EFFECT OF INTERNAL AND EXTERNAL KNEE ROTATION ON HOOP STRAIN IN THE MEDIAL MENISCUS

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INTRODUCTION

Menisci contribute to load distribution, damping and stabilization of the knee. Meniscal tears are a common injury in the young and active population and can lead to posttraumatic osteoarthritis. Despite the high incidence and debilitating potential of meniscal tears, surprisingly few studies have addressed meniscus function and injury mechanisms. Meniscal tears are believed to occur during combined axial loading and twisting of the knee, and are most prevalent in the medial meniscus (Nielson, 1991). However, no study to date measured the effect of such combined axial and rotational loading on meniscus strain *in situ*.
This research examined the effect of combined axial loading and internal / external knee rotation on hoop strain in the medial meniscus of human cadaveric specimens with intact ligamentous and capsular constraints. Results of this study describe functional aspects of the intact meniscus, and hold implications for meniscal repair strategies.

METHODS

Four fresh-frozen human lower extremities (average age 74 years) were osteotomized 120 mm above and below the tibial plateau. Muscle tissue was removed, and the joint capsule and ligamentous structures were preserved. The diaphyses of each specimen were rigidly potted in base fixtures. Two arthrotomies of 1.5 cm length were made 1cm anterior and posterior to the middle of the medial collateral ligament in height of the joint line. Through these incisions, differential variable reluctance transducers (M-DVRT-3, MicroStrain Inc., Williston, VT) were placed in the peripheral border into the mid-substance of the medial meniscus. These DVRTs captured circumferential hoop strain ε_{AM} and ε_{PM} in the anteromedial and posteromedial medial meniscus, respectively. Each specimen was mounted in a knee loading simulator, driven by a bi-axial material test system (Instron 7800, Canton, MA) (Fig. 1).

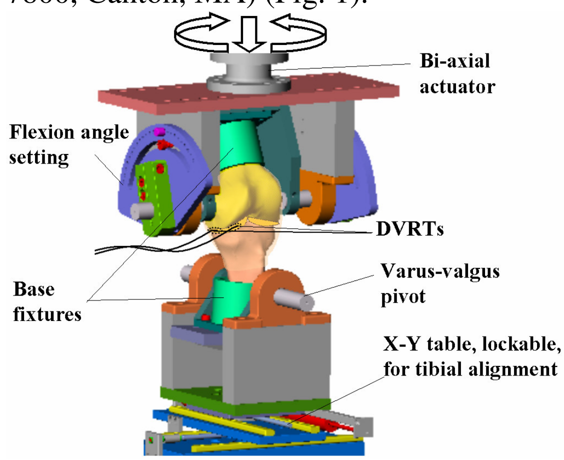

Fig. 1: Axial + rotational knee loading setup.

To ensure physiological loading, this setup accounted for anteroposterior and mediolateral tibial alignment, neutral varus/valgus alignment, and 60% medial / 40% lateral load distribution on the tibial plateau. Knee flexion angles could be fixed between 10° and 60° in 10° intervals. Each specimen was subjected to a loading sequence, starting with purely axial loading of 1,4 KN (2 x Bodyweight (BW)) at 140N/s under load control. While maintaining this axial load, 10° tibial internal rotation and 10° external tibial rotation were subsequently applied at 1°/s in displacement control. After testing at 30° knee flexion, the entire loading sequence was repeated from 10° to 60° flexion in 10° intervals. For each test, strain reports were extracted at 1,4 KN axial loading, and after 10° internal and 10° external tibial rotation. Effects of axial and rotation loading on meniscal strain were statistically analyzed with paired, two-tailed Student's t-tests at α=0.05.

RESULTS

Both, ε_{AM} and ε_{PM} yielded similar strain histories during the loading sequence (Fig. 2). No significant differences between ε_{AM} and ε_{PM} magnitudes were observed for any loading condition. Therefore, DVRT reports ε_{AM} and ε_{PM} were averaged as ε_{AVG}.

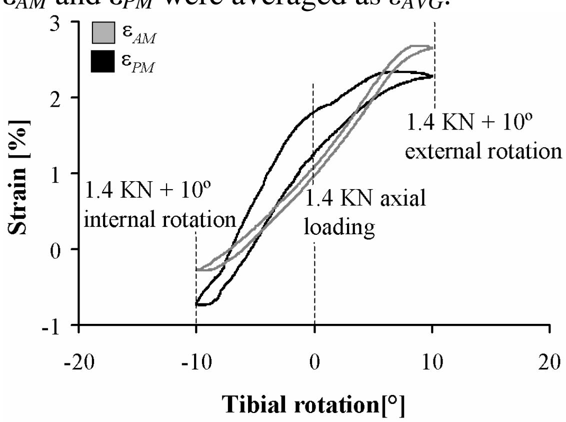

Fig. 2: Exemplary strain history of ε_{AM} and ε_{PM} for one load sequence at 30° flexion.

At 30° flexion, 1.4 KN axial loading induced meniscal hoop strain of ε_{AVG} = 0.9%±0.4%. External rotation resulted in a significant strain increase to ε_{AVG} = 2.1%±0.8% (p= 0.003). Internal rotation caused a decrease in ε_{AVG} to 0.2%±0.7%, however, this decrease was not significant. Knee flexion significantly affected meniscal hoop strain (Figure 3). At 10° knee flexion, 10° external rotation yielded ε_{AVG}=2.8%±1.3%. At 60° knee flexion, 10° external rotation induced significantly less strain, with ε_{AVG}= 1.3%±0.9%. This decrease of ε_{AVG} for increasing flexion angles was not significant for axial loading alone, or for axial loading and internal rotation. For knee flexion from 10° to 50°, combined external rotation and axial loading caused significantly higher strain as compared to axial loading alone.

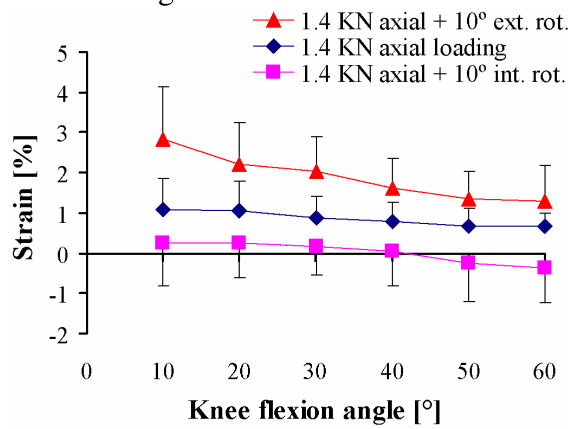

Fig. 3: Effect of knee flexion on ε_{AVG}.

DISCUSSION

This study documented for the first time strain in the medial meniscus under combined axial and torsional loading. Strain results for axial loading alone correlate with Jones et al. (1996), reporting medial meniscus strain in the range of 1.5% to 2.9% in response to axial loads of 3x body weight. The finding that meniscal strain can increase over two-fold during 10° external rotation holds implications for injury biomechanics and meniscal repair strategies.

REFERENCES

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ACKNOWLEDGEMENTS

Supported by Stryker Europe