Mapping the Mechanical Environment of a Fracture Nonunion Gap Pre- and Post-Revision Surgery Can Determine Healing Potential: A Finite Element Analysis

Benedikt J. Braun; *Maximilian M. Menger; Tina Histing; Steven C. Herath; Mika F. Rollmann; Tanja Maisenbacher; Annchristin Andres; Stefan Diebels; Michael Roland*

Purpose: Impaired bone healing is a major burden for both the patient as well as socio-economically. Apart from biology, the mechanical fracture environment is a key factor contributing to nonunion development. A novel simulation workflow from our group has shown that the mechanical boundary conditions for fracture healing can be determined individually with finite element simulation. The aim of this study was to apply this workflow in different nonunion situations, determine the mechanical adequacy of primary and revision treatments, and match the mechanical conditions to the healing potential to define safe, mechanical boundaries for nonunion healing.

Methods: In a prospective, case series of nonunion patients requiring operative revisions a mechanical simulation was performed. Pre- and postoperative CT scans were used to construct individual 3D computer-aided design models. From individual motion capturing the resulting forces were computed in a simulation-driven workflow. These forces in combination with the 3D models are used to simulate implant stresses, as well as interfragmentary strain.

Results: 30 patients have been included in this study (10 humerus, 12 femur, 8 tibia). The simulation workflow was able to calculate implant stresses, fracture movement, and resulting strain in all tested locations. These can then be mapped to known healing boundary conditions. When addressed, the mechanical effects of revision surgery on the nonunion mechanics could be clearly simulated and their impact on nonunion areas transferred to within proven healing boundary conditions visualized (Fig. 1; humeral shaft nonunion): AP radiograph before revision (a), with high implant (b) and callus strain (c) distribution before revision; AP radiograph 3 months after revision with additive plate osteosynthesis showing radiographic healing (d), and markedly reduced implant (e) and callus strain (f)). Boundary conditions for safe healing of the nonunion gap could be derived and confirmed by the individual clinical course.

Conclusion: The workflow is able to visualize the mechanical conditions of a nonunion situation and determine the amount of a nonunion gap within or outside of published healing boundaries. This allows the identification of the mechanical contribution to nonunion development, can guide revision surgery to address deficits in stability, and enable a postoperative estimation of the healing potential. In mechanically adequate situations it can gear the therapy toward further biologic measures.