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Biomechanical analysis of the fixation systems for anterior column and posterior hemi-transverse acetabular fractures

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ABSTRACT

Objective: The aim of this study was to evaluate the biomechanical properties of common fixation systems for complex acetabular fractures.
Methods: A finite element (FE) pelvic model with anterior column and posterior hemi-transverse acetabular fractures was created. Three common fixation systems were used to fix the posterior wall acetabular fractures: 1. Anterior column plate combined with posterior column screws (group I), 2. Anterior column plate combined with quadrilateral area screws (group II) and 3. Double-column plates (group III). And 600 N, representing the body weight, was loaded on the upper surface of the sacrum to simulate the double-limb stance. The amounts of total and relative displacements were compared between the groups.
Results: The total amount of displacement was 2.76 mm in group II, 2.81 mm in group III, and 2.83 mm in group I. The amount of relative displacement was 0.0078 mm in group II, 0.0093 mm in group III and 0.014 mm in group I.
Conclusion: Our results suggested that all fixation systems enhance biomechanical stability significantly. Anterior column plate combined with quadrilateral area screws has quite comparable results to double column plates, they were superior to anterior column plate combined with posterior screws.

Acetabular fractures are a relatively common type of fracture. Among these fractures, simple fractures account for a very small proportion.[1] Approximately 35% of acetabular fractures involve the posterior wall. This pattern is the most common, and roughly 76% of these injuries are accompanied by additional fractures.[2] Few studies have considered complex pelvic fractures separately or determined functional outcomes using validated instruments.[2–4] Specifically, the anterior column and posterior hemi-transverse acetabular fractures account to about 5% of all pelvic fractures and are very difficult to manage.[5]

Acetabular fractures are commonly treated through open reduction and internal fixation, especially if the incongruity exceeds 3 mm and/or the hip joint is unstable.[6] An extended or combined approach that involves column plates and lag screws has been utilized for complex pelvic fractures. Sawaguchi et al used anterior column lag screw fixation combined with posterior column plate to fix the transverse acetabular fracture, and found that this method could provide a degree of stability indifferent from that of other methods, and with minimal exposure and devascularization of the pelvis.[7] Wolf et al used two column plates to treat the complex fractures and concluded that this modification could provide a helpful and easy alternative to the more demanding original exposure.[8] Yildirim et al[9] tested the five different fixation alternatives of stabilization of transverse acetabular fractures under two basic physiological loading conditions: standing and sitting utilizing a finite element (FE) model. The authors found that the posterior column plating combined with an anterior column screw has quite comparable results to a double column plating in transverse fractures, suggesting that the two column fixations might be unnecessary. Thus, the anterior column plate combined with posterior column screws (P&PS) and the double column plates (P*2) are commonly used to treat the anterior column and posterior hemi-transverse acetabular fractures. Except for a few simple ones,

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almost all acetabular fractures involve the quadrilateral area.[10] Placing quadrilateral area lag screws via an anterior approach was a novel method to cure complex acetabular fractures, which could generate a certain clinical result and had obtained a China state patent.[11] To enhance the stability of fracture fixations, researchers in orthopedic trauma management generally apply anterior column plate combined with quadrilateral area screws (P&QS).[11]

In this study, our aim was to evaluate the biomechanics of three fixation systems for the anterior column and posterior hemi-transverse acetabular fractures through FE analysis. The biomechanics of these fixation systems are assessed based on the effective stiffness levels, stress distributions, force transfer and displacements difference along their fracture lines.

Materials and methods

FE model of the pelvis

The model of a 40-year-old, 175 cm tall subject weighing 65 kg was created through laser topography using a 16-slice spiral CT with an accuracy of 0.5 mm. The accurate geometric model of the pelvis was established according to the bony contour that can be distinguished in the CT gray scale in Mimics software.[6,12] The point cloud was converted to the surface of the pelvis. Bony tissues were meshed using a combined artificial and automatic division method using the ANSYS-ICEM and Hypermesh software. Cortical bones were meshed into eight nodes with non-linear solid hexahedron elements (C3D8), which were offset from the cancellous bone in Hypermesh. The soft tissues (i.e. end-plates, cartilage and pubic symphysis) between the pelvic bones were meshed into hexahedron elements in Hypermesh (Fig. 1). In order to ensure the convergence of optimization and the consistence of displacement between adjacent tissues, the shared nodes contact was used between tissues in the Hypermesh software. Tied contacts were used between tissues with surfaces that were adjacent to each other in the Abaqus 12.0 software to ensure that no relative displacement occurs. Mesh sensitivity studies revealed that further refinement does not improve calculation accuracy significantly. Table 1 presents the properties of the pelvic bone.

