

# QUANTITATIVE PREDICTION OF ARTICULAR CARTILAGE DEGENERATION FOLLOWING INCONGRUOUS INTRA-ARTICULAR FRACTURE REDUCTION

Yang Dai<sup>2</sup>, Thomas D. Brown<sup>1,2</sup>, J. Lawrence Marsh<sup>1</sup>

<sup>1</sup>Department of Orthopaedics and Rehabilitation, University of Iowa, Iowa City, IA, USA

<sup>2</sup>Department of Biomedical Engineering, University of Iowa, Iowa City, IA, USA

E-mail: [tom-brown@uiowa.edu](mailto:tom-brown@uiowa.edu)

## INTRODUCTION

Treatment of a displaced intra-articular fracture poses great orthopaedic challenges. It is believed that the residual incongruities after treatment induce stress aberration in the articular cartilage, and provoke an adverse mechano-response leading to degeneration of the cartilage (secondary osteoarthritis). Therefore, reduction of the fracture, to restore as smoothly congruent an articular surface as possible, is often viewed as critical to patient management <sup>[3]</sup>.

Conventionally, geometric descriptors (e.g. gaps, step-offs) obtained from xrays or intra-operative fluoroscopic images are utilized to evaluate the accuracy of the reduction. Such geometric estimations are not only surgeon- and image- dependent, but they have limited relationship with quantity of primary physical interest: the cartilage stress magnitude accompanying residual incongruity.

A new formulation using Discrete Element Analysis (DEA) <sup>[2]</sup> was developed to expeditiously compute the stress distribution throughout the gait cycle for an incongruous fracture situation. Combining such stress data with activity level, cumulative pressure exposure can be calculated, to assess the functional adequacy of provisional reductions and to find optimum fragment realignment.

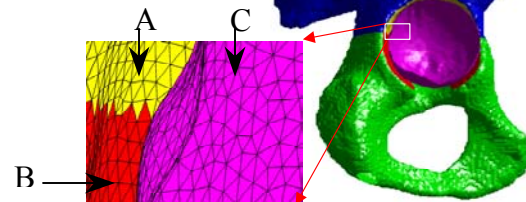
## METHODS

Acetabular fractures are useful as an example to present the method. A 3D voxel

hip joint model was reconstructed from segmented serial CT slices. A custom-written Matlab program was developed to pave the potential contact surfaces of the femoral head and acetabulum with smoothed triangular facets (Fig. 1).

Figure 1

A: Proximal fragment cartilage  
B: Distal fragment cartilage  
C: Femoral head cartilage



Treating the femoral head and acetabulum as rigid bodies, the region between them, i.e. the cartilage, is represented as an array of linear elastic compressive springs. The springs pass from the centroids of the acetabular facets to the nearest counterparts on the femoral head surface. The springs' stiffnesses in the normal direction (Equation 1) depend on the cartilage modulus ( $E$ ), Poisson ratio ( $\nu$ ) and thickness ( $h$ ). Due to the lubrication of the joint, the stiffness in the shear direction can be neglected.

$$k_n = \frac{E(1-\nu)}{(1+\nu)(1-2\nu)h} \quad [1]$$

A trans-tectal displaced fracture model was created by transversely sectioning the acetabulum, and displacing the proximal fragment in the supero-medial direction. Serial input ( $n=16$ ) loads and positions of the femoral head, corresponding to discrete

instants in the gait cycle, were used to calculate the stress distribution. For each facet, the difference between the deformed spring length and the intact spring length in the normal direction was used to compute the local pressure on the acetabular surface. From the stress distribution (P) thus obtained, a pressure damage threshold ( $P_d$ , 2MPa<sup>[1]</sup>), the time elapsed for each gait cycle increment ( $t_i$ ), and number of steps (N, 2 million) and seconds (SY) in a year, cumulative pressure exposure ( $P_c$ ) for the cartilage was calculated (Equation 2). The results were scaled to compare with literature on chronic cartilage pressure tolerance.<sup>[1]</sup>

$$P_c = \frac{\sum_{i=1}^{16} (P - P_d) t_i * N}{SY} * Years \quad [2]$$

## RESULTS AND DISCUSSION

For different residual step-offs (2.5, 2.0, 1.5, 1.0, 0.5 and 0mm), the cumulative pressure exposures were calculated for a 2-year time span. Taking 10MPa-years as a threshold for OA onset<sup>[1]</sup>, any region experiencing a supra-threshold cumulative pressure dosage is considered as at risk for degeneration. (Figure 2)

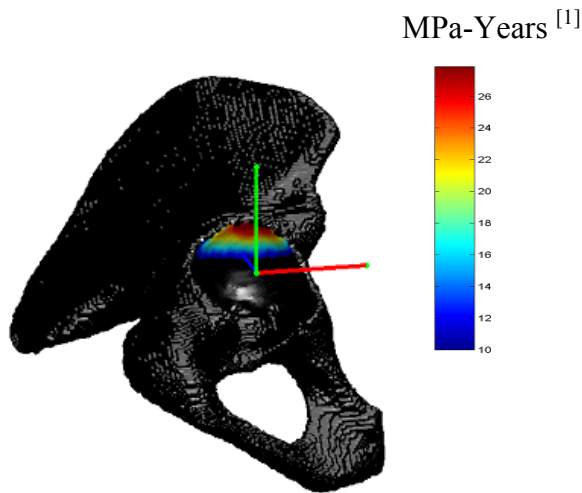


Fig. 2 Distribution of cumulative pressure exposure at 2 years, for a 2mm step-off

**Table 1:** Cartilage area experiencing over 10MPa-years of cumulative over-pressure (Total potential contact area = 3402.9mm<sup>2</sup>)

Step-off (mm)	2-year Overpressure Area (mm <sup>2</sup> )	Years needed for 5% area to reach 10MPa-years
0	0	N/A
0.5	6.68	2.3
1.0	486.89	1.5
1.5	576.34	1.2
2.0	700.60	0.9
2.5	988.94	0.6

From the results, the area with  $P_c$  over 10MPa-years, and the rate at which that threshold is approached increase with the enlargement of the step-offs. For the displaced intra-articular fractures with over 1mm of residual step-off, more than 15% of the acetabular cartilage becomes at risk for degeneration in 2 or less years. OA onset times in the range of 0.5-2 years are commonly observed clinically for similar injuries.<sup>[3]</sup>

For this particular fracture model, most of the degeneration-prone regions are at the superior rim of the acetabulum. The reason is that, with "widening" of the acetabulum due to the incongruity, the femoral head can be displaced (subluxated) under loading. With such displacement, the femoral head comes into preferential contact with the rim of the acetabulum.

With refinement this technique lends itself to use computerized datasets to predict clinically relevant joint contact loading for articular fractures. This information could help determine the need for operative intervention, assess the predicted loading and prognosis after operative intervention and in the future be used real-time during surgery to guide operative decision making.

## REFERENCES

- [1] Hadley *et al*: *J. Ortho. Res.* 8: 504-513, 1990 [2] Kawai *et al*: *Conf. Comp. in Civ. Engn.*: 1-16, NY, 1981 [3] Matta *et al*: *JBJS* 1996 78A 1632-45