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Extreme Lateral Lumbar Interbody Fusion Surgery with a Robot-Assisted System in a Swine Model

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ABSTRACT

AIM: To evaluate the technical aspects of the Da Vinci Xi Surgical System in minimally invasive extreme lateral lumbar interbody fusion (XLIF) surgery in a swine model.

MATERIAL and METHODS: Endoscopic discectomy and XLIF cage insertion were performed using a robot-assisted system. The time taken and the pros and cons of each steps were recorded.

RESULTS: A total of 4 ports were used for the surgical access; one for the camera, two for bipolar forcepses, and one auxiliary port for modified discectomy. Punch and curette were used for discectomy. The cage was inserted through the auxiliary port. Cage position was manipulated and checked by using the C-arm fluoroscopy. The operative time was 80 minutes. No complications or cage malposition was noted throughout the procedure.

CONCLUSION: This study shows that the robot-assisted XLIF approach is safe and feasible, and helps to protect the neurovascular structures. Moreover, a high image quality was also obtained during the procedure.

KEYWORDS: Robotic surgical procedures, Spinal fusion, Discectomy, Spine

ABBREVIATIONS: ALIF: Anterior lumbar interbody fusion, **FDA:** Food and Drugs Administration, **TLIF:** Transforaminal lumbar interbody fusion, **XLIF:** Extreme lateral lumbar interbody fusion

INTRODUCTION

Robotic surgical procedures are becoming increasingly popular with advances in technology. Minimally invasive procedures have gained considerable attention in the recent decade to overcome common complications associated with conventional spinal procedures (17). Despite being minimally invasive, the preference for robotic surgical procedures among spinal surgeons is low compared with other specialists. The robotic systems used for spinal procedures are Mazor (Medtronic Navigation, Louisville, CO, USA), Excelsius

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(Globus Medical, Inc., Audubon, PA, USA), ROSA Spine Robot (Zimmer Biomet, Warsaw, IN, USA), Cirq Spinal Robot (Brainlab AG, Munich, Germany), Fusion Robotics Spinal Navigation and Robotic System (Boulder, CO, USA), and TiRobot (TINAVI Medical Technologies, Beijing, China) (1). The Da Vinci Xi Surgical System (Intuitive Surgical, Sunnyvale, CA, USA) has been approved by the Food and Drug Administration (FDA) in the United States for minimally invasive interventions (3,4,27). This system is a convenient tool in urology, ear-nose-throat, cardiothoracic surgery, and general surgery; however, many neurosurgeons remain unfamiliar with it.

Robotic surgical procedures are recommended for operations requiring effective reconstructive techniques (39), as the instruments provide flexibility and steadiness to surgeons hands and the cameras and two high-resolution lenses provide three-dimensional vision (9,56). Compared with microscopic surgery, robotic surgical procedures have advantages and disadvantages. They provide an ergonomic console to better command the robot by scaling the surgeon's movements (4). The major disadvantages are the lack of tactile feedback and relatively high costs (56). Operational ergonomics is as important as control and precision in spinal operations (43). Robotic surgical procedures improve the comfort of surgeons, shorten hospital stay, and decrease postoperative pain and morbidity (26). Other limitations, such as insufficient power to manipulate procedures while cutting bones, have delayed the progress of robot-assisted spinal surgery (56). Cadaver and animal studies have attempted to overcome these limitations (26,43,56). However, there is still a knowledge gap and further need for animal and clinical studies to better delineate the role of robotic surgical procedures in spinal surgery. Extreme lateral lumbar interbody fusion (XLIF) is an indirect and minimally invasive procedure for neural spinal decompression. To the best of our knowledge, robot-assisted discectomy and XLIF cage insertion have not been reported in the literature.

The transperitoneal or retroperitoneal approach to the lumbosacral vertebrae, transoral approach to the skull base, and craniocervical junction are considered appropriate locations for robotic surgical procedures in the field of neurosurgery (29). Swine models are appropriate for spinal surgery studies because they are similar to humans in size and tissue (43,56). In this study, we aimed to investigate the feasibility of robot-assisted discectomy and cage insertion using an extreme lateral approach to the lumbar vertebra in a swine model. We also aimed to identify the advantages and disadvantages of the robot-assisted system in this scenario.

MATERIAL and METHODS

This study was conducted with approval from the Acıbadem Mehmet Ali Aydınlar University Clinical Simulation and Advanced Endoscopic Robotic Surgery Training Center. A robot-assisted lateral approach was used on the lumbar spine of a 52-kg frozen swine cadaver. Surgical procedures were performed by two neurosurgeons who received robot-assisted surgery certification for the Da Vinci Xi Surgical System. The surgical procedure for the thoracic spine and surgical steps have been previously described in detail (19). The swine was placed in the left lateral decubitus position. Four ports were used: one 12-mm port for the endoscope camera, two 8-mm ports for the robotic arms (bipolar forceps), and one 12-mm auxiliary port for discectomy and cage insertion. CO_2 was administered for inflation of the abdomen. An 8-mm, 0° Da Vinci Xi 3D endoscope camera was used; an 8-mm, 30° endoscope camera was also available for use if required. A curved bipolar dissector, bipolar forceps, and robotic instruments were used for dissection and homeostasis. Discectomy and cage insertion were performed through the auxiliary port. Cage level and position were confirmed using the C-arm. The duration of the surgical procedure was recorded. Surgical notes were maintained to record the anatomical structures encountered during the procedure, robotic maneuvers during discectomy and cage insertion, and complications, if any.

RESULTS

The 12-mm port for the endoscope camera was inserted using a suitable trocar. The abdomen was then inflated with CO_2 for proper anatomical visualization for the lumbar spinal approach. The 8-mm ports were placed on the left and right sides at least 5 cm from the endoscopic port. These ports were placed under the direction of green laser of the robotic system. The port for the endoscope camera was positioned at the junction of the green guidelines. Later in the process, the robot-assisted system was positioned according to laser instructions. Perforated bipolar forceps on the left robotic arm and curved bipolar forceps on the right robotic arm were inserted intraperitoneally through lateral ports. At this stage, the endoscope was modified to provide an intraperitoneal view. Initially, the intestines were viewed in the intra-abdominal space. Continuous CO_2 inflation enabled spontaneous intestinal retraction, following which the right kidney was observed. The right kidney was separated from the surrounding tissues using the curved bipolar forceps and retracted anteriorly. The iliopsoas muscle was observed following the displacement of the kidney (Figure 1). Then, the lumbar spine and adjacent central vascular structures were identified in the inferomedial aspect of the iliopsoas muscle. Dissection of the iliopsoas muscle revealed the lateral portion of the vertebral corpus and posterior portion of the inferior vena cava. Care was taken to protect the vital organs, ureter, primary vascular structures, and neural plexus during the iliopsoas muscle dissection. The area of interest (disc level) was confirmed using the C-arm, which remained stable throughout the procedure. After confirming the disc level with the C-arm, the muscle and ligament structures around the intervertebral disc were separated via posterior iliopsoas muscle dissection (Figure 2). An assistant surgeon with an endoscopic view of the robot-assisted system performed discectomy via the auxiliary port (12-mm), using a punch and curette, and cage insertion (Figure 3). The level and position of the cage were controlled using the C-arm (Figure 4). At the end of the procedure, all instruments were carefully removed under endoscopic guidance, and the entry points were sutured.

No complications were observed during the procedure. The operative time was 80 min: positioning and preparing the

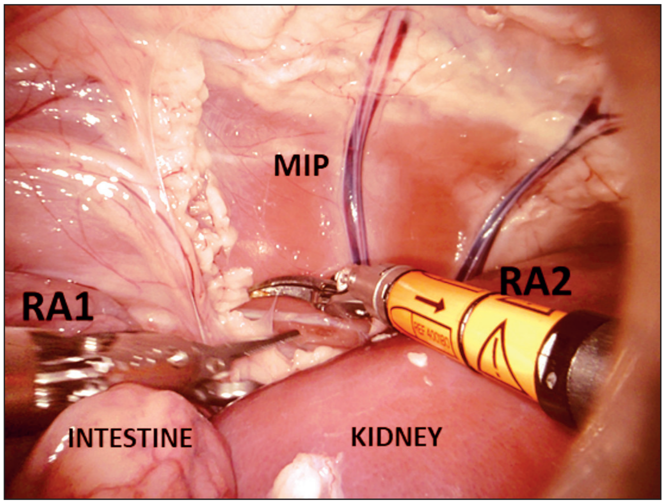

Figure 1: Illiopsoas muscle (MIP) is observed by retracting kidney anteriorly. **RA 1:** Robotic Arm 1 (fenestrated bipolar forceps). **RA 2:** Robotic Arm 2 (curved bipolar dissector).

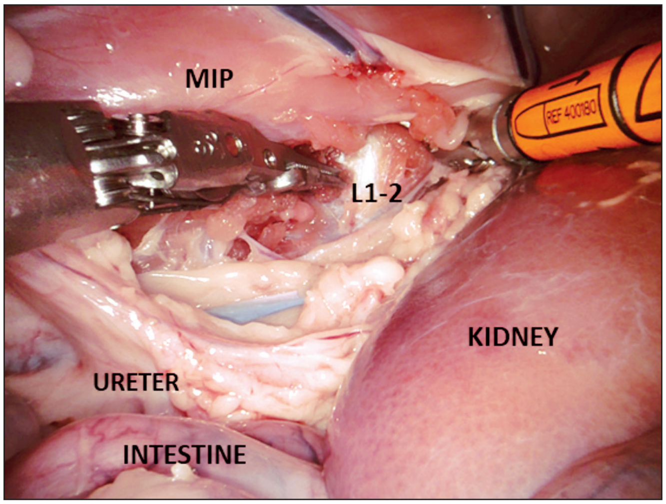

Figure 2: Following the confirmation of the spinal level by the C-arm fluoroscopy, the disc space is exposed by dissection of iliopsoas muscle (MIP) posteriorly. **RA 1:** Robotic Arm 1 (fenestrated bipolar forceps). **RA 2:** Robotic Arm 2 (curved bipolar dissector).

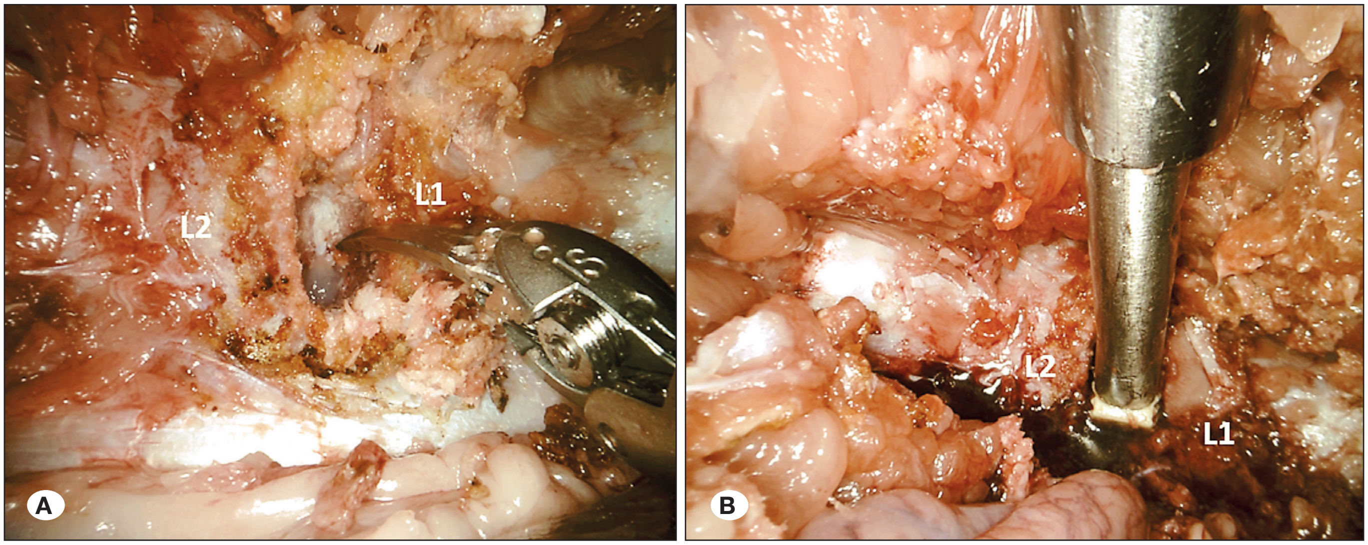

Figure 3: A, B) L1-2 discectomy is performed by the robotic instruments. Following total discectomy, the cage is placed by manually via robotic arm.

robot-assisted system, 20 min; port placement, connection, and intraperitoneal placement of robotic arms, 15 min; confirmation of the level with C-arm, 20 min; discectomy and cage insertion, 15 min; and control and locking the cage in position with the C-arm, 10 min.

DISCUSSION

Robot-assisted systems have not received the expected attention in the fields of neurosurgery and spinal surgery, despite their frequent use in urology, cardiothoracic surgery, gynecology, and general surgery (56). Minimally invasive procedures have become more popular for decreasing the complications of spinal surgery. Robot-assisted surgery is a minimally invasive procedure. The Da Vinci Surgical System, approved by the FDA in 2000, has been used in many surgical fields (12,32,37). The Da Vinci Xi Surgical System consists of four robotic arms and a monitor for the assistant. Each arm consists of a main joint and link joint that offers ergonomics similar to six-way hand movements. Because of this feature, the robotic system has a mechanical ergonomic advantage over the traditional laparoscopic system (23).

XLIF has been used to prevent vascular injuries observed with anterior lumbar interbody fusion (ALIF) and extra muscular dissection associated with transforaminal lumbar interbody fusion (TLIF), posterior lumbar interbody fusion (PLIF), and posterolateral lumbar fusion (15). In addition, XLIF surgeries have almost one-third shorter operative times and two-thirds lesser intraoperative bleeding amounts than TLIF surgeries

Figure 4: The level and position of the cage is confirmed by the C-arm fluoroscopy.

(20). However, anatomical studies have shown that dissection through the iliopsoas muscle puts the lumbar plexus and iliohypogastric, ilioinguinal, lateral femoral cutaneous, genitofemoral, and subcostal nerves at risk of injury (2,18,53). Numerous studies have reported high rates of new sensory (5.15%–75%), new motor (5.15%–40%), and vascular (0.03%–0.04%) injuries following XLIF procedures (15,16,25,30,42,47). Uribe et al. defined safe working zones for minimally invasive XLIF in a cadaveric study (53). All parts of the lumbar plexus, including nerve roots, were found within the psoas muscle posterior to the dorsal fourth of the vertebral body. Safe zones for dissections during minimally invasive XLIF were the middle posterior quarter of the vertebral body from L1-L2 to L3-L4 and midpoint of the vertebral body at the L4-L5 disc space (53). During the transpsoas approach, the subcostal nerve is the dominant nerve observed in the lateral position (2). Complete or partial nerve injuries can occur during the retroperitoneal transpsoas approach when performing blunt retroperitoneal dissection or when using retractor blades (18). In this study, we observed the nerves and vascular structures through an endoscopic view and could safely retract them together with the psoas muscle.

Vascular injury during XLIF surgeries (trauma to the great arteries, segmental arteries, and great vessels leading to retroperitoneal hematoma) has rarely been reported in the literature (13,41,46). Bowel perforation is another important issue in XLIF surgery (14), and has been reported at a range of 0.03%–12.5% in patients receiving XLIF insertion (5,16,21,40,45,48,51,54). Hwang et al. reported an increased risk of bowel perforation when there are more than three levels of operated segments using the lateral retroperitoneal approach or when the procedure is performed specifically at the L2-L3 and/or L3-L4 levels (21). Bowel perforation is associated with a high mortality (11.1%–79%) and morbidity risk (7,8). An endoscopic view not only prevents nerve injuries but also bowel and vascular injuries. Hence, a robot-assisted approach can be valuable in this sense.

Cage malposition and overhang are co-factors causing pseudoarthrosis because of unsuccessful fusion attempts at the operated levels (11,13,44). Cage insertion zones within the disc space for XLIF are the central (45%), anterior one-third (34%), and posterior one-third (7%) parts. Cage overhang was observed in 45% of cases with cage insertion in the anterior one-third of the disc space (44). In addition to preoperative planning with computed tomography and magnetic resonance imaging, a clear direct intraoperative view increases the success of XLIF surgery for proper cage insertion.

Several studies have reported that surgeons frequently experience discomfort because of non-ergonomic working positions (34,36). Although ergonomic studies on spinal surgeries are lacking, poor ergonomics undoubtedly limits the quality of surgical results. In contrast, surgeons using robot-assisted systems have lower discomfort levels even during day-long operations (43). Robot-assisted systems are likely to improve the quality of spinal surgery by improving the ergonomics of spine surgeons. The surgical console reduces potential unwanted injuries by converting large movements into much smaller precise movements. Tremor filtering and motion scaling functions also contribute to this feature (38). Robot-assisted systems provide better magnification and depth perception than traditional laparoscopic systems with three-dimensional image perception. Two parallel optical systems combined with the right and left eyes allow the three-dimensional image to be projected onto the surgeon's eyes. The adaptation of microscopic specialists, such as neurosurgeons, to this system is more effortless than that of other professionals.

Massive vascular injuries and marked increase in retrograde ejaculation in male patients because of strong traction, cutting, and coagulation of autonomic nerves are significant disadvantages of the laparoscopic anterior approach to the lumbar vertebra (10,22,24). Several studies have reported a low incidence of sexual dysfunction following dissection and nerve-sparing procedures using robotic systems in radical prostatectomy (31,50,52). This technique has been safely and successfully applied to animals and humans for ALIF insertion into the lower lumbar spine (6,28,56). One study used a robotic system for oblique lumbar interbody fusion (OLIF) surgery. However, in this case, the authors used the robotic system for the insertion of transpedicular screws, not the cage itself (55). There have been no reported cases of XLIF cage insertion via robotic systems till date. The endoscopic view of the robotic system made the dissection of the nerves and vascular structures out of view easy. Hence, a safe corridor for discectomy and cage insertion can be obtained. In addition, it was easier to accommodate the cage within the disc space. A recent comparative study revealed that lateral approaches at the lower lumbar levels had greater radiation exposure (49). In the present study, we used the C-arm twice: once for confirmation of the surgical level and once for confirmation of the cage position within the disc space.

To analyze the superiority of these procedures, robot-assisted and conventional laparoscopic surgical procedures should be compared first in cadavers and then in clinical practice.

Robot-assisted systems have advanced significantly over the last two decades. However, they have clear limitations in neurosurgery and spinal surgery. Haptic feedback is important for maintaining important structures intact during operations. The lack of haptic feedback is a significant drawback in robotic systems (33). However, experience and visual attention can overcome this drawback, as shown in other surgical disciplines. A more important limitation of the current Da Vinci Xi Surgical System is that it has no toolkit for managing bone structures. In addition, robotic systems have high start-up, training, and maintenance costs compared with traditional surgical methods (33). Some studies have evaluated the cost-effectiveness of robot-assisted spinal surgery and shown promising results at the 1-year follow-up because of fewer revision surgeries, lower infection rates, reduced operative times, and shorted in-hospital stay (35).

Anatomically, swine and humans exhibit differences. In swine, the disc space is narrower, and the thoracic and lumbar spine have kyphotic curvature (26,43). Therefore, a smaller cage was used in the present study. Lumbar kyphotic curvature causes the spine to remain closer to important structures such as the kidney and intestine during the procedure. Lumbar lordotic curvature in humans would make robot-assisted surgery easier.

Because of the COVID-19 pandemic, there may be limitations and delays in the application of surgical procedures. In addition, doctors, nurses, and other healthcare professionals are at high risk of infection (57). Robot-assisted minimally invasive surgical procedures would shorten the duration of surgeries and of in-hospital stay and decrease bleeding. Thus, the risk of COVID-19 could be reduced with less contact with patients, doctors, and other healthcare workers.

CONCLUSION

This study showed that robot-assisted surgery for XLIF can be successfully performed and dissection of neurovascular structures can be performed from the operative field with more ease and without harm. Discectomy and proper cage insertion were smoothly performed compared with the conventional open or mini XLIF procedures. Higher costs and maintenance fees are the drawbacks of robot-assisted XLIF surgeries; however, it reduces cost in the long-term as fewer revision surgeries are required. Further cadaveric and clinical studies are warranted to better delineate the superiority of robot-assisted spinal procedures over conventional laparoscopic procedures.

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AUTHORSHIP CONTRIBUTION

Study conception and design: AG, MSE, MBG

Data collection: GB, AG, BO

Analysis and interpretation of results: GB, AG, MSE

Draft manuscript preparation: GB, AG, BO, SA, EA

Critical revision of the article: GB, AG, BO

Other (study supervision, fundings, materials, etc...): CC, MEA, MSE

All authors (GB, AG, MBG, BO, SA, EA, CC, MEA, MSE) reviewed the results and approved the final version of the manuscript.

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