IN-SITU DETERMINATION OF SPATIAL STRAIN MAPS IN PORCINE GROWTH PLATES BASED ON MRI LOADING EXPERIMENTS

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Introduction

Mechanical loading is one of the regulating factors for longitudinal bone growth. Within physiological limits, compression of the growth plate (GP) has a stimulating effect, whereas exceeding a critical load is linked to the progression of deformities in the skeletally immature [1]. To implement growth modulating interventions, the relationship between mechanical loading and the resulting alteration in growth behavior must be understood. Because of the inhomogeneous morphology of the GP, knowledge of the continuous spatial distribution of strains throughout the GP thickness is of particular interest [2]. Therefore, the aim of this study was to assess the spatial strain distribution of porcine femoral GP under compressive loading.

Materials and Methods

Six fresh porcine knee joints (age: ~6 month) were dissected and mounted in an MRI compatible loading apparatus (Fig. 1), which allowed controlled axial compressive loading [3]. T1-weighted MR images were acquired using a 3T MRI scanner (Philips Medical Systems) for both unloaded and loaded (500 N, 1000 N) conditions [4]. Rigid and non-rigid image registration were performed to obtain the deformation of the femoral GP including the adjacent proximal and distal layers under the respective loads [3,4]. After segmentation of the GP, a distinct transition layer between the GP and the femoral metaphysis (GP_{tran}), along with layers of the femoral metaphysis (F_{meta}) and epiphysis (F_{epi}), a hexahedral finite element model was created using customized MATLAB routines. Finally, the obtained deformation field was applied to the finite element model to calculate strain maps using ABAQUS. Based on the median strain for each distinct layer, statistical analyses were performed using SPSS, while $p \leq 0.05$ was considered statistically significant.

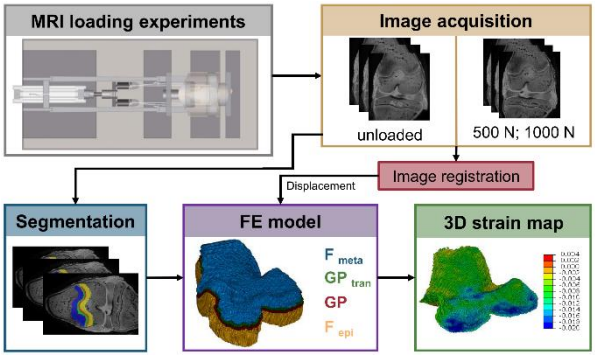

Fig 1: Schematic illustration of the strain map determination based on MRI loading experiments.

Results

The axial compressive strains in the GP and transition layer (GP_{tran}) were significantly increased by up to 264% compared to the femoral epiphysis (F_{epi}, $p \leq 0.022$) for both loading conditions (Fig. 2). In addition, axial strains increased significantly after doubling the load from 500 N to 1000 N ($p \leq 0.028$) for all layers. The maximum compressive strain of 7.9% occurred in the anterior region of the GP. Regarding the stains in lateral-medial direction, no significant differences were observed. In contrast, the strains in the anterior-posterior direction of the GP were significantly higher than in the proximal transition layer (GP_{tran}, $p \leq 0.005$) and femoral metaphysis (F_{meta}, $p \leq 0.005$) for both load levels.

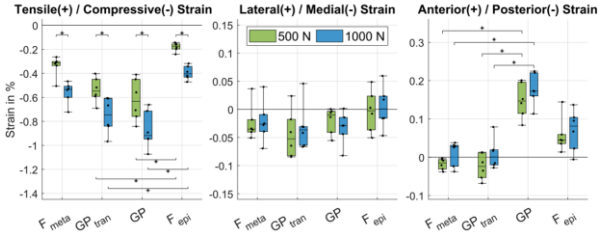

Fig 2: Box plots of the determined spatial strains for all tissue layer and load levels.

Discussion

To our knowledge, this was the first study reporting on continuous spatial strain maps of the femoral GP *in situ* under physiological compressive load conditions in a large animal model. The most important finding of the study indicates that the compressive strains within the cartilaginous GP were up to three times higher than in the adjacent bone tissue. Further, it was found that the strain distribution in the GP was highly inhomogeneous for all six specimens. This knowledge can contribute to a better understanding of the mechanobiology of the GP by identifying the strain patterns in different regions. Based on the determined spatial strain maps combined with the applied load during the experiments, region-dependent material properties can be identified using inverse FE analyses [5]. Moreover, the current approach can potentially be transferred to *in vivo* applications in human adolescents and thus may provide new insights for epiphysiodesis.

References

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