3D Positioning of ACL Attachment Sites During Flexion

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Introduction

It is essential when performing anterior cruciate ligament (ACL) reconstruction, that the replacement ligament has sufficient mechanical properties to function during all activities; in addition, it should ideally be positioned as anatomically as possible. In order to mechanically test a synthetic ligament and assess how well it will function, it is necessary to know how the device will be loaded both axially and in torsion for different activities.

Very little information is published on dynamic knee movement for healthy weight-bearing patients. Johal *et al.* assessed patients using an open MRI which enabled weight-bearing MRI scans to be taken at different degrees of flexion so weight bearing motion was recorded directly [1]. The present study aims to examine whether the information published in Johal's study could be used to create a generic model of knee movement allowing the forces applied to a synthetic ligament to be approximated for different flexion angles.

Methodology

MRI scans from eighteen patients in a supine position (9 female, 9 male) were retrospectively collected, all scans were taken at 3-tesla resolution. None of the patients had a history of ACL damage and in all scans the ACL appeared healthy. The patient tibial and femoral geometry was determined from the scans using image segmentation software (MIMICS, version 14.1, Materialise) and the segmented mesh geometry was then output as a mesh. Co-ordinates attachment sites of the ACL were identified. The landmark points used by Johal *et al.* were identified on each patient's knee geometry.

Flexion Angle (°)	Weight Bearing		Passive Motion	
	Medial	Lateral	Medial	Lateral
0	21.2	25.0	24.8	26.1
10	21.3	20.0	23.8	24.7
20	21.9	17.5	23.7	24.0
30	22.0	15.2	24.1	23.7
40	22.1	14.5	24.6	23.3
50	22.2	13.3	24.9	22.5
60	22.6	12.4	24.9	21.2
70	22.8	12.0	24.6	19.6
80	22.6	11.6	24.2	17.8
90	22.6	10.8	23.7	16.0
100	21.7	10.0	23.2	14.3
110	20.6	9.0	22.9	13.0
120	19.2	7.7	22.7	12.0

Table 1. Interpolated distances (mm) from the posterior centre of the femoral condyles to the posterior tibial cortex as measured by Johal *et al*. for up to 120 degrees of flexion.

All calculations for the 3D knee motion were performed using Python (Version 2.7.3, Python Software Fdn). The movement each condyle in relation to the tibial cortex specified by Johal *et al.* were input to the model as a proportion of the condyle length (Table 1). For each patient geometry, rigid body transformations were used to position the femur in relation to the tibia so that the measurements made by Johal *et al.* were met. The corresponding twist and elongation of the synthetic ACL was calculated assuming the device was 6 mm diameter, had a stiffness of 97 Nmm^{-1}, representing the stiffness of an elderly patient, and a shear modulus of 0.00172 GPa.

Results and Discussion

The model was run for both weight bearing and passive motion. For both loading scenarios, ligament twist was relatively linear throughout flexion, a maximum range of 95.5 degrees in the axis of the ligament was found (Fig 1), which would result in a maximum torsional force of 3.9 N. Ligament strain peaked at approximately 50 degrees of flexion for weight bearing motion, passive motion showed no significant strain up until beyond 100 degrees of flexion which correlates well with the literature (Fig 2).

