Development and validation of a Finite Element Model to predict patello-femoral wear in a TKA

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Introduction:

UHMWPE wear in Knee Arthroplasty (KA) components is one of the main reasons for failure and subsequent revision of an implant [1]. Experimental wear tests can be used to quantify wear in an implant but these procedures are quite expensive and time consuming. A validated numerical model could therefore be useful to predict wear in less time with less cost. For these reasons, the aim of this study was to develop and validate a numerical methodology to predict patello-femoral (PF) wear in KA.

Initially, the wear model was calibrated using the results of an experimental roll-on-plane wear test. Afterwards, the developed wear model was applied to predict patello-femoral wear and the numerical model was validated by comparing the numerically predicted wear with experimental wear results.

Materials and Methods:

Wear model

To analyze adhesive/abrasive wear behavior, we used the Archard model [2], in which linear wear h is determined using the following equation:

$$h = k_w p\, s;$$

where k_w is the wear factor, p is the contact pressure and s is the sliding distance. In this expression, delamination, pitting and third body wear are not included as literature study reports these effects are negligible in arthroplasty [3]. To include the friction parameter μ in the model we adopted the Sakar modification to the Archard model [4],

$$h = k_w\, p\, s\, \sqrt{(1 + 3\mu^2)}.$$

Roll-on- plane calibration

Three blocks of UHMWPE (GUR 1020) underwent an experimental roll-on-plane wear test (Fig. 1a). The experimental test consisted of $6x10^6$ cycles. The CoCr rolls were loaded with a sinusoidal force (average 1450 N, peak to peak amplitude 200N, frequency 1.2 Hz) and moved over the UHMWPE surface in a sinusoidal fashion (peak to peak amplitude 30mm; frequency: 1.2Hz). The wear of the polyethylene block was measured for each specimen every 500.000 cycles.

The full experimental test was reproduced by finite element analysis (Fig. 1b) and the wear model was implemented during the simulation as illustrated in Figure 2. The geometry of the block was updated every 500.000 cycles to reflect the loss of material due to wear. The wear factor was calibrated to fit the numerical prediction to the experimental results.

Patello-femoral wear prediction

Three Oxinium femoral components (Genesis II, Smith&Nephew, Memphis, TN) and the corresponding patellar components were tested in a wear simulator (Fig. 3a) simulating $2x10^6$ cycles of walking [5].

The same components were numerically analysed in a finite element model (Fig. 3b) using the same boundary conditions as applied by the wear simulator. The PF wear was predicted using the calibrated wear model (Fig. 2).

Experimental volume wear data and numerical volume wear prediction were finally compared.

Results:

Roll-on- plane

Using a $k_w = 1.83x10^{-8}$ mm^3/Nm, the FEM results show a linear wear of 0.127 mm, very close to the linear wear measured experimentally (0.125 mm, SD =0.01mm).

Patello-femoral

FEM results show a total volume wear of 0.389965 mm^3 after $2x10^6$ cycles while the mean volume wear measured experimentally for the same number of cycles for three samples, is 0.3766 ± 0.326 [5].

Discussion and Conclusion:

In this study a wear model was developed and calibrated comparing an experimental and a numerical roll on plane test with the same boundary conditions.

The wear model was later validated comparing the volume wear predicted by the numerical model and the wear obtained experimentally, with the same boundary conditions, for the PF interaction after $2x10^6$ cycles of walking.

The validated wear model can now be used to predict wear between components for the PF and the tibiofemoral articulations for several configurations to predict the TKA long-term performance in patients and to optimize and improve implants designs.

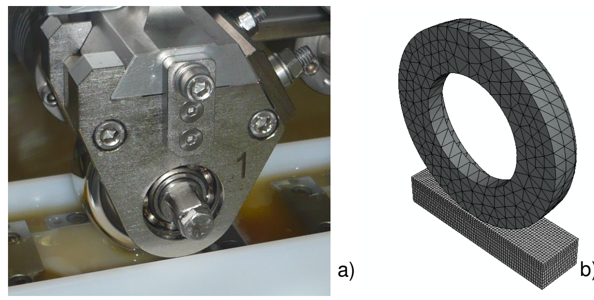

Fig. 1: a) detail of roll-on-plane experimental machine; b) numerical roll-on-plane simulation

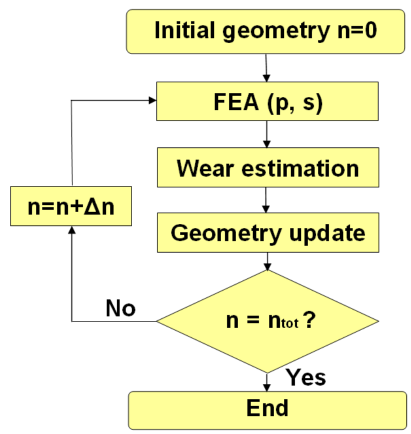

Fig. 2: flow chart of the wear estimation during the FE modeling

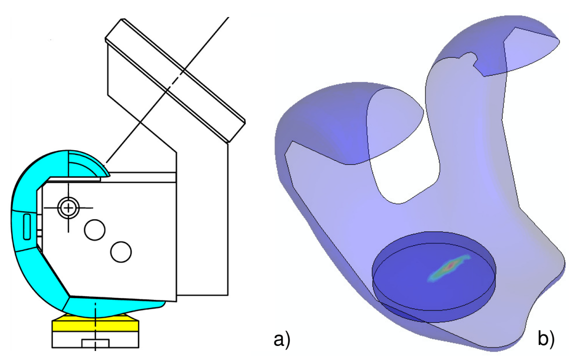

Fig. 3: a) PF experimental model (scheme); b) PF numerical model

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