ABRASIVE WEAR SIMULATION IN TOTAL KNEE ARTHROPLASTY

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Relevance to Musculoskeletal Condition: Performance of total knee implants is often limited by wear behavior. Simulator test methods should account for the in vivo conditions which cause the greatest contribution to the targeted wear mechanism.

Introduction: Knee simulator wear testing is still in its infancy. It is unclear what the targeted wear mechanisms should be. It is hypothesized that third-body wear or scratched femoral components, both forms of abrasive wear, account for most of the non-fatigue-type wear. It is of interest to compare the relative contributions of third-body particles and scratched femoral components (two-body wear) to Tibial component wear. In this study, a knee simulator was used to investigate wear using a clinically based gait cycle under clean conditions and two types of abrasive conditions.

Methods: Wear cycling was performed using a six-station, four-axis knee simulator (AMTI, Watertown, MA) with closed loop control of flexion/extension, internal/external rotation, anteroposterior translation, and compressive force. Three groups of right total knee replacements (Genesis II, Smith & Nephew, Memphis, TN), three assemblies per group, were tested using a gait pattern derived directly from fluoroscopic measurements during treadmill walking at 1 m/s of a patient with a well-functioning cruciate retaining TKR. Load and motion ranges for this gait cycle were as follows: Load: 50 to 2400N, FE: 4° to 60° flexion, tubial IE: 2.5° external to 7.5° internal, and femoral AP: 7.5 mm posterior to 6.0 mm anterior. For the “pre-scratched” abrasive condition, 25 mg crushed bone cement (zirconia-containing) particles (0.5 - 0.85 mm) were embedded in each tibial plateau at weekly intervals. Wear testing was conducted at 1 Hz, in 50% bovine serum / 50% water, 37°C.

Results: The clean conditions produced a mean UHMWPE wear rate of only 1.42 ± 0.4 mm/10⁶ cycles (Fig. 1). This is 20-100 times lower than clinical or simulated hip wear. The third-body conditions resulted in visible scratching of the femoral condyles and no residual cement particles embedded in the UHMWPE. Despite this, there was no increase in UHMWPE wear, the mean value actually being slightly lower at 1.07 ± 0.8 mm/10⁶ cycles (Figs. 1 and 2). The pre-scratched conditions resulted in a dramatically increased mean UHMWPE wear rate of 118.45 ± 9.8 mm/10⁶ cycles (Fig. 2). The wear curve exhibited a significant decrease in wear rate with time. This was consistent with the measured reduction in scratch peaks at the end of the test.

Discussion: Because the clinical targets for TKR wear rates and mechanisms are unclear, the relevance of the simulator results in this study is difficult to verify. It is suspected that UHMWPE wear rates which are 20-100 times lower than those reported for hip wear are of limited clinical concern. In addition, sources of error are magnified at these low levels of wear. An optimized abrasive knee simulator wear test should generate UHMWPE wear rates somewhere between the two extremes exhibited in this study. We recommend accomplishing this by reproducing the oblique scratch patterns observed on retrieved femoral components, either prior to the test or during the test. It may be necessary to identify the motion cycles which cause these oblique scratches, in which case fluoroscopic measurements of TKR patients during various activities are recommended. The result will be an improved, clinically based knee simulator test methodology.


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Fig. 1: Mean UHMWPE wear for clean and third-body TKR conditions

Fig. 2: Mean UHMWPE wear for third-body and pre-scratched TKR conditions

Oblique scratches have been observed on retrieved femoral components; the maximum angles relative to the direction of articulation are typically 30°. An optimized abrasive knee simulator wear test should generate UHMWPE wear rates somewhere between the two extremes exhibited in this study. We recommend accomplishing this by reproducing the oblique scratch patterns observed on retrieved femoral components, either prior to the test or during the test. It may be necessary to identify the motion cycles which cause these oblique scratches, in which case fluoroscopic measurements of TKR patients during various activities are recommended. The result will be an improved, clinically based knee simulator test methodology.

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