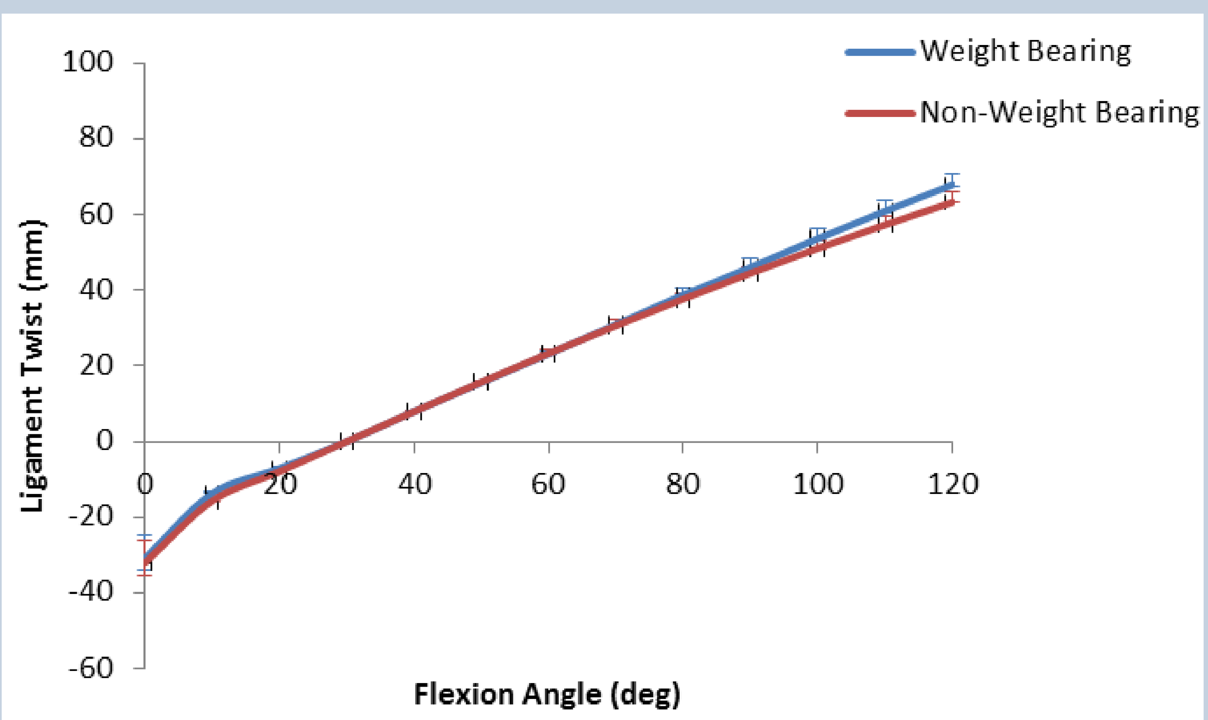
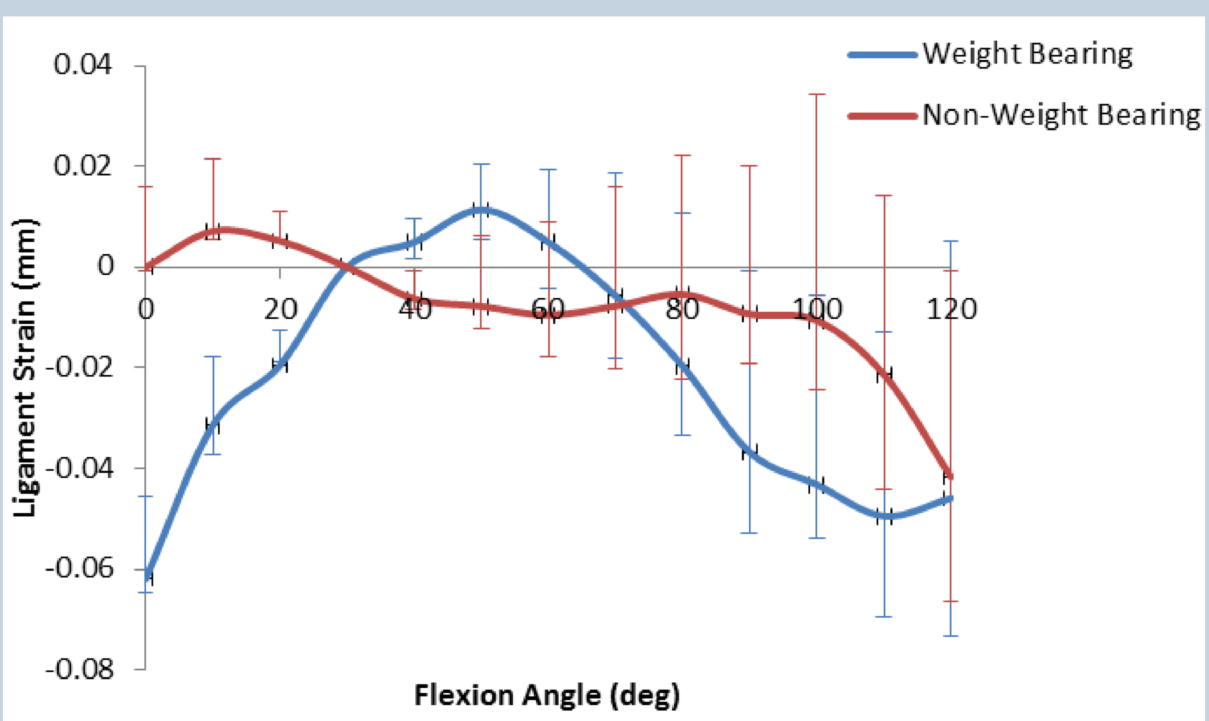


Figure 1. Twist of the ACL at different flexion angles. Error bars represent the inter-quartile range.

Figure 2. Strain in the ACL at different flexion angles. Error bars represent the inter-quartile range.



Conclusions

This study highlights the importance of considering both ligament twist as well as elongation when testing synthetic ligaments for ACL reconstructions. Abrasive fibre wear is a common issue with synthetic ACL replacements, it is possible that cyclic torsional loading tests could predict these problems.

[1] P Johal, A Williams, P Wragg, D Hunt, W Gedroyc. J Biomechanics (2005) Vol 38, Issue 2, p 269-276