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Structural stability of different reconstruction techniques following total sacrectomy: A biomechanical study

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ABSTRACT

Background: The biomechanical stability of spino-pelvis structure after varying reconstruction methods following total sacrectomy remains poorly defined. The objective of this study was to compare the structural stability of different reconstruction techniques.

Methods: Six fresh human cadavers (L2-pelvis-femora) were used to compare biomechanical stability after reconstruction using four different techniques: (1) sacral rod reconstruction; (2) bilateral fibular flap reconstruction; (3) four-rod reconstruction; and (4) improved compound reconstruction. After total sacrectomy, the construction was carried out using each method once in each cadaver. Structural stiffness was evaluated by linear and angular ranges of motion. L5 relative shift-down displacement, abduction angle on the coronal plane and rotation angle on the sagittal plane, were calculated based on displacement of the identification point under 500 N axial loading. Overall stiffness was estimated using load displacement curve.

Findings: Improved compound reconstruction resulted in significantly higher stiffness than all three other techniques. The structural stability following bilateral fibular flap reconstruction was superior to that after sacral rod reconstruction. Four-rod reconstruction achieved worst stability due to the lack of anterior bracing applied in three other methods.

Interpretation: Improved compound reconstruction produces optimal structural stability after total sacrectomy. This finding suggests that both anterior bracing and alternation of screw trajectory are important in achieving optimal structural stability.

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1. Introduction

Total sacrectomy is a treatment option for highly aggressive diseases such as sacral vertebral carcinoma and tuberculosis. Following total sacrectomy, the continuity between the spine and pelvis must be resored. To achieve structural stability necessary for ambulation, it is critical to maintain the spino-pelvic physical bearing bow and overall frame motion stiffness on the coronal and sagittal planes.

Pedicle screw-rod construct, represented by the Galveston L-rod technique, initially developed by Allen in 1978, is the most frequently used technique for re-establishing the connectivity between the spine and pelvis. Based on the use of two rods with pedicle screw fixation from L3 to L5, various techniques have been developed. These techniques could be grouped into two main categories: the triangular frame reconstruction (TFR) (Murakami et al., 2002) and modified Galveston reconstruction (MGR) (Gokaslan et al., 1997). Murakami et al. (2002) compared the two methods in a mechanical study, and concluded that with TFR, there is excessive stress on the iliac bone around the sacral rod, which in turn could cause loosening of the sacral rod. With MGR, excessive stress concentrates at the spinal rod between the spine and pelvis could result in failure of the spinal rod. In recent years, various new reconstruction techniques have been developed. These techniques include sacral rod reconstruction (SRR) (Kawahara et al., 2003), bilateral fibular flap reconstruction (BFFR) (Dickey et al., 2005), and four-rod reconstruction (FRR) (Shen et al., 2006). These techniques provide the destabilized spino-pelvis with solid construction, but the rate of fixation failure (e.g., fixation breakage and loosening) still remains at a high level. Kawahara et al. (2003) compared the efficacy of SRR with TFR and MGR following total sacrectomy in theoretical biomechanical study, but not in human cadaveric study. To date, biomechanical stability of spino-pelvis after treatment with these different techniques has not been studied in human cadaver.

We recently developed an improved compound reconstruction (ICR) technique. A custom-designed experimental rig was employed to imitate the human physiological standing state. The impact of ICR on structural stiffness following total sacrectomy was compared with three classical techniques (SRR, BFFR and FRR). The results from the current study indicated that ICR is a better option after total sacrectomy.

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2. Methods

2.1. Specimen preparation

Six fresh human cadaveric L2-pelvis-femora specimens (3 men, 3 women; age: 28–76 years) were used in the current study. All cadavers were radiographically examined and the specimens with anatomical abnormalities and/or gross osteopenia were excluded. Finally there was no unqualified specimen upon radiographic examination. Soft bone tissues were carefully removed. The ligaments, bones and discs were preserved.

To avoid force deflection during compression loading, a round polyester resin platform was placed on the L2 superior endplate. In addition, a hemispherical groove was created using the loading bulb of a universal testing machine (CSS-44000; CRIMS Co., Ltd., Changchun, China) before the platform shaping. A rig (No. ZL200720076386.X, CN PAT) was custom-designed as previously reported (Hugate et al., 2006) and used to firmly fix the cadaveric femora into bilateral sleeves using 8-point locked screws instead of two metal dumbbells to minimize the movement at the bone-metal interface. Each sleeve was fixed on a slider. Just underneath was a standard deep-groove linear guide for ball-bearings, which was set on a firm base of steel, and used to reduce friction. To simulate human physiological posture maintained by muscle in double-leg stance, an adjustable metal hook was set in the middle of the guide and used to maintain the plane (consisting of the synchondroses pubis and bilateral anterior superior spine) vertical to the horizontal plane through holding the pelvis (Fig. 1).

The linear and angular ranges of motion (ROMs) were calculated by displacement of identification points that had been pasted on the cadaver, and two scales, used for demarcating the actual value, were pasted onto the loading round platform (Fig. 2). The graded movement was photographed with two digital cameras (0.5 Megapixels) that were set perpendicular to each another on a fixed stand with the illumination positioned at a fix distance from the cadaver. Displacement of identification points (in unit of pixel) was measured on the photographs with an image analyzing software (Image J, version 1.42, NIH, USA). The scale on each photograph was used for converting pixel into actual displacement.

