A Comparison of Different Minimally Invasive and Open Posterior Spinal Procedures Using Volumetric Measurements of the Surgical Exposures

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Study Design: A Prospective observational study.

Summary of the Background Data: Minimally invasive (MI) spine surgery techniques strive to minimize the damage to paraspinal soft tissues. Previous studies used only the length of the surgical incision to quantify the invasiveness of certain MI procedures. However, this method does not take into account the volume of muscle tissue that is dissected and retracted from the spine to achieve sufficient exposure. To date, no simple method has been reported to measure the volume of the surgical exposure and to quantify the degree of surgery invasiveness.

Study Objectives: To obtain and compare volumetric measures of various MI and open posterior-approached spinal surgical exposures.

Methods: The length, the depth, and the volume of the surgical exposure were obtained from 57 patients who underwent either open or MI posterior lumbar surgery. MI procedures included the following: tubular discectomy, laminotomy, and transforaminal interbody fusion. Open procedures included the following: discectomy, laminectomy, transforaminal interbody fusion, or posterior-lateral instrumented fusion. Four attending spine surgeons at our unit performed the surgeries. To reduce variability, only single-level procedures performed between L4 and S1 vertebrae were used. The volume of exposure was obtained by measuring the amount of saline needed to fill the surgical wound completely once the surgical retractors were deployed and opened.

Results: The average volumes in mililiters of exposure for a single-level MI procedure ranged from 9.8 ± 2.8 to 75 ± 11.7 mL and were significantly smaller than the average volumes of exposure for a single level open procedures that ranged from 44 ± 21 to 277 ± 47.9 $P < 0.001$. The average skin-incision lengths for single-level MI procedures ranged from 1.7 ± 0.2 to 7.7 ± 1.6 cm and were significantly smaller than the average skin-incision lengths for open procedures [5.2 ± 1.4 (Table 3) to 11.3 ± 2 cm, $P < 0.001$]. The measured surgical depths were similar in MI and open groups ($P = 0.138$). MI decompression and posterior fusion procedures yielded 92% and 73% reductions in the volumes of exposure, respectively. However, absolute differences in exposure volumes were larger for fusion (202 mL) compared with decompression alone (110.7 mL).

Conclusions: Direct volumetric measurement of the surgical exposure is obtained easily by measuring the amount of saline needed to fill the exposed cavity. Using this method, the needed surgical exposure of different spinal procedures can be quantified and compared. This volumetric measurement combined with the measure of retraction force, the duration of retraction, and the impact on soft tissue vascularity can help build a model that assesses the relative invasiveness of different spinal procedures.

Key Words: volumetric measurement, surgical exposure, minimally invasive, lumbar spine

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In recent years, minimally invasive (MI) spine surgery procedures have gained increasing popularity among surgeons. Unlike laparoscopic or thoracoscopic surgical procedures, where the surgery is performed inside an anatomic cavity, the posterior aspect of the spine contains tightly packed muscles that are attached to the posterior elements of the spine. Thus, performing spine surgery through the posterior approach requires the surgeon to detach and retract these muscles to establish a surgical corridor.

There are a growing number of different procedures and surgical instruments that provide the surgeon with the ability to perform spinal decompression and fusion while limiting the detachment of muscles from the posterior elements of the vertebrae, reducing the pressure that is applied on the muscles using table-mounted retractors, and by minimizing the width of the surgical corridor.[1,2]

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TABLE 1. Surgical Retractor Systems

Open Procedures	Retractor System	MI Procedures	Retractor System
1. Discectomy	Taylor retractor	1. Tubular discectomy	MetRx tubular retractor system
2. Laminectomy	Anderson-Adson Retractor	2. Laminotomy	MetRx tubular retractor system
3. Open Fusion	Clear view super-slide lumbar retractor	3. MI TLIF	Quadrant tubular retractor system

MetRx and Quadrant retractor systems—Medtronic Inc., Minneapolis, MN.
Anderson-Adson and Taylor retractor systems—Aesculap Inc., Tuttingen, Germany.
Clear view super-slide lumbar retractor system—Koros USA Inc., Moorpark, CA.
MI indicates minimally invasive; TLIF, transforaminal interbody fusion.

