Clinical Biomechanics 30 (2015) 657–661

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Biomechanical study of unilateral pedicle screw combined with contralateral translaminar facet screw in transforaminal lumbar interbody fusion

Beier Luo [a], Ming Yan [b], Jinghui Huang [b], Wei Duan [b], Zhiping Huang [c], Jianting Chen [c], Zhuojing Luo [b,*], Qingan Zhu [c,**], Ming Li [a,***]

[a] Department of Orthopaedics, Changhai Hospital, The Second Military Medical University, Shanghai 200433, China
[b] Department of Orthopaedics, Xijing Hospital, The Fourth Military Medical University, Xi'an 710032, China
[c] Department of Orthopaedic and Spinal Surgery, Nanfang Hospital, Southern Medical University, Guangzhou, Guangdong, China

ARTICLE INFO

Article history:
Received 30 April 2014
Accepted 14 May 2015

Keywords:
Facet screw
Pedicle screw
Transforaminal lumbar interbody fusion
Biomechanics

ABSTRACT

Background: The biomechanical stability of unilateral pedicle screw (UPS) combined with contralateral translaminar facet screw (TLFS), especially long-term stability, still needs to be compared to traditional UPS or bilateral pedicle screws (BPSs) in details.

Methods: Twenty-four porcine spines (L2–L5) were tested for flexibility with pure moments of 5 Nm under intact status and transforaminal lumbar interbody fusion status using UPS + TLFS, UPS or BPS at L3–L4. After short-term (3 cycles) and long-term cyclic loading (18,000 cycles), the range of motion was obtained and analyzed for single-level constructs in flexion/extension, lateral bending and axial rotation modes. In addition, the relative displacement of contralateral articular processes was recorded in a real time fashion.

Findings: The range of motion was significantly reduced in all instrumented constructs. In all movement directions, UPS + TLFS achieved similar range of motion to BPS after short and long-term loading, which were significantly lower than that in UPS. A significantly larger displacement of contralateral articular process was recorded in UPS than UPS + TLFS and BPS during extension/flexion, lateral bending and axial rotation, suggesting its compromised stability.

Interpretation: The hybrid construct of UPS + TLFS showed instant and long-term equivalent biomechanical ability to that of traditional BPS, making it an alternative option to BPS that could be less invasive while maintains a stable and effective instrumentation.

1. Introduction

Transforaminal lumbar interbody fusion (TLIF) has been widely utilized in treating degenerative disc disease and spinal instability. Since its first application in 1982 (Harms and Rolinger, 1982), TLIF has been shown to be an effective and safe technique that results in satisfying clinical outcomes, providing an effective interbody fusion rates higher than 90% (Lowe et al., 2002; Potter et al., 2005). Over recent years, minimally invasive spine surgery techniques have demonstrated their advantages, including less tissue damage, shorter hospital stays and lower infection rates as compared with open surgeries. It has been widely accepted that minimally invasive TLIF is capable of achieving equivalent clinical outcomes to open TLIF (Schwender et al., 2005; Park and Ha, 2007; Dhall et al., 2008; Lee et al., 2012).

Bilateral pedicle screw (BPS) construct is the most commonly used instrumentation providing rigid fixation and achieving high fusion rate, but high stress shielding effect of BPS drove surgeons to peruse alternative instrumentations (Kotani et al., 1998). Subsequently, a unilateral pedicle screw (UPS) was proposed to restrict the motion at the fused segment. Although comparable fusion rate was achieved by BPS and UPS in clinical application (Suk et al., 2000), concerns have been raised regarding whether UPS is adequate for stabilization as BPS could provide because of the inherent construct asymmetry (Slucky et al., 2006). In the evolving surgical trend of minimally invasive spinal surgery, a hybrid TLIF construct of UPS supplemented with a single contralateral translaminar facet screw (TLFS) has been proposed over recent years (Best and Sasso, 2006), which would significantly reduce the surgical invasiveness.

