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Biomechanical characterization of three iliac screw fixation techniques: A finite element study

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ABSTRACT

We aim to characterize the biomechanical properties of a modified iliac screw fixation method compared with the classic iliac screw fixation and the S2 alar iliac screw (S2AI) fixation using a FEM.

A three-dimensional, non-linear FEM of lumbosacral spine and pelvis (L1-pelvis) was modified to simulate 3 different iliac screw fixations based on posterior screw fusion. The peak von Mises stress (PVMS) values of the iliac screws in the 3 different iliac screw fixations were recorded in during flexion/extension/axial rotation/lateral bending. The interaction stress which arose between the screw head and the shaft of iliac screws, was also measured for each case.

The PVMS values of the 3 different iliac screw fixation techniques were lower than the fatigue strength levels under physiological loadings. PVMS of iliac screws was observed in the screw shaft for S2AI, in the screw neck for the modified iliac screw technique, and in the offset connectors of the classic iliac screw technique. The interaction between the screw head and the neck was compressed in modified iliac screw fixation technique. On the other hand, distraction force was observed in the S2AI technique between the screw head and the screw shaft.

This FEM study supports our previous clinical results, which found that the modified iliac screw fixation technique can be an effective alternative sacropelvic fixation technique comparable to the classic iliac screw and the S2AI technique.

1. Introduction

To overcome the complications associated with fusions ending at S1, several methods, such as sacropelvic fixation or the use of a S2 alar screw, have been introduced [1–6].

Modern instrumentation techniques allow for the insertion of screws into the ilium independently of the proximal construct and connection to longitudinal rods by offset connectors [7]. Their pullout strength is 3 times than that of Galveston rods. It has also been shown that additional iliac screws may effectively protect S1 screws and enhance the fusion rates at the lumbosacral junction [8–10].

However, this technique is also associated with pain and prominent screw heads, especially in small and thin patients, necessitating implant removal in as many as 22% of cases [11]. Likewise, Tsuchiya et al. [10] reported seven cases of iliac screw breakage and 23 cases necessary removal due to prominence in a 5 year follow-up study of 67 adult patients with spinal deformities.

The S2 alar iliac screw (S2AI) method appears to provide a solution to the problem of prominence because the screw head is concealed underneath the posterior superior iliac spine [8]. The

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method also allows for the placement of screws with longer and larger diameters through the S2 alar iliac. In addition, as S2AI screws would be in line with S1 screws, the need to use offset connectors is eliminated. However, a recent study revealed that the failure rate of S2AI screws was higher than that of iliac screws with lateral connectors [12]. One of the main causes was the acute angle that develops between the screw head and the shaft of the S2AI screws [12].

We previously reported a modified iliac screw fixation technique which addressed the limitations of these two techniques. That technique showed good clinical results in adult patients [13].

In the present study, we aim to compare our modified iliac screw fixation technique to the classic iliac screw technique and to the S2AI screw fixation technique by using a finite element model (FEM).

2. Methods

2.1. FEM of a normal lumbosacral spine and pelvis

To develop a 3-dimensional (3D) FEM of the lumbosacral spine and pelvis, computerized tomography was utilized with 1 mm intervals on the spine (L1-pelvis) of a normal adult person. The FEM consisted of the vertebral body (cancellous and cortical bone), the spinous process, intervertebral discs, and 17 ligaments (the anterior longitudinal ligament, posterior longitudinal ligament, ligamentum flavum, capsular ligament, intertransverse ligament, interspinous ligament, supraspinous ligament, anterior sacroiliac ligament, posterior sacroiliac ligament, interosseous sacroiliac ligament, sacrospinous ligament, sacrospinous ligament, sacrotuberous ligament, superior pubic ligament, arcuate pubic ligament, inguinal ligament, and the iliolumbar ligament). The elastic behavior of the annulus fibers was taken from work by Smit et al. [14] who combined material values from Goel et al. [15] and Shirazi et al. [16]. The nonlinear behavior of the ligaments was incorporated by defining different material properties at different strains. The ligament attachment points were based on anatomical data. Based on the research by Goel et al. [15], the gap between the facet joints was set to 0.5 mm, and the contact direction was set perpendicular to the articular surface. Material properties were selected from various sources in the literature (Tables 1 and 2) [16–23]. The present study used 3-Matics software package (Materialise NV, Leuven, Belgium) and ABAQUS (version 6.5, ABAQUS Inc., Providence, RI, USA). The lumbar FEM for the purposes of the present study was verified in our previous study [24,25]. The lumbosacral spine and pelvis FEM with ligament attachments are illustrated in Fig. 1. This study was approved by the institutional review boards at Seoul National University Hospital (H-1308-124-517).