When comparing open and MI procedures, previous studies used the length of the surgical incisions to quantify the invasiveness of MI procedures, whereas other studies used indirect measurements such as the intraoperative blood loss or postoperative creatine phosphokinase levels.[3–5] However, none of these methods took into account the volume of muscle tissue that is dissected and retracted from the spine to establish the necessary surgical corridor. To the best of our knowledge, there have been no previous reports of a quantitative method to measure the volume of the surgical exposure or to calculate the amount of lateral retraction that is produced using different surgical approaches.

The objective of the present study was to assess quantitatively the amount of soft tissue dissection and retraction that takes place during the surgical exposure of different posterior spinal procedures.

METHODS

The Patient Population

This study was approved by our local Institutional Review Board. Patient consent was obtained before enrollment. The length of the surgical incision and the volume of the surgical corridor were measured in patients undergoing MI or open spinal surgery using the posterior approach. The procedures and the surgical retractor systems that were used in this study are detailed in Table 1. To reduce variability, only single-level procedures performed between L4 and S1 vertebrae were used. The volumes and the depths of exposure and lengths of the skin incision were collected for 57 patients. All the measurements were taken by a single investigator, and surgeries were performed by 4 attending surgeons (2 orthopedic surgeons and 2 neurosurgeons). All participants were recruited among patients who came to our spine unit for elective surgery.

The Measurement Technique

The volume of the surgical corridor was obtained by measuring the volume of saline required to fill the created surgical wound completely once the surgical exposure was completed and surgical retractors were deployed and opened. The length of the surgical incision was measured at the end of wound closure. The depth of the surgical exposure, from the skin to the vertebra lamina, was calculated using either direct intraoperative measurement or preoperative computed tomography or magnetic resonance imaging sagittal imaging.

Data Analysis

The average volume, the incision length, and the surgical depth were calculated for each procedure. Exposure values were compared using a 1-way analysis of variance pairwise comparison for the different procedures using the Tukey Kramer test for post hoc analysis. The SAS for Windows version 9.2 was used for statistical analysis. Alpha was set to 0.01, with an expected power of analysis of above 90%.

RESULTS

Patients' demographic data are summarized in Table 2. The average body mass index was similar in all studied groups ($P = 0.12$) (Table 2), and no significant difference in the measures of surgical depth between the MI and the open groups was observed ($P = 0.138$) (Table 3). As the surgical exposures and retractors used for both MI discectomy and laminotomy were identical, we chose to join both group data for comparing them with open discectomy and open laminectomy.

The measured volume of the surgical corridor ranged from 7 mL for a single-level MI discectomy to 470 mL for an open fusion. MI decompression and posterior fusion procedures yielded 92% and 73% reduction in the volumes of exposure, respectively (Fig. 1). However, when comparing between analogous open and MI procedures, MI transforaminal interbody fusion with

TABLE 2. Patients' Demographics

Open Procedures	Male/Female	Age	Body Mass Index	MI Procedures	Male/Female	Age	Body Mass Index
1. Discectomy	3/7	55 ± 10	28 ± 8	1. MI discectomy and laminotomy	7/8	48 ± 16	27 ± 6
2. Laminectomy	4/6	72 ± 7	27 ± 4	2. MI TLIF	5/5	59 ± 11	27 ± 3
3. Open Fusion	3/9	60 ± 13	29 ± 4				

MI indicates minimally invasive; TLIF, transforaminal interbody fusion.

TABLE 3. Surgical Skin Incision Lengths and the Volume of Exposures

	Length of Skin Incision (cm)	Depth of the Surgical Exposure (cm)	Volume of Exposure (mL)
MI laminotomy and discectomy	1.7 ± 0.2	5.54 ± 1.03	9.8 ± 2.8
Open discectomy	5.2 ± 1.4	6.56 ± 1.29	44.0 ± 21.0
Open laminectomy	8.4 ± 2.1	6.38 ± 0.96	120.7 ± 83.3
MI TLIF and Perc*	6.3 ± 3.2	6.93 ± 1.20	31.7 ± 2.9
MI TLIF and MO†	7.7 ± 1.6	7.27 ± 0.02	75.0 ± 11.7
Open TLIF	11.3 ± 2.0	6.68 ± 3.66	277.0 ± 47.9

