Differences in knee ligament moment arms might contribute to the higher rate of ligament injuries in women compared to men

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Summary
Differences in knee ligament moment arms might contribute to the sex-disparity in knee ligament injuries. We used a population model of the knee to create finite element simulations of varus-valgus rotations and found that the moment arms of the medial and lateral collateral ligaments were smaller in women compared to men. This might potentially contribute to the higher rate of ligament injuries in women.

Introduction
Women are more prone to knee ligament injuries than men [1]. Differences in anatomy, biology, biomechanics and neuromuscular control have been cited as playing a role in this sex-disparity [2]. The moment arms of the ligaments provide a direct measurement of the mechanical advantage to support joint moments at the knee. However, there is no knowledge of the sex-differences in knee ligament moment arms. We have previously established that a female femur, when scaled to the same length as a male femur, has a reduced femoral epicondylar width by ~10mm [3]. The purpose of this study was to determine whether this difference in knee width would result in reduced moment arms of the lateral and medial collateral ligaments (LCL and MCL, respectively) to support varus and valgus moments.

Methods
Femur shape data from an existing shape model of 204 femurs [3] were used to scale a finite element model of the tibiofemoral joint to match three femur lengths (average; +1SD, and -1SD) and their corresponding male or female epicondylar widths, resulting in six models. The bones and cartilages were modelled as rigid bodies, and the ligaments were modelled as multiple nonlinear springs and optimized using joint laxity data from the literature [4]. We then applied a force of -5 to 6 N to the distal tibia, simulating five degrees varus to five degrees valgus rotation. The moment arms of the LCL and MCL were calculated as the perpendicular distance between the ligament and the location of peak tibial cartilage contact pressure. In this manner, the condylar mechanics of the knee were taken into account to define the appropriate axis of rotation.

Results and Discussion
The moment arms of the MCL and LCL were smaller for the female knees compared to the male knees (Figure 1 & Table 1). The largest moment arm difference was found in the LCL under a varus rotation (~5mm or 7.4% reduction comparing females to males). This indicates that the female LCL has a reduced mechanical advantage of 7.4%, compared to a male LCL with a comparable femur length.

In future work we will generate knee models across our population of 204 individuals to build a statistical model to predict the knee ligament moment arms from bone shape. Similar analyses can be performed to investigate muscle moment arms. This tool will have application to knee modellers and could also be used as a clinical tool to identify individuals who might be at risk of knee ligament injuries by virtue of having small moment arms.

![Mean moment arm difference (men–women) (±SD) (mm)](Image)

**Figure 1:** Mean differences in ligament moment arms (men – women). Smaller moment arms found in women compared to men.

**Table 1:** Mean female and male MCL and LCL moment arms found in varus and valgus rotation.

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<thead>
<tr>
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<th>Mean moment arm (±SD) (mm)</th>
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<tr>
<td></td>
<td>Varus (5 degrees)</td>
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<tr>
<td>LCL</td>
<td>MCL</td>
</tr>
<tr>
<td>Male</td>
<td>65.8 (±1.4)</td>
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<tr>
<td>Female</td>
<td>60.9 (±1.7)</td>
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Conclusions
Females have smaller varus-valgus moment arms of the MCL and LCL in comparison to males. This might potentially contribute to the higher rate of ligament injuries in women compared to men.

Acknowledgments
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References