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Individualized Determination of the Mechanical Fracture Environment in lower extremity non-unions - A Simulation-Based Study

A. Andres[1]*, M. Roland[1], K. Wickert[1], S. Diebels[1], T. Histing[2] and B. Braun[2]

[1] Saarland University, Chair of Applied Mechanics, Campus A4 2, D-66123 Saarbrücken, Germany, m.roland@mx.uni-saarland.de, https://www.uni-saarland.de/lehrstuhl/diebels.html

[2] University Hospital Tuebingen on Behalf of the Eberhard-Karls-University Tuebingen, Faculty of Medicine, BG Hospital Tuebingen, Schnarrenbergstraße 95, D-72076 Tuebingen, Germany, bbraun@bgu-tuebingen.de, https://www.bg-kliniken.de/klinik-tuebingen/

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Interfragmentary movement (IFM) is a key quantity for healing in mechanically compromised non-union situations. Based on the clinical workflow for patient monitoring presented in [1], we have generated high-resolution computational models for several patients with fracture non-unions of the lower extremity. These models are used to simulate and to analyse patient-specific issues of healing parameters, local micro-mechanics inside the fracture gap and personalized implant strategies both before and after surgical non-union revision.

Our established clinical workflow consists of the following steps: (1) Monitoring of the patients during the planning and follow-up visits with a motion capturing system (Xsens™), (2) transfer of the motion data into the musculoskeletal simulation system AnyBody™ to achieve the corresponding individual muscle and joint forces, as well as moments. (3) Clinical imaging of the patients if available via post-operative computed tomography (CT) scans ideally combined with a six-rod bone density calibration phantom. (4) Segmentation of the CT images and generation of the corresponding adaptive finite element (FE) meshes of the bone-implant-systems, including the material parameters based on the Hounsfield units and the calibration phantom via the software ScanIP™ (Synopsys, US). (5) All information from the musculoskeletal simulation were passed as patient-specific boundary conditions to our biomechanical FE simulation process based on the patient-specific meshes. This workflow (Figure 1) allows us to simulate individual patient models based on their respective real motion data over their treatment course. This enables us to analyse questions about mechanical influences during primary and revision surgery contributing to non-union development, as well as consecutive healing. Based on the described workflow, different motion patterns were analysed and compared with respect to the effects on the micromechanics of the non-union situation. Thereby, it is shown that both the individual motion parameters and the individual fracture morphology have a lasting influence on the local healing parameters. In addition, such simulations allow an investigation of the von Mises stress distribution of the implant systems during the movement of the individual patient, which allows various conclusions for future design optimizations. The results allow a first estimation of the individual non-union healing capability based on fracture gap mechanics. However, additional studies and larger patient cohorts are needed to further substantiate the conclusions. A limitation of this study also lies in the definition of the mechanically meaningful healing window for fractures. Here, further factors will certainly have to be included in future simulations and virtual studies.

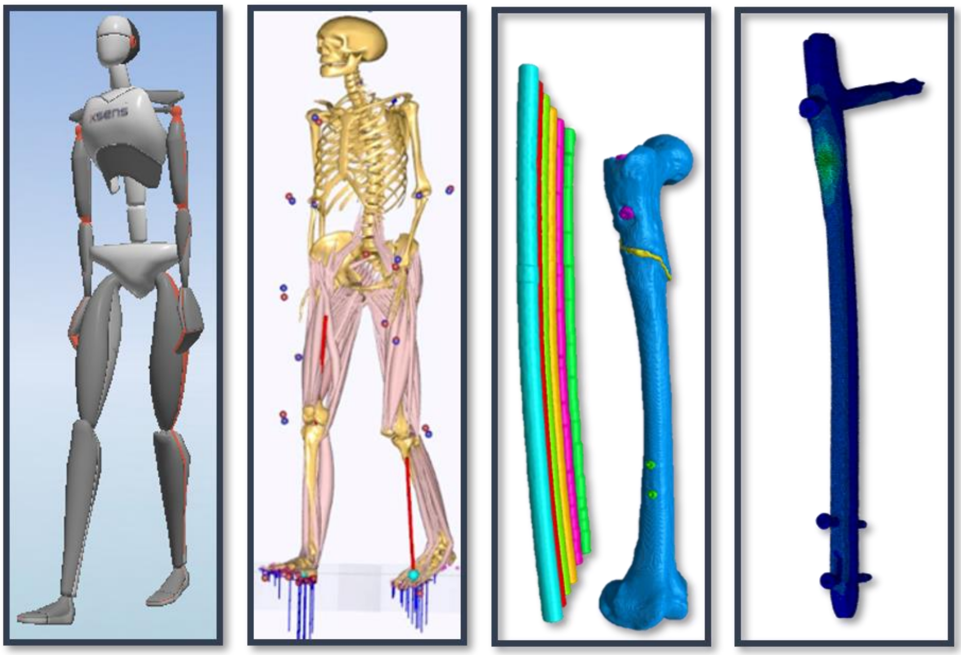

Figure 1:
a) Digital Avatar of Xsens^{TM}
b) Musculoskeletal simulation with AnyBody^{TM}
c) Segmentation with ScanIP^{TM}
d) Simulation with finite element analysis software

REFERENCES

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