CLINICAL ARTICLE

Biomechanical Assessment of Unilateral Pedicle Screws plus Contralateral Transfacetopedicular Screws after Transforaminal Lumbar Interbody Fusion with Two Cages

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Objective: To assess the biomechanical stability of unilateral pedicle screws (UPS) plus contralateral transfacetopedicular screws (TFPS) after transforaminal lumbar interbody fusion (TLIF) with two cages.

Methods: Range of motion (ROM) testing was performed in 28 fresh-frozen human cadaveric lumbar spine motion segments. The sequential test configurations included supplemental constructs after TLIF such as UPS, UPS plus contralateral TFPS and bilateral pedicle screws (BPS). All test specimens were fixated in the normal lordotic lignent, then mounted in a three-dimensional (3-D) motion testing machine and fixed to the load frame of a six degrees of freedom spine simulator. Each of the test constructs were subjected to three load-unload cycles in each of the physiologic planes generating flexion-extension, right-left lateral bending and right-left axial rotation load-displacement curves. Statistical analysis was performed on the ROM data. Comparison of data was performed by repeated-measures analysis of variance for independent samples followed by Bonferroni analysis for multiple comparison procedures.

Results: The ROMs for UPS, BPS and UPS plus TFPS fixation after TLIF were significantly smaller than those of the intact spine in all modes. The ROM for UPS plus TFPS fixation was between the largest for UPS and the smallest for BPS. The differences between ROMs of UPS and UPS plus TFPS were significant for both lateral bending and rotation. There were no significant differences between BPS and UPS plus TFPS in any mode.

Conclusion: Because the UPS construct provides the least stability, especially during lateral bending and rotation, it should be used prudently. After TLIF with two cages, UPS plus TFPS provides stability comparable to that of TLIF with BPS. It is thus an acceptable option in minimally invasive surgery.

Key words: Biomechanical assessment; Pedicle screws; Transfacetopedicular screw; Transforaminal lumbar interbody fusion

Introduction

In 1982, Harms and Rolinger popularized the surgical technique of transforaminal lumbar interbody fusion (TLIF), which has the advantages of a posterior unilateral epidural approach combined with interbody support and bilateral

posterior segmental pedicle screw fixation¹. TLIF is fairly well accepted as the routine technique for lumbar arthrodesis because it achieves high rates of clinical fusion²⁻⁵. However, supplemental fixation is reportedly necessary after TLIF to promote fusion^{6,7}. The amount of instrumentation has been

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significantly increased in an attempt to increase stabilization. TLIF can be performed in conjunction with bilateral and ipsilateral pedicle screw fixation. Unilateral pedicle screw (UPS) with contralateral percutaneous facet screw, translaminar facet screw (TLFS) and contralateral transfacetopedicular screw (TFPS) are all considered to be effective, because they can all further increase stiffness and they provide the surgical advantages of unilateral pedicle screw placement with stability comparable to TLIF with bilateral pedicle screws (BPS)^{8–10}. A biomechanical comparison of supplementary posterior TLFS and TFPS after anterior lumbar interbody fusion (ALIF) concluded that TFPSs can be placed percutaneously, which makes posterior facet fixation minimally invasive. Therefore, TFPS fixation is considered a good alternative to TLFS fixation¹¹. However, to date almost no-one has performed a biomechanical assessment of unilateral pedicle screw with contralateral TFPS after TLIF.

Materials and Methods

Specimen Preparation

Twenty-eight fresh human cadaver lumbar spines (L₁–L₅) were collected during routine necropsies from Chinese subjects of average age 29.3 years (range, 18–38 years), who had been ambulatory before death and had no history of any disease or treatment known to affect the mechanical properties of skeletal tissue. Ethical approval to undertake this study was obtained from Southern Medical University's Human Research Ethics Committee, who had obtained the permission of family members for research on the cadavers. Prior to storage, the spines had been radiographed in the anteroposterior and lateral planes to ensure the absence of fractures, deformities and any metastatic disease. In addition, the spines were carefully denuded of skin, paravertebral musculature and fatty tissue only, care being taken to completely preserve the bony and ligamentous structures of the locomotor segment during this preparation. The cranial and caudal ends of the vertebral bodies of the motion segments were embedded in cold curing methylmethacrylate resin in special molds. Following preparation, the specimens were stored frozen at –20°C for one week in double-sealed plastic bags, and thawed at room temperature for 12 h prior to testing.

