# INDEX SURGERY COST OF FLUOROSCOPIC FREEHAND VS ROBOTIC-ASSISTED PEDICLE SCREW PLACEMENT IN LUMBAR INSTRUMENTATION; AN AGE, SEX, AND APPROACH MATCHED COHORT COMPARISON

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# Background

- Robotic-assisted procedures are becoming increasingly common in orthopedics, especially in total knee arthroplasty and spinal instrumentation. Pedicle screws are an established and widely accepted method utilized for spinal fixation for the treatment of deformities, traumas, and neoplasms of the thoracolumbar spine.[1] Robot guided pedicle screw placement is meant to provide improved accuracy and precision in pedicle screw placement along with a reduction in exposure to radiation for surgeon, patient, and operating room (OR) staff.[2-14] Several robotic systems have found recent increased usage in spinal instrumentation, most notably the MAZOR X (Medtronic Navigation Louisville, CO).[15] Evidence that the use of robotics will lead to improved survival, function, patient-reported outcomes, and decreased complications is not consistent and while there is some evidence of benefits over a fluoroscopic approach, many studies have shown equivalent or variable outcomes.[16-19]

- Spine surgery costs are notoriously high and there are already criticisms and concerns over the economic impacts.[20,21] Some studies have looked at overall costs, costs of different approaches to the spine, and geographic variation in costs[22-24]; however, there are few studies directly evaluating costs in robotic-assisted spine surgeries compared to more traditional non-robotic techniques. Passias et al.[25] looked at cost in robotic-assisted cases compared to matched minimally invasive (MIS) and open cases, finding significantly higher costs with the robot. In contrast Menger et al.[26] found robotic assisted cases to be cost-effective, and Garcia et al[27] suggested cost-effectiveness dependent on individual OR and institution admission costs.

- To date there is still minimal and conflicting literature investigating the cost of robotic-assisted spine instrumentation (rLF) versus fluoroscopic freehand instrumentation (fLF). This study looks to compare the early costs between matched lumbar rLF and fLF through (1) index surgery costs including supplies utilized, length of surgery, length of stay (LOS) and (2) reoperations secondary to complications or revisions within 3 months.

# Methods

- **Patient Selection**
  - After institutional review board approval was received (IRB #2021-105), we retrospectively reviewed all patients undergoing robotic spinal fusion by one fellowship trained senior spine surgeon at our institution, and a matched cohort undergoing fluoroscopic freehand spine fusion by another fellowship trained spine surgeon during the first-year adoption of the robot at the institution (2018-2021). All robotic procedures were performed using the MAZOR X robotic system. Initial inclusion criteria included a robotic lumbar spinal fusion. Exclusion criteria included open spinal surgery and prior surgical history of posterior lumbar spine fusion. All included cases were minimally invasive/percutaneous surgeries. Patients meeting inclusion criteria were reviewed in depth for demographic data, body mass index (BMI), underlying diagnosis, spine approach, levels of fusion, length of stay, length of surgery, 90-day readmissions, 90-day perioperative mortality, and 90-day revisions or returns to the OR.
  - Of the initial 73 rLF patients, some were unable to be confirmed as robotic cases (17) or had additional procedures performed at the time of index fusion (6). 50 met the final inclusion criteria. These robotic-assisted cases were matched to non-robotic cases by the other spine surgeon for age (within 6 years), sex, approach to the spine (PLIF – posterolateral interbody fusion and TLIF – transforaminal lumbar interbody fusion only), and number of levels fused. 42 patients were able to be matched. Cost data was available for 39 patients. Primary outcomes were day of surgery variable direct costs (VDC). This included direct operating room (OR) costs, supply costs, services costs, and LOS costs.
- **Cost Data Acquisition**
  - The term "costs" for this study refers to the actual variable direct cost to the institution with each individual patient encounter. "Costs" were NOT the charges to the payor. The overall direct variable costs for each patient encounter included direct variable supply costs (including disposables) and other direct variable costs that included O) costs and costs related to time in the OR. Cost variables were acquired from the director of financial decision and support at our institution.
- **Cost definitions**
  - Direct costs are thought to be a more accurate representation of true costs.[28] For this study, total direct costs are the sum of the variable expenses directly related to patient care. Variable direct costs represent incremental costs which would not have occurred if the surgery was not performed. These costs vary with patient activity (i.e., medications and medical tests). Included in these costs are labor wages for all of the personnel required for patient care of each surgical patient being treated, supplies (gowns, drapes IV equipment, etc, including robotic instruments), and drugs. In contrast, fixed direct costs (which were not evaluated in our study) represent incremental costs that would still have occurred even if the surgery was not performed. This includes ongoing equipment costs (depreciation, maintenance contracts and repairs), consulting fees, and administrative costs for both personnel (office manager, secretarial staff, etc) and the office supplies/furnishings required to support this staff. Finally, the total direct costs were a summation of direct supply costs, direct cost of operative time, and direct cost of services utilized. All variables were evaluated independent of the total cost and were compared between the approaches. Capital investment for both fluoroscopic freehand and robotic setups were not included in our summaries. Indirect costs that were not directly related to individual **patient care were not included in this study.**
- **Data analysis**
  - For analysis we used Statistics Kingdom (statskingdom.com) and Past4 version 4.09 (Hammer et al, University of Oslo, Norway). The Shapiro-Wilk test was performed to assess the normality of the continuous variables. The categorical variables were analyzed using a Pearson's chi-squared test for association and the continuous variables were analyzed using the Mann-Whitney U test. For all analyses, a p-value of $< 0.05$ was considered statistically significant.

