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Biomechanical effect of interspinous dynamic stabilization adjacent to single-level fusion on range of motion of the transition segment and the adjacent segment

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Background: Despite numerous biomechanical studies have been carried out on dynamic stabilizers, there is very little information on their hybrid application, especially when combined interspinous dynamic stabilization with single-level fusion. The aim of this study is to assess the biomechanical effect of interspinous dynamic stabilization adjacent to single-level fusion on range of motion of the transition segment and the adjacent segment.
Methods: Six fresh lumbosacral spines (L2-S1) were tested in the following sequence: 1) intact (Construct A); 2) fusion in L5/S1 and intact in L4/5 (Construct B); 3) fusion in L5/S1 and unstable state in L4/5 (Construct C); 4) fusion in L5/S1 and Coflex in L4/5 (Construct D). Range of motion (at L3/4 and L4/5) was recorded and calculated.
Findings: Range of motion in L3/4 in the four constructs showed no difference under all motion states. Under flexion/extension, the range of motion of L4/5 in Construct B and Construct C increased, while the range of motion of L4/5 in Construct D decreased compared with Construct A. Compared with Construct D, the range of motion of L4/5 in Constructs B and C showed a significant increase. Under lateral bending and axial rotation, Construct A showed similar range of motion of L3/4 compared with other constructs.
Interpretation: Fusion combined with Coflex is able to stabilize the transition segment and restrict flexion and extension in that segment, while having no significant effect on the range of motion of the adjacent segment or the range of motion of the transition segment under lateral bending and axial rotation.

1. Introduction

Many different surgical treatments for lumbar spinal stenosis (LSS) caused by the degeneration of discs, facet joints or ligaments exist. The gold standard is a decompressive surgery (Amundsen et al., 2000; Simotas et al., 2000), which however, may cause an instability of the spine column (Fujiwara et al., 2000). Rigid fixation and spinal fusion were most commonly used to restabilize the unstable spine column (Akamaru et al., 2003). However, spinal fusion changes the biomechanics of the spine by creating a significant increase in stress on the segments adjacent to the fused level, resulting in increased intradiscal pressure, increased facet loading and hypermobility (Hilibrand and Robbins, 2004; Miwa et al., 2013; Park et al., 2004). Although clinical studies remain contradictory, adjacent segment degeneration (ASD) remains a concern when it is necessary to fuse multiple segments. Thus it is essential to choose the correct segment to fuse for patients with degeneration of two segments or more.

Coflex is one type of posterior interspinous device, which is designed to distract the interspinous processes and thereby to flex the spinal canal and the neural foramina, supposedly to reduce the clinical symptoms of neurogenic claudication. Biomechanical studies have proved that Coflex can limit extension of the spine while having no significant effect on the adjacent segment, which may compensate for hypermobility of an adjacent segment after fusion (Lin and De, 2009; Wilke et al., 2008). Consequently the use of fusion combined with Coflex–as a transitional procedure–offers one possible option to avoid progression of superior adjacent segment degeneration.

To date, there have been few studies investigating the biomechanical situation resulting from such instrumentation. Liu et al. (Ying et al., 2013) studied a hybrid construct using Coflex in the segment superior to single level fusion, employing finite element model analysis. After biomechanical testing, they found that this hybrid construct could reduce the intradiscal pressure and facet loading in the transition segment, but they did not study the effect on the superior segment adjacent to the dynamic segment. In the present cadaveric study, we aimed to evaluate the range of motion of the transition segment and the adjacent segment when fixated with a hybrid posterior implant. The hypothesis was that this treatment approach would result in limitation of motion of the Coflex level compared to a single-level fixation, while having no

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significant effect on the segment superior to the dynamic segment compared to the intact spine.

2. Methods

2.1. Specimen preparation

Six intact spines (L2-S1) from human cadavers were employed for biomechanical testing. Plain film X-rays were taken to exclude fractures, deformities, tumors and scoliosis. The specimens were cryo-preserved until the day of testing, when they were gradually thawed to room temperature before embedding. Specimens were kept moist with saline solution throughout the testing procedure. Three male and three female lumbar spines were tested with a mean age of 47.5 years. According to the testing protocol of Wilke et al. (1998), soft tissue was dissected from the specimens, while leaving the capsules of the facet joints, supporting structures, and ligaments intact. Specimen ends were embedded in polymethyl methacrylate (Dental Materials Factory of Shanghai Medical Instruments Co. Ltd, Shanghai, China) using custom-made casting containers, for mounting in the spine-testing device.

2.2. Spine tester

Biomechanical testing was performed in a spinal testing device (Fig. 1). The caudal vertebra of each spine section was embedded and fixed to the base frame with the lower vertebral body. The upper body was connected to an industrial robot (NX100MH6, Kabushiki-gaisha Yasukawa Denki, Kitakyushu, Japan), which allowed unconstrained movement in all three planes. Three markers were integrated on L3, L4 and the base. Range of motion was obtained by capturing the position of these markers using a 3D optoelectric camera system (Optotrak Certus, Northern Digital Inc, Waterloo, ON, Canada) in all three motion planes: flexion/extension, lateral bending and axial rotation. Force-moment sensors (Gamma, ATI Industrial Automation, Ontario, Canada) were used to measure the applied load and provide feedback for the robot and the data acquisition was synchronized at 10 Hz. The sensors were also used to measure the off-axis forces and moments to provide feedback to ensure that a pure moment was being applied along the primary axis of motion of the spine.

