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Cross Shear, Contact Pressure, and Contact Area in a Simplified TKR Wear Simulation

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Introduction

Current wear algorithms, which are functions of contact kinematics (ie cross shear (CS)) and contact pressure (CP), predict wear in total knee replacement (TKR) with moderate success[1]. Recent pin-on-disk experiments, however, have demonstrated a dependence of wear on CS[2] and contact area (CA)[3], but not CP. When the CP term is removed from wear algorithms, their predictive power is unaffected[1]. To elucidate the relative contributions of CP, CS, and CA in TKR we performed a wear simulation on flat tibial inserts under two values of maximum load and two levels of IE rotation. In this simplified model, we hypothesized that wear would depend strongly on CA and CS but not CP.

Materials and methods

A knee simulator (AMTI, Watertown, MA) applied four different simulation programs for 3 million cycles (Mcyc). Input waveforms[4] differed in maximum vertical load (VL) and internal/external (IE) rotation but maintained flexion/extension (FE) and anterior/posterior (AP) motions (Table 1) yielding different CP, CS, and CA conditions that were quantified via in silico simulation[1].

I. VL^{Hi} IE^{5°	**II. VL^{Low} IE^{5°**
VL = 3560 N	VL = 1780 N
FE = 0-58º	FE = 0-58º
IE = ±5º	IE = ±5º
AP = 10 mm	AP = 10 mm
III. VL^{Hi} IE^{0°	**IV. VL^{Low} IE^{0°**
VL = 3560 N	VL = 1780 N
FE = 0-58º	FE = 0-58º
IE = 0º	IE = 0º
AP = 10 mm	AP = 10 mm

Table 1: Exp. Design.

Testing was conducted using six sets (n=3 each) of PFC Sigma fixed bearing cruciate retaining knee system (DePuy, Warsaw IN). Inserts were machined to 8 mm thickness and presoaked in water for 30 days. Similar to ISO 14243 components were carefully positioned and each joint was tested in 25% bovine calf serum (Hyclone Laboratories, Logan UT), which was recirculated at 37±2°C. Serum was supplemented with sodium azide (0.2%wt) and EDTA (20mM, 7.45 g/L). Due to limited wear stations, the four programs were run in two phases. Programs I and IV were run first, then after 3 Mcyc the inserts were remachined (down to 7.5mm) and the two remaining programs were run an additional 3 Mcyc. Wear was quantified via gravimetric methods based on ISO 14234-2. Tibial inserts were weighed on a digital balance (XP250, Mettler-Toledo) at 0 Mcyc and then after 0.5 Mcyc. Wear values were compensated by group-specific load soak controls. Comparisons were made using ANOVA with Tukey's post-hoc analysis.

Results and Discussion

All groups wore steadily (Fig 1) and uniquely ($p<0.05$). Higher wear values were associated with higher vertical load and IE rotation. Interestingly, program II (VL^{Low} IE^{5°) wore more than III (VL^{Hi} IE^{0°), reinforcing the importance of crossing motions. In silico rigid body simulation revealed that CA and maximum CP each scale by ~1.4 when the load doubles, neither of which fully explains the ~1.9 fold change in wear that is observed when the maximum load doubles (I:II and III:IV). Lastly, programs with unidirectional sliding (II and IV) produced appreciable wear with little or no crossing motion. Low CS values correspond with immeasurable small wear.

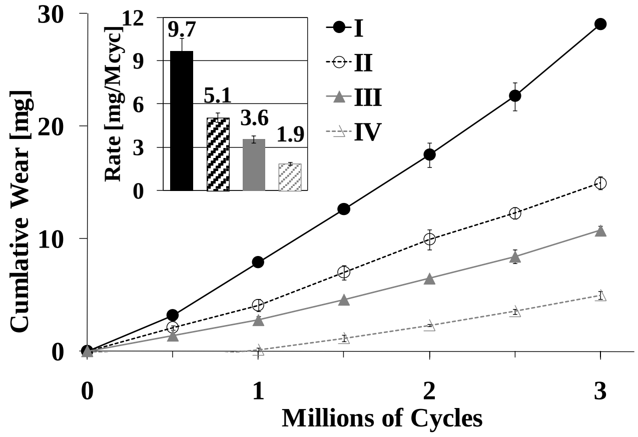

Fig. 1: Cumulative wear of flat polyethylene inserts. The Inset reports mean wear rates. All error bars represent SD

Conclusion

The effect of CS appears more prominent than CA and CP. Wear did not scale linearly with CA or CP. Wear approximately doubled when CP and CA scaled by 1.4. More experimentation and computational refinement is needed to better understand CS behavior and separate the effects of CA and CP.

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