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► To cite this version:

Damien Subit, Patrick Chabrand, Catherine Masson, Christian Brunet. Modelling of the mechanical behaviour of the insertion of the ligament to bone in the knee joint. Congress of the European Society of Biomechanics, 2004, Hertogenbosch, Netherlands. hal-00088443

HAL Id: hal-00088443

<https://hal.science/hal-00088443>

Submitted on 25 Sep 2023

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MODELLING OF THE MECHANICAL BEHAVIOUR OF THE INSERTION OF THE LIGAMENT TO BONE IN THE KNEE JOINT.

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The anterior and posterior cruciate ligaments (PCL and ACL), and the lateral and medial collateral ligaments play a fundamental role in the stability of the knee joint. This joint - especially the ligaments - is commonly injured in road accidents. There are not fatal but can result in permanent disability.

Clinical studies (Atkinson, 2000) show that the ligament could be injured in the midsubstance as well as in the tibial or femoral insertion sites (enthesis). Our study aims at modelling the mechanical behaviour of the enthesis which is a transitional material linking a hard tissue (bone) and a soft one (ligament). Besides it is surprisingly solid. There are studies on the ligament behaviour (Arnoux, 2002) but they do not take into account the enthesis mechanical behaviour.

STRUCTURE OF THE ENTHESES

Our bibliography study leads us to carry out a histological study of the enthesis of the four knee ligaments ourselves. The main result is that the transition between the bone and the ligament is really sharp. Modelling the enthesis as an interface becomes then pertinent.

A MODEL OF INTERFACE COUPLING CONTACT, FRICTION AND ADHERENCE

The model chosen for the enthesis consists in attributing a mechanical behaviour to the interface (Pithioux, 2002): (1) the non-penetration conditions (known as Signorini conditions), (2) the friction law of Coulomb, and (3) an adhesive reaction ($F \geq 0$) that must be attempted to break the interface. According to Signorini conditions, whether the two systems are in contact ($[u_n]=0$, $[u_n]$ is the normal relative displacement between the antagonist surfaces), then the normal reaction at the interface is not null ($R_n < 0$), or the two systems are not in contact ($[u_n] < 0$) and the normal reaction is null ($R_n = 0$). According to the friction law of Coulomb, the tangential (R_t) and normal (R_n) reactions at the interface are linked: the tangential reaction is compared to a threshold (μR_n) depending on the normal reaction. Finally, the adherence modifies the laws (1) and (2) by adding F , i.e. R_n is replaced by $R_n + F$ in the thresholds given

before. Then, the whole model coupling contact, friction and adherence is under quasi-static hypothesis:

- (1) $[u_n] \leq 0$, $R_n + F \leq 0$ and $[u_n](R_n + F) = 0$
- (2) $|R_t| \leq \mu |R_n + F|$ in general,
 - (a) $|R_t| < \mu |R_n + F| \Rightarrow [u_t] = 0$
 - (b) $|R_t| = \mu |R_n + F| \Rightarrow \exists \lambda > 0 / R_t = -\lambda [u_t]$
and $|R_t| = \mu |R_n|$

$[u_t]$ is the tangential relative displacement.

IMPLEMENTATION OF THE MODEL

The model was first validated on academic problems. Using an X-ray scanner, we obtain the geometry of a LCP. The model is implemented in an industrial software (Abaqus 6.3) using a user subroutine to describe the interface behaviour. We considered plane strain formulation with elastic and isotropic materials (bone: $E=18$ GPa, $\nu=0.3$; ligament: $E=9$ MPa, $\nu=0.3$) in the quasi-static case.

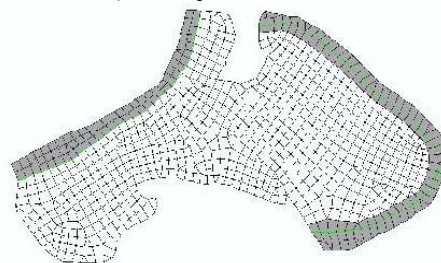


Figure 1: Problem meshing. White: ligament; Grey: bone. Boundary conditions: fixed (right); imposed (left).

RESULTS AND DISCUSSION

On the force-displacement curve, we observe breaking of process composed of a successive loss of cohesion between the bone and the ligament at the interface. We could compare these results with the experimental one.

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