Surgical Procedure

Seven spines were left intact and TLIF surgeries were performed on the remaining 21 specimens. Left lateral access to the L_{3–4} disc space through the intervertebral foramen was selected. Discotomies were performed and two polyetheretherketone cages inserted symmetrically into the disc space. These 21 specimens were allocated to three groups: seven specimens were fixed with pedicle screws on the left (UPS), seven with bilateral pedicle screws (BPSs), and the remaining seven with pedicle screws on the left plus transfacetopedicular screws on the right (UPS + TFPS) (Fig. 1). The transfacetopedicular screws were placed medially from the inferior facet and directed laterally toward the superior facet. Each of these

Fig. 1 Three types of supplemented constructs after transforaminal posterior lumbar interbody fusion (TLIF) with two cages. (A1–A3) Unilateral pedicle screws (UPS). (B1–B3) Unilateral pedicle screws plus contralateral transfacetopedicular screw (TFPS). (C1–C3) Bilateral pedicle screws (BPS).

4.5 mm × 50 mm transfacetopedicular screws was inserted and directed downward and outward, parallel to the caudal edge of the lamina at an angle of 45°, and passed through the two facets of the articulation. All the pedicle screws used in present study were of the same dimensions, namely 65 mm long and 4.5 mm in diameter. The lengths and heights of the cages were 22 mm and 12 mm, respectively. All the rods were identical with a diameter of 6 mm and were not pre-bent during the surgery. All the screws were inserted directly into the bones because all the specimens were purely lumbar vertebrae, the skins and muscles having previously been removed.

Biomechanical Testing

All test specimens were fixated in the normal lordotic alignment, then mounted in a three-dimensional (3-D) motion testing machine and fixed to the load frame of a six degrees of freedom spine simulator. Two markers of different colors were secured rigidly to the anterior bilateral aspects of the L₃ vertebral bodies, and another two in the same way to the L₄ vertebral bodies (Fig. 2a). The specimens were kept moist throughout testing by spraying them with 0.9% saline. All tests were performed at a room temperature of 25°C. Each of the test constructs were subjected to three load–unload cycles in each of the physiologic planes generating flexion–extension, right–left

Fig. 2 Biomechanical testing. (A) A model mounted in the testing equipment. (B) Sample image obtained by 3D laser scanner. (C–F) ROM images captured by Geomagic software (C, flexion; D, extension; E, bending; F, rotation).

lateral bending and right-left axial rotation load-displacement curves. Moment loading was applied without preload by means of a cable and disc arrangement in ten increments to 10 Nm in flexion/extension and lateral bending, and axial rotation. Five loadings were applied for each test. The first four were not recorded in order to negate viscoelastic effects, whereas in the fifth test the curves of the markers attached to the vertebral bodies were drawn by 3-D laser scanner (Fig. 2b). The fifth motion of the specimen was measured using an ultrasound based motion analysis system with a resolution of 0.1. Three-dimensional intervertebral rotation was obtained from the data files in the form of Euler angles (degrees) about the X, Y and Z axes: +Rx/–Rx, +Ry/–Ry and +Rz/–Rz denoting flexion-extension, right-left axial rotation, and right-left lateral bending range of motion (ROM), respectively. The Euler sequence used in this study was xzy (Fig. 2c–f).

Statistical Analysis

Statistical analysis was performed on the ROM data. Comparison of data was performed by repeated-measures analysis of variance for independent samples followed by Bonferroni analysis for multiple comparison procedures. Significance was accepted at $P < 0.05$.

Results

Range of Motion in All Loading Modes

The largest ROM in the intact group was for flexion and this decreased the most significantly of all directions tested. Each type of fixation decreased ROM significantly in every direction tested. The ROM of UPS + TFPS was between the largest for UPS and the smallest for BPS (Fig. 3). The ROMs for UPS, BPS and UPS plus TFPS fixation after TLIF were significantly smaller than those of the intact spine in all modes.

