For Lower Wear of Total Knee Replacements, is Higher or Lower Contact Area Better?

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INTRODUCTION:

Total knee replacement (TKR) designs are known to require a large articular contact surface area to reduce stress and supposedly wear. Increasing contact area is typically done by increasing sagittal and/or coronal conformity, which also raises constraint and therefore comes with a price. Higher constraint may require more exacting soft tissue balancing and the higher forces and torques transmitted to the bone or its cement interface may jeopardize fixation. In this study we questioned the widely held belief that higher contact area leads to lower wear. In older generation TKRs, wear could be excessive due to delamination that was indeed caused by stress fatigue initiated about 1mm under the surface. This was especially significant when ultra high molecular weight polyethylene (UHMWPE) bearings were riddled with oxidation problems from sterilization in air and/or excessive shelf lives. Even medium stresses caused delamination of oxidized UHMWPE bearings, so reducing stress by increasing contact area was a wise solution. We hypothesized that for contemporary TKR designs with modern UHMWPE bearings, contact stress would be low enough to mitigate stress fatigue induced delamination, and therefore larger TKR sizes with (scaled) larger contact areas may actually cause higher not lower wear.

METHODS:

We pooled data from eight separate full-scale knee wear simulator tests conducted in our lab on different TKR designs, materials, and conditions. Each test compared the wear rate of large versus small(er) size TKRs which were otherwise identical in every way, with a sample size range of 2-4 per group. *A priori* power analysis on two separate wear tests from our lab both showed a minimum sample number needed per size group of n=2, for 85% statistical power, based on 0.05 alpha error. We used the same force-control testing methodology of ISO 14243-1&2 simulating human walking, under the same dynamic multi-axial loads, at 1Hz frequency and 37°C temperature, with diluted bovine serum lubrication with 20 g/l protein concentration. The UHMWPE wear was measured gravimetrically after correction with loaded liquid absorption soak "controls." All the tests ran for at least 5 million cycles (MC), except for two shorter (2 MC) tests with accelerated abrasive wear conditions using femoral components deliberately pre-scratched as would be after years in vivo. The student t test was conducted on each of the seven tests to calculate the one-tailed p value of rejecting our hypotheses. The composite bar chart below summarizes the test matrix and wear results, showing for each test (column/pair of bars) the TKR design, material, and size groups compared, *post-hoc* statistical power, and p value of the wear comparison. Two of the subgroup tests were labeled having had everything the same, including size, but had different surface conformity and thus differed in only contact area. Another two sub-groups showed the extra abrasive tests on two UHMWPE materials. These abrasive tests were carried out together with (non-scratched) "control" equivalents shown on their left in the chart, so the chart's rightmost 4 pairs were of one TKR manufacturer's generic design.

RESULTS:

None of UHMWPE bearings of the 14 sub-groups (7 pairs of large vs. small sub-groups) showed any signs of delamination wear, confirming that the stresses could not have been excessive in any of these contemporary TKR designs. The wear rates varied among the TKR designs and UHMWPE materials, and as expected, the extra abrasion tests showed significantly higher wear ($p<<0.050$) than their respective controls.

In all the eight tests including the two extra-abrasive tests, the wear of the larger size TKR was statistically significantly higher ($p\leq0.05$) than its equivalent smaller version. The difference in wear (size effect) varied since the difference in sizes of the implants tested was not the same. The *post-hoc* power analysis echoed the *a priori* version in six tests (>85% power), but not in the other two due to small sample numbers. With the sufficient sample numbers in six of the tests (different TKR designs, materials, and conditions) and with the numbers available for study in the two lower (*post hoc*) powered tests, our hypothesis was supported; namely, that the larger TKRs had greater wear rate than the smaller ones. Lastly, regarding the two identical large size TKRs articulating against a high or low conformity bearing, these tests found that the version with the higher conformity had a wear rate of 24.9±2.94 mg/MC, significantly higher ($p=0.048$) than the 19.9±4.23 mg/Mc of the lower conformity version.

DISCUSSION AND CONCLUSION:

Increasing contact area will increase both adhesive and abrasive wear. Decreasing contact area will result in higher contact stress, which if excessive may cause fatigue wear and delamination. Therefore, a certain optimum threshold of stress balances these conflicting trends. This can be implicitly interpreted from some published pin-on-disk test results, other TKR tests, and there is well-documented awareness of this phenomenon in total hip replacements. Larger hips are known to wear more than smaller ones under the same loads despite their lower contact stresses. The findings of the current study confirm our hypothesis and challenge the dogma that increasing contact area to reduce stress decreases wear in TKR designs. This data could shine a new beacon to guide future knee designers to be weary of excessively high contact area. With everything else equal, larger TKRs wear more than smaller ones. With equally sized contemporary designs and similar kinematics, a TKR with more conforming articular surfaces may wear more than less-conforming designs. With modern materials and processing, increasing contact area to decrease contact stress may be counter-productive and may result in increased wear.