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Interfragmentary movement of percutaneous fixation of acetabular fractures during gait – a finite element study

Vickie Shim, Kumar Mithraratne, Christopher Josten and Joerg Bohme

***Abstract*— Posterior wall fractures is the most common fracture type of the acetabulum. Conventional way of fixing this fracture is to use open reduction and internal fixation with plates and screws. However recently a new way of fixing this fracture was developed, which is a minimally invasive surgery utilizing only two screws. Yet the biomechanics of this type of fracture fixation has not been studied extensively yet. Previously we have reported that this percutaneous fixation generated interfragmentary movement comparable to the conventional plate fixation in static full stance position. In this study, we predicted the interfragmentary movement of percutaneous fixation during gait. We found that the movement was still very small with less than 2mm for most of the cycle. The toe off point in gait cycle generated the biggest movement while the foot flat point was the smallest. Future works include characterizing the role of screw positions as well as muscle forces in generating this movement during gait.**

I. Introduction

The posterior wall fracture is the most common fracture type of the acetabulum[1] and open reduction and internal fixation (ORIF) is the treatment of choice in these fractures. However ORIF often leads to major blood loss and significant complications[2] due to considerable exposure required during surgery. Percutaneous screw fixations, which requires minimal amount of exposure, can minimize blood loss and risk of infection and has become an attractive alternative to ORIF. There have been some biomechanical investigations especially in terms of comparing various different stabilization techniques in posterior wall fractures [3].

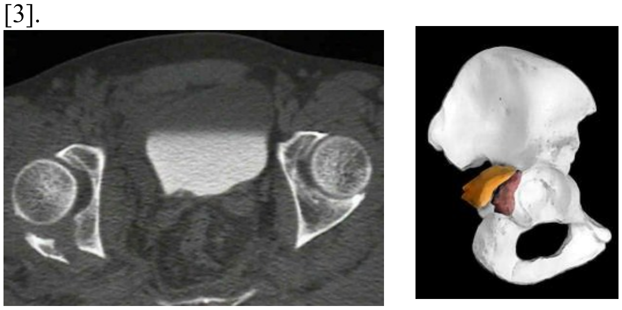

Figure 1. Typical CT scans of posterior wall fracture of the acetabulum (left) and the 3D view of the fracture (right)

But it is interfragmentary movement that exerts major influences on the primary stability and fracture healing [4, 5]. Previously we have developed and validated an efficient method of predicting interfragmentary movement in percutaneous fixation of acetabular fractures using finite element analysis [6]. This method utilized 3D FE models generated from CT scans to predict the stability of percutaneous fixation according to the positions of screws placed during percutaneous fixation. The aim of this study is to apply this method to predict interfragmentary movement of percutaneous fixation during gait in order to identify the pattern of the movement. Moreover the role of screw positions in interfragmentary movement was also investigated.

II. Material and Methods

A. Finite element model generation

A finite element model of a pelvis with a posterior wall fracture was generated from a synthetic bone (Full Male Pelvis 1301-1, Sawbones, Pacific Research Laboratories, INC, Washington, WA, USA). The posterior wall fracture was generated from a previous experiment[7]. The pelvis was then fixed with two screws (3.5mm Titan Screws, Synthes, Umkirch, Germany) by an experienced surgeon (JB). This was then scanned with a Faro Arm (Siler Series Faro Arm) and a laser scanner (Model Maker H40 Laser Scanner). Clouds of data points were obtained from the laser scanner, which accurately described the shape of the fragment and location of the two screws. A previously developed and validated FE model of the pelvis was then fitted to the pelvis data points to generate a fractured pelvis model. A FE model of the fragment was generated from the fragment data set by performing geometric fitting to the laser scanned data set. Our FE models

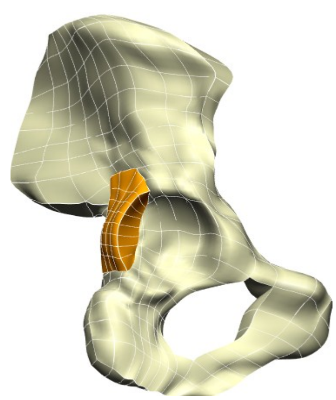

Figure 2. FE model of a pelvis with a posterior wall fracture

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Vickie Shim is with the Auckland Bioengineering Institute, University of Auckland, Auckland, New Zealand (phone: 64 3737599x86932; fax: 64 9 367 7157; e-mail: v.shim@auckland.ac.nz).

