An Outcome and Cost Analysis Comparing Single-Level Minimally Invasive Transforaminal Lumbar Interbody Fusion Using Intraoperative Fluoroscopy versus Computed Tomography–Guided Navigation

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■ BACKGROUND: **Minimally invasive transforaminal lumbar interbody fusion (TLIF) has undergone significant evolution since its conception as a fusion technique to treat lumbar spondylosis. Minimally invasive TLIF is commonly performed using intraoperative two-dimensional fluoroscopic x-rays. However, intraoperative computed tomography (CT)–based navigation during minimally invasive TLIF is gaining popularity for improvements in visualizing anatomy and reducing intraoperative radiation to surgeons and operating room staff. This is the first study to compare clinical outcomes and cost between these 2 imaging techniques during minimally invasive TLIF.**

■ METHODS: **For comparison, 28 patients who underwent single-level minimally invasive TLIF using fluoroscopy were matched to 28 patients undergoing single-level minimally invasive TLIF using CT navigation based on race, sex, age, smoking status, payer type, and medical comorbidities (Charlson Comorbidity Index). The minimum follow-up time was 6 months. The 2 groups were compared in regard to clinical outcomes and hospital reimbursement from the payer perspective.**

■ RESULTS: **Average surgery time, anesthesia time, and hospital length of stay were similar for both groups, but average estimated blood loss was lower in the fluoroscopy group compared with the CT navigation group (154 mL vs. 262 mL; $P = 0.016$). Oswestry Disability Index, back visual analog scale, and leg visual analog scale scores similarly improved in both groups ($P > 0.05$) at 6-month follow-up. Cost analysis showed that average hospital payments were similar in the fluoroscopy versus the CT navigation groups ($32,347 vs. $32,656; $P = 0.925$) as well as payments for the operating room ($P = 0.868$).**

■ CONCLUSIONS: **Single minimally invasive TLIF performed with fluoroscopy versus CT navigation showed similar clinical outcomes and cost at 6 months.**

INTRODUCTION

Because of the frequency and high cost of lumbar spinal fusion, it is important to ensure that the techniques used are cost-effective.[1,2] Transforaminal lumbar interbody fusion (TLIF), used to treat low back pain associated with spondylolisthesis, recurrent disc herniation, and degenerative disc disease,[3] has been demonstrated to be cost-effective by current standards.[4] Minimally invasive TLIF using a muscle-dilating approach with two-dimensional (2-D) fluoroscopic guidance has been developed to minimize iatrogenic soft tissue injury and has been associated with reduced blood loss, shorter length of hospital stay, improved quality of life, and improved cost-effectiveness relative to open TLIF.[1,3,5]

Key words
- Cost analysis
- Cost-effectiveness
- Intraoperative navigation
- Minimally invasive
- SF-6D
- Transforaminal lumbar interbody fusion
- VAS

Abbreviations and Acronyms
2-D: Two-dimensional
CCI: Charlson Comorbidity Index
CT: Computed tomography
ODI: Oswestry Disability Index
OR: Operating room
QALY: Quality-adjusted life years
TLIF: Transforaminal lumbar interbody fusion
VAS: Visual analog scale

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Newer intraoperative navigation techniques, such as cone-beam computed tomography (CT), which combines preoperative and intermittent intraoperative CT, have further advanced minimally invasive TLIF techniques. Relative to 2-D fluoroscopy, these techniques offer superior radiologic anatomic resolution, reduced incision length, and decreased radiation exposure to surgeons and operating room (OR) staff.[6] Additionally, a study, although not comparing just minimally invasive surgery, found shorter rehabilitation time, less blood loss, and shorter hospitalization, while maintaining equivalent outcomes relative to open surgery.[7] However, no studies to our knowledge have compared the outcomes and cost of advanced intraoperative CT navigation with traditional 2-D fluoroscopic navigation during minimally invasive TLIF. We performed a retrospective study to compare the costs and surgical outcomes of 2-D fluoroscopic-guided single-level minimally invasive TLIF and minimally invasive TLIF with advanced intraoperative CT navigation from the payer's perspective.

MATERIALS AND METHODS

Patient Population

Patients were identified using an institution-specific prospective registry identifying all patients undergoing TLIF procedures. Institutional review board approval was obtained. A retrospective analysis was conducted for all patients with degenerative lumbar spinal disease who underwent a single-level minimally invasive TLIF between January 27, 2009, and November 7, 2013. All patients had failed at least 6 weeks of conservative management and were treated at a single academic medical center by 2 neurosurgery spine surgeons (R.G.F. and T.R.K.) (1 performing minimally invasive TLIF with 2-D fluoroscopy and 1 performing minimally invasive TLIF with CT navigation). Patients were excluded if they 1) required $\geq$2 levels of fusion, 2) were $<$18 years old, 3) were $>$80 years old, 4) were undergoing revision surgery, or 5) had an active medical or worker's compensation lawsuit. A minimum 6-month follow-up period was required for inclusion. These criteria were met by 28 patients who had TLIF with advanced intraoperative CT navigation. These patients were matched based on frequency with 28 patients who had TLIF using traditional 2-D fluoroscopic navigation during the same time period. Patients were matched based on race, sex, age, smoking status, payer type, and medical comorbidities using the Charlson Comorbidity Index (CCI). The CCI is an index calculated using administrative health data to predict morbidity-related outcomes.[8]

Surgical Technique

TLIF Using Fluoroscopy. Patients were placed in the prone position on an open OSI Jackson table. The lumbar area of interest was identified. A midline incision was proposed and opened sharply. Suprafascial dissection was performed, and 2 fascial incisions were created. Under anteroposterior fluoroscopic view, the tip of the Jamshidi needle was advanced through the paraspinal muscles and docked at the lateral border of the pedicle. The needle was advanced into the pedicle in a lateral to medial triangulated fashion such that there was no violation of the medial border of the pedicle after 25 mm of advancement. The same procedure was repeated on the contralateral side. Under lateral fluoroscopic view, Kirschner wires were placed through the Jamshidi needles into the vertebral body. The Jamshidi needles were withdrawn, leaving the Kirschner wires in the vertebra. The same procedure was repeated at the lower vertebra. Sequential dilation was performed through the paraspinal muscles between the Kirschner wires. A working tubular table-mounted retractor was placed and docked usually at the level of the facet joint.

TLIF was performed through the working tubular retractor. Following a total facetectomy and radical diskectomy, an interbody fusion cage was placed. A cannulated tap was placed guided by the Kirschner wire to cannulate the pedicle. Next, percutaneous pedicle screws with extended tabs or tulips were placed into the pedicle guided by the Kirschner wire at the cranial vertebra. Cannulated pedicle screws guided by the Kirschner wires were placed in the caudal vertebra, following which the Kirschner wires were withdrawn. Using a rod introducer, a rod was placed subfascially engaging the pedicle screw heads. Set screws were applied, and the extended tabs were removed or broken off the screw heads.

TLIF Using CT-Guided Navigation. Patients in the intraoperative CT navigation group were treated using neural navigation for minimally invasive placement of screws as described more recently.[6] Briefly, the patient was placed in the prone position on the open OSI Jackson table. The navigation frame was embedded in the posterior superior iliac crest, surgical instruments were registered for intraoperative navigation, and the O-Arm (Medtronic, Dublin, Ireland) was used to generate three-dimensional intraoperative CT. Superficial midline and bilateral paraspinal incisions 4.5 cm from the midline were created. Using intraoperative navigation, navigable dilators were advanced and docked on the relevant facets or pars interarticularis bilaterally and replaced with a Kirschner wire. Sequential dilators were employed to dilate the paraspinal muscles, and screws were inserted using a navigable dilator. Finally, a rod was placed to connect the screws on each side.

Clinical Outcome Measures

Patient demographics, disease characteristics, and treatment variables were reviewed retrospectively for each case. Surgical time was defined as from the opening of the skin to closing of the skin, and anesthesia time was defined as from induction of the patient to the patient's arrival to the postanesthesia care unit. Preoperative and 6-month follow-up patient outcomes were assessed during clinic follow-up appointments. Patient-reported outcome instruments included the commonly used Oswestry Disability Index (ODI),[9-11] visual analog scale (VAS) for leg pain, and VAS for low back pain.[12] ODI indicates disability from lower back pain, with higher scores representing increased disability; VAS indicates increased leg and low back pain on a scale of 0 to 10. Quality-adjusted life years (QALYs) were used to measure quality of life. QALYs are a frequently used scale that encompasses survival and quality of life, where 1 QALY is equivalent to 1 year of optimal health.[13] We calculated QALYs from the SF-6D, a preference-based subset of the widely used 36-Item Short Form questionnaire that has been validated for use in the United States for estimation of QALYs and quality of life.[13-15] Finally, fusion was assessed using flexion-extension x-rays at 6 months. In any issues of dispute, a CT scan of the lumbar spine was obtained.