FINITE ELEMENT ANALYSIS OF THE FOUR-HOLE DYNAMIC COMPRESSION PLATE DURING GAIT

INTRODUCTION: One common pelvic injury deals with the disruption of the pubic symphysis which results in significant blood loss and an extremely unstable pelvis. Many anterior fixation devices have been designed to restore the stability of the disrupted pelvis. The main approach of stabilizing a disrupted symphysis is through the use of thin plates and screws; namely, two-hole anterior fixation, four-hole dynamic compression plate, combined two-hole and four-hole plates, and six hole plates (Lange et al., 1985). The clinical shortcomings in almost all the above designs are that they do not accommodate physiologic symphseal displacements and the existing multiple fulcrum points cause breaking of the plate and loosening of the screws (*Simonian et al, 1996). In addition they have been found to be too rigid for simple day to day activities such as walking.

Here we focus on the design of 4-hole dynamic compression plate for fixation of disrupted symphysis. We use the finite element method to develop a full pelvic model to simulate the displacements in the pubic symphysis, during walking, for both a intact pelvis and a pelvis fixed using the 4-hole dynamic compression plate. We hypothesize that, the 4-hole dynamic compression plate provides significant overfixity of the joint which results in elevated levels of shear stress acting on the plate and specially the screws resulting in loosening and potentially pull-out.

METHODS: The subject specific finite element model of the pelvis was developed from CT scans using MIMICS software and the finite element analysis was performed using ABAQUS/CAE. The ilium consists of approximately 25000 tetrahedral elements; sacrum consists of 20500 tetrahedral elements; the sacroiliac ligament consists of 104 tetrahedral elements on each side. The Young’s modulus and Poisson’s ratio for the ilium and sacrum were assumed to be 17 GPa and 0.3 (Dalstra, et al, 1995). The material properties for the sacroiliac ligament and the pubic symphysis were adjusted to match with the displacement obtained in an experimental study (Francis, 2005) that measured the displacement of pelvic ring and pubic symphysis at standing position in cadaveric pelvis. The pelvis was loaded through acetabulum cups. The stress distribution in the acetabulum during gait was obtained from Eisenhart R et al (1999). The gait was divided into 4 stances which were heel-strike, midstance, heel-off and toe-off. The gait has been defined as follows: step 1-2, right heel-strike and left heel-off, step 2-3, left toe-off and right heel-strike, step 3-4, left midstance, step 4-5, left heel-strike and right heel-off, step 5-6, right toe-off and step 6-7, left midstance. The pelvis was in the anatomical position during the application of the load. The disruption of the pubic symphysis was simulated by making a cut 1 mm wide in the symphyseal region. The finite element models of intact and fixated pelvis (using the four hole dynamic compression plate) are shown in Figure 1.

RESULTS AND DISCUSSION: Displacements were measured in all three directions (u1, u2, and u3, Figure 1) at nodes superior and inferior near the pubic symphysis, on the left and right ilium, for both intact and fixated pelvises. The maximum difference (between nodes of left and right ilium) in the displacements (u1: medial-lateral) of superior nodes was found to be 0.5mm in the case of the intact pelvis and 0.55mm in the case of the fixated pelvis both observed during heel-strike. This indicates that the displacement, u1, of the superior nodes, for the fixated pelvis, is close to that of the intact one. However, the maximum difference in the displacements, u1, of inferior nodes was found to be 2mm in the case of intact pelvis, which is significantly lower than 5.3mm for the fixated pelvis, Figure 2. Both were observed during the heel strike.

In the u2 direction (anterior-posterior), the maximum difference in the displacements of the superior nodes was 1.6mm in the case of intact pelvis and 7mm in the case of fixated pelvis; both observed during toe-off. However, the difference in the displacements of the inferior nodes was almost the same throughout the gait cycle. The large difference in the displacement of the superior nodes indicates the failure of the fixation device to control the displacement. In the u3 direction (superior-inferior), the maximum difference in the displacements of the superior nodes of the intact pelvis was 5.3 mm observed during midstance and almost zero in the case of fixated pelvis throughout the gait cycle. The difference in the displacements of the inferior nodes of the intact pelvis was 3mm observed during midstance but close to zero in the case of fixated pelvis throughout the gait cycle indicating that the fixation is too rigid. Because of the overfixity of joint in certain direction and laxity in other directions, the stresses in the plate, screws and the contact area between the screws and the bone are elevated. Stress distribution in the plate and screws during gait is shown in Figure 3 (the top portions of the middle screws are under extreme shear stress). High shear stresses acting on the screws are indicative of possible screw loosening and pull-out.

CONCLUSION: Our finite element simulations during gait, show that the 4-hole dynamic compression plate fails to provide adequate stability to the pelvis.

REFERENCE:
Eisenhart R et al (1999), J Orth Reh, 17(4):532-539