The pelvic ligaments were modeled as truss elements (element length was 2 mm), which permitted only axial tensile force transmission. The pelvic ligaments included all the major ligaments: the sacroiliac ligament ring, sacrospinous, sacrotuberous, inguinal, superior pubic, and arcuate pubic. Table 2 depicts the properties of these ligaments.

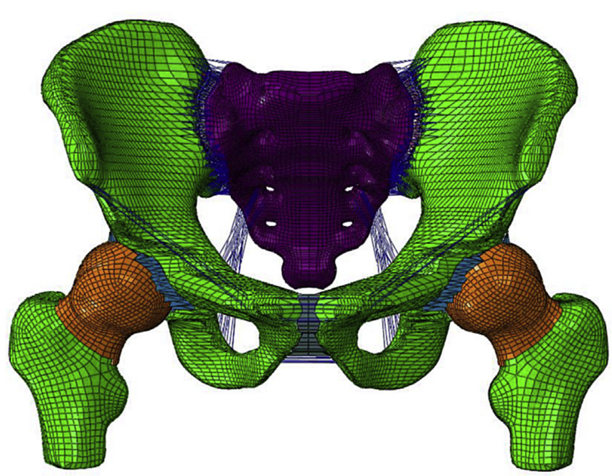

Fig. 1. Finite element model of the pelvis.

Table 1
Material properties of the pelvic bone.[2,8]

Tissue	Elasticity modulus (MPa)	Poisson ratio (υ)	Thickness (mm)
Cortical bone	17000	0.3	
Cancellous bone	150	0.2	
End plate (sacrum)	24	0.4	0.23
Cartilage (sacrum)	54	0.4	3.00
Cartilage (ilium)	24	0.4	1.00
End plate (ilium)	54	0.4	0.36
Pubic symphysis	5	0.495	

Fragment lines

The anterior column and posterior hemi-transverse acetabular fractures was determined by two converging lines. The former originates from the anterior superior spine and the latter from the ischial spine or just above this part (Fig. 2).[10] Additionally, the elasticity modulus of the elements along the fracture line weakens to one tenth of normal cancellous bone.

Surgical techniques

Anterior column and posterior hemi-transverse acetabular fractures can be effectively treated through open reduction and internal fixation that use column plates and lag screws.[13] The fixation device was composed of Nitinol (NiTi), a shape-memory alloy due to its inherent advantages, including: the shape-memory effect, remarkable resistance to wear and corrosion and good histocompatibility.[14]

In the anterior column plate combined with posterior column screws (P&PS) technique, the anterior column plate was implemented from the inner surface of the ilium to the superior surface of the superior pubic ramus. The screw was incorporated from the outer surface of the quadrilateral area superior to the arcuate line and into the ischial spine. The column plate was bent to meet the surgical requirement. The interface between the plates and the bone was modeled as face-to-face contact with a frictional coefficient of 0.1 to simulate the slide between the joint surfaces.[15,16] The embedded contact type was used to restrict the slide between the interfaces of the screws and the bones.[17] The screws were simulated as rod-like structures, which had a diameter of 3.5 mm.

In the anterior column plate combined with quadrilateral area screws (P&QS) technique, the position at which the column plate attached was almost similar to that in the former system. The screws in the quadrilateral area were inserted into the outer surface along the arcuate line and into the ischial spine. Two quadrilateral area screws were fixed by the column plate and cortical bone.

Table 2
Material properties of the pelvic ligaments.[2,8]

Tissue	Elasticity modulus (MPa)	Poisson ratio (υ)
Sacroiliac ligament ring	350	0.495
Sacrospinous	29	0.495
Sacrotuberous	33	0.495
Inguinal	2.6	0.495
Superior pubic	19	0.495
Arcuate pubic	20	0.495

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