Prognosticating Acetabular Fractures Using CT Analysis

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Introduction:
Displaced acetabular fractures occur in young adults as the result of high-energy trauma. In many cases, surgical reconstruction leads to excellent patient outcome [1]; however, it is recognized that some fracture patterns have worse prognoses than others. Current methods of analysis and classification of fractures are limited in their ability to predict functional outcome in acetabular fractures [2].

Previous CT based study of healthy acetabuli showed that measured bone density distributions corresponded with areas considered to be under the highest load (in agreement with Wolff’s Law, the concept that bone grows in response to mechanical loading). It is hypothesized that measurement of damage to the regions of highest mechanical load will give a better prediction of patient outcome than is currently available, allowing clinicians to improve treatment planning for patients with poor prognoses.

This study aims: 1) to quantify initial damage to acetabular subchondral bone through measurement of bone density and the location and extent of fracture lines in relation to twelve previously defined regions of the acetabulum and 2) to evaluate these values as predictors of patient specific functional outcome.

Materials and Methods:

Preoperative CT scans were analyzed from 25 patients who received surgery for unilateral acetabular fractures. Using AmiraDev4.1 (Visage Imaging, Carlsbad, USA) and custom image-analysis code, an intensity map was generated from the CT scans for the broken acetabuli and the contralateral healthy acetab. Each broken acetabulum was manually reconstructed prior to the generation of the intensity maps.

Intensity maps were split into twelve regions corresponding to those previously studied in healthy acetabuli: four quadrants (superior, inferior, posterior and anterior) that were each split into radial thirds. The average intensity of the CT scan was measured for each of these twelve regions (Figure 1). If the bone was too badly damaged to allow full reconstruction (without gaps), areas without bone in the acetabulum were defined to have a minimal intensity value. The number of fracture lines and their lengths were also recorded for each region.

All patients completed a quality of life survey package at least two years post-operatively. Scores to quantify functional outcome were generated from the MFA lower extremity domain (Move), SF-36 “Physical Functioning” (PF) and SF-36 “Bodily Pain” (BP).

For each acetabulum (intact and fractured), regional densities were normalized to the average density of all regions in that acetabulum. The average length of a fracture line in a region was examined over multiple and individual regions.

Results:

The 25 patients in the study had an average age of 39 years (range 19 to 74, median 40). There were 19 males and 6 females.

The normalized density of regions 8 and 12 of the fractured acetabulum was statistically significantly correlated with the average functional outcome score ($R^2 = 0.230, 0.267$ respectively, $p<0.05$). Adjusting for normalized regional density on the intact side resulted in an even stronger association of injured regional bone density with function in regions 3, 8, 9, and 12. The strongest correlation was observed between the average adjusted density in regions 8, 9 and 12, and the average functional outcome score ($R^2 = 0.404, p<0.001$).

Decreased density in regions 8, 9, and 12 correlated with negative outcomes. When regions 8, 9, and 12 were injured, region 3 tended to remain intact resulting in a negative correlation between adjusted density in region 3 and functional outcome. Similar associations were observed in regions 8 and 12 when fractured acetabuli were normalized directly to their contralateral healthy acetab.

The average length of a fracture line in all regions excluding the inner 4 regions (1-4) was weakly and negatively correlated with functional outcome ($R^2 = 0.211, p<0.05$). Unlike the regional dependency for the density / outcome relationship (regions 8, 9, and 12), the average fracture length in individual regions showed no association with functional outcome.

A multiple regression of average fracture line length and the difference in density distribution for regions 8, 9, and 12 yielded the strongest correlation with functional outcome (Adjusted $R^2 = 0.519$, $p<0.0005$, Figure 2).

Discussion:

Damage to the posterior wall (region 9) and dome (region 8 and 12) of the acetabulum may result in more severe functional compromise due to the high mechanical loads experienced by those regions. Referencing the intact acetabulum for the density distribution data minimizes the effect of inter-patient variability, improving the predictive ability of the analysis. It was found that smaller average fracture lengths over regions 5-12 corresponded with worse functional outcome. This indicates a comminuted fracture with many small components may affect functional outcome more negatively than long simple fracture lines.

The ability to prognosticate functional outcome based on CT analysis at the time of injury can be used to guide the development of new surgical techniques designed specifically around cases with poor outcomes and can facilitate accurate comparisons of current surgical techniques by providing an expected outcome for reference. While patients with acetabular trauma frequently suffer from multiple traumatic injuries, making it difficult to isolate the acetabulum’s effect on the patient’s well-being, we have shown that damage to the subchondral bone in key regions of a fractured acetabulum can be successfully quantified and used in the prognosis of functional outcomes. Further research is needed to refine and fully automate this CT analysis based method before these measurements can translate into a clinical prognostic tool.

References:


Figure 1: Left: average acetabulum densities shown in twelve regions of a right unfractured acetabulum. Right: density map of a fractured left acetabulum. Yellow landmarks follow fracture lines and unrecoverable bone is identified by the dark blue (low density) surface.

Figure 2: Predicted outcome based on multiple regression of the average difference in normalized density distribution for regions 8, 9, and 12 and the average length per fracture line recorded in regions 5-12 to predict the averaged outcome score. The two variables were uncorrelated, allowing them to be included in the same model.