Many studies have been performed to compare the biomechanical ability between TLFS + UPS and BPS (Slucky et al., 2006; Sethi et al., 2011; Gong et al., 2014). Finite element based simulations were useful

---

[*] Corresponding author.
[**] Corresponding author.
[***] Correspondence to: M. Li, Department of Orthopaedics, Changhai Hospital, No.168 Changhai Road, Yangpu District, Shanghai 200433, China.
E-mail addresses: zjluo@fmmu.edu.cn, zhuojingl@163.com (Z. Luo), qinanzhu@gmail.com (Q. Zhu), limingch@21cn.com (M. Li).

http://dx.doi.org/10.1016/j.clinbiomech.2015.05.009

and efficient to evaluate the biomechanical ability of different fixation techniques (Freutel et al., 2014). The finite element model could accurately simulate the movement of the lumbar spine in all directions to investigate the changes in internal stress accumulated on multiple areas of the lumbar spine and fixation devices during movement. In a previous study, an infinite element analysis showed that UPS + TLFS fixation is superior to either UPS or BPS in improving stability and reducing stress (Gong et al., 2014). However, all the mechanical parameters were set under normal conditions for the finite element model and some conditions seen in clinical settings were ignored when experimental parameters were set, such as vertebral body flexibility and effect of muscle tissues. Therefore, *in vitro* biomechanical studies were performed. In an *in vitro*short-term biomechanics study, UPS + TLFS has been shown to provide similar stiffness to BPS (Slucky et al., 2006), highlighting its potential application in clinical settings. However, concerns that the facet screw might easily cause fixation loosening after the long-term periodic motions rise during clinical application. Thus far, the biomechanical performance of TLFS + UPS after long-term cyclic loading has not been clear. Therefore, the present study was designed to compare the biomechanical characteristics of UPS + TLFS, UPS or BPS after short-term and long-term cyclic loading using an *in vitro* porcine spine model, hoping to add new knowledge to the current literature.

2. Methods

2.1. Specimen preparation

Twenty-four fresh lumbar spinal sections (L2–L5) from a 6-month-old porcine with homogeneity in weight and spine condition were harvested. The porcine spines were provided by the Department of Orthopaedic and Spinal Surgery, Nanfang Hospital, Southern Medical University. Paravertebral musculature was carefully stripped while the spinal ligaments, joint capsules and intervertebral discs were preserved (Tai et al., 2008; Wilke et al., 2011). CT images of each specimen were obtained and three-dimensional images were analyzed using semiautomatic segmentation software to ensure the absence of fractures or deformities. Following dissection and CT scanning, the L2 to L5 vertebras were mounted in dental polymethylmethacrylate cement such that the spine maintained its natural lumbosacral lordosis. The L3/4 segment remained free for our protocol.

2.2. Specimen instrumentation

Each specimen was instrumented in a random manner, left-sided TLIF and various spine instrumentations were performed by experienced spine surgeons using standard clinical techniques at L3–L4 (Fig. 1A–C). The interbody spacers used were plastic replicas of femoral ring segments, which are invisible under CT scanning. In brief, after removal of the nucleus pulposus, sequentially sized curettes and interspace shapers were used to prepare the disc space for an interbody graft. The interbody spacer with height of 12 mm was then inserted in a transverse fashion until proper position was achieved.

The TLFS was inserted using Magerl technique (Magerl, 1984) and pedicle screw insertion followed the protocol described previously (Ferrara et al., 2003). The TLFS used was facet screws with 4.5 mm in diameter and 40 mm in depth (NuVasive Inc., San Diego, CA, USA). Polyaxial pedicle screws with 6.5 mm in diameter and 45 mm in depth (Medtronic Sofamor Danek, USA) were used at the L3–L4 levels and connected by 5.5 mm diameter rods (Medtronic Sofamor Danek, USA). All the screws and rods were composed of a titanium alloy (Ti6A14V). Instrumented constructs were subjected to the same load control protocol for flexibility testing. After each test, the specimens with implants were subjected to CT scanning and three dimensional reconstructions to ensure the consistency in the location of instrumentation construct in the specimens (Fig. 1A–C). Saline solution was frequently sprayed on all specimens for hydration throughout testing.

