Wear Simulation of High-Flexion Activities of Daily Living: Stair Climbing in Displacement Control

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STATEMENT OF PURPOSE: Total knee replacements are being designed with an increased range of motion to meet the increasing demands of an active and global demographic. Current ISO test conditions[1] do not recreate high-flexion activities of daily living. This realization has led to the development of novel simulator programs. This study investigates displacement controlled stair ascent and descent, two high flexion activities of daily living.

METHODS: Kinematic input waveforms for upstairs and downstairs programs (Figs. 1 and 2) were developed from the literature (Table 1). Simulations were performed in a six-station knee simulator (AMTI, Watertown, MA) using the PFC Sigma Knee System (PFC Sigma CR Fixed Bearing, DePuy, Warsaw, IN). Inserts having two different relative conformities were investigated (n=3 each) following a separate investigation[2]. The more conforming "CurVeD" (CVD) inserts and less conforming "Posterior Lipped Inserts" (PLI) were tested with polished cobalt-chrome tibial trays and femoral components. Tibial inserts were gamma sterilized in foil barrier packaging to 40 kGy. Each station was lubricated via recirculating 25% (18 mg/ml) bovine calf serum (Hyclone Laboratories, Logan, UT) at 37°± 2°C, with 0.2% mass fraction sodium azide to retard bacterial growth and 20mM (7.45 g/L) EDTA to prevent calcium precipitation. Loaded soak controls were used to account for insert fluid absorption. Vertical load was applied with 60:40 medial:lateral load offset. Wear was measured gravimetrically using a Sartorius R-200D digital microbalance (Sartorius, Inc, Long Island, NY) every 0.2M cycles, at lubricant change intervals.

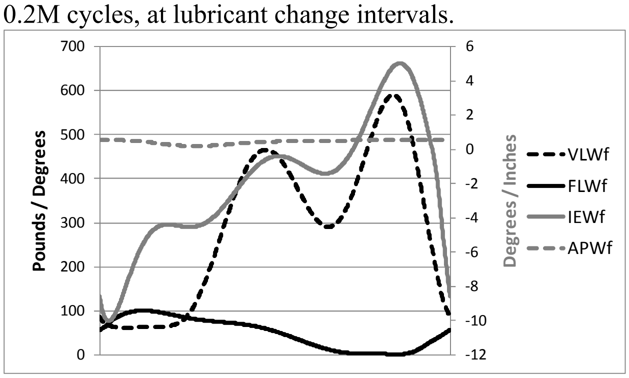

Fig. 1. Kinematic profiles for upstairs displacement control

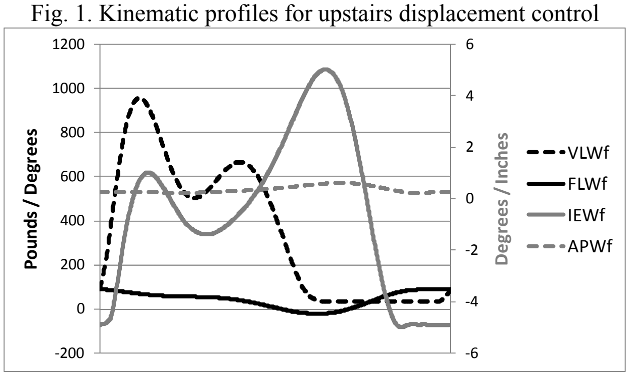

Fig. 2. Kinematic profiles for downstairs displacement control

The study began with 0.2M cycles of stair climbing, followed by two 0.2M cycle intervals of stair decent, and completed with another 0.2M cycle interval of stair climbing. Femoral/tibial component pairs were kept together for the duration of the test, but switched from bank to bank every 0.4M cycles in order to accommodate any difference from one side of the machine to the other.

Table 1. Sources of kinematics

Waveform	Upstairs	Downstairs
Vertical Load (VLWf)	Costigan[3]	Paul[5]
Flexion-Extension (FlWf)	Friegly[4]	Rowe[6]
Internal-External (IEWf)	Costigan[3]	Maletsky[7]
Anterior-Posterior (APWf)	Costigan[3]	Maletsky[7]

RESULTS: The resulting UHMWPE wear rates (mg/Mcyc ±1SD) for CVD and PLI under the displacement control upstairs program were 11.2±4.1 and 4.0±1.9 respectively, while under the displacement control downstairs program, rates were 4.0±0.6 and 0.9±0.5, respectively (Fig. 3). The CVD inserts wore significantly more than the PLI in both programs (Student's t-test, $p < 0.05$).

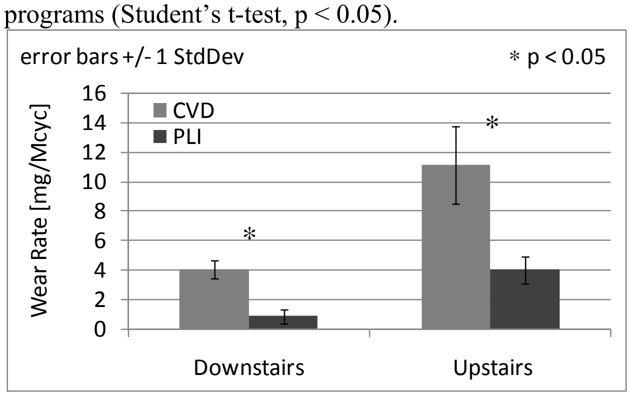

Fig. 3. Wear results for stair stepping kinematics

CONCLUSIONS: Surprisingly the downstairs program yielded lower wear rates in spite of an elevated vertical load. This maximum load, however, occurs at extension rather than flexion, suggesting that the phase relationship among inputs can influence wear results. A single data set that included properly phased inputs would have been preferred, but was unavailable in the literature. Also in this study, an insert with less conformity demonstrated decreased wear when tested under displacement controlled stairs programs. However, we have shown previously that a force driven program can produce the opposite conclusion[2]. Future testing under force and displacement control is required to elucidate the in vivo kinematics and wear for various activities of daily living.

REFERENCES: 1) ISO 14243, 2002. 2) Render T. 8th WBC. 2008; #1304 3) Costigan PA. Gait Posture. 2002;16:31-37. 4) Friegly BJ, J Biomech. 2005;38:305-314. 5) Paul JP. Proc Royal Soc. 1974;192:163-172. 6) Rowe PJ, Gait Posture. 2000;12:143-155. 7) Maletsky L. DePuy Internal Report. 1994.