INTRODUCTION: Surfaces of retrieved total knee arthroplasty (TKA) femoral components reveal that roughening often occurs *in vivo* [1,2]. Many scratches have plowed-up adjacent peaks often with some crosshatching, and appear to be created by abrasive particles, such as bone cement, metal, or bone debris. *In vitro* studies have shown that scratches, particularly those at an angle to the direction of motion, can increase ultra-high molecular weight polyethylene (UHMWPE) wear [3,4]. To better characterize femoral component material performance in the laboratory, simulator testing should be conducted under abrasive conditions as well as with traditional non-abrasive or “clean” conditions. Several methodologies were investigated to select an abrasive test protocol that created clinically relevant scratches.

METHODS: All knee femoral components were medium-sized, cruciate-retaining, Genesis II® TKA prostheses (Smith & Nephew, Inc, Memphis, TN). Femoral components were made of either a cobalt-chrome (CoCr) alloy (Co-28%Cr-6%Mo) or Oxidized Zirconium (OxZr) [5]. The polyethylene inserts were EtO-sterilized, ram-extruded, GUR 1050 UHMWPE. Wear testing was performed on a six-station, four-axis, physiologic knee simulator (AMTI, Watertown, MA). The test lubricant was 50% bovine serum in water with sodium azide and EDTA. The lubricant was held at 37°C, recirculated, and replaced weekly. A 90% normal gait and 10% stair-climbing activity pattern was used, based in part on fluoroscopy measurements of cruciate-retaining TKA patients [2,4]. Gravimetric measurements were taken to determine volumetric wear. Additionally, a Surcom 575A Profilometer (Tokyo Seimitsu) with a 2 μm radius stylus tip and 0.8 mm cut-off length was used to measure surface roughness (20 scans per knee). Two-tailed t-tests were performed to determine statistically significant differences. Early experiments with bone cement created scratches that were more broad and rounded than those typically seen on retrievals. Alumina particles were then chosen because they produced scratches that were more clinically relevant (sharp and narrow). There were three phases of protocol development:

**Phase I:** Drops of test lubricant with 0.2 mg/ml of alumina particles (ranging in size from 0.3 μm to 150 μm) were placed on the articulating surface of a tibial insert. An aggressive “twisting program” (±20° rotation for 18 cycles each at six different positions of flexion) was started. After abrasion, femoral components and test stations were cleaned. Tests were then run with new tibial inserts, clean (no abrasives) serum, and the standard walking/stair climbing routine. **Phase II:** A 50 ml solution of either 1 μm or 10 μm alumina particles was added to a running simulator test where the serum recirculation was cut-off for about 2 hours at the start of the test [6]. The final system abrasive concentration of the running and recirculating test was 0.2 mg/ml. A periodic twisting motion was added to the standard motion pattern in an attempt to produce more crossing scratches. **Phase III:** Components (3 each of CoCr and OxZr) were tumbled with 25 μm alumina powder and plastic cone media in a centrifugal finishing barrel [7]. These components were ultrasonically cleaned and tested in clean serum.

RESULTS: **Phase I:** After pre-test abrading, some crosshatch scratching was observed on the femoral components. However, when the test was stopped for weight measurements it was noted that scratches became re-oriented in the anterior-posterior (A-P) direction. On some components, an almost mirror-like surface was seen. Gravimetric data showed that the UHMWPE wear rates were not significantly different from those obtained in clean conditions. Microscopic examination of the tibial insert surface showed what appeared to be embedded alumina particles. **Phase II:** Few non-A-P scratches were observed after running tests with abrasives in the solution. Roughness data showed that CoCr components became significantly rougher (Ra, Rpm, and Rpk) than OxZr components when roughened with the same size alumina particles (p<0.01) [6]. During testing, serum became opaque with gray debris for CoCr stations, while the serum from the OxZr stations remained unchanged. As in Phase I, wear rates were not appreciably different from those obtained in clean conditions. **Phase III:** Tumbling CoCr components significantly increased Ra, Rpm, and Rpk (p<0.01) over non-tumbled components, as seen in Figure 1. Included in this figure are the mean Ra and Rpm obtained from ten cemented retrieved femoral components [1,2]. Roughness of tumbled CoCr components were within the range of those obtained on clinical retrievals. After wear testing, Ra increased significantly again (p<0.001). Tumbling OxZr components significantly increased Rpm (p<0.05) but the increase was less than 0.05 μm. With wear testing, Ra increased significantly for OxZr (p<0.01), although the increase was less than 0.03 μm.

![Figure 1. Roughness (Ra, Rpm, and Rpk) for CoCr and OxZr femoral components, before and after tumbling, and after wear testing.](image)

![Figure 2a and 2b. Interferometer images of CoCr components scratched *in vivo* (left) [1,2] and by tumbling (right).](image)

Scratches on the tumbled CoCr components were similar in shape and orientation to those found on retrieved components, as shown in Figures 1 and 2. Visual inspection at each weighing interval showed the femoral components to have maintained randomly oriented scratches. Additionally, on CoCr and occasionally on OxZr, there were scratches observed in the A-P direction that occurred during wear testing. The tibial inserts that were articulated against CoCr exhibited approximately 8.7 times greater aggregate wear rate than inserts articulated against OxZr (aggregate wear rate ± standard error: 46.1 ± 4.73 mm³/Mcycle and 5.27 ± 0.64 mm³/Mcycle, respectively), as shown in Figure 3. This difference is statistically significant (p<0.01). Wear rates obtained in abrasive conditions resulted in at least a seven-fold increase of those obtained in clean conditions [5].

DISCUSSION: If abrasive particles are introduced during testing, femoral component scratches orient almost exclusively in the A-P direction. Even with tumbling and ultrasonic cleaning, particles were freed from the CoCr and OxZr surfaces during wear testing. However, the tumbling method introduces the fewest particles into the wear test. As a result, many of the randomly oriented scratches formed during tumbling survived the wear test. Tumbling the femoral components resulted in increased UHMWPE wear rates over those in clean conditions for both femoral materials, while OxZr maintained its superior performance over CoCr.