To ensure that the spinal segment (L2-S1) was positioned in a neutral posture, the L3–4 disc was oriented horizontally. The coordinate system definition for each vertebra and set of adjacent vertebral bodies was based on the International Society of Biomechanics 2002 Standard (Wu et al., 2002), with one slight modification regarding the definition of the origin (Mageswaran et al., 2012). Y-axis was the line passing through the centers of the vertebra's upper and lower endplates, and pointing cephalad. Z-axis is parallel to a line joining similar landmarks on the bases of the right and left pedicles, and pointing to the right. X-axis is the line perpendicular to the Y- and Z-axis. Theoretically, the origin is the intersection of adjacent axis Y in the common position. But in NDI system, we were not able to position the origin in the specimen. When the directions of axes are defined, the position of the origin only affects translations and has no effect on angle. So in this study, the origin was positioned in the test table (Fig. 2).

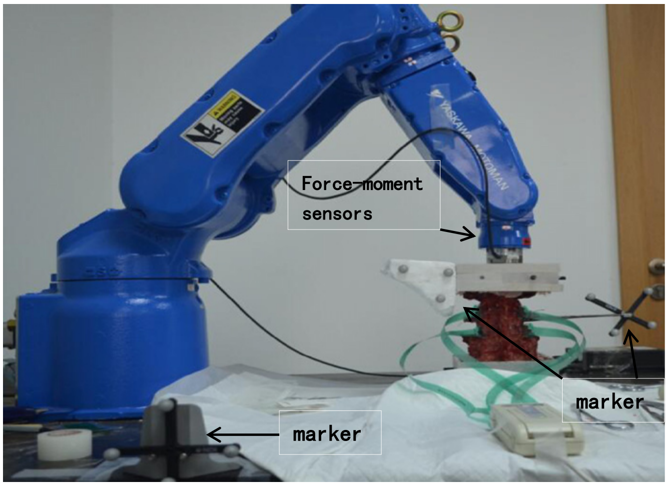

Fig. 1. Image of the biomechanical testing device with a specimen embedded.

Testing was performed according to the hybrid testing protocol recommended by Panjabi et al. (2007), preserving the motion range of the intact spine while applying increasing moments, a method which is intended to reflect the movement strategy of treated patients. Each of the test constructs was subjected to three load-unload cycles in each of the physiologic planes, generating flexion-extension, lateral bending, and axial rotation load–displacement curves. First, a load control protocol with |7.0| Nm moments applied at a rate of 1.0°/s was used to establish intact values. The segment L3–L5 range of motion (ROM) and the ROM for segment L3/4 were recorded. Flexibility testing using a displacement control was carried for all other surgical constructs. The recorded ROM of segment L3–L5 of the intact spine was applied to the surgically modified spinal segments. The applied relative moments needed to reach the intact spinal segment L3–L5 ROM and segmental ROM for L3/4 were measured for each condition. All measurements were repeated twice.

2.3. Testing conditions

Four testing conditions were created by varying the posterior instrumentation: Construct A (intact spine), Construct B (single-level fusion at level L5/S1), Construct C (single-level fusion at level L5/S1 + unstable state at level L4/5), and Construct D (dynamically fixated at level L4/5, superior to rigid fixation of level L5/S1). According to Wilke et al. (2008), the unstable state at level L4/5 consisted of a bilateral hemifacetectomy (the lowed two third of the inferior articular process has been resected) with a resection of both flaval ligaments. The fusion conditions were simulated by posterior pedicle screw and rod instrumentation, without intervertebral instrumentation. For the insertion

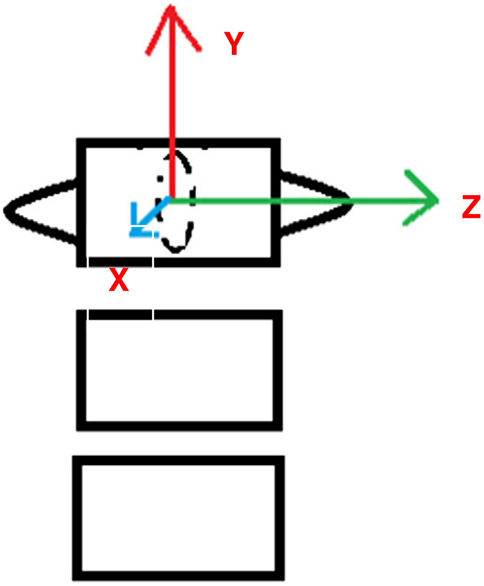

Fig. 2. Illustration of the vertebral coordinate system (XYZ). Y-axis was the line passing through the centers of the vertebra's upper and lower endplates, and pointing cephalad. Z-axis is parallel to a line joining similar landmarks on the bases of the right and left pedicles, and pointing to the right. X-axis is the line perpendicular to the Y- and Z-axes.