Biomechanic Simulations of Fracture Nonunions can Determine the Need for Additional Biologic Procedures during Revision Surgery – A Finite Element Analysis

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INTRODUCTION:

Fracture nonunions are associated with a significant personal and socioeconomic burden of disease. If infection is ruled out the two main determinants of nonunion are vascularity and local mechanics. Aim of our study was to test the capability of our in vivo simulation workflow to calculate the mechanical environment of a nonunion fracture gap, determine the mechanical adequacy of primary and revision treatments, and estimate the need for additional biologic measures in a revision setting.

METHODS:

In a prospective, case series of nonunion patients requiring operative revisions a musculoskeletal simulation was performed. Clinical imaging was used to construct a three-dimensional CAD-model of the treatment situation before and after nonunion revision. Resulting forces are then computed in a simulation-driven workflow (Braun et al. Frontiers in Surgery 2021) based on motion capturing data. The forces are used to simulate the mechanical fracture environment. From the simulation implant stresses for the initial and revision situation, as well as interfragmentary movement and resulting strain, are calculated and compared to the clinical course.

RESULTS:

Twenty patients have been included in this study to date. Overall 2 clavicle nonunions, 5 humeral, 2 forearm, 7 femoral, and 4 tibial nonunions were included. The simulation workflow was able to calculate implant stresses, interfragmentary movement, and resulting stresses in all anatomical locations. The mechanical changes through implant revision could be accurately calculated. By increasing stability, as simulated, hypertrophic nonunions showed clinical healing by simply addressing the mechanical nonunion aspect. Atrophic nonunions were additionally treated with autologous bone graft. The simulation model was also able to adequately predict high implant stresses in cases with initial implant failure before nonunion revision.

DISCUSSION AND CONCLUSION:

Our workflow is able to simulate the mechanical environment of a fracture fixation, calculate implant stresses, interfragmentary movement, and the resulting strain (Fig. 1). Critical mechanical boundary conditions for nonunion healing can be calculated in relation to patient specific motion capturing. The simulation can assist in determining the best treatment pathway during nonunion revision surgery, especially for considering additional biologic measures in not purely mechanical nonunions.