INFLUENCE OF UNICONDYLAR KNEE DESIGN ON JOINT KINEMATICS IN A KNEE SIMULATOR

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INTRODUCTION

The Oxford mobile-bearing, unicondylar knee replacement was first implanted in 1982 and has had a high revision rate (7.4% medial, 13.9% lateral) with dislocation and component loosening being the most common cause for revision.[1] A 'self-aligning' unicondylar knee replacement (UKR) has recently been developed and is characterized by a curved tibial tray surface and a multiradial femoral component. Since implant design influences kinematics,[2] the goal of this mobile-bearing device is to reduce the anterior-posterior (AP) displacement of the tray and polyethylene insert, reduce the internal-external (IE) rotation of the insert, and ultimately reduce wear damage and dislocation rates.

The objective of this study was to evaluate and compare the kinematics of geometrically different prototypes of this UKR system in a load controlled knee simulator under normal gait conditions.

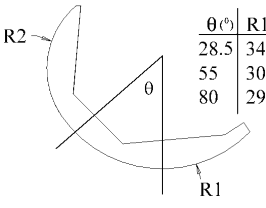
METHODS

Prototypes for the UKR were tested in one of four stations within an Instron-Stanmore knee simulator. Three femoral components were tested with angles (θ) of 28.5, 55, and 80°, where θ was defined as the transition angle from extension radius (R1) to flexion radius (R2) (Figure 2). Three tibial components were tested with convex, flat, and concave tibial trays, along with their corresponding inserts (Figure 1). The radius of surface curvature was 120mm for the superior surface of both the convex and concave tibial trays as well as the inferior surface of the corresponding insert (fully conforming). Two insert thicknesses were examined: 5 and 11mm thick. In summary, the three design variables were femoral component geometry, tibial tray geometry, and tibial insert thickness resulting in 18 different UKR design configurations. The prototype femoral component was fixed to the lateral side of the femoral fixture, and half of an Insall Burstein II size64 femoral component (θ = 19.7°) was cemented to the medial side (Figure 3). A polyethylene insert was machined with a V-shaped wedge to match the medial femoral condyle and help constrain the joint from excessive medial-lateral movement. Custom polyethylene fixtures were made to hold the tibial trays in place. The simulator springs were pre-compressed with no gap and had a spring constant of 14.48 N/mm.

The design configurations were tested in a random order with normal gait cycle waveforms of a right knee,[3] and nine cycles were recorded. The loading and displacement profiles include flexion angle, axial force, AP force, and IE torque. Kinematic outputs from the knee simulator provided the global motion of the tibial tray - the IE rotation and AP displacement of the tray with respect to the femoral component. To capture the relative motion of the insert, markings on the custom polyethylene mounts were used to visualize overall AP displacement of the insert with respect to the tray. The IE rotation of the insert with respect to the femoral component was visually scored: ~0°, 0-20°, 20-40°, and >40°. The results are presented as the mean and standard deviation.

a. Convex b. Flat c. Concave

Figure 1. UKR metal trays and corresponding polyethylene inserts



θ (°)	R1 (mm)	R2 (mm)
28.5	34.4	21.9
55	30	20
80	29	18

Figure 2. Lateral view of femoral component

Figure 3. Posterior view of UKR knee simulator assembly

RESULTS

By grouping the design variable of tray geometry, the average global tray displacement for the convex, flat, and concