Biomechanics of the Transitional Zone between the Meniscus and Its Ligamentous Attachments

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Introduction: Meniscal root tears can occur as bony avulsion of the attachment ligament, as tear of the attachment ligament itself, or as tear of the transition zone between ligament and meniscal body [1,3]. While the meniscal ligaments and meniscal tissue have been studied before, there is little known about the transitional zone between meniscal body and its horn attachments. Therefore, the aim of this study was to biomechanically characterize this zone. Due to the structural differences between ligament and the fibrocartilaginous meniscal body it was hypothesized that the transitional zone is the structure most likely to fail during tensile loading.

Methods: Two dumbbell shaped samples (waist size: width 2 mm, length 3.4 mm), oriented parallel to the main fiber direction of the anterior and posterior horns were obtained from the lateral and medial menisci of six human donor knees (67.5 ± 19.5yrs; Fig.1A, B). To obtain further insight the samples were divided into a central (C) and a tibial (T) layer with a thickness of 1mm (n_total=96; Fig.1C). The specimens were clamped in a materials testing machine (Z10, Zwick, Ulm, Germany) using custom made grips. After preconditioning at 10% strain for 10 minutes the samples were tested to failure at a displacement rate of 100% L_0/min. Maximum stress and strain (σ_max, ε_max) and the linear modulus (E_lin) were determined from the stress-strain curves. E_lin was computed between ε_1=10% and ε_2=15%. During testing the specimens were kept moist. Normally distributed data were statistically analyzed using a paired t-test (SPSS). p≤0.05 was considered statistically significant.

Results: Compared to the central layer σ_max,TIB of the tibial layer was statistically higher for the antero-medial and postero-medial samples (Fig. 2; p<0.05). ε_max of the anterior medial transitional zone was significantly higher (p≤0.05) than those of the other locations (data not shown). E_lin showed the tendency to be higher in the tibial layer compared to the central layer (Fig. 3). 90% of the samples ruptured at the region of the transitional line. The remaining 10% showed no distinct tear pattern.

Discussion: This study investigated the tensile properties of the transitional zone between meniscus and horn attachment for the first time. Mean E_lin (80 MPa) of the transitional zone was between those of circumferential samples of human menisci (68 MPa [5]) and human meniscal attachment ligaments (13 MPa [2]). This shows the smooth transition from meniscal to ligamentous tissue. At the same time the strength σ_max (12.4 MPa) was found to be lower than the strength of both meniscus (24.5 MPa [2]) and ligamentous attachment (16.7 MPa [6]). This confirms our hypothesis that the transition zone is the weakest link in the meniscus-meniscal attachment complex.
**Significance:** The mechanical properties of the transition zone of the meniscal attachment assessed in the present study will help to model the transitional zone more accurately in finite element studies. It may also be useful for the development of fixation strategies of new meniscal substitutes. It further contributes to a better understanding of the origin of a meniscal root tear, and possibly enhance the surgical treatment of this injury [4].