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Influence of Wear Algorithm Formulation on Computational-Experimental Corroboration.

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Introduction:

Experimental wear testing is well-established as an important part of the TKR design process. Recently, *in-silico* models have proved their value to corroborate long-term *in-vitro* results on a much shorter timescale [1]. Both FE-based models & multi-body dynamics can be used to predict contact pressures, sliding distances and cross-shear (CS). The precise mechanisms of wear are not sufficiently understood to permit analytical calculations, and so empirical formulations are used to estimate wear depths & volumes.

Most early simulations were based on a modified Archard/Lancaster formulation; more recently a number of alternative formulations for cross shear have been proposed; it is unclear which is the most robust or accurate for the widest range of activities. The aim of this study was to develop and corroborate a fast *in-silico* wear model, and use this to compare different wear formulations.

Methods:

A rigid-body tibiofemoral model was constructed in MSC.ADAMS, and coded to calculate wear based on a number of published algorithms, including Archard wear [2], the basic ML÷AP CS form & the 'principle direction' A÷B alternative, the bounded forms of these two, and also the proposed crossing intensity (σ*) method [3]. The model was first corroborated against existing *in-silico* & *in-vitro* wear predictions, for different TKR designs (fixed & mobile bearing, with different levels of gait kinematics [4, 5], and for force- & displacement-driven adaptive wear simulations [6, 7].

Once it was demonstrated that the results compared well to existing models, this fast model was used to compare these six different wear formulations for several different fixed CR knee designs tested under standard ISO force-driven gait conditions. The same empirical constants derived from corroborated tests were used for these comparison studies.

Results:

The initial comparisons against previous studies demonstrated that the fast model corroborated well; predicted wear matched experimental results with a strong correlation across different designs (Fig.1); this gives good confidence in the use of the model for development and research work.

The most immediate difference in wear models is between the 'Archard' model (based on sliding distance only) and the 5 other CS-based models (Fig.2). Models which include CS can much more clearly distinguish between low- and high-wearing designs, predicting a wider variation in wear for different activities and kinematics (e.g. in Fig.2 wear rates vary by as much as threefold when CS is included, whereas Archard wear does not clearly differentiate the designs). Although the CS models are comparable, some (e.g. ML÷AP) are prone to numerical singularities (Fig.3), and slight variation in wear volumes is seen, suggesting that the experimental constant should be chosen based on the specific CS formulation.

Discussion:

Clearly, *in-silico* methods can provide an effective short-timescale alternative to *in-vitro* studies for situations limited to adhesive/abrasive wear modes. The closer correlation of the predicted and experimentally measured wear rate demonstrates that the technique is becoming a viable tool in the pre-clinical assessment of new TKR designs.

The choice of wear formulation is important, but the principle differences are between models with and without CS; distinctions between CS models are generally small. Nonetheless, these differences should be considered when choosing wear constants based on different formulations. Numerically, a bounded form (e.g. ML÷{ML+AP}) is to be preferred, to avoid singularities. The models based on principle sliding direction, though more computationally expensive, are also more robust.

This study re-affirms the value of computational wear modeling, illustrating that fast numerical models do not compromise accuracy, and demonstrating the influence of the choice of wear formulation. There remains scope for further *in-vitro* corroboration with different designs & activity loading profiles, and also scope for the development of models for different wear modes (i.e. beyond adhesive/abrasive wear only).

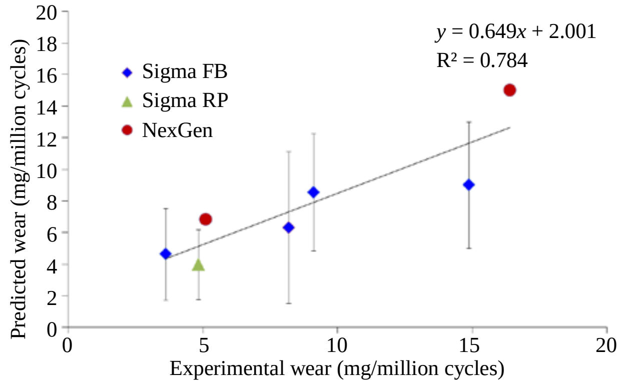

Figure 1: Corroborating calculated wear values with published *in-vitro* results [4-7]. Error bars represent ±1 S.D. of the experimental mean

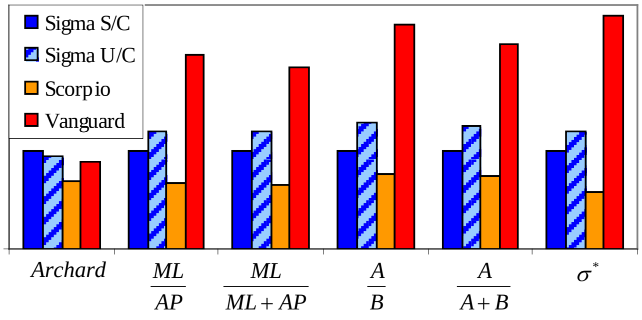

Figure 2: Wear volumes for four of the designs under test (Sigma semi-constrained & unconstrained, Scorpio & Vanguard), normalized with respect to the Sigma S/C. Note that Archard wear does not match the consistent trends seen for all five of the other CS-based models.

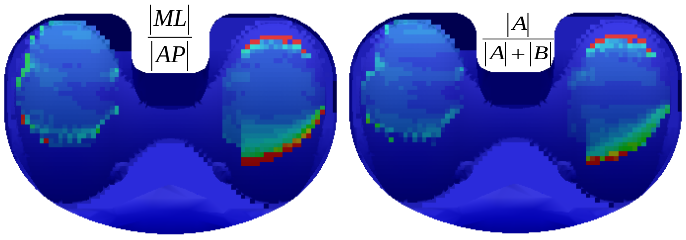

Figure 3: Comparison of CS formulations for stair descent. CS maps were generally similar for all formulations.

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