*Percutaneous contralateral screw insertion.
†Miniopen contralateral screw insertion.
MI indicates minimally invasive; TLIF, transforaminal interbody fusion.

contralateral percutaneous pedicle screw instrumentation yielded the greatest reduction in exposure volume compared with open fusion (31.7 ± 2.9 vs. 277 ± 47.9 mL) (Table 3). In contrast, an MI discectomy yielded the least reduction in exposure volume compared with an open discectomy (9.8 ± 2.8 vs. 44.00 ± 21.0 mL, respectively). MI laminotomy reduced the volume of exposure by 110 mL compared with open laminectomy (Table 3).

All MI procedures resulted in shorter surgical incisions compared with their open analogs. Average skin-incision lengths for a single-level MI procedures ranged from 1.7 ± 0.2 to 7.7 ± 1.6 cm and were significantly smaller than the average skin incision lengths for open procedures (5.2 ± 1.4 to 11.3 ± 2 cm, $P < 0.001$). However, the magnitudes of reduction in skin-incision lengths were relatively less than the magnitudes of reduction in exposure volumes between MI and open procedures (Table 3). The null hypothesis that there was no difference in the volume between open and MI methods was rejected with statistical significance ($P = 0.025$) and an observed power above 90%.

DISCUSSION

Posterior spinal surgery may injure the paraspinal muscles causing irreversible damage and dysfunction. The goal of MI techniques have focused on decreasing the amount of muscle injury through the use of retractor systems that produce less intramuscular pressure,[6] less muscle stripping, and less denervation.[7] Measurement of the length of the surgical incision alone does not provide a good enough estimate of the invasiveness of the procedure as it does not take into account the amount of tissue that needs to be dissected and displaced to establish a sufficient surgical corridor. Kawaguchi et al[8] defined the factors responsible for muscle necrosis after open posterior spine surgery.[9] They reported that extending the length of the skin incision might paradoxically reduce damage to the paraspinal muscles, as it relieves the pressure caused by the application of self-retaining retractors during surgery.[10]

Similarly, measurement of the exposure volume alone may not correlate with the damage to paraspinal muscles as it does not necessarily reflect the amount of lateral retraction that is produced by surgical retractors. The amount of lateral tissue displacement depends on both the length of the incision and the volume of the surgical corridor. In line with the findings of Kawaguchi and colleagues, the amplitude of surgical exposure observed in our study correlates with the overall tissue muscle mass that is detached and retracted and not with

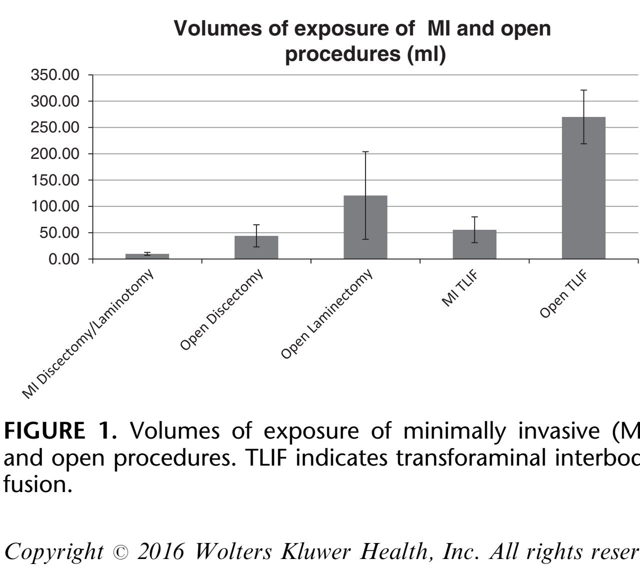

FIGURE 1. Volumes of exposure of minimally invasive (MI) and open procedures. TLIF indicates transforaminal interbody fusion.

