QUANTITATIVE MEASUREMENT OF HUMAN MENISCAL STRAIN

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Introduction

The structure and composition of the medial and lateral menisci of the human knee play significant role in force transmission across the knee joint. These C-shaped discs are composed primarily of fibrocartilage aligned circumferentially along the outer edges of the tibial plateau. According to the hoop stress theory of meniscal function, axial loads across the knee joint are distributed throughout the menisci as tension in these circumferentially arranged fibers. Presently, no quantitative means exists to measure this direct indication of meniscus function.

In a society where “weekend warriors” and dedicated athletes perform side-by-side, meniscal injury presents itself as one of the most common orthopaedic complaints. Tears are often treated with partial or total meniscectomy; though repair, replacement and grafting exist as alternative options. Without means to properly evaluate meniscus mechanics, the effectiveness of such treatments, as well as developing techniques, is merely subjective.

A Differential Variable Reluctance Transducer (DVRT, Microstrain Inc.) is proposed for the direct measurement of the circumferential expansion, or “hoop” strain, exhibited by the meniscus during loading to varied weights and at varied postural configurations. To facilitate such testing on human cadaveric specimens, an experimental testing mechanism is developed to accurately simulate the movement and loading of the knee. In addition to the DVRT measurements, Fuji Pressure Sensitive Film® is employed to simultaneously evaluate internal knee pressures. By comparing Fuji Film impressions with DVRT data, use of the DVRT is validated and a more meaningful understanding of meniscal mechanics is attained.

Methods

An experimental testing jig and set of protocols have been designed and implemented to measure hoop strain in the human meniscus. The jig includes top “hip” and bottom “ankle” assemblies that are mounted onto a series 4200 Instron machine. When used with a cadaveric knee specimen, the jig simulates knee motion with full kinematic freedom. To facilitate bent-knee, quasi-static testing, a quadriiceps tendon clamp and tensioning mechanism have been developed. Together, they allow the knee to flex while applying quadriiceps load up to 2500 N (3.5 x body weight), similar to those seen in vivo during squatting or walking. A DVRT is used for direct measurement of meniscus fiber deformation in response to axial loads across the knee joint. It consists of a rod and tube, each attached to a barb. The barbs are inserted into the tissue. Therefore, by measuring the displacement of the rod in tube, the longitudinal deformation of these circumferential fibers in response to knee joint load is recorded. In addition, pressure sensitive film is used to obtain contact areas and pressures within the knee capsule. Static and quasi-dynamic motion analyses are thus performed to assess the function of the human meniscus in response to knee joint loads, translations, and rotations.

Loads are first applied to the knee constrained in a straight-leg configuration. Approximately 800 N, 1200 N, and 1600 N are applied in turn, through several cycles. DVRT as well as Fuji Film data is recorded. Next, the knee is unconstrained and the quadriiceps tensioning mechanism engaged. Again, the knee is loaded corresponding with Instron forces between 800 N and 1200 N. The quadriiceps device is then slackened, allowing further flexion, and the loading repeated. As greater flexion angles are achieved, lesser load must be applied through the Instron to maintain comparable internal knee loads.

Internal knee loads are calculated as a function of the externally applied load and testing configuration. They are statically determined as a result of Instron force applied, quadriiceps tension, and knee flexion angle. Greater flexion angles result in larger internal forces for the same externally applied load by the Instron.

Discussion

The use of a DVRT strain gauge provides greater insight into meniscal function and pathology by directly measuring the deformation of the fibrocartilage as it expands by hoop stress. Compared to Fuji Film, which does not indicate shear, the DVRT may be used during both straight and bent–knee testing, maintaining its significance to meniscus function.

From the preliminary data presented, DVRT strain gauge results follow similar trends across multiple specimens. This indicates the potential for stronger correlations given further investigation with a greater number of specimens. The DVRT strain gauge provides a quantitative means for strain measurement and can be further explored to provide clinically relevant information regarding meniscus tears and methods of repair.

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