2.2. Validation of the FEM

To validate the FEM, Equivalent loading conditions were applied and the load displacement behavior of the sacroiliac joint (SIJ) was compared to previously published in vitro data by Miller et al. [26]: (1) 42-Nm of flexion, extension, axial rotation, and lateral bending; (2) 294-N of anterior, posterior, superior, and inferior translation (Fig. 2). Good correspondence was observed.

2.3. Lumbosacral spine and pelvis fusion model with three iliac screw fixation techniques

The FEM of the intact lumbosacral spine-pelvis was modified to simulate 3 different iliac screw fixation models (L1-pelvis) based on posterior screw fusion. The 3 different iliac screw fixation techniques- the classic iliac screw technique, the S2AI screw fixation technique, and the modified iliac screw fixation technique-are described in detail in the literature [12,13]. A model of the lumbosacral spine and pelvis fusion with these 3 different iliac screw fixation techniques is illustrated in Fig. 3.

2.4. Loading and boundary conditions

A multi-segment spinal fusion model from L1 to the pelvis was used to compare and analyze the peak von Mises stress (PVMS) values of the implants. All nodal points of both acetabula were confined, while the upper endplate of the highest segment was subjected to a pure moment of 10 Nm of flexion/extension/axial rotation/lateral bending. A compressive follower load of 400 N was added to the validated intact lumbar spinal model in the follower load path direction as suggested by Patwardhan et al. [27]. Full fusion between bony structures and instrumentation was assumed.

The PVMS of the iliac screw in the 3 different iliac screw fixation techniques were recorded for each loading condition.

Table 2
Material properties used in finite element model of pelvic ligaments.

Materials	Stiffness coefficient (N/mm)	Reference
Anterior sacroiliac ligament	700	Zheng et al. (1997)
Posterior sacroiliac ligament (long)	1000	
Posterior sacroiliac ligament (short)	400	
Interosseous sacroiliac ligament	2800	
Sacrospinous ligament	1400	
Sacrotuberous ligament	1500	
Superior pubic ligament	500	
Accurate pubic ligament	500	
Inguinal ligament	250	Phillips et al. (2007)
Iliolumbar ligament	1000	

Table 1
Material properties used in finite element model of lumbosacral spine and pelvis.

Part	Materials	Young's modulus (MPa)	Poisson's ratio (n)	Reference
Bone	Ilium cortical	17,000	0.3	Dalsta et al. (1995)
	Ilium cancellous	132	0.2	Dalsta et al. (1995)
	Sacrum cortical	6140	0.3	Hakim et al. (1979)
	Sacrum cancellous	1400	0.3	Hakim et al. (1979)
	Lumbar cortical	12,000	0.3	Kawahara et al. (2003)
	Lumbar cancellous	100	0.3	Kawahara et al. (2003)
Soft tissue	Sacrum cartilage	54	0.4	Miura (1987)
	Ilium cartilage	54	0.4	Miura (1987)
	Pubic symphysis	5	0.45	Shi et al. (2014)
	Nucleus pulposus	1	0.4999	Shirazi et al. (1984)
	Annulus fiber	450		
	Annulus metrix	30		
	Endplate	100		

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