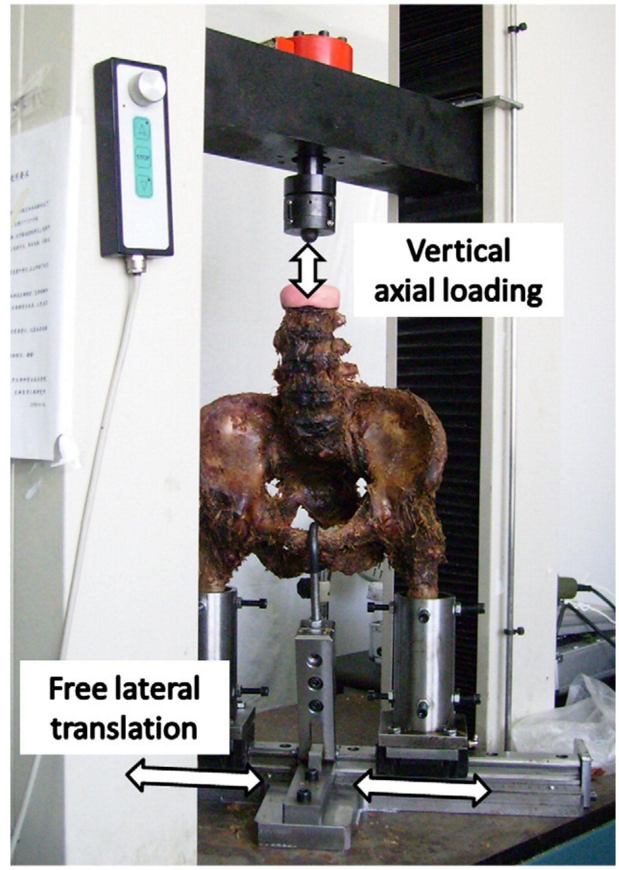

Fig. 1. Photograph of the testing equipment. A round polyester resin platform was placed on the L2 superior endplate, and cadaveric femora were firmly fixed into bilateral sleeves of the custom-designed experimental rig using 8-point locked screws. This positioning was maintained by an adjustable metal hook. A pre-programmed universal testing machine controlled the compressive mode.

2.2. Establishment of operating conditions

The pedicle screw-rod construct was positioned with different techniques in each specimen using titanium instrumentation for posterior spinal fixation (Kanghui Medical Innovation Co., Ltd., Changzhou, China). Each specimen was tested in five operating conditions: (1) intact, (2) SRR, (3) BFFR, (4) FRR, and (5) ICR. During instrumentation of these four techniques, the manufacturers' surgical technique manuals were strictly followed. The test order was from the least to the most destructive (invasive).

In the SRR condition, two pedicle screws were arranged under the L5 inferior endplate, and a baffle was fixed between the screws and the endplate to enlarge the stress area and decrease the pressure, so that the screws were prevented from falling into the vertebral canal. Then the sacral rod was inserted through two screws under the L5 inferior endplate and the contralateral iliac wing parallel to the horizontal plane; the entry point was about 1 cm forward of the posterior superior iliac spine, horizontally. In the BFFR condition, we used the upper and middle sections of the fibula from the same specimen, supplied with the donor site. Two isometric fibular grafts were used to construct a triangular frame. On the contacting interface of the frame's upper apex, an oval receptacle (about 1 cm × 2 cm) was created using a burr in the center of the inferior aspect of the remaining lower vertebral body, whereas docking sites of the bilateral frame angulus inferiors (about 1 cm × 1 cm) were created at the convergence of the iliopectineal lines and the acetabular apex axes. Then two fibular grafts were placed to create a solid triangular construct. In the FRR condition, we placed four separate longitudinal rods across the lumbo-pelvic junction according to two well-defined screw trajectories: the Roy-Camille "straight ahead" (medial) and the Magerl "lateral-to medial-converging" (lateral) pedicle screw placements. The ICR condition utilized the sacral rod and the fibular triangular construct in the anterior approach; the alternating screw

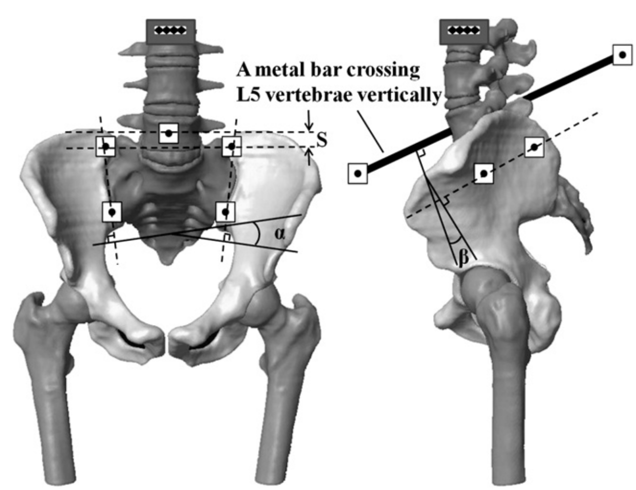

Fig. 2. Pasted position of identification points and scales in anterio-posterior and lateral position. L5 shift-down displacement, abduction angle on the coronal plane and rotation angle on the sagittal plane were respectively the variety of S, ∠α and ∠β.

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