# Results

- **Demographics and clinical outcomes**
  - A total of 78 patients met criteria and were included in the study (39 rLF, 39 fLF – 17 PLIF, 22 TLIF in each cohort). There were fifty-four 1-level fusions, eighteen 2-level fusions, and six 3-level fusions. Primary diagnoses in rLF included spondylolisthesis (32), degenerative disc disease (4), discitis (1), disc herniation (1), and vertebral fracture (1). Primary diagnosis for fLF included spondylolisthesis (35), degenerative disc disease (1), spinal stenosis (1), and discitis (1). There was no significant difference in age, sex, BMI, history of lumbar spine surgery, OR time, or LOS **(Table 1)**. rLF patients were more likely to have an ASA rating of II (p=0.04), and fLF patients were more likely to have an ASA rating of III (p =0.012). There was no significant difference in 90-day readmissions between rLF and fLF respectively (7.7% versus 2.6 %, p=0.305), or 90-day reoperations (7.7% versus 0%, p=0.077). All readmissions in the robotic cohort underwent reoperation; one patient had incomplete relief from an L4-L5 fusion (spondylolisthesis) and underwent and L3-L4 fusion, one patient had an interbody cage complication, and one patient had a surgical site infection. In the fluoroscopic cohort, one patient was readmitted for pain control due to sided radicular pain.
- **Total Encounter Costs**
  - When comparing rLF to fLF, rLF had higher median total encounter costs ($23122 ± 11006 versus $18328 ± 7215, p=0.009), and higher encounter VDC costs ($15867 ± 7458 versus $13580 ± 3861, p=0.001).
- **Day of Surgery Costs**
  - rLF had higher day of surgery total VDC ($14444 ± 8503 versus $13012 ± 5468, p=0.005), including higher VDC anesthesia ($376.70 ± 354.87 versus $311.66 ± 157.00, p=0.006), higher VDC supplies ($11367 ± 6914, p=0.0183) and VDC OR time ($1521 ± 1246 versus $880 ± 454, p <0.001) (**Table 2, figure 1**). There were no VDC differences in imaging, labs, physical therapy/occupational therapy/speech services, room and board, post-op recovery, and prescriptions. The three reoperations for the rLF cohort had an average day of surgery cost of $6571.80. Multivariate linear regression showed no relationship with age, BMI, or LOS with day of surgery VDC for either rLF vs fLF. OR time was similarly not related to cost for fLF. OR time did have a positive relationship with cost in rLF (r=0.72, p <0.001) (**Figure 2**).