Kumar Mithraratne is with the Auckland Bioengineering Institute, University of Auckland (e-mail: p.mithraratne@auckland.ac.nz).

Christopher Josten is with the Department of Trauma and Orthopaedic Surgery at the University of Leipzig, Germany (Christoph.Josten@medizin.uni-leipzig.de)

Joerg Bohme is with the Department of Trauma and Orthopaedic Surgery at the University of Leipzig, Germany (Joerg.Boehme@medizin.uni-leipzig.de)

use high order cubic Hermite basis functions and are made up of 188 elements and 454 nodes for the pelvis, 144 elements and 245 nodes for the femoral head and 32 elements and 90 nodes for the fragment. Although the numbers of nodes and elements are fewer than other conventional FE models, the use of high order basis function allowed us to accurately capture the geometry [8]. Moreover we used Gauss points inside the elements to assign material properties. Therefore our elements had inhomogeneous location dependent material properties despite large element size and different material properties were assigned.[9, 10]. Therefore different modulus values were assigned to cortical and cancellous values as shown in Table 1.

	Modulus (MPa)	Poisson's ratio	References
Cortical Bone	17000	0.3	[11]
Cancellous Bone	650	0.3	[12]

Table 1. Material Properties assigned to model

The contact between the bone and fragment was modeled with frictional contact with a friction coefficient of 0.3 while the faces where the screws were placed were modeled as a tied contact to simulate the support provided by the screws that connect the fragment and bone. In this way, we were able to model the behaviour between bone and fragment without including the model of screws.

B. Gait analysis for obtaining boundary conditions for walking

An 8-camera motion capture system (VICON) was used to record kinematic data of a subject (29 yrs old, female) at 100Hz for normal level walking. The ground reaction force, centre of pressure and vertical torque were also acquired simultaneously at 1000Hz using a 2-force plate system (Bertec) and synchronised with motion capture data. Each segment of the lower limb model was rigidly transformed using the 3-point method. The standard inverse dynamic approach was used to estimate the net joint force. The kinematics from the motion capture data were used as displacement boundary condition that prescribes the positions of the pelvis and femur. The net joint forces from inverse dynamics were used as force boundary condition.

C. Calculation of interfragmentary movement

The fragment movements were obtained in three directions – horizontal, vertical, and lateral - using two different viewpoints as seen below based on our experimental system [6]. Lateral and vertical movements were measured from the side view while horizontal movement was measured from the frontal view.

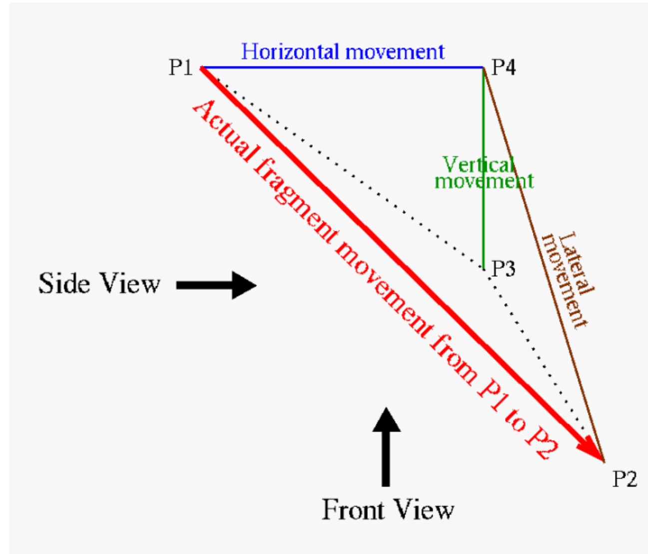
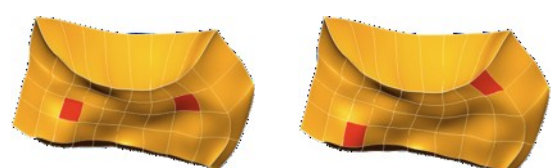