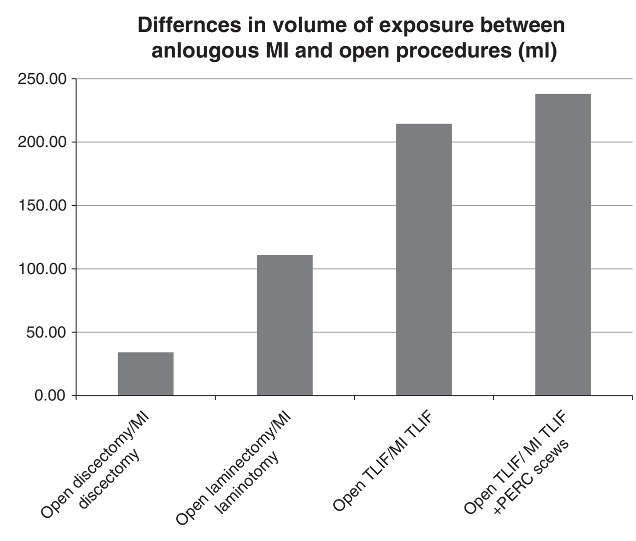

FIGURE 2. Differences in volumes of exposure of analogous surgery measures according to the technical approach. MI indicates minimally invasive; TLIF, transforaminal interbody fusion.

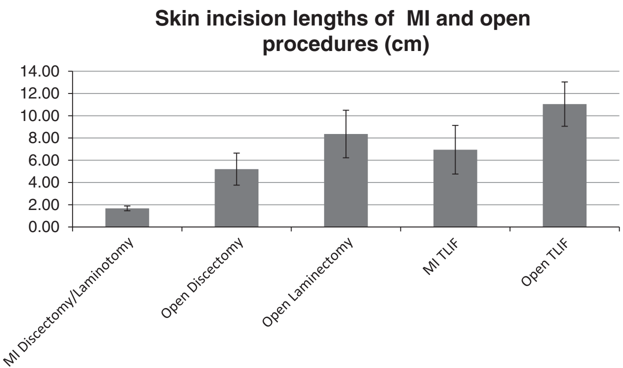

FIGURE 3. Lengths of skin incisions of the different minimally invasive (MI) and open procedures. TLIF indicates transforaminal interbody fusion.

the length of the skin incision. The measured differences in the skin incision length between open and MI procedures in our study were found to be relatively less remarkable compared with the major differences in the volume of the surgical exposure.

The technique we developed to measure the volume of the surgical corridor is simple, straightforward, and can be reproduced for any of the posterior procedures and retractor systems in a large number of patients without the use of imaging studies or expensive measuring devices.

Measuring the volume of exposure for a variety of MI and open procedures enable us to not only quantify the amount of soft tissue retraction of each procedure but also to assess the amplitude of the surgery exposure of analogous procedures and in the future correlate them with patient outcomes.

Our findings suggest that the advantage of MI, in terms of decreasing invasiveness, is significant when performing larger procedures such as a laminectomy or fusion, but is less remarkable for smaller procedures such as discectomy. This result may explain findings from previous studies, which reported significant statistical reduction in postoperative back pain, creatine phosphokinase, and C-Reactive protein levels in patients undergoing MI instead of open spinal fusion, but failed to find such significant differences when comparing MI and open discectomy.[11,12]

Comparing surgical volumes of exposure has several limitations that should be recognized. This technique is not appropriate for anterior-approach surgeries, such as anterior lumbar interbody fusion and lateral lumbar interbody fusion. As the surgical approach is performed inside an existing anatomical cavity, the measured volume of exposure does not correlate to the amount of soft tissue retraction in these procedures. Individual variability in the volume of exposure for the same spinal procedure might be caused by several factors. Among these are the operated spinal level, changes in the body habitus, and specific surgical techniques. To minimize the influence of these factors in this study, we limited our comparison with surgeries at the L4-5 and L5-S1 levels and used identical surgical techniques in each group. Further studies using a larger patient cohort are needed to determine the influence of these factors in a broader spectrum of surgeries (Figs. 2 and 3).

CONCLUSIONS

Direct volumetric measurement of the surgical exposure is obtained easily and reliably by measuring the amount of water needed to fill the exposed cavity. The volume of exposure can be used to assess the degree of soft tissue retraction that is applied on the paraspinal muscles by various surgical techniques. This method in combination with the measured retraction force, the duration of retraction, and the impact on vascularity can help build a model that assesses and compares the relative invasiveness of different spinal procedures.

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