Table 1

| | rLF (39) median ± SD | fLF (39) median ± SD | p-value |
|---|---|---|---|
| Age | 62.4 ± 10.2 | 62.4 ± 10.8 | 0.9722 |
| Sex | 22 female, 17 male | 22 female, 17 male | 1 |
| BMI | 30.6 ± 4.9 | 31.2 ± 5.1 | 0.7842 |
| History of lumbar spine surgery | 5 (12.8%) | 3 (7.7%) | 0.4554 |
| ASA | | | |
| I | 0 | 0 | 1 |
| II | 22 | 13 | 0.04047 |
| III | 15 | 26 | 0.01262 |
| IV | 1 | 0 | 0.3142 |
| | | | |
| OR time (minutes) | 172 ± 47.1 | 152.0 ± 39.1 | 0.1501 |
| LOS | 2.1 ± 1.7 | 2.1 ± 2.5 | 0.5194 |
| 90-day readmission related to surgery | 3 (7.7%) | 1 (2.6%) | 0.6439 |
| Reoperations within 90 days | 3 | 0 | 0.07734 |

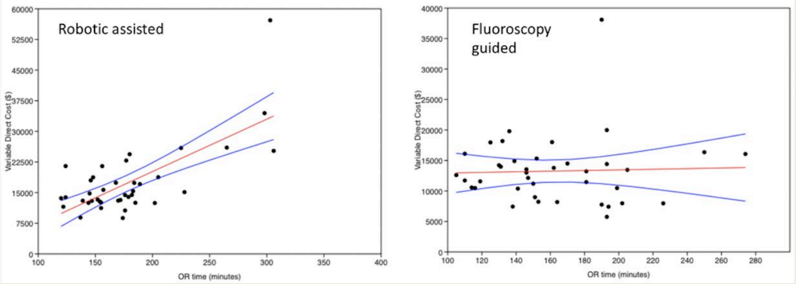

Figure 2

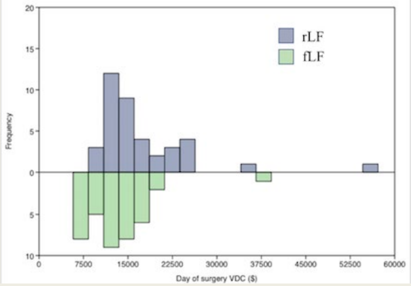

Figure 1

# Discussion 1

- In our study, we found multiple factors that led to an overall increased cost in spine surgery with the use of rLF in comparison to fLF. Day of surgery cost and total encounter VDC was 11% and 16% more expensive for the rLF group than the fLF group. The majority of the difference between the two groups was found in the medical surgical supplies category, which had a 14% increase in cost for the robotic-assisted group.
- *Clinical Outcomes*
  - We found no difference in OR time or LOS between the cohorts. Readmissions and reoperations within 90 days were also similar but trended to have higher reoperations in the rLF group. The current literature indicates that the accuracy and precision with the use of robotics is highly effective, both in cadaver studies and patient cases.[29] Complication rate was seen to be reduced in two studies reviewing robot-assisted MIS in comparison with fluoroscopy-guided surgeries[3,30], and there were few papers that indicated lower reoperation and revision rates with the use of robotics.[3,31,32] Kantelhardt et al. reported a reduction within average length of hospital stay by 27%.[3] However, a recent paper by Passias et al. showed a significant increase in post-op complications in robotic surgeries, without change in revision rates.[25] In contrast, a multi-center prospective study with 485 patients with 1 year follow-up between rLF and fLF found a 5.8x higher hazard ratio and 11.0x higher hazard ratio for fLF for complications and revisions respectively.[33] In our study, we did not find a correlation with less revisions and complications in the early adoption of robotic spine surgery. We aimed to look at short term revisions and malpositioned screws that would necessitate early revision surgery.
- *Costs*
  - Our cost comparison showed several factors that led to an overall increased cost in spine surgery with the use of rLF in comparison to fLF. Most of the cost differences in the cohorts came from surgical supply utilization (14% increase with rLF) and OR time (72% increase with rLF). This also implies that there is a higher cost per minute in the OR with rLF. There was a significant difference also found in costs related to anesthesia, but this cost difference was minimal in comparison to the total VDC. Other fluctuations in price were also too minor to be impactful.
  - Few papers discuss cost with most reviewing cost to the health care system but utilizing measures other than VDC, in contrast to our paper. Menger et al. utilized a predictive model considering their caseload of 557 cases that resulted in an estimated $608,000 USD of savings over a 1-year period for one major academic center, with a majority of the savings coming from reduced infections, reduced revision surgeries, and decreased length of hospital stay.[26] They utilized a "diagnosis related group" as a basis for revenue calculations through reimbursement from Medicare or commercial insurances. Passias et al. similarly looked at Medicare reimbursement and found that surgery costs were similar between open and minimally invasive surgery (MIS), but robotic-assisted surgery resulted in the highest total cost.[25] They also analyzed cost per quality adjusted life year (QALY) as a main outcome measure, which showed robotic surgery to have the highest cost per QALY between groups, with MIS at the lowest cost per QALY. They also calculated the incremental cost effectiveness ratio (ICER, summary measure representing the economic value of an intervention), finding that MIS provided the highest effectiveness per cost ratio, followed by open surgery, then robotic surgery with the lowest ratio.
  - Garcia et al. utilized point estimates and Monte Carlo methods to evaluate cost-effectiveness. [27] Cost-effectiveness was found to be sensitive to operating room/materials and admission costs. They also looked at willingness-to-pay threshold per quality-adjusted life year (QALY), and found that within the framework of $50,000/QALY, robotic-assisted MIS was cost-effective in 63% of simulations. The results from Kantelhardt et al. showed a reduction in the average length of hospital stay is possibly indicative of the cost-effectiveness of the use of robotics.[3] Multiple studies also emphasized the reduction in surgery time based on the learning curve of a specific surgeon.[11,34]

