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Comparison of Multifidus Muscle Atrophy and Trunk Extension Muscle Strength

Percutaneous *Versus* Open Pedicle Screw Fixation

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Study Design. This study was conducted by retrospective case selection and prospective observation of longitudinal changes of the multifidus muscle cross-sectional area and of trunk extension muscle strength in percutaneous and open pedicle screw fixations.

Objectives. To compare postoperative multifidus muscle atrophy and trunk muscle performance of percutaneous pedicle screw fixation against those of open pedicle screw fixation.

Summary of Background Data. Recent attempts to combine percutaneous pedicle screw fixation with minimally invasive fusion techniques are based on an anecdotal presupposition that percutaneous pedicle screw fixation is superior to its open counterpart. However, the benefits of percutaneous pedicle screw fixation are currently poorly defined.

Methods. Nineteen enrolled patients were divided as follows: 11 in the open pedicle screw fixation group (OPF group) and eight in the percutaneous pedicle screw fixation group (PPF group). The preoperative and postoperative cross-sectional area and T2-weighted signal intensity of multifidus muscle were measured by MRI, and trunk extension muscle strength was measured. In addition, various clinical variables were compared between two groups.

Results. There was significant decrease in the cross-sectional area of multifidus muscle in the OPF group. In contrast, the results in the PPF group showed no statistical difference between preoperative results and that of the follow-up MRI. Although percutaneous pedicle screw fixation had positive effects on postoperative trunk muscle performance, clinical outcomes were not significantly different in areas of pain score, JOA score, and patient's opinion regarding the outcome of the surgery. However, percutaneous pedicle screw fixation caused less blood loss, and the proportion of patients who did not need postoperative oral analgesics was greater in the PPF group.

Conclusions. Percutaneous pedicle screw fixation caused less paraspinal muscle damage than open pediclescrew fixation and had positive effects on postoperative trunk muscle performance.

Key words: percutaneous surgery, pedicle screw, lumbar spine, multifidus muscle. **Spine 2005;30:123–129**

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Surgical approaches using minimally invasive technique including percutaneous pedicle screw fixation are becoming more widespread in spine surgeries. Most surgeons augment interbody fusion with pedicle screw fixation to enhance the initial stiffness of the fusion construct despite the additional surgical risks associated with conventional pedicle screw instrumentation.[1,2] These include a higher infection rate, elevated blood loss, more damage to paraspinal musculature, prolonged operative time and postoperative length of stay, and risk of instrumentation failure and neurologic injury.[2–4]

Recently, there have been attempts to combine percutaneous pedicle screw fixation with an anterior lumbar interbody fusion (ALIF) procedure or a minimally invasive percutaneous posterior lumbar interbody fusion (PLIF) to reduce the drawbacks of conventional pedicle screw instrumentation.[5–7] Those attempts are based on the anecdotal presupposition that percutaneous pedicle screw fixation is superior to its open counterpart. However, the benefits of percutaneous pedicle screw fixation, as yet, lack definitive clarification. To the authors' knowledge, there has been no publication that provides convincing evidence that the benefits of percutaneous pedicle screw fixation exceed those of conventional pedicle screw fixation.

Questions to be answered to achieve rationale of the superiority of percutaneous pedicle screw fixation are as follows: 1) Does percutaneous pedicle screw fixation cause less paraspinal muscle damage than open pedicle screw fixation as it is presumed? 2) Does less damage on paraspinal muscle enhance postoperative trunk muscle performance? 3) Can percutaneous pedicle screw fixation be performed with acceptable efficacy and safety? 4) Does percutaneous pedicle screw fixation make the patient recover earlier and ultimately more completely? This study was conducted with a focus on discovering answers to first two questions. The purpose of this study was thus to compare postoperative multifidus muscle atrophy, trunk muscle performance, and other clinical variables of percutaneous pedicle screw fixation against those of open pedicle screw fixation.

Materials and Methods

Study Design. This study was conducted by retrospective case selection and prospective observation. The study population was selected from consecutive patients who underwent open or percutaneous pedicle screw instrumentation in Wooridul Spine Hospital from June 2000 to June 2001. To be included, a patient had to have 1) a preoperative magnetic resonance imaging

Table 1. Characteristics of the Patients in the Percutaneous and Open Pedicle Screw Fixation Groups

	PPF Group	OPF Group	P
No. of cases	8	11	
Male/female	3/5	4/7	NS*
Age (years) [mean (range)]	60.3 (46–76)	52.4 (35–72)	NS†
Diagnosis			NS*
Spondylolytic spondylolisthesis	6	9	
Degenerative spondylolisthesis	1	1	
Foraminal stenosis	1	1	
Level			NS*
L4–L5	1	6	
L5–S1	6	4	
L4–L5–S1	1	1	

PPF = percutaneous pedicle screw fixation; OPF = open pedicle screw fixation; NS = not significant.
*χ^2 test.
†Mann-Whitney U test.

(MRI) performed in the authors' institute with enough resolution quality to measure cross-sectional area and T2-weighted signal intensity of multifidus muscle, 2) a preoperative trunk extension muscle strength test, measured with a kinetic measurement system, which had been performed for other clinical research. Patients were excluded if they had 1) a history of a previous back operation, 2) atrophy of the paraspinal musculature on preoperative MRI, 3) the inability to undergo follow-up MRI in the authors' institute, 4) a spinal malignancy, and 5) a spinal infection. Thirty-eight patients satisfied the above selection criteria and 19 patients consented to participate in this study. The enrolled 19 patients underwent follow-up MRI, trunk extension muscle strength test with a kinetic measurement system, clinical examination, and completed a follow-up questionnaire during their last appointment. The mean follow-up period was not different significantly between the two groups (20.6 months in the PPF group, 21.5 months in the OPF group). Tolerable physical activities were encouraged during the follow-up period; however, no lumbar exercise program was prescribed after surgery. Preoperative and postoperative multifidus muscle cross-sectional area, T2-weighted signal intensity of multifidus muscle, trunk extension muscle strength, and other clinical variables were compared between open and percutaneous pedicle screw fixation groups.

Patient Population. Nineteen patients were divided with 11 in the open pedicle screw fixation group (OPF group) and 8 in the percutaneous pedicle screw fixation group (PPF group). Five patients of the OPF group combined PLIF procedure with the open procedure, and six combined it with ALIF procedure. In the PPF group, all patients combined the percutaneous pedicle screw fixation with the ALIF procedure. Table 1 provides a brief summary of clinical features of the OPF and PPF groups. The study group comprised 7 men and 12 women. The age of these patients at the time of the operation ranged from 35 to 76 years (mean, 55.7 years). The postoperative follow-up period was 18 to 31 months (mean, 21.2 months). Grade I spondylolytic spondylolisthesis was present in 15 patients, degenerative spondylolisthesis in 2, and foraminal stenosis with instability in 2.

Surgical Technique of Percutaneous Pedicle Screw Fixation. An open mini-ALIF by midline extraperitoneal approach was performed first, using a suitable intervertebral graft construct. The patient was then turned prone on a radiolucent operating table that allowed radiography to be performed throughout a full range of 360°. The procedure was performed under the control of a C-arm image intensifier. The lumbar area was next prepared and draped in a sterile fashion. The image intensifier was oriented in a perfect anteroposterior direction. A small incision was made with a No. 11 scalpel blade. A disposable 11-gauge bone marrow needle was positioned with its tip on the lateral margin of the pedicle oval and advanced until the stylet tip abutted the bone under anteroposterior view. A small depression was made in the cortex before the image intensifier was rotated to a lateral view. The needle is advanced through the cortex by tapping its back end with a mallet under lateral view. The lateral view showed the needle passing parallel to the superior and inferior edges of the pedicle. Minor adjustment was sometimes required. With the needle tip located on the posterior vertebral body line under lateral view, intrapedicular location of the needle was confirmed under the anteroposterior view. After confirmation, the needle was advanced to locate its tip at the junction of the middle and posterior third of the vertebral body. A 1.8-mm K-wire was exchanged through the needle and the skin incision was extended to allow passage of dilators. Using serial three metallic tubular dilators of the METRx set (Medtronic Sofamor Danek), the path through the soft tissue was spread over the guiding K-wire. With the K-wire still in place, a hole was drilled in the pedicle using a 5.0-mm cannulated drill bit. After removal of the K-wire, a long straight beaded-tip probe was placed into the pedicle and the pedicle walls were evaluated for possible infractions. A pedicle screw was inserted into the prepared hole with the same orientation as the wire under the fluoroscopic guidance. Similar procedures were repeated on other target pedicles.

For each ipsilateral pair of pedicles within the segment fused, a custom-made curved trocar with blunt tip was then advanced through the same stab wound and muscle layer until the tip contacted the first screw head. With advance of the trocar under muscular layer from the first screw to the second screw head under fluoroscopic control, the soft tissue passage for rod insertion was dilated (Figure 1). A precontoured rod was then inserted through the same stab wound and passed

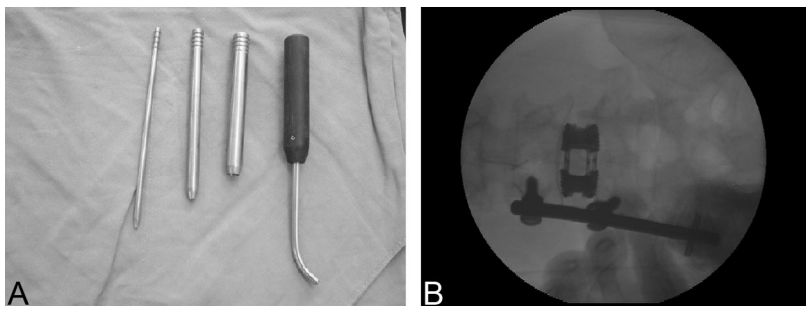

Figure 1. **A**: Serial three metallic tubular dilators (left three) and custom-made curved trocar (right) with blunt tip for submuscular dilation of soft tissue passage for rod insertion. **B**: With advance of the curved trocar under muscular layer from the first screw to the second screw head under fluoroscopic control, the soft tissue passage for rod insertion is dilated.

firmly through both screw heads. Fluoroscopic confirmation of the rod passage through the screw heads was obtained in both planes to ensure acquisition of the rod. A locking bolt was introduced into the screw head through the same stab wound and tightened under fluoroscopic guidance or direct vision with brief retraction of the stab wound. The procedure was repeated on the contralateral side of the spine, after which the incisions were irrigated and closed.

Surgical Technique of Open Pedicle Screw Fixation. A standard posterior midline incision was made from the upper end of the spinous process two levels above the uppermost instrumented pedicle to the lower end of the lamina of the lowest instrumented vertebra. The cautery dissection was carried to the supraspinous ligament and spinous processes through the lumbodorsal fascia. The paraspinous muscles were stripped bilaterally, staying strictly subperiosteal to reduce bleeding. Subperiosteal dissection proceeded from dorsal to volar along the flank of the spinous process. After stripping the paraspinous muscles down to the level of the lamina, the elevator was turned over. Dissection was carried down over the lateral margin of the superior facet onto medial margin of the transverse process. Posterolateral fusion was not performed on our sample group.

Evaluation of Back Muscle Injury. Back muscle injury was evaluated by a decrease in the multifidus muscle cross-sectional area and deposition of fat and connective tissue, which appeared as high signal intensity on the T2-weighted images.[8–11] Magnetic resonance imaging was performed on a 1.5 Tesla System MRI (Siemens, Erlangen, Germany). All images were obtained using T2-weighted fast spin echo pulse sequence. The pixel size was 0.94 X 0.47 mm, the matrix size was 255 X 512, and the field of view was 240 X 240 mm. Direct visualization of multifidus muscle in the level of fusion was inadequate because of interference by the metal artifact of the screws and rods. A 4-mm-thick, T2-weighted axial image was made at the supra-adjacent disc space of the fused segment on follow-up MRI and the most inferior axial image without metal artifact was selected for evaluation. The most similar axial image to the selected follow-up axial image of the preoperative T2-weighted axial images of the same level was also selected with regard to facet configuration.

The selected two axial images (preoperative and follow-up) were analyzed by an experienced musculoskeletal radiologist blinded to the operation method. The measurements were obtained with a picture archiving and communication system, or PACS, workstation (Mediface, Seoul, Korea) and embedded region of interest (ROI) and grayscale histogram software. To determine the multifidus muscle, the ROI was drawn around bilateral multifidus muscles respectively with care to avoid nearby fat, bony structures, and other soft tissues. The sum of cross-sectional area of bilateral multifidus was calculated. Signal intensity of multifidus muscles on T2-weighted axial image was evaluated quantitatively by grayscale histogram software of PACS, in which a higher score means a higher signal intensity. Signal intensity of psoas muscle of the same axial image was also evaluated from a 100-mm^2 circular ROI placed in the center of the psoas muscle. Signal intensity ratio of multifidus to psoas muscle was calculated.

The intraobserver reliability was tested by repeated measurements with same protocol, and intraclass correlation coefficients of the cross-sectional area and T2-weighted signal intensity were 0.98 and 0.91, respectively. Because intraclass correlation coefficients indicated high test-retest reliability, measurements were taken three times and the mean of the readings was used.

Measurement of Trunk Extension Muscle Strength. Trunk extension muscle strength was measured with the Medx back extension machine (Ocala, FL). This testing device allows for a standardized, isolated strength measurement of the low back extensor musculature.[12,13] All patients received identical instructions and went through a set of warm-up exercises. The pelvis was stabilized, allowing no lateral, vertical, or rotational movement, thereby ensuring isolation of the back extensors. The test was performed isometrically at standardized positions of 0, 12, 24, 36, 48, 60, and 72 of lumbar flexion. The test began with the patient flexing the lumbar spine to 72, or as far as the spine could flex. The tester then locked the patient in this position. The patient then was instructed to gradually build up the muscle tension during a 2- to 3-second period. As maximum tension was achieved, the patient was instructed to maintain the tension for an additional 1 second and to slowly release the tension for another 3 seconds. The maximal isometric torque generated was measured with a load cell attached to the movement arm of the machine and displayed on a computer screen in front of the participant as concurrent visual feedback. All patients were encouraged verbally during the test to give their maximum effort at each tested angle. The procedure was repeated at the subsequent angles throughout the arc of motion. A 10-second rest interval was given after each isometric test performed on a given angle.

Clinical Variables. Data were collected retrospectively from clinical records regarding operative and clinical parameters such as the 10-point visual analog scale for back pain and leg pain, length of operation time, amount of blood loss, duration of postoperative hospital stay, and number of analgesics injections performed on patient's demand, and general operative complications. For clinical outcome assessment, a Japanese Orthopedic Association (JOA) score was determined, along with a visual analog scale for back pain and leg pain, and a completed questionnaire recorded during the final follow-up visit. Patients were asked to provide their opinion regarding the outcome of the surgery with two questions. The satisfaction question asked "Over the course of treatment for your low back pain or leg pain, how satisfied were you with your operation?" and the recommendation question inquired "Would you recommend the same operation to a family member for the same result?" The answers were categorized as follows: 1 = definitely no; 2 = probably no; 3 = neither yes nor no; 4 = probably yes; 5 = definitely yes. Satisfactory outcome was defined as a score of 4 or 5 on the respective questions. The questionnaire also covered duration of postoperative oral analgesics medication. Radiologic fusion was determined with flexion-extension radiographs. The fusion was regarded as successful when definite bony continuity, or increase in bone density between fusion segments without motion was seen on flexion-extension radiographs.

Statistical Analysis. For the statistical analysis, SPSS 10.0 software was used. The Wilcoxon signed ranks test was used for statistical analysis of the difference of noncategorical variables between preoperative and postoperative assessments in both groups. For comparison of noncategorical variables between the two groups, a Mann-Whitney U test was used. Cat-

