Robotic-Assisted Surgery and Navigation in Deformity Surgery

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KEYWORDS

• Navigation guidance • Robotics • Advanced technology • Adult spinal deformity • Surgery

KEY POINTS

- As three-dimensional (3D) navigation and robotic-assisted deformity surgery are becoming increasingly popular, there are currently increasing data on the impact of robotics use on patient-related outcomes including instrumentation failure, complication rates, and surgical efficiency.
- Navigation-guided approaches have been developed to maximize screw placement success and minimize injury.
- Despite the potential advantages of 3D navigation and robotics systems, there is limited data available demonstrating superiority of these advanced technology over the traditional freehand fluoroscopy-guided method specifically in the setting of spinal deformity.

INTRODUCTION

Adult spinal deformity (ASD) is characterized by misalignment and imbalance in the sagittal and coronal planes that may result in disability in daily activities of living and significant negative impact in quality of life.[1–3] The current prevalence is estimated to be up to 70% in those of age 60 years or older and is projected to increase with the aging population.[4,5]

The goal of ASD surgery is to correct the deformity based on appropriate spinopelvic parameters. Advances in surgical techniques and perioperative care have increased the pursuit of surgical treatment for ASD with promising potential in improving pain and disability.[6–8] However, surgery is still not without risks. Postoperative complications such as instrumentation failure and infection, blood loss, and long duration of surgery remain challenging issues.

The development of intraoperative navigation and surgical robotics has been rapidly progressing and has made significant advancement in spine surgery in terms of improved preoperative visualization and planning, screw placement accuracy, and reduced postoperative complications.[9–13] As robots are becoming more capable of handling increasingly complex spinal procedures, robotic-assisted surgery is beginning to become more widely adopted in spine procedures including deformity corrections.[14,15]

DISCUSSION

Instrumentation

Pedicle screw placement with intraoperative fluoroscopy is a popular and established technique for reconstructive surgery for deformity. However, the pedicle wall breach rate using the freehand technique can range up to 23%.[16] Factors that can affect accuracy include the surgeon's experience, case complexity, limitations of two-dimensional (2D) imaging, and patient-specific factors. Two-dimensional imaging resulting from

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fluoroscopy/plain films has limitations in assessing the true anatomy, which is critical for accurate pedicle screw placement. This is especially pronounced in patients with spinal deformity who have difficult anatomy and yet often require extensive constructs.[17,18] Moreover, about a quarter of all patients who have malpositioned instrumentation may require implant revision or removal, which is associated with high cost and morbidity.[17,19] To this end, three-dimensional (3D) intraoperative imaging techniques such as computed tomography (CT) imaging may improve screw placement accuracy.[17,20–22] Intraoperative 3D imaging allows the surgeon to identify misplaced screws during the procedure and replace these screws before completion of the operation. In addition, CT-guided navigation can provide real-time 3D feedback for the surgeon by using preoperative and/or intraoperative CT scan to digitally reconstruct an anatomic map for the surgeon during the operation. The ability to see the 3D anatomy of the spine may be useful in complex deformity surgery, revision surgery, and pelvic fixation where visualization and understanding of the deformed spine are essential.

In addition to 3D imaging, the integration of robotics into spine surgery has been an integral part of improving the instrumentation accuracy especially in the realm of minimally invasive surgery (MIS) (**Figs. 1** and **2**). For spinal fusion procedures, previous studies have demonstrated numerous advantages of robotic-assisted navigation with accuracy rates up to 98%.[11,23] In addition to increased accuracy, robotic-assisted spine surgery results in minimal intraoperative blood loss and less tissue destruction compared with the conventional freehand technique and MIS.[24–26]

Despite the benefits of navigation- and robotic-guided spine surgery, the currently available evidence demonstrates similar performance for guided navigation and traditional freehand technique.[27–29] Although there are no studies demonstrating a definitive advantage of navigated techniques in the setting of spinal deformity, the use of navigated techniques may be a valuable aid to the surgeons in complex spine cases per their preference.

Sacroiliac Fixation

Successful lumbosacral fusions have been difficult to achieve, with high postoperative complications and pseudoarthrosis rates due to the unfavorable anatomical structure and biomechanical profile of the lumbosacral junction.[30] Bilateral iliac screws were traditionally used to strengthen the caudal end of lumbosacral constructs during posterior lumbosacral instrumented fusion.[31,32] Studies have shown that iliac screw fixation increases the biomechanical strength at the lumbosacral junction with good clinical outcomes.[30,32,33] Robotic-assisted iliac screw fixation has been increasingly pursued when considering a minimally invasive

Fig. 1. An example of a surgical robot for spinal fusion surgery.

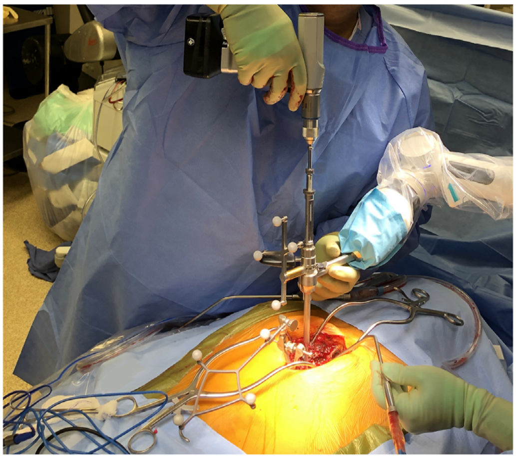

Fig. 2. Depiction of pedicle screw placement in a spinal fusion surgery which involves the robotic arm guidance for pedicle screw placement followed by insertion of pedicle screw in the trajectory defined by the robotic arm.

approach due to the heterogeneity and suboptimal visualization of the pelvic anatomy.[34,35] Iliac screw fixation is critical to a variety of indications including long-segment constructs, high-grade spondylolisthesis, pseudoarthrosis, and deformity correction. Studies have shown that image-guided sacroiliac screw fixation allows for minimally invasive approach without compromising the strength of the sacropelvic fixation that enhances bony fusion.[36–39] Furthermore, navigated sacroiliac surgeries reduce surrounding tissue damage, minimize bleeding, and decrease the risk for wound infection and disunion[40–43] while maintaining accuracy rate as high as 95%.[43–45]

However, due to their lateral positioning relative to the axis of lumbar screws, these iliac screw heads require additional contorting of the rods or needing to be accompanied by an offset connector, both of which contribute to increasing the risk of potential mechanical failure. As an alternative strategy to reduce the need for unnatural rod adjustments and an extra component for instrumentation, bilateral sacroiliac screws were introduced in which the heads of the screws can align with the rest of the lumbosacral screws in a long construct.[36] Particularly, S2 alar-iliac screws demonstrate improved outcomes for pelvic obliquity correction and anchor stability compared with traditional iliac fixation.[46] More recently, studies have shown that image-guided sacroiliac screw fixation allows for minimally invasive approach without compromising the strength of the sacropelvic fixation that enhances bony fusion.[36–39] Furthermore, navigated sacroiliac surgeries may further reduce surrounding tissue damage, minimize bleeding, and decrease the risk for wound infection and disunion.[40,41]

Radiation Exposure

Radiation exposure to the surgeon during spine surgery is another disadvantage of the freehand technique which often requires multiple fluoroscopic images for confirmation. The 3D navigation and robotics systems have been shown to significantly decrease the radiation exposure for the surgeon compared with the freehand technique.[11,12,47–49] However, due to the use of intraoperative CT scan, radiation exposure may not be decreased (and, in some instances, increased) for the patient using the 3D navigation and robotics systems.[50] Although the reduction in radiation exposure for the surgical team is a significant benefit, this may come at the expense of increased radiation to the patient; hence, the surgeon should be aware of this risk when evaluating patients and selecting the most appropriate surgical approach.

Disadvantages

Three-dimensional navigation and robotics have many potential benefits including improved instrumentation accuracy, better appreciation of anatomy, and reduced radiation exposure to the surgical team. Despite these advantages, there still exist significant limitations in fully adopting this technology. First, one of the important limitations is the cost.[14] As novel robotics systems are hitting the market, the cost is also proportionally increasing with the newer models approaching over $1 million US dollars.[51] Currently, there are no studies to date that demonstrate superior cost-effectiveness of these advanced guidance systems in deformity surgery. Second, particularly for senior surgeons with experience and proficiency using freehand fluoroscopy-guided techniques, the addition of 3D navigation or robotic technology may increase operative time without imparting a meaningful clinical benefit in terms of improved patient outcomes due to the learning curve that may be associated with its initial use.[48,52–56] Over time, these advanced instrumentation tools may improve complication and reoperation rates related to malpositioned screws as well as reduce total operative time, particularly in patients with abnormal and complex spine anatomy. Finally, reliance on navigation technology can compromise the anatomy skills of surgeons in training which may lead to suboptimal outcomes in circumstances of technology failure or when technology support is not available (eg, nights and weekends). Hence, surgeons must take caution against relying too heavily on navigational assistance and use it primarily as an assistive tool to augment their understanding of the patient-specific anatomy to allow for safer and more efficient surgeries.

SUMMARY

The use of 3D navigation systems and robotics in deformity surgery is an area of rapid advancement in the treatment of ASD. In spinal fusion surgery, robotics has led to increased intraoperative accuracy for pedicle screw placement while decreasing radiation exposure, complication rates, blood loss, and recovery time for patients. Compared with the historically accepted freehand fluoroscopy-assisted instrumentation, there is currently insufficient evidence suggesting any definitive advantages of robotics over the traditional freehand technique. Most of the studies demonstrating superiority of robotic systems are relatively small and are retrospective given the early stages of these technologies for use in deformity surgery.

Also, the incorporation of these advanced navigation systems can be financially and chronologically costly. Ideally, the surgeon should use this advanced technology as a tool for enhancing their surgical workflow but should not rely on this technology to replace surgical experience, a detailed understanding of spine anatomy, and sound clinical judgment.

CLINICS CARE POINTS

- Robotic-assisted spinal fusion and sacroiliac fixation surgeries have suggested high accuracy rates, minimal intraoperative blood loss, and less injury to surrounding tissue compared with the conventional freehand technique.
- The three-dimensional (3D) navigation and robotics systems have been shown to significantly decrease the radiation exposure for the surgical team compared with the freehand technique; however, due to the use of intraoperative computed tomography scan, radiation exposure may not be significantly decreased for the patient.
- Limitations to 3D navigation and robotics include cost, learning curve, and technology dependence.
- Further evidence is needed to validate the advantages of robotics over the traditional freehand technique in deformity surgery.

DISCLOSURE

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