Institute of Medical & Biological Engineering

Creep Behaviour of Human Tibiofemoral Joint under Body Weight

UNIVERSITY OF LEEDS

[1]Qingen Meng, [1, 2]Zhongmin Jin, [1]Ruth Wilcox, [1]John Fisher,
[1]iMBE, School of Mechanical Engineering, University of Leeds, UK, [2]School of Mechanical Engineering, Xi'an Jiaotong, China
q.meng@leeds.ac.uk

Introduction

• Characterizing the creep behaviour of the knee joint is important for understanding the mechanical function of the cartilage and menisci and the mechanical environment of the knee joint.

• Due to the natural complexity of the problem, the time-dependent contact behaviour of the knee joint under physiological conditions is still not clear.

• The aim of this study was to characterize the time-dependent contact behaviour of intact and meniscectomy knee joints under body weight.

Methods

• The geometry of the investigated human tibiofemoral joint was from the Open Knee Project [1].

• Both intact and meniscectomy joints in the full extension position were simulated using finite element (FE) models.

• Fibril-reinforced biphasic materials were used for cartilage and menisci (Table 1).

Table 1. Material properties of cartilage and meniscus.

	Equilibrium compressive modulus (MPa)	Poison's ratio	Tensile modulus (MPa)	Permeability (mm^4/Ns)
Femoral cartilage	0.64 [2]	0.08 [2]	5.6 [3]	0.00116 [2]
Tibial cartilage	0.84 [4]	0.03 [4]	5.6 [3]	0.00326 [4]
Meniscus	1.0 [5]	0.03 [6]	Circumferential: 40.0 [7] Radial: 10.0 [8]	0.00100 [6]

• Bone was assumed to be rigid [9]. Ligaments were not included.

Methods

• The tibia was fully fixed. Instantaneous and time-dependent vertical loads were applied to the femur (Figure 1).

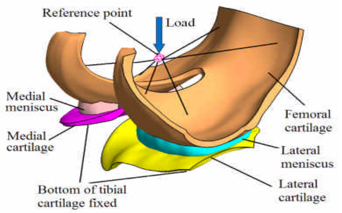

Figure 1. The investigated intact tibiofemoral joint model.

• The loading position was medially shifted from the joint center [10].

• Initially, three instantaneous loads (500 N, 1000 N and 1500 N) were considered. The predicted femoral vertical displacement and total contact area were compared with published experimental data.

• Then a load of 800 N was applied in 1 second and kept for a further 1200 seconds. The time-dependent variations in a number of important mechanical parameters were characterized.

• The FE models were solved using FEBio (Version 1.5.0) [11].

Results & Discussion

Table 2. Comparison of femoral displacement (mm).

500 N		1000 N		1500 N	
Experiment [11]	This study	Experiment [11]	This study	Experiment [11]	This study
0.66 ± 0.17	0.79	0.87 ± 0.17	1.02	1.04 ± 0.23	1.17

Results & Discussion

• For the instantaneous loads, the femoral displacement and contact area (not shown) agreed well with experiments (Table 2). Model was validated to some extend.

• The variation in the femoral displacement and contact area of the whole joint showed typical creep characteristics. After 1200 seconds, the femoral displacement and contact area increased from 0.89 to 1.52 mm and 10.98 to 12.53 cm^2, respectively.

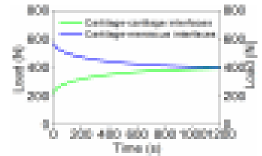

Figure 2. The variation in the load transmitted by the cartilage-cartilage and cartilage-meniscus interfaces with time.

• When the load was just applied, 72% was sustained by the meniscus-cartilage interface. As creep developed, more force was transferred to the cartilage-cartilage interface (Figure 2).

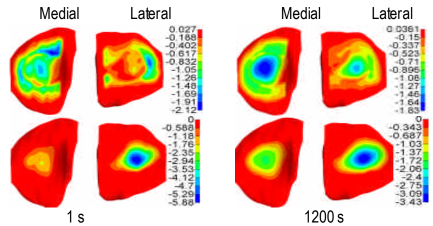

Figure 3. Comparison of the 3rd principal stress between the intact knee and menisectomy knee at different instants.

• During the whole creep period, the stress in the menisectomy joint was considerably higher than that in the intact joint (Figure 3).

Results & Discussion

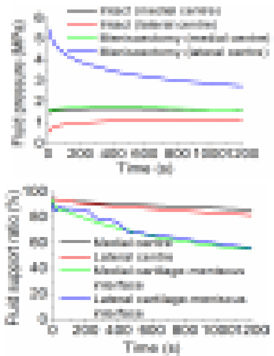

Figure 4. The variation in (a) fluid pressure at the condyle centres of the intact and menisectomy joints; (b) fluid support ratio between different positions of the intact joint.

• The fluid pressure level at the condyle centres of both the intact and menisectomy knee joints remained remarkably high for 1200 seconds (Figure 4 a). This is desirable for protecting the cartilage.

• The fluid support ratio at the cartilage-meniscus interfaces of the intact joint decreased more rapidly than at the condyle centres (Figure 4 b). This may have adverse implications for the cartilage in these areas.

Significance

• The time-dependent contact behaviour of intact and meniscectomy knee joints was investigated under body weight. The findings are important for understanding the mechanical environment of the joint, biomechanical functions of the components, and the pathology of the knee joint.

References

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