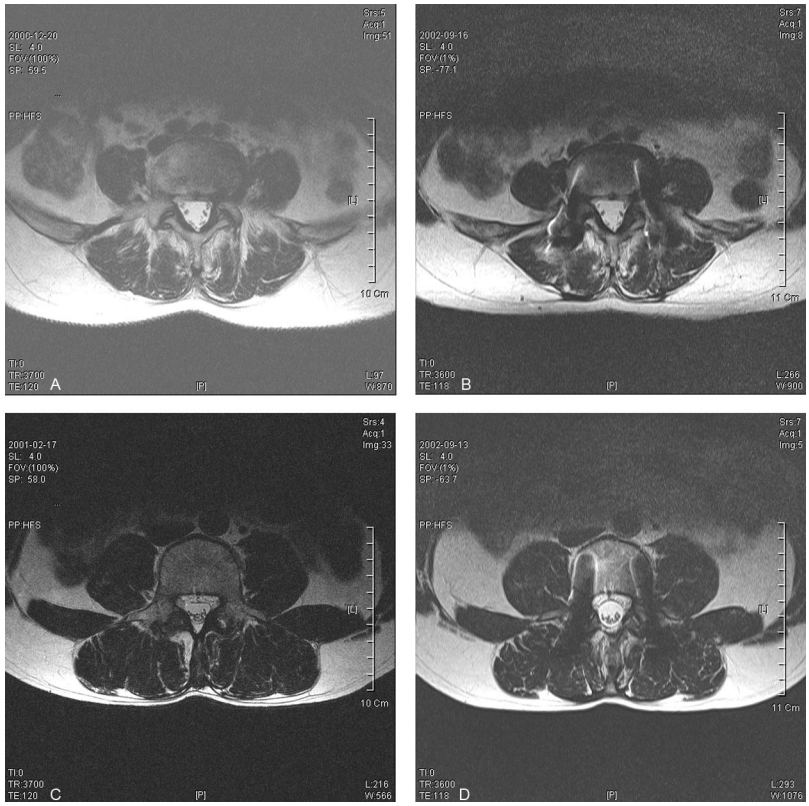

Figure 2. Magnetic resonance imaging changes of the multifidus muscles in a 56-year-old woman in the percutaneous pedicle screw fixation group (**A**: preoperative; **B**: follow-up) and in a 41-year-old man in the open pedicle screw fixation group (**C**: preoperative; **D**: follow-up). Note the significant multifidus muscle atrophy on the follow-up imaging of open pedicle screw fixation group (D).

egorical variables were analyzed using Fisher's exact test or a χ^2 test. Intraclass correlation coefficient was calculated for testing intraobserver reliability. Statistical significance corresponded to $P < 0.05$.

■ Results

Multifidus Muscle Cross-sectional Area

The longitudinal changes of the cross-sectional area of multifidus muscle in the OPF and PPF groups are shown in Figures 2 and 3. The results showed that there is significant decrease in the cross-sectional area of multifidus muscle in the OPF group. In the OPF group, the cross-sectional area of multifidus muscle was 1137.2 ± 240.7 mm^2 and 792.1 ± 261.9 mm^2 on preoperative and follow-up MRI, respectively ($P = 0.003$, Wilcoxon signed ranks test). In contrast, the results in the PPF group showed no statistical difference between preoperative and follow-up MRI. In the PPF group, the cross-sectional area of multifidus muscle was 1321.9 ± 366.0 mm^2 and 1273.3 ± 302.1 mm^2 on preoperative and follow-up MRI, respectively ($P = 0.484$, Wilcoxon signed ranks test).

T2-Weighted Signal Intensity of Multifidus Muscle

There was no significant increase in signal intensity ratios of multifidus to psoas muscle in either the PPF or the OPF group. In the OPF group, signal intensity ratio of multifidus to psoas muscle was 3.4 ± 1.1 and 3.5 ± 1.6 on preoperative and follow-up MRI, respectively ($P > 0.05$, Wilcoxon signed ranks test). In the PPF group, signal intensity ratio of multifidus to psoas muscle was 3.7 ± 0.8 and 3.7 ± 1.6 on preoperative and follow-up MRI, respectively ($P > 0.05$, Wilcoxon signed ranks test).

Trunk Extension Muscle Strength

The longitudinal changes of trunk extension muscle strength in OPF and PPF groups are shown in Figure 4. Preoperative extension muscle strength was 128.3 ± 39.7 ft-lb in the OPF group and 111.4 ± 19.2 ft-lb in the PPF group. On follow-up examination, there was significant improvement in extension muscle strength in the

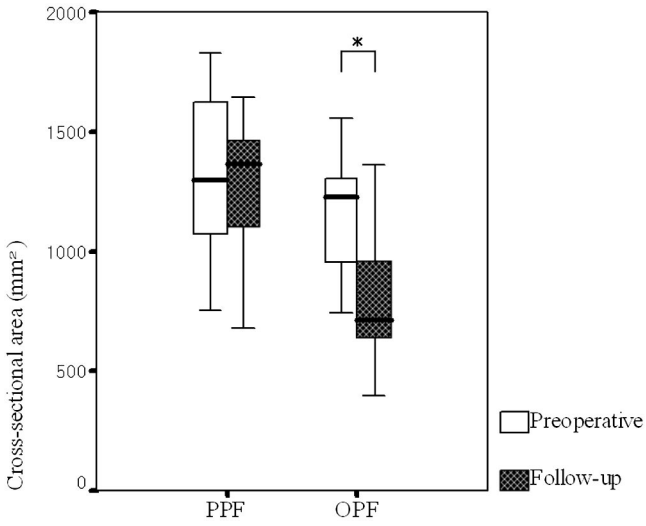

Figure 3. Box plot showing the longitudinal changes of cross-sectional area of multifidus muscle in the percutaneous and open pedicle screw fixation groups. Box plots show the median value (horizontal line in box), and interquartile range (25%–75%) is represented by the box. Whiskers encompass the 5% to 95% range. *$P < 0.05$ (Wilcoxon signed ranks test). PPF = percutaneous pedicle screw fixation; OPF = open pedicle screw fixation.

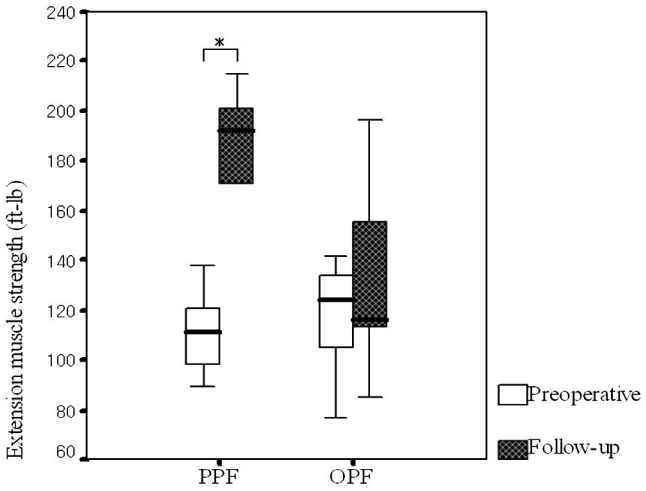

Figure 4. Box plot showing the longitudinal changes of trunk extension muscle strength in the percutaneous and open pedicle screw fixation groups. Box plots show the median value (horizontal line in box), and interquartile range (25%–75%) is represented by the box. Whiskers encompass the 5% to 95% range. *$P < 0.05$ (Wilcoxon signed ranks test). PPF = percutaneous pedicle screw fixation; OPF = open pedicle screw fixation.

PPF group (165.0 ± 41.0 ft-lb; $P = 0.043$, Wilcoxon signed ranks test). In the OPF group, there was also an increase in trunk extension muscle strength in the OPF group (146.8 ± 51.2 ft-lb); however, it did not reach statistical significance ($P = 0.173$, Wilcoxon signed ranks test).

Perioperative Parameters

The mean estimated blood loss was 261.3 ± 69.0 mL in the PPF group and 769.1 ± 253.6 mL in the OPF group. The difference was statistically significant (Mann-Whitney U test, $P < 0.0001$). Operative time, postoperative hospital stay, and postoperative analgesics injection on patient's demand did not differ significantly (Table 2).

Clinical Outcome Assessments

The results are summarized in Table 3. There was no statistical difference between the groups in preoperative or postoperative pain score, nor in JOA score at follow-up. In both groups, there was significant improvement in pain score of low back pain and leg pain between preoperative and postoperative assessments, although pain score of low back pain in PPF group did not reach statistical significance. Results of the satisfaction and recommendation question are illustrated in Table 4. Satisfactory outcome of the satisfaction question, defined as indicating either 4 or 5 in response to the question, was achieved in 75% (6 of 8) of the PPF group and 81.8% (9 of 11) of the OPF group. Satisfactory outcome of the recommendation question, defined again as a score of either 4 or 5 on the question, was achieved in 87.5% (7 of 8) of the PPF group and 72.7% (8 of 11) of the OPF group. The difference was not significant between the groups ($P > 0.05$, Fisher's exact test)

Table 2. Perioperative Parameters of the Cases

	PPF Group (N = 8)	OPF Group (N = 11)	P
Operative time (min)	260 (225–320)	258.6 (165–390)	NS
Estimated blood loss (mL)	261.3 (150–380)	769.1 (450–1300)	<0.0001
Hospital stay (days)	8 (5–14)	9.2 (7–12)	NS
Analgesic injection (no.)/day	1.8 (0.9–3.8)	1.9 (0.3–3.6)	NS

Values are mean (range) and statistical significance.
NS = not significant (Mann-Whitney U test).

Duration of postoperative oral analgesics medication is summarized in Table 5. Postoperative oral analgesics was unnecessary in 62.5% (5 of 8) of the PPF group and 9.1% (1 of 10) of the OPF group. The numbers suggest a significant difference between the groups ($P = 0.041$, Fisher's exact test). It should be noted, however, that postoperative oral analgesics were necessary for less than 3 months in 72.7% (8 of 11) of the OPF group.

There was one nonunion in the OPF group and none in the PPF group. There was one superficial infection in the PPF group, which was resolved completely with antibiotics. One case of retrograde ejaculation was reported in the PPF group and one case of transient deep vein thrombosis was noted in the OPF group. Screw malposition was not detected in both groups.

■ Discussion

Pedicle screw fixation for augmentation of fusion has become popular in spine surgeries because of its biomechanically sound internal spinal fixation.[1,2] Although the biomechanical and clinical advantages of conventional pedicle screw fixation are widely accepted, open posterior spinal fusion with instrumentation requires extensive soft tissue and muscle dissection. This muscle dissection, accompanied by denervation of facet capsules and weakening of other supportive structures, gives rise to the lingering effect of less than optimal functional recovery.[14–17] In addition, open pedicle screw fixation is associated with excessive blood loss, higher infection rate, as well as prolonged operative time and postoperative length of stay.[2–4]

To minimize these negative effects of open pedicle screw fixation, there have been several reports of clinical application of percutaneous pedicle screw fixation. They have been used in cases of external spondylolisthesis reduction[18,19] and acute spinal trauma or spinal osteomyelitis.[20] They have been used as a test to evaluate whether the likelihood of spinal stabilization through arthrodesis will lead to a successful clinical result.[21–23] Percutaneous pedicle screw fixation with concomitant percutaneous posterolateral interbody fusion or mini-ALIF also has been described by several authors.[24–26] In those reports, the longitudinal connective plates or rods were placed either externally or superficially. Although minimally invasive approaches for performing lumbar fusion are in their infancy and long-term follow-up results are lacking, there have been attempts to combine percutaneous pedicle screw fixation placed in a standard submuscular position combined with laparoscopic or open mini-ALIF or

Table 3. Outcome of the Cases

	PPF Group			OPF Group		
	Preoperative	Follow-up	P	Preoperative	Follow-up	P
VAS of LBP	6.9 (4–10)	4.3 (1–8)	0.058	8.6 (5–10)	5.0 (1–10)	0.011
VAS of leg pain	9.1 (6–10)	4.0 (1–9)	0.018	8.3 (0–10)	4.2 (0–10)	0.016
JOA score	NA	22.9 (19–28)		NA	21.7 (14–27)	

Values are mean (range) and statistical significance.
VAS = visual analog scale; LBP = low back pain; JOA = Japanese Orthopedic Association; NA = not available.

percutaneous PLIF as a result of the advent of surgical devices and techniques.[5–7]

The purpose of minimally invasive surgery is not simply the reduction in the size of the skin incision, but rather reducing to a minimum the physical trauma inflicted on the patient, while achieving the maximum therapeutic result.[27,28] Although most of the concepts of newer minimally invasive procedures are fancy and technically feasible, most of those procedures have not been scientifically scrutinized. Minimally invasive procedures also are not without additional shortcomings including a steep learning curve, a higher complication rate, and an overextended operation time during the learning period, along with additional surgical devices and costs. To achieve an acceptable rationale, minimally invasive procedures should be scrutinized as critically as traditional open procedures have been.

The results of the current study demonstrated that percutaneous pedicle screw fixation causes less paraspinal muscle damage than open pedicle screw fixation and has positive effects on postoperative trunk muscle performance. The multifidus muscles represent the deepest muscle group in the lumbar region and the principal action of the multifidus muscle is rotation in the sagittal plane.[29–31] Force exerted by the back muscles stiffens the functional lumbar spinal unit, and the strongest influence is that of the multifidus.[32] Previous investigators have reported that dissection and retraction of the paraspinal musculature can lead to denervation and atrophy, which result in an increased risk of failed back surgery syndrome.[16,17,33] Histologic, enzymatic, and radiologic evidences of back muscle injury in lumbar surgery have been confirmed by several authors.[10,15,34,35] Minimally invasive procedures have been developed as a potential solution to this problem.

While the percutaneous pedicle screw fixation group indicated less multifidus muscle atrophy and better trunk muscle performance in clinical outcomes, there were no significant differences from the OPF group in terms of pain score, JOA score, and patient's opinion regarding the outcome of the surgery. However, percutaneous pedicle screw fixation caused less blood loss, and the proportion of patients who did not need postoperative oral analgesics was greater in the PPF group.

There are three primary limitations of the present study that deserve mention. First, since this study was conducted retrospectively in perioperative variables and clinical outcome assessment, and case selection was not randomized and controlled, the level of evidence of perioperative variables and clinical outcome is low. Caution must be exercised in drawing conclusions because the primary objective of the study was to compare postoperative multifidus muscle atrophy and trunk muscle performance between the PPF and OPF groups, not clinical outcome per se. However, the authors think that level of evidence in evaluation of back muscle atrophy and trunk extension muscle strength is high because the evaluation was conducted prospectively and longitudinally.

Second, unfortunately, direct visualization of multifidus muscle in the level of fusion was impossible because of interference by the metal artifact of the screws and rods. T2-weighted axial images of the supra-adjacent disc space level were used for measurement. However, it is the authors' belief that difference in muscle atrophy between the two groups in the level of fusion would be more profound because muscle retraction pressure would be greater in the

Table 4. Answers to Satisfaction and Recommendation Questions

	Satisfaction Question*		Recommendation Question†	
	PPF Group	OPF Group	PPF Group	OPF Group
Definitely no		1		
Probably no	1		1	1
Neither yes nor no	1	1		2
Probably yes	4	5	2	2
Definitely yes	2	4	5	6

*Over the course of treatment for your low back pain or leg pain, how satisfied were you with your operation?
†Would you recommend the same operation to your family member for the same result?

Table 5. Duration of Postoperative Oral Nonopioid Analgesic Medication

	PPF Group	OPF Group
Unnecessary	5 (62.5)	1 (9.1)
1–3 months	3 (37.5)	7 (63.6)
3–6 months	—	2 (18.2)
>12 months	—	1 (9.1)

Values in parentheses are percentages.
PPF = percutaneous pedicle screw fixation; OPF = open pedicle screw fixation.

level of fusion than in the supra-adjacent disc level during operation in the open pedicle screw fixation group.

Lastly, the patients enrolled in this study were the authors' early experience of the percutaneous pedicle screw fixation. As our surgical technique evolved, we required less operation time, especially for rod placement and locking bolts within the screw heads. We believe that over time and with a larger series of patients, perioperative variables such as hospital stay and operation time would improve for the percutaneous pedicle screw fixation.

■ Conclusion

Percutaneous pedicle screw fixation caused less paraspinal muscle damage than open pedicle screw fixation and had positive effects on postoperative trunk muscle performance. Although perioperative variables, such as intraoperative blood loss and need for postoperative oral analgesics, were favorable to percutaneous pedicle screw fixation, short-term clinical outcomes were similar between the two groups. Future studies with prospective randomized controlled trials will need to address issues, including safety and efficacy of this technique, and whether less muscle injury has positive effects on long-term functional outcome.

■ Key Points

- Postoperative multifidus muscle atrophy, trunk muscle performance, and clinical variables were compared between percutaneous and open pedicle screw fixation.
- Percutaneous pedicle screw fixation caused less paraspinal muscle damage than open pedicle screw fixation and had positive effects on postoperative trunk muscle performance.
- Although perioperative variables, such as intraoperative blood loss and need for postoperative oral analgesics, were favorable to percutaneous pedicle screw fixation, short-term clinical outcomes were not significantly different between the two groups.

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