Interactive Three-Dimensional Computational Reconstruction of Intra-Articular Fractures

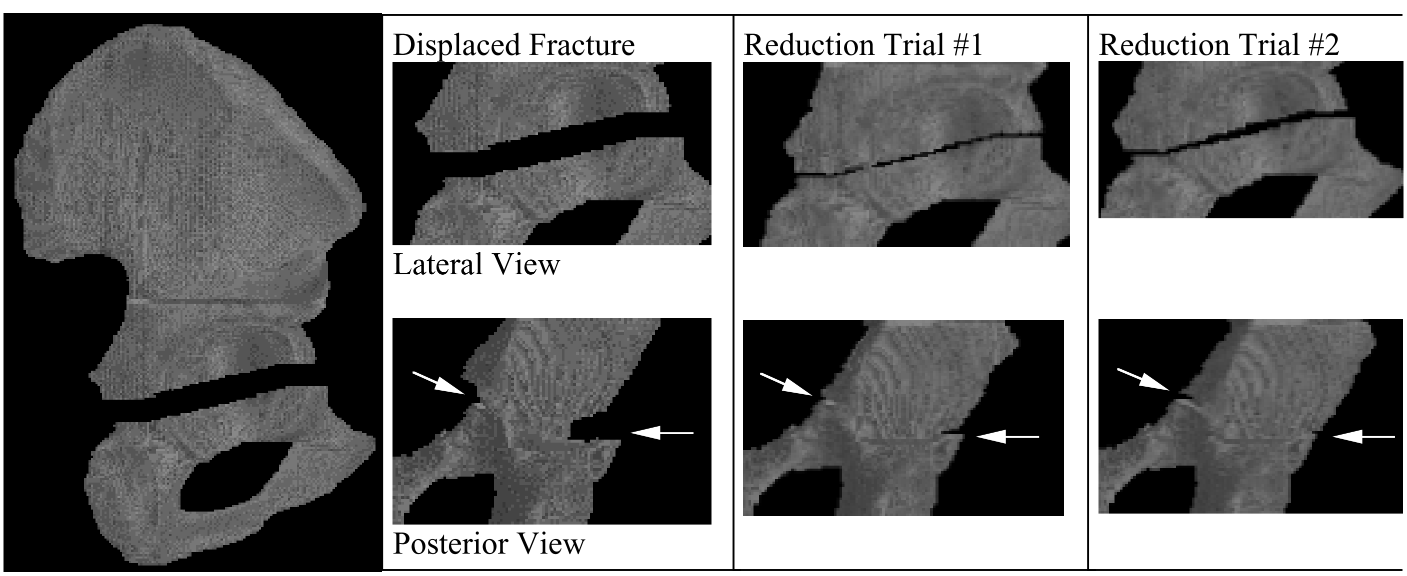
Yang Dai, Douglas R. Pedersen, Nicole M. Grosland, and Thomas D. Brown
Orthopaedic Biomechanics Laboratory, University of Iowa

Introduction: Reducing intra-articular fractures poses a number of orthopaedic intra-operative challenges. These include identifying the fracture surfaces themselves, and finding anatomically admissible kinematic pathways to manipulate the fracture fragments so as to optimally restore articular surface congruity. And, once a reduction is provisionally obtained, assurance is needed as regards avoidance of excessive cartilage contact stress. Clinical cases are not an effective research vehicle for systematic study of these issues, owing to injury heterogeneity, and to the compelling need to prioritize individual patient welfare above evaluating treatment alternatives. Various human cadaveric models and animal models have studied contact stress aberrations from geometrically simplified incongruities (e.g. step-offs, gaps), but such geometrical idealizations have limited correspondence to the complexity of actual fracture sites.

We here report a new approach, using computational manipulations of fragments segmented from CT-scans, analogous to the physical manipulations performed intra-operatively by the trauma surgeon. The result is a digital reconstruction of the fractured articular surface(s), suitable for geometric measures of residual incongruity, as well as voxel-based finite element contact stress analysis.

Methods: Using a PV-Wave programming environment, manually segmented fragments of a displaced intra-articular fracture are incrementally translated and/or rotated, in three dimensions, under operator control. By means of viewpoint shifts and zooms, the operator re-apposes fragments, analogous to the process of putting together the pieces of a puzzle. Commanded incremental fragment motions that would involve inter-penetration of bony members are disallowed, and the operator is correspondingly cued. After each incremental motion, the fragment is re-sampled in the original global coordinate system, thus allowing running tabulation of point-to-point separations (decrements from ideal re-apposition of the fracture surface), as well as global indices of reduction adequacy.

Results & Discussion: Typical best-effort trials of computational reconstructions of a transverse acetabular fracture (Figure) mimic the intra-operative difficulty of obtaining anatomically exact re-apposition of a complex, irregular fracture surface. Each such computational result effectively represents a pseudo-CT-scan of the corresponding provisional reconstruction, from which both kinematic and kinetic measures of reduction accuracy can be evaluated for purposes of planning the physical surgical procedure. Moreover, looking ahead, the fragment translation/rotation sequence resulting in a clinically optimal fragment reduction is available as input to robotic actuators, for purposes of physical implementation in an image-guided-surgery environment.



Acknowledgements Financial support provided by NIH AR46601.