In total, four conditions were tested in our investigation:

1. Intact
2. TLIF + unilateral pedicle screws at L3–L4 (TLIF with UPS,Fig. 1A)
3. TLIF + unilateral pedicle screws combined with contralateral translaminar facet screw at L3–L4 (TLIF with UPS + TLFS, Fig. 1B)
4. TLIF + bilateral pedicle screws at L3–L4 (TLIF with BPS,Fig. 1C).

2.3. Flexibility test protocol

After instrumentation, the specimen was securely fixed to an electromechanically driven texting apparatus. A pure moment of 5 Nm was applied to the superior-most free vertebra (L2) in flexion/extension, lateral bending, and axial rotation for each surgical condition using the University of British Columbia (UBC) Spine Motion Simulator (Goertzen et al., 2004). The simulator maintained the inferior vertebra (L5) in a fixed position while the rest of the specimen, including the splined moment application arm, was allowed to move unconstrained in three dimensions in response to the applied moment. The rate of moment application was approximately 0.5°/s in all directions until a load of 5.0 Nm was achieved at which point the load was reversed at the same rate. For short-tem loading, 3 cycles of moment were applied with the first two served to pre-condition the specimen and the third load cycle used for the kinematic analysis. Besides short-tem loading, long-term cyclic loading was further applied to evaluate the mechanical behavior at the bone–metal interface after cyclic daily spinal loading that occurs *in vivo*. For long-term cyclic loading, 18,000 cycles (4 s/cycle) were applied to the specimen, which has been shown to be able to simulate approximately 6 weeks of daily spinal loading (Ferrara et al., 2003). If a fusion was not achieved within 6 weeks, excessive stresses and strain would be accumulated on spine implants and bone at the bone–implant interface, thus increasing the risk of early implant failure. All cyclic loading was performed with an offset flexion configuration. Four infrared markers were attached to polyethylene

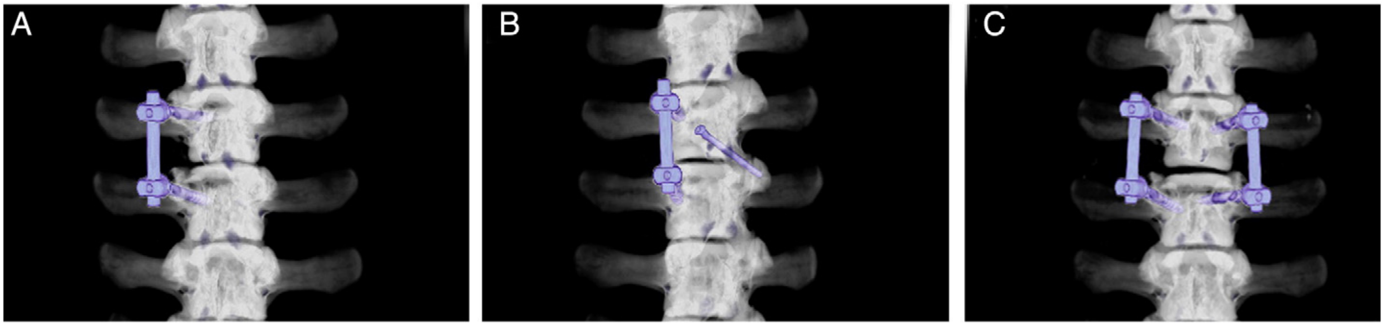

Fig. 1. CT reconstruction images showed typical examples of various instrumentation groups. A: TLIF using UPS; B: TLIF using UPS + TLFS; C: TLIF using BPS.