Accurate predictions of fracture load and fracture initiation location of acetabular fractures with non linear finite element models

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Introduction: Despite great advances in hip fractures made during the last century, “fractures of the acetabulum remain an enigma to the orthopaedic surgeon”[1]. Questions regarding the use of various operative and non operative procedures such as the role of minimally invasive techniques still remain unanswered. Moreover, in spite of general acceptance of the principles in management of acetabular fractures, complications occur rather frequently, resulting in about 20% of patients having less than perfect results. Added to these problems is the fact that acetabular fractures are relatively uncommon, thus the average orthopaedic surgeon never gains wide experience with them. Therefore the use of biomechanical tools such as finite element models in investigating various treatment and patient management options will be very valuable. The aim of current project is to develop a finite element model of the pelvis that can accurately predict the acetabular fracture load and location and validate its performance with mechanical experiment.

Materials and Methods: Three sets of synthetic pelvis and femur models (Pacific Research Laboratory, WA, USA) were used to develop an experimental set-up for acetabular fracture testing. The loading condition was similar to the one described in Dalstra et al[2], which simulated standing position. Each pelvis was positioned upside down into a mounting pane and the iliac crests were fixed in acrylic cement. The matching femoral head was cut from the femoral neck and then attached to the crosshead of the Instron Machine (the 5800 series, Instron Ltd., Norwood, USA) (Figure 1). To achieve more stable and better fit between the synthetic femoral head and the acetabulum, the femoral head was dipped into liquid latex to cover it with a compliant material to obtain an effect similar to having a layer of cartilage. A vertically directed force was applied to the acetabulum until failure at a rate of 40N/s. Resulting fracture load and location were recorded.

The synthetic pelvis model was then CT scanned and a FE model was generated using a previously validated FE mesh generation method[3]. For mechanical simulations, we used finite deformation elasticity rather than linear elasticity. This required the use of full Green's strain tensors and a strain energy function in the governing equation. Although computationally more expensive, this setup allowed us to use any constitutive relations as well as nonlinear material behaviours, required in fracture analysis. Two materials – solid rigid polyurethane foam and cellular foam – were incorporated and their properties were obtained from the manufacturer. The latex layer was also modelled with properties obtained from the literature. The contact between the femoral head and the acetabulum was modeled using a contact mechanics penalty method involving Coulomb friction (μ=0.3). The same loading and boundary condition as the experiment were used and the FE model of the pelvis was also loaded with a vertical force in steps of 500N until failure is detected. To predict the fracture load of a femur, a factor of safety (FOS) for each gauss point was computed using the distortion energy theory of failure[4]. The fracture load and location were compared with experimental results.

Results: The same experiment was repeated three times to check whether the result is consistent. All three pelves showed a very similar fracture patterns, that is posterior column fracture (Figure 1). The average fracture load was 3600N (3200-4000N). The FE models failed at a similar load (4000N) and the location where the fracture started was superior dome of the acetabulum, which closely matched the pattern of posterior column fracture (Figure 2).

Discussion: The current study demonstrated that non linear finite element models with finite deformation assumption can predict fracture load and fracture initiation location accurately. Although validated with synthetic bones, the agreement achieved between the experiment and FE simulation can be a good indicator for the usefulness of our model. Future works will involve biomechanical assessments of various treatment options for the acetabular fractures using the current model.