HYPERELASTIC MATERIAL PROPERTIES OF PORCINE GROWTH PLATES VARY BY ANATOMICAL LOCATION

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Introduction

Simulation models of the knee can be used to investigate the local mechanical loading in the growth plate (GP) e.g. during gait. In order to obtain valid models, boundary conditions such as the material properties must be known. The cartilage of which the GP consists shows a typical viscoelastic behavior [1]. Since the fluid exchange of the growth plate with the surrounding tissue is slow, simplified material models, such as hyperelastic models, are also appropriate for various models [2]. The material behavior of the GP is highly inhomogeneous in relation to the depth [1] and anatomical location [3]. This study therefore aims to investigate the material properties of the different areas of the GP and to correlate them with histological examinations of the specimens.

Materials and Methods

Compression tests were conducted at cylindrical porcine bone-GP-bone samples (⌀ 8 mm), from different anatomical locations. The tests were carried out according to the termination point method, to separate equilibrium elasticity from the viscoelastic behaviour. Here, the sample was loaded and unloaded in 10 N steps up 50 N (≈ 4x body weight (BW)). At each step, the deformation was kept constant for 300 s. The termination points represent the stress-strain curve in equilibrium [4]. A hyperelastic material model after Yeoh was fitted to the loading path of each sample.
Samples were processed for histology and safranin O/fast green and MOVAT's pentachrome stainings. Histomorphometric analysis included determination of the height of the growth plate (GP) and of the resting (RZ), proliferative (PZ) and hypertrophic (HZ) zones, as well as chondrocyte area in the hypertrophic zone.

Results

The hyperelastic model after Yeoh is sufficient to describe the test data with a minimal R^2 of 0.941 (mean R^2 of 0.995) for all data sets. A statistical analysis showed a difference in medial and lateral samples, were for the same stress medial samples showed a higher strain. This was significant above stresses equivalent 76% BW (Figure 1).
The average growth plate height was slightly lower in the lateral region compared to the medial (733±47 and 973±227 µm, respectively), which seemed to be mostly impacted by a slightly lower resting zone (217±59 and 417±171 µm in the lateral and medial regions, respectively; Fig. 2 A, B). The resting zone represented about 29% of the total height of the growth plate in the lateral region, but about 41% in the medial region. The proliferative region represented about 43 and 35% and the hypertrophic 23 and 27% in the lateral and medial regions.

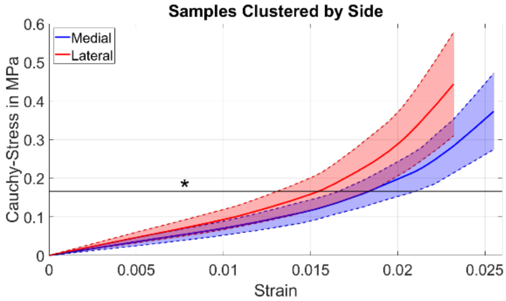

Figure 1: Stress / Strain relation, clustered by the medial (blue) and lateral (red) side of the growth plate. The asterisk indicates the significance level, above medial and lateral samples are significant different

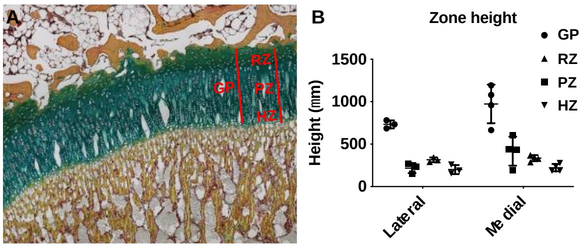

Figure 2: Histomorphometrical analyses of lateral and medial regions of porcine distal femoral growth plate. (B) MOVAT's pentachrome staining with height of total growth plate (GP), resting (RZ), proliferation (PZ), and hypertrophic (HZ) zones.

Discussion

It was shown, that the material behavior of the GP is non-linear in equilibrium state, which is particularly important for alternating loads, such as the gait.
The height of the growth plate, particularly of the resting zone, was shown to be variable in the different regions. Differences in the tissue histomorphometry within the resting zones could explain their different mechanical behavior. Where the softer medial samples had a higher height of the GP and thus more deformable material compared to the lateral samples.
This study provides a testing protocol to investigate the GP material in its equilibrium state in physiological load conditions.

References

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