Figure 3. Calculation of fragment movement in 3D

The actual movement of the fragment is from P1 to P2 from no load to full load conditions. The front view movement gives the triangle P1P4P3, allowing us to calculate horizontal and vertical movement. The side view movement gives the triangle P4P2P3, which allows us to calculate lateral movement. From these, the actual fragment movement was estimated. The accuracy of this method was validated in our previous study[6].

D. Simulation of screw positions.

In our previous work[6], we identified the optimum screw positions that resulted in the smallest interfragmentary movement during stance position shown below.



(a) Original screw (b) Optimized

Figure 4. Screw positions tested in this study

In this study, we have simulated the interfragmentary movements from the original screw position. The locations of screws on the fragment FE mesh were identified first by superimposing laser scanned data points onto the fragment mesh. Then, tied contact that ensures perfect bond between two objects was imposed on identified faces to simulate the bond that screws provide when connecting the fragment with the bone. The rest of fragment faces were modeled with frictional contact with a friction coefficient of 0.3. This combination of frictional and tied contact conditions allowed us to simulate the relative movement of fragment compare to the bone in the fracture reduced pelvis efficiently. The hip joint force obtained from gait analysis data was applied from the femoral head to the fracture acetabular and the displacement between the fragment and bone was measured.

III. Results

A. *Interfragmentary movement during gait*

The interfragmentary movement during the stance phase of the gait was simulated.

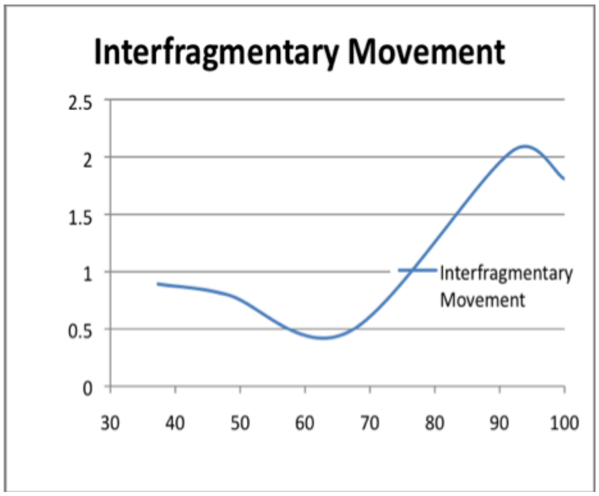


Figure 5. Interfragmentary movement during gait

As can be seen from the graph above, the interfragmentary movement was the greatest during the toe off phase of the gait and smallest during the foot flat phase of the gait. Interesting finding was that toe off generated more movement than hill strike. In particular, apart from the interfragmentary movement during toe off, the movements during gait cycle were less than 2mm, which is regarded as the maximum acceptable amount of interfragmentary movement that can induce fracture fixation. Therefore in this case, the screw fixation provided adequate fracture fixation stability.

IV. Conclusion

This study investigated the amount of interfragmentary movement in the acetabular fracture fixation of posterior wall fractures. Since posterior wall fractures is one of the most frequent fracture types of the acetabulum, it is important to investigate the biomechanics of the fracture fixation technique. In particular, we have investigated the percutaneous screw fixations. Although plate fixation technique is still a gold standard in acetabular fracture fixation, percutaneous fixation is being regarded as a hopeful alternative to the plate fixation, which has a number of complications such as extensive blood loss and large exposure.

We have found out that the interfragmentary movement for percutaneous fixation was less than 2mm during most of the gait cycle. The movement was greatest at the toe off point, which had a greater movement than the movement during the hill strike phase of gait cycle. Therefore future work will include optimizing the screw positions according to the values at the toe off region. Moreover the influence of muscle forces in interfragmentary movement will be investigated.

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