# Discussion 2

- Training spine surgeons to perform robotic cases is another factor. Not all surgeons have access to this methodology as part of residency training. Future training may take a considerable amount of money, effort, and otherwise productive procedural or clinic time.[35,36] Hu et al. noted that the rate of success with robotic surgery improved after 30 procedures with a lower conversion rate to manual techniques.[4]

- Robotic assisted surgery is slowly becoming more commonplace, and many studies do show some improved patient outcomes.[36] Robotics in orthopedics continues to grow which may drive down the cost of larger cost variables, such as the overall price and maintenance of the robot. Although investing in the technology for robotic assisted surgery may have a higher upfront cost, there is cost-saving potential if it is found to consistently have fewer postoperative complications or revisions, and decreased length of hospital stay. Data from our study implies that although the use of robotics is innovative and has possible positive patient reported outcomes, the cost of implementation is currently higher to the health care system than its fluoroscopic-guided counterpart. If robotic-assisted spine surgery eventually leads to less reoperations or less infections as suggested in other literature, it would be important to evaluate postoperative costs over a longer time frame. While our study indicates that the cost of robotic-assisted lumbar fusion procedures is currently higher than its fluoroscopic freehand counterpart, future research looking into the long-term postoperative costs across multiple health care systems would be beneficial.

- There are other factors that play a role in the cost-benefit analysis of implementing robotic surgery in a specific institution. Hospital reputation with the use of cutting edge technology, patient perception of robotic surgery, and comfort of practicing surgeons, among other reasons, are various factors that may play a role in deciding whether introducing robotic surgery is worthwhile for a specific health care system.

- Robot Pricing and Maintenance
  - A portion of the cost that was not accounted for within the total costs of our study is the initial cost and maintenance of the robotics system. The cost of the MAZOR X robotic system is approximately $550,000 - $850,000 USD.[24,37] Additionally, there may be yearly maintenance fees and an estimated disposable supply cost per case of $1,500.[24,37]

- **Limitations**
  - This study has a few limitations that are important to mention. The data is provided from one health care system within the United States. There may be a high degree of variability between costs between US institutions and especially between worldwide health care systems, in labor costs, OR time, and medical supplies. Another limitation in this study is a relatively small sample size. After inclusion and exclusion criteria was applied, the cases from 39 patients provided the only acceptable data for this study. We also did not have the cost of preoperative CT for rLF, nor labor which has its own cost variation dependent on the institution. Another point of consideration is that while this study focused on the cost to the health system, the cost to the payor is also an important factor. The biggest strength of this study comes from details of our cost breakdown. This division allows for a better understanding of where these increased costs come from.

# Conclusion

- Using VDC as our proxy for cost, results from our study show that rLF is associated with a higher index surgery cost. The main factor driving increased cost is supply costs, with other variables too small in difference to make a significant financial impact. Future studies should focus on postoperative costs, including readmission and episode of care costs, and should consider the cost to the payor along with VDC. rLF will become more common and other institutions may need to take a closer financial look at this more novel instrumentation before adoption.

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