Flexion and Extension

The instrumented ROMs were all significantly smaller than the intact ROMs ($5.1^\circ \pm 2.7^\circ$; $P < 0.05$). The ROM of UPS ($2.0^\circ \pm 1.0^\circ$) was dramatically reduced to 40% of the ROM of Intact, followed by that of UPS + TFPS ($1.2^\circ \pm 0.7^\circ$) and BPS ($1.0^\circ \pm 0.6^\circ$). The ROMs of BPS and UPS did not differ significantly ($P = 0.500$). The ROMs of UPS + TFPS constructs did not differ significantly from those of either UPS or BPS ($P > 0.05$).

Lateral Bending

The instrumented ROMs were all significantly smaller than the intact ROMs ($5.2^\circ \pm 0.8^\circ$; $P < 0.05$), the ROM of UPS ($2.9^\circ \pm 0.4^\circ$) being largest, followed by those of UPS + TFPS ($1.6^\circ \pm 0.7^\circ$) and BPS ($1.2^\circ \pm 1.0^\circ$). The BPS and UPS + TFPS constructs both had significantly smaller ROMs than that of UPS. The difference in ROMs between BPS and UPS + TFPS was not statistically significant ($P > 0.05$).

Axial Rotation

The instrumented ROMs were all significantly smaller than the intact ROMs ($2.3^\circ \pm 0.9^\circ$; $P < 0.05$). The ROM of UPS + TFPS ($1.0^\circ \pm 0.4^\circ$) was between that of UPS ($1.6^\circ \pm 0.5^\circ$) and BPS ($0.9^\circ \pm 0.3^\circ$). The ROMs of BPS ($P = 0.008$) and UPS + TFPS ($P = 0.022$) constructs were significantly smaller than that of UPS. The difference of ROM between BPS and UPS + TFPS constructs was not significant ($P = 1.000$).

Discussion

Since Harms and Rolinger introduced TLIF³, it has been widely adopted as a more lateralized unilateral approach than posterior lumbar interbody fusion (PLIF)^{5,12–15}. The unilateral nature of TLIF confers obvious advantages, including less destruction of the posterior elements and less gross destabilization of the spine, thus maximizing fusion stability¹⁵. BPS instrumented TLIF is a widely accepted method for managing a variety of spinal conditions. This standard procedure provides rigid fixation and confers both biomechanical and clinical advantages^{16–18}, including those confirmed by the present

Fig. 3 Comparison of ROM in flexion, extension, lateral bending and axial rotation showing that ROMs of surgical specimens were dramatically smaller, especially for BPS fixation, than those of intact specimens. The ROM of UPS + TFPS is between those of UPS and BPS. BPS, bilateral pedicle screws; TFPS, transfacetopedicular screw; UPS, unilateral pedicle screws.

study, in which we found that the ROMs of BPS instrumented TLIF were dramatically smaller than those of intact specimens. These ROMs were 1.0° and 5.1°, respectively, for flexion and extension, 1.2° and 5.2°, respectively, for lateral bending and 0.9 and 2.3, respectively, for axial rotation. This rigid form of fixation has been confirmed to improve fusion rates, fusion rates with BPS instrumentation reportedly being in the range of 90% to 100%¹⁹. However, several researchers have shown that excessively rigid fixation may result in clinically adverse effects, such as device-related osteoporosis because of stress shielding of vertebrae, absorption of grafted bone, thus reducing the fusion rate, and adjacent segment degeneration^{20–22}. All these negative results suggest that we should not blindly pursue higher rigid fixation and fusion rates.

To reduce this rigidity, in 1992 Kabins *et al.* reported favorable results from using a UPS system to perform lumbar fusion²³. Goel *et al.* reported that the UPS system does indeed reduce stress shielding of the vertebrae and diminish peak stress arising in the adjacent levels above and below the fusion²⁴. In a biomechanics study, Chen *et al.* demonstrated that unilateral fixation is good enough to maintain spinal stability²⁵. In the present study, the mean degrees of ROM of UPS after TLIF in the sagittal plane, coronal plane and rotation, were 2.0, 2.9 and 1.6, respectively, compared with 5.1, 5.2 and 2.3, respectively, for intact specimens. The differences in ROMs between intact and post-UPS spines were all significant. Our findings also confirm that UPS with two cages does provide enough stability. Unilateral pedicle screw fixation has been confirmed to provide a greater fusion rate²⁶, less tissue injury and blood loss^{19,27}, less

postoperative pain and earlier recovery and rehabilitation than other techniques^{19,28}. Furthermore, it prevents regional osteopenia²⁴. These data make UPS with TLIF increasingly attractive.

However, other investigators are less positive about the ability of unilateral fixation for fusion to provide adequate support for the spine, especially from a biomechanical point of view. An *in vitro* study showed unilateral constructs to be 57% as stiff as bilateral constructs in flexion/extension, 20% as stiff in lateral bending, and 18% as stiff in axial rotation, which demonstrates that unilateral constructs are consistently less stable than bilateral constructs²⁴. The present authors are also skeptical about the stiffness of UPS. We therefore used two cages for interbody fusion in this study. We obtained similar results to those of Goel *et al.*²⁴. In flexion and extension, the ROM in UPS (2.0°) was twice that in BPS (1.0°); however, this difference was not significant ($P = 0.500$). Furthermore, UPS resulted a significantly larger range of motion during lateral bending ($P < 0.05$) and axial rotation ($P = 0.008$) than did BPS. Other researchers have also reported that unilateral fixation is inadequate compared with bilateral fixation, whether symmetrical or asymmetrical, for stabilizing unilateral lesions²⁹. Slucky *et al.* demonstrated that unilateral posterior instrumentation allows for a significantly increased segmental range of motion and less stiffness, while also producing off-axis movement, which suggest a probable high rate of instrument failure and pseudoarthrosis with long term follow-up³⁰. In the series by Suk *et al.*, more patients failed in the unilateral fixation group than in the bilateral fixation group³¹.

Although the amount of stability required for spinal fusion is unknown, UPS constructs reportedly result in inadequate spine stiffness with inferior results and higher rates of hardware failure than other techniques^{23,30}. However, bilateral pedicle screws have been implicated as a risk factor in the development of adjacent-level disease (ASD)^{32,33}. For these reasons, unilateral pedicle screw and rod fixation with TLFS is gaining acceptance, as evidenced by recent reports^{8,19,34,35}. A biomechanical comparison of supplementary posterior translamina facet and TFPS fixation after ALIF showed that TFPS fixation provides a slightly inferior result: TFPSs can be placed percutaneously, which makes posterior facet fixation minimally invasive¹¹. Therefore, TFPS fixation can be considered a good alternative to TLFS fixation. However, no biomechanical studies of TFPS after PLIF have yet been reported. In the present study, the ROMs of UPS + TFPS after TLIF for every direction were between those of UPS and BPS, and much less than that of intact specimens. Compared with intact specimens, the ROMs of UPS + TFPS were significantly smaller in all directions. The difference in ROM between BPS and UPS + TFPS was not significant for any movement. That is, the stability provided by UPS + TFPS and BPS are comparable. Biomechanical comparison of UPS and UPS + TFPS showed that the latter prevents more instability of a functional spinal unit in lateral bending ($P < 0.001$) and

axial rotation ($P = 0.022$), but there were no significant differences in ROMs between them during flexion and extension.

Overall, this biomechanical assessment demonstrates that, after TLIF with two cages, supplemented UPS, BPS and UPS + TFPS constructs may be sufficient to achieve monosegmental fusion with satisfactory results, because all of them provide dramatically smaller ROMs than those of intact specimens. The UPS construct provided the least stability, especially during lateral bending and rotation, which indicates that this construct should be used prudently, particularly in patients with lateral and/or rotatory spinal instability. BPS and UPS + TFPS constructs are comparable in all loading modes. After TLIF with two cages, the UPS + TFPS construct is the best compromise between UPS and BPS, because it is superior to the UPS construct in terms of initial stability imparted and is causes less rigidity than does BPS fixation. Furthermore, TFPS can be placed percutaneously, thus minimizing the extent of tissue injury and unnecessary blood loss during open or minimally invasive surgery, which may result in less postoperative pain and earlier recovery. The results of the present study should be further examined in clinical practice, because removal of the soft tissues before testing meant that the rigidly controlled ROM of the segment was quite different from that in living subjects.

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