Use of navigation-assisted fluoroscopy to decrease radiation exposure during minimally invasive spine surgery

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Abstract

BACKGROUND: Minimally invasive surgery decreases postoperative pain and disability. However, limited views of the surgical field require extensive use of intraoperative fluoroscopy that may expose the surgical team to higher levels of ionizing radiation.

PURPOSE: To assess the feasibility and safety of navigation-assisted fluoroscopy during minimally invasive spine surgery.

STUDY DESIGN: A combined cadaveric and human study comparing minimally invasive transforaminal lumbar interbody fusion (MIS TLIF) using navigation-assisted fluoroscopy with standard intraoperative fluoroscopy to determine differences in surgical times and radiation exposures.

METHODS: Eighteen fresh cadaveric spines underwent unilateral MIS TLIF by using either navigation-assisted fluoroscopy or standard fluoroscopy. Times for specific surgical steps were compared. In addition, a prospective short-term evaluation of the intraoperative and perioperative results of 10 patients undergoing navigation-assisted MIS TLIF (NAV group) compared with a retrospective review of 8 patients undergoing MIS TLIF performed by using standard fluoroscopy (FLUORO group).

RESULTS: In the cadaveric study, the times were similar between the NAV group and the FLUORO group for most key steps. No statistically significant differences were obtained for approach, exposure, screw insertion, facetectomy/decompression, or total surgical times. Statistically significant differences were obtained for the setup time and total fluoroscopy time. The setup time for the NAV group averaged 9.67 (standard deviation [SD], 3.74) minutes compared with 4.78 (SD, 2.11) minutes for the FLUORO group (p = 0.034). The total fluoroscopy time was higher for the FLUORO group compared with the NAV group (41.9 seconds vs. 28.7 seconds, p = 0.042). Radiation exposure was undetectable when navigation-assisted fluoroscopy is used (NAV group). In contrast, an average 12.4 milli-REM (mREM) of radiation exposure is delivered to the surgeon during unilateral MIS TLIF procedure without navigation (FLUORO group). In the clinical series, the total fluoro time for the NAV group was 57.1 seconds (SD, 37.3; range, 18–120) compared with 147.2 seconds (SD, 73.3; range, 73–295) for FLUORO group (p = 0.02). No statistically significant differences are noted for operating time, estimated blood loss, or hospital stay. No inadvertent durotomies, postoperative weakness, or new radiculopathy were noted in the NAV group. One inadvertent durotomy was encountered in the FLUORO group that was repaired intraoperatively without clinical sequelae.

CONCLUSION: The use of navigation-assisted fluoroscopy is feasible and safe for minimally invasive spine surgery. Radiation exposure is decreased to the patient as well as the surgical team.

Keywords: Image guidance; Ionizing radiation; Occupational safety; Interbody fusion

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Introduction

The concept of minimally invasive spine (MIS) surgery rests on the tenet of minimizing soft-tissue disruption by limiting exposure to the necessary surgical corridor and using specialized retractors that distribute pressures evenly. This is best accomplished with the use of intraoperative fluoroscopy to aim retractors directly over the surgical target, guide accurate insertion of implants, and assist with various key steps of the surgical procedure such as decompression and discectomy. Unfortunately, the use of intraoperative fluoroscopy has significant drawbacks. First, the entire surgical team (surgeon, assistant surgeon, and scrub nurse) must remain at the surgical field, directly adjacent to the image intensifier. Rampersaud et al. [1] reported that fluoroscopically assisted pedicle screw placement exposes the spine surgeon to significantly greater radiation levels than other nonspinal procedures. In fact, dose rates are up to 10 to 12 times greater [2]. Second, the use of intraoperative fluoroscopy can be cumbersome and inconvenient. The surgical team must don protective equipment such as lead aprons and thyroid shields. This gear is extremely uncomfortable, especially when the C-arm encroaches on the surgical field and forces the surgical team to work in awkward positions. Image-guided spine surgery using computer-assisted navigation is a promising technique that addresses many of these concerns [3–7]. We describe the use of navigation-assisted fluoroscopy to perform minimally invasive transforaminal lumbar interbody fusion (MIS TLIF). A cadaveric model is used to compare various surgical parameters between MIS TLIF performed with standard fluoroscopy versus MIS TLIF performed with navigation assistance (NAV-MIS TLIF).

Radiation exposure to the surgeon for each technique was determined. In addition, a prospective analysis of 10 consecutive patients is used to show safety and feasibility, along with surgical times, and total fluoroscopy times by using the NAV-MIS TLIF technique. This is compared with a retrospective review of 8 patients undergoing MIS TLIF using standard fluoroscopy.

Materials and methods

Cadaveric study of NAV-MIS TLIF

Eighteen unilateral TLIFs were performed on 4 cadaveric specimens from L1–2 through L5–S1 as described previously [8,9]. Randomization of each level and side was determined by using a Latin-square design before examination of the cadavers. Two disc-space levels were omitted because of severe disc-space collapse. A navigation-assisted fluoroscopy system (FluoroNav; Medtronic Navigation, Louisville, CO) was used to perform 9 separate TLIF procedures as described later (NAV group). The comparison group underwent MIS TLIF by using standard fluoroscopic techniques (FLUORO group). Specified steps in the procedure were timed by a separate observer. The set-up time begins at the completion of draping and ends with the start of the skin incision. This includes insertion of the patient reference tracker into the posterior superior iliac spine, manipulation of the C-arm, acquisition of the C-arm images, and registration of the navigation instruments. The total fluoroscopy time is determined automatically by the internal timer of the C-arm unit measured in seconds. In the NAV group, the C-arm is used mostly during setup because all the images are obtained at the beginning of the procedure. For the FLUORO group, the C-arm remains in the surgical field and is used intermittently throughout the procedure, particularly during pedicle screw insertion and cage placement.

The approach time is at skin incision until the retractor is fully deployed. The exposure time begins once the retractor is deployed and ends after the facet, hemilamina, and pedicle entry points are exposed. The screw-insertion time is averaged for two screws. The facetectomy time begins immediately after the last screw is inserted until the start of disectomy. The disectomy time begins from the annulotomy to insertion of the interbody cage. The surgery time is the total time for the procedure and begins when draping is complete until the locking nuts are tightened with the torque wrench. Radiation-detection badges were worn by the surgeon on the outside of the lead protective gear, directly anterior to the thyroid. A separate badge was worn for each procedure and analyzed by an independent laboratory (Landauer, Glenwood, IL). No measurement was performed for the patient or cadaver specimen. All procedures were performed by a single surgeon (CWK).

NAV-MIS TLIF technique

The patient reference tracker is placed into the posterior superior iliac spine by using a 5-mm fluted pin (Fig. 1A). A standard 9-inch C-arm (OEC 9800; GE London, UK) is fitted with the navigation tracker to allow image capture by the navigation computer. Multiple images of the lumbar spine are obtained and stored in the navigation system. During image acquisition, the surgical team can step away from the surgical field and behind lead shielding. No lead aprons are worn by the surgical team. Once the desired images are obtained, the C-arm is taken out of the surgical field. The navigation computer imports the fluoroscopic virtual images from the C-arm and relates them to patient reference tracker, which in turn orients the navigation instruments and fluoroscopic images in three-dimensional space. The navigation pointer is used to plan the incision. The entry point to a path directly in line with the disc space on the lateral image and down the lateral aspect of the facet joint on the anteroposterior (AP) and oblique images is marked (Fig. 1). The skin and dorsal fascia are incised, and blunt finger dissection is performed between the multifidus and
longissimus muscles. The pedicles are entered by using the navigation awl (or drill with a universal navigation attachment), blunt pedicle probe, and tap (Fig. 1). By using a split-screen monitor, 4 separate images can be view simultaneously (Fig. 2). The pedicle screw of the appropriate size is inserted with the navigation screw driver (Fig. 3). All screws are placed before the discectomy because the motion segment becomes hypermobile and thus may decrease the accuracy of the navigation images.

A complete facetectomy and contralateral decompression is performed as described by Weiner et al. [10,11] and McCulloch et al. [12,13]. If necessary, a navigation osteotome is used to remove the overhanging rim of the posterior vertebral end plate during discectomy (Fig. 3C). Navigated, angled curettes are used to remove disc from the contralateral side (Fig. 3D). The navigation pointer can be used to determine the extent of the discectomy anteriorly (Fig. 3E) and the position of the spacer in the AP plane (Fig. 3F). Final C-arm images are obtained to confirm satisfactory implant position and spinal alignment. Again, the surgical team steps away from the operative field during image acquisition.

**Review of clinical series**

Ten patients underwent treatment of grade 1 spondylolisthesis via NAV-MIS TLIF. Intraoperative and perioperative parameters were obtained prospectively. Times for specific steps of the procedure, including time for each screw insertion, were measured by an independent observer (Table 1). Surgery time, estimated blood loss, intraoperative and perioperative complications, and hospital stay were assessed. The total fluoroscopy time was determined from the internal timer of the C-arm. In addition, eight patients undergoing MIS TLIF using standard fluoroscopic technique without navigation were retrospectively studied. Chart review obtained information on total operating room time, estimated blood loss, hospital stay, and complications. Total fluoroscopy time was obtained from a radiation log sheet.
used to monitor C-arm use. These values are also obtained from the internal timer of the C-arm.

Statistical analysis

All comparisons were statistically analyzed by using a one-way analysis of variance and a Fisher comparison t test. Significance level was p < .05.

Results

Cadaveric study of NAV-MIS TLIF

Times for various steps during the surgical procedure are shown in Figure 4. For most key steps, the times were similar between the NAV group and the FLUORO group. No statistically significant differences were obtained for approach, exposure, screw insertion, facetectomy/decompression, or total surgical times. Statistically significant differences were obtained for the setup time and total fluoroscopy time. The setup time for the NAV group averaged 9.67 (standard deviation [SD], 3.74) minutes compared with 4.78 (SD, 2.11) minutes for the FLUORO group (p = .034). The total fluoroscopy time was higher for the FLUORO group compared with the NAV group (41.9 seconds vs. 28.7 seconds, p = .042). The total surgery time for the NAV and FLUORO groups were 50.2 (SD, 10.2) minutes and 46.8 (SD 4.8) minutes, respectively (p = .39).

Radiation exposure is undetectable when navigation-assisted fluoroscopy is used (NAV group). In contrast, an average 12.4 mREM of radiation exposure is delivered to the surgeon during unilateral MIS TLIF procedure without navigation (FLUORO group).

Clinical series

The clinical results of 10 patients undergoing the NAV-MIS TLIF procedure were assessed prospectively. Table 1 shows specific times for setup, exposure, screw-insertion time, facetectomy/decompression, discectomy/cage insertion, and total surgery time. All procedures were performed by a single surgeon (CWK) by using the same C-arm. The setup time was 18.0 minutes (SD, 6.8; range, 5–26). The approach time was 22 minutes (SD, 11.9; range, 6–45). The average time for screw insertion was 10.3 minutes per screw (SD, 5.7; range, 2–24). All screws were in satisfactory position using postoperative radiographs independently evaluated by a musculoskeletal radiologist. The time for facetectomy and contralateral decompression using the MIS laminoplasty technique was 54.9 minutes (SD, 22.7; range, 27–94). The time for discectomy was 28.5 minutes (SD, 7.9; range, 17–39).

Table 1 compares NAV-MIS TLIF with MIS TLIF without navigation for total fluoroscopy time, total operating
room time, and hospital stay. No statistically significant differences are noted for operating room time, estimated blood loss, or hospital stay. There is a statistically significant decrease in total fluoroscopy time with navigation. The total fluoroscopy time for the NAV group was 57.1 seconds (SD, 37.3; range, 18–120) compared with 147.2 seconds (SD, 73.3; range, 73–295) for the FLUORO group (p=.02). No inadvertent durotomy, postoperative weakness, or new radiculopathy were noted in the NAV group. One inadvertent durotomy was encountered in the FLUORO group, which was repaired intraoperatively without clinical sequelae. In one case in the NAV group, the patient tracker was inadvertently bumped out of position. The acquisition of new images used an additional 32 seconds of fluoroscopy time.

Discussion

Minimally invasive spinal fusion using the MIS TLIF technique is efficacious and safe [8,9]. However, the need for intraoperative fluoroscopy poses significant disadvantages. In terms of relative risk, a spine surgeon performing MIS procedures such as kyphoplasty will be at 50 times greater risk of fatal cancer compared with a hip surgeon [14]. With the use of navigation-assisted fluoroscopy, the...
surgical team can step away from the surgical field and thus eliminate direct radiation exposure. Navigation-assisted fluoroscopy will not prevent exposure to the patient since they must remain in the radiation field during image acquisition. Fortunately, radiation exposure to patients is limited to the procedure itself. Unless they are undergoing multiple procedures involving fluoroscopy, their risk has been negligible. In a recent experimental study of radiation exposure to the fetus, it was estimated that at least 35 minutes of fluoroscopy would be needed for the induction of radiation-related effects [15]. Most studies show that exposure to the patient during various fluoroscopy-intensive procedures such as angioplasty and hepatic neoplasm chemoembolization is low [16].

This study shows that navigation-assisted fluoroscopy is a promising method to decrease radiation exposure during MIS surgery. The method is simple and straightforward, with an acceptable clinical safety profile. This particular technique addresses many of the previous drawbacks of navigation. No additional preoperative images are necessary, and thus there is no need for fiducial readings to “match up” the navigation image with a computed tomography scan. Familiar fluoroscopic techniques are enhanced with four simultaneous images of the spine in anteroposterior, lateral, and oblique views. Furthermore, because all navigation images are obtained at the beginning of surgery, there is less repositioning of the C-arm. This is shown in the clinical series in which C-arm usage (as measured by the total fluoroscopy time) for navigation-assisted surgery is less than that for standard fluoroscopic surgery. However, it is important to point out that in the clinical series the data for the NAV group was obtained prospectively and the FLUORO group retrospectively. This may lead to certain biases because the surgeon was aware that he was being timed and may be more proficient in MIS techniques. The cadaveric studies may be more representative of the true difference in C-arm usage because the NAV and FLUORO groups were randomized and the procedures were performed by a single surgeon during the same study period. The cadaveric study also shows that the C-arm usage is decreased with navigation-assisted MIS surgery. This can be advantageous when the fluoroscope technician is inexperienced and/or uninterested.

The navigation-assisted fluoroscopic MIS surgery offers several other advantages. Desired screw sizes and rod lengths can be determined. The extent of the discectomy and the position of the interbody graft can be assessed. Operating room ergonomics is improved by clearing the surgical field. The operating microscope can be brought in without interference from the C-arm. The need for heavy, restrictive protective gear is eliminated because all navigation images are obtained while the surgical team steps away from the path of radiation scatter.

Although there is a preconception that use of navigation-assisted fluoroscopy adds time-consuming tasks to the procedure, our cadaveric studies show that overall surgical times are not affected. There is additional time needed at the beginning of the procedure to acquire and download all the images into the navigation computer. This step can be perceived as excessively long, particularly to the expeditious spine surgeon. However, overall fluoroscopy time is decreased with navigation by eliminating the time-consuming task of bringing the C-arm in and out of the surgical field and obtaining additional scout images to reestablish the desired views. By avoiding these steps, the time spent for navigation setup is offset by the time needed to take additional images and for the fluoroscope technician to reposition the C-arm.

**Conclusions**

The technique of NAV-MIS TLIF is simple and readily applicable for most spine surgeons. The technique
described eliminates cumbersome preoperative imaging as well as intraoperative image registration using fiducial points. It retains fluoroscopic techniques familiar to most spine surgeons. Initial, short-term clinical results support its feasibility and safety. The surgical team benefits from reduced exposure to ionizing radiation and improved operating room ergonomics.

References


Farthing described a 6-year-old boy hit by a car, sustaining a posterior dislocation of the skull on the first cervical vertebra. In the emergency room, when the child’s head was extended, his respirations and cardiac rhythm ceased immediately but resumed when his head was returned to the flexed position. The child’s initial neurologic examination was normal, and remained normal during the course of treatment.

The child was treated first by halter traction with the neck flexed for 2 weeks, then manual vertical traction and a plaster cuirass for 4 months, then a neck brace for another 4 months. At 12 months postinjury, full range of motion was permitted and X-rays showed the reduction was maintained. At 2 years postinjury, the child continued to have full range of motion with no residual disability.

Reference
