the screw heads.

Baseline Characteristics

Most baseline parameters (± SD) did not differ between the robot-guided and fluoroscopy-guided groups and subgroups (Table 1) with a few exceptions. There were fewer females in Subgroup IB than in Subgroup IA (p < 0.01) and Group II (p = 0.01). Body mass index (BMI) was higher in Group II (Group I, 24.7 ± 3.7; Group II, 28.0 ± 6.1 [p < 0.01]). The number of screws and instrumented segments in Subgroup IA was higher than in Subgroup IB (p = 0.04), and the number of instrumented levels was higher in Group II than in Subgroup IB (p = 0.04). The overall average number of levels was 2.4 ± 0.9 (robot Group I, 2.3 ± 0.7; fluoroscopy-guided Group II: 2.4 ± 1.2 [p = 0.22]) (Table 1).

Associated procedures in addition to pedicle screw fixation included 1) PLIF in 36 patients in the robot group (Group I) and 21 patients in the fluoroscopy-guided group (Group II); 2) TLIF in 12 patients in the robot group (Group I) and 5 patients in the fluoroscopy-guided group (Group II); and 3) dynamic instrumentation in 2 patients in the robot group (Group I) and 2 patients in the fluoroscopy-guided group (Group II) (Table 2).

The primary outcome measure was screw accuracy. Postoperative CT scans with axial, coronal, and sagittal reconstructions were obtained in all patients, and the accuracy of screw placement was evaluated according to the Gertzbein and Robbins scale (from Grade A to E: A, perfect intrapedicular localization; E, > 6 mm deviation from ideal intrapedicular trajectory; Fig. 1). For grading, the radiological incidence and slice with the largest de-
viation from the pedicle was chosen. A neuroradiologist (V.C.) was blinded to type of treatment and evaluated all CT scans in both groups. While screws graded A and B are clinically acceptable, screws graded C, D, and E have a significant deviation from the intended trajectory. The rating “R” was added as a separate category to describe a screw that was inserted as guided by the robot, but which needed to be revised by hand because of poor screw purchase or blatantly deviant trajectory on lateral fluoroscopy.

Pedicle and Screw Sizes

The pedicle and screw sizes are provided for every level and subgroup in Table 3.

Secondary Parameters

We recorded the duration of intervention and the need for revision of a misplaced screw or other complications. The LOS was recorded starting from the day of surgery. Postoperative neurological evaluation was performed in all cases. Moreover, we recorded intraoperative blood loss and the cumulative dose of morphine during the patients stay. We also noted whether the patient was discharged under opiate therapy.

The Student t-test, Mann-Whitney U-test, and chi-square test were used for statistical analysis. Mean values are presented as the mean ± SD.

Results

Screw Accuracy

A detailed listing of pedicle screw accuracy grades is provided in Table 4, and the subgroup comparison is shown in Table 5. Overall, in the robot group (Group I), a perfect trajectory (A) was observed in 204 screws (83.6%). The remaining screws were graded B (n = 19, 7.8%), C (n = 9, 3.7%), D (n = 4, 1.6%), E (n = 2, 0.8%), and R (revised) (n = 6, 2.5%). In the fluoroscopy-guided group (Group II), a completely intrapedicular course graded A was found in 79.8% (n = 130). The remaining screws were graded B (n = 12, 7.4%), C (n = 10, 6.1%), D (n = 6, 3.7%), and E (n = 5, 3.1%). The comparison of “clinically acceptable” A and B screws (Group I, 223 [91.4%] of 244; Group II, 142 [87.1%] of 163; p = 0.19) was not statistically different between groups. Screws with a poor trajectory (graded C, D, E, and R) occurred with a frequency of 21 (8.6%) of 244 screws in the robot group (Group I), and 21 (12.9%) of 163 screws in the fluoroscopy-guided group (Group II), which also failed to reach significance (p = 0.09).

The direction of misplacement was recorded for all screws that were not perfectly intrapedicular (B to E, total n = 67). In 7 cases, the screw was displaced in 2 directions, leading to a total of 73 counts, which therefore exceeds the total number of misplaced screws (Table 6). Even minimal measurable cranial breach of the pedicle occurred in 4 Group I and 4 Group II cases, caudal displacement in 5 Group I and 3 Group II, medial displacements in 13 Group I and 12 Group II, and lateral displacement in 20 Group I and 12 Group II placements.

Subgroup Comparison

In Subgroup IA, 75 (90.4%) of 83 screws and in Subgroup IB, 148 (91.9%) of 161 screws were graded as clinically acceptable. The comparison of robotic Subgroups IA and IB revealed no difference with regard to screw accuracy (p = 0.81). The direct comparison of the initial open

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**TABLE 1: Baseline characteristics**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value*</th>
<th>p Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Group I</td>
</tr>
<tr>
<td>no. of patients</td>
<td>95</td>
<td>55</td>
</tr>
<tr>
<td>sex</td>
<td></td>
<td></td>
</tr>
<tr>
<td>female</td>
<td>57 (60)</td>
<td>29 (52.7)</td>
</tr>
<tr>
<td>male</td>
<td>38 (40)</td>
<td>26 (47.3)</td>
</tr>
<tr>
<td>age in yrs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median</td>
<td>55</td>
<td>52</td>
</tr>
<tr>
<td>mean BMI</td>
<td>26.1 ± 5.0</td>
<td>24.7 ± 3.7</td>
</tr>
<tr>
<td>previous op</td>
<td>33 (34.8)</td>
<td>23 (41.8)</td>
</tr>
<tr>
<td>mean no. of screws/case</td>
<td>4.5 ± 2.5</td>
<td>4.3 ± 2.3</td>
</tr>
<tr>
<td>mean no. of vertebrae</td>
<td>2.4 ± 0.9</td>
<td>2.3 ± 0.7</td>
</tr>
</tbody>
</table>

* Values are the number of patients (%) unless otherwise indicated. Mean values are presented as the mean ± SD.
† Values that appear in boldface are statistically significant (p < 0.05).

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**TABLE 2: Associated procedures**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Group I (n = 55)</th>
<th>Group II (n = 40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLIF</td>
<td>36</td>
<td>21</td>
</tr>
<tr>
<td>TLIF</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>dynamic fixation</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

* Procedures associated with posterior instrumentation were similar in both groups.
robotic surgery Subgroup IA with fluoroscopy-guided Group II also showed no difference (p = 0.53). Percutaneous robotic screw placement (Subgroup IB) had the highest rate of clinically acceptable screws (91.9%) but still failed to reach significance compared with Group II (p = 0.20; Table 5).

Intraoperatively Revised (R) Screws

A total of 6 robot-guided screws required intraoperative revision (6 [2.5%] of 244). The surgeon needed to revise 3 (1.2%) of the 244 screws inserted using robotic assistance (grade R screws) because the screw did not show sufficient bone grip. All these screws were repositioned after choosing a new trajectory based on anatomical landmarks and fluoroscopy (Table 4). In 3 additional instances, lateral fluoroscopy showed us that the entry point indicated by the robot was not pointing directly on the craniocaudal center of the pedicle. In these cases, we reprogrammed the screw trajectory by lowering or raising the trajectory by a few millimeters. Without lateral fluoroscopy, this kind of inaccuracy may have gone unnoticed. These 3 instances were rated “R” for intraoperative revision as well. All R-rated screws were categorized as poor at the expense of the robot group, regardless of the end result. Therefore, the modification of a trajectory proposed by the robot on grounds of fluoroscopic discordance was taken into account in our analysis.

Complications

There was no difference in infection rates between the 2 groups (Group I, 1 patient [1.8%]; Group II, 1 patient [2.5%]). Neurological injury occurred in 1 case in the fluoroscopy-guided group; a screw that transgressed the lower border of the pedicle in L-4 caused a painful radiculopathy without deficit due to foraminal impingement. A second surgery was required to re-place the screw, and the radiculopathy resolved. This was the only revision surgery.

Secondary Parameters

The mean duration of surgery was 200 ± 43 minutes overall (Group I, 205 ± 44 minutes; Group II, 189 ± 39 minutes [p = 0.06]). Blood loss during surgery was 488 ± 369 ml overall and was significantly lower in the robot group (Group I, 375 ± 263 minutes; Group II, 713 ± 455 [p < 0.01]). The overall LOS was 10.0 ± 5.1 days (Group I, 9.8 ± 5.1; Group II, 10.3 ± 5.6 [p = 0.35]).

The mean cumulative dose of morphine was 227 ± 351 mg overall (Group I, 218 ± 292 mg; Group II, 239 ± 422 mg [p = 0.39]) and did not differ significantly between the groups (Table 7).

Discussion

Advances in Accuracy and Safety of Pedicle Screw Placement

The SpineAssist system is only one tool in a long list of auxiliary measures and devices designed to improve pedicle screw accuracy and, thus, safety. Image-guided systems, such as frameless navigation and intraoperative imaging have helped achieve a safer environment for spine surgery. Additional methods exist to improve screw safety, such as conductivity measurement devices that detect cortical defects in the screw trajectory. Malposition rates with conventional screw placements are high in some historical series. However, the term “malposition” is not well defined and depends on the various grading systems, which are available to evaluate screw position. The majority of pedicle screws with minor breach of pedicle cortex may still have excellent biome-

![Computed tomography scans demonstrating the Gertzbein and Robbins classification. The grading system reflects the deviation of the screw from the "ideal" intrapedicular trajectory. The grades are as follows: A is an intrapedicular screw without breach of the cortical layer of the pedicle. B describes a screw that breaches the cortical layer of the pedicle but does not exceed it laterally by more than 2 mm. C and D reflect a penetration of less than 4 and 6 mm, respectively. We attributed Grade E to screws that do not pass through the pedicle or that, at any given point in their intended intrapedicular course, breach the cortical layer of the pedicle in any direction by more than 6 mm. Note that the screw that was marked with “D” has a deviation of more than 4 mm from the intrapedicular direction. However, in this case of a thoracic pedicle screw this deviation was intentional. Because of the very thin pedicles, we used the in-out-in technique to allow for optimal screw purchase in this case.](image-url)
chancical properties. Thus, one may define malposition as a screw with the potential of clinically apparent neurological or vascular impairment or biomechanical insufficiency. Consequently, manifestations of screw malposition include instability, fractures, and injury to dura, vessels, or nervous structures. In contrast to mere malposition on imaging, the incidence of neurological complications of pedicle screw placement in the literature is extremely low.

Presently Available Literature on Robotic Spine Surgery

A retrospective series summarizing the first experiences with robotic spine surgery of 14 spine centers worldwide found a 98% rate of clinically acceptable screw placements using the SpineAssist robot. No permanent nerve damage occurred using the robot. Although this is a strong statement, the majority of screws in that series were not controlled by postoperative CT scanning. In the 139 patients with postoperative CT scans, 89.3% of screws were intrapedicular and 9% of screws showed a minor pedicle breach.

The first series of 31 patients undergoing PLIF with SpineAssist showed that up to 98.3% of screws were within 2 mm of the preoperative planning. This indicates that screws were well positioned, but it does not necessarily reflect pedicle breach such as indicated according to the Gertzbein and Robbins classification. More recently, Kantelhardt and colleagues performed a retrospective comparison of conventional, open robot-guided and percutaneous robot-guided techniques. The authors found an accuracy rate of 94.5% in the robot group compared with 91.4% in conventionally placed screws. This is also the only report that explicitly mentions the use and accuracy of thoracic pedicle screws.

In the only prospective study using the robot, Ringel et al. found that the use of the robot led to a higher rate of laterally misplaced screws, which is in keeping with our observation that the majority of misplaced screws are lateral. While lateral misplacement can be regarded as an inaccuracy, it is the less neurologically threatening misplacement compared with medial or inferior misplacement. Moreover, in their series conventional placement of pedicle screws had superior accuracy compared with robot-placed screws. The lesser accuracy in their study may in part be due to the fact that the authors attached part of the robotic system to the operating table. This technique, while providing more stability to the robot, harbors the risk of movement between the patient and the system. Three main possibilities exist to attach the robot. The first is a table-mounted fixation, the second is a fixation on the spinous process and the third is the Hover-T arm with sacral and lumbar pins. Contrary to the prospective negative trial by Ringel et al., we rigorously used spinous process fixation. The rationale is that in case of minimal movements, the robot is attached to the spine and follows its movements. No control mechanism exists to compensate for potential misalignment due to a loosening of the spinous process clamp during surgery, except for a rerегистration procedure.

Limitations of the Cohort Comparison

Herein, we compared 2 matched cohorts that underwent surgery performed by the same surgeon either using robot assistance or fluoroscopic guidance. One limitation is that the control group underwent surgery using an open technique, while the larger, percutaneous robot group underwent a minimally invasive-type surgery. The aim of the present analysis was to compare accuracy, which is a radiological assessment. While no difference was found

### TABLE 3: Pedicle and screw sizes*

<table>
<thead>
<tr>
<th>Segment</th>
<th>Group I †</th>
<th>Subgroup IA</th>
<th>Subgroup IB</th>
<th>Group II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Screws</td>
<td>Pedicle</td>
<td>Screw</td>
<td>No. of Screws</td>
</tr>
<tr>
<td>L-1</td>
<td>2</td>
<td>11.3 ± 4.5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>L-2</td>
<td>8</td>
<td>7.7 ± 2.5</td>
<td>5.4 ± 0.9</td>
<td>4</td>
</tr>
<tr>
<td>L-3</td>
<td>18</td>
<td>8.5 ± 1.4</td>
<td>5.2 ± 0.8</td>
<td>6</td>
</tr>
<tr>
<td>L-4</td>
<td>80</td>
<td>11.0 ± 2.0</td>
<td>6.2 ± 0.6</td>
<td>28</td>
</tr>
<tr>
<td>L-5</td>
<td>91</td>
<td>15.1 ± 2.6</td>
<td>6.2 ± 0.5</td>
<td>30</td>
</tr>
<tr>
<td>S-1</td>
<td>42</td>
<td>21.5 ± 3.5</td>
<td>6.5 ± 0.4</td>
<td>14</td>
</tr>
<tr>
<td>overall</td>
<td>241</td>
<td>14.2 ± 4.7</td>
<td>6.1 ± 0.7</td>
<td>82</td>
</tr>
</tbody>
</table>

* Pedicle and screw diameters are provided in millimeters as mean ± SD.
† Three screws in Group I that were partly revised are not included in this analysis.
Robot-assisted spine surgery

TABLE 5: Comparison of accuracy by group

<table>
<thead>
<tr>
<th>Gertzbein &amp; Robbins Scale Grade</th>
<th>Group I</th>
<th>Subgroup IA</th>
<th>Subgroup IB</th>
<th>Group II</th>
<th>Subgroup IA vs IB</th>
<th>Subgroup IB vs Group II</th>
<th>Subgroup IA vs Group II</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A &amp; B</td>
<td>223 (91.4)</td>
<td>75 (90.4)</td>
<td>148 (91.9)</td>
<td>142 (87.1)</td>
<td>0.19</td>
<td>0.81</td>
<td>0.20</td>
<td>0.53</td>
</tr>
<tr>
<td>C, D, E, &amp; R</td>
<td>21 (8.6)</td>
<td>8 (9.6)</td>
<td>13 (8.1)</td>
<td>21 (12.9)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>244</td>
<td>83</td>
<td>161</td>
<td>163</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

in accuracy between groups, our data do not allow us to conclude that the compared groups are equivalent in terms of surgical outcomes. Despite an attempt to match the groups, minor heterogeneities were found: the BMI was higher in the fluoroscopy-guided group (Group II), which may be potentially associated with a more demanding surgery. The number of screws and instrumented segments and the number of instrumented levels was higher in the fluoroscopy-guided group (Group II) than in the percutaneous robot cohort (Subgroup IB), which may equally have contributed to a more difficult surgery in the fluoroscopy-guided group. Hypothetically, without this heterogeneity, the number of well-positioned screws in the fluoroscopy group may have been somewhat higher. On average, screw accuracy scores were slightly higher in the robot cohorts but were far from reaching significance. Therefore, it is unlikely that a few more favorable scores in the fluoroscopy-guided group would change the primary outcome and message of the current report.

Secondary Parameters

In the fluoroscopy-guided group, surgical blood loss was significantly higher than in the robot group. Nevertheless, this finding was expected, because the percutaneous technique that was applied in the majority of robot cases (n = 38) helps decrease blood loss because open dissection is minimized. The remaining secondary parameters including LOS, duration of surgery, and cumulative dose of morphine, were comparable between fluoroscopy-guided and robot groups.

Applications of the System

One of the advantages of the system is that it does not require registration using bony landmarks. It can thus be applied even on difficult, previously surgically treated, and distorted spines. One such case is illustrated in Fig. 2. Although the addition of the robot was helpful in this case, it cannot replace the knowledge of surgical anatomy and the ability to manage unexpected intraoperative events.

The second advantage is that the robot system does not rely on a camera tracking mechanism. This avoids all the problems of reconnaissance between camera and navigated instruments or targets. Pitfalls in the Use of the Robotic System

In 3 instances, lateral fluoroscopy showed us that the entry point indicated by the robot was not pointing directly on the craniocaudal middle of the pedicle. In these cases, we reprogrammed the screw trajectory by lowering or raising the trajectory by a few millimeters. Without lateral fluoroscopy, this kind of inaccuracy may have gone unnoticed. These 3 instances were rated “R” for intraoperative revision and were included in the analysis. In 3 other cases, a robot-guided screw showed no grip and had to be revised openly. Therefore, a total of 6 “R” cases were recorded. These cases were included in the analysis as poor screw positioning.

One of the possible and most difficult-to-prevent mechanisms of inaccuracy despite good registration is the phenomenon of a cannula sliding off an angled bone surface as mentioned by Ringel et al. 

It is possible to minimize the occurrence of this complication either by tightly securing the teeth of the working cannula on the bone either by choosing an ideal entry point of the drill onto a flat bony surface. The sliding off occurs normally lateral to the facet joint, which may explain the more frequently observed lateral inaccuracy of robot-assisted screws.

Despite precision of this robotic procedure, 3 screws in the lumbar spine were subjectively felt by the surgeon to have insufficient bony purchase and were repositioned by hand. These instances, although with no clinical consequence, highlight the importance of a careful review of the trajectories when using the robot.

Conclusions

The introduction of the SpineAssist system in our practice has led to increased overall accuracy of lumbar pedicle screws, but the results were not statistically significant. We conclude that robot-guided pedicle screw placement is a safe and useful tool for assisting spine surgeons in degenerative spinal cases. Nonetheless, technical difficulties remain, and fluoroscopy backup is advocated.

TABLE 6: Cases of screw deviation*

<table>
<thead>
<tr>
<th>Deviation</th>
<th>Group I (%)</th>
<th>Group II (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cranial</td>
<td>4 (10)</td>
<td>4 (13)</td>
</tr>
<tr>
<td>caudal</td>
<td>5 (12)</td>
<td>3 (9)</td>
</tr>
<tr>
<td>medial</td>
<td>13 (31)</td>
<td>12 (39)</td>
</tr>
<tr>
<td>lateral</td>
<td>20 (47)</td>
<td>12 (39)</td>
</tr>
<tr>
<td>total</td>
<td>42</td>
<td>31</td>
</tr>
</tbody>
</table>

* The direction of misplacement is provided for all screws that were not perfectly intrapedicular (Grade B to E, total n = 67). In 7 cases, the screw was displaced in 2 directions, leading to a total of 73 counts, which exceeds the total number of misplaced screws.
TABLE 7: Secondary parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (mean ± SD)</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Group IA</td>
</tr>
<tr>
<td>mean duration of op (mins)</td>
<td>200 ± 43</td>
<td>205 ± 44</td>
</tr>
<tr>
<td>LOS (days)</td>
<td>10.0 ± 5.1</td>
<td>9.8 ± 5.1</td>
</tr>
<tr>
<td>blood loss (ml)</td>
<td>488 ± 369</td>
<td>375 ± 263</td>
</tr>
<tr>
<td>cumulative morphine (mg)</td>
<td>227 ± 351</td>
<td>218 ± 292</td>
</tr>
</tbody>
</table>

* Values that appear in boldface are statistically significant.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper. The University Hospital of Geneva functions as a training site for this particular technology (Mazor Robotics).

Author contributions to the study and manuscript preparation include the following. Conception and design: Tessitore, Schatlo. Acquisition of data: Tessitore, Schatlo, Molliqaj, Cuvvinciu, Kotowski. Analysis and interpretation of data: all authors. Drafting the article: Schatlo, Molliqaj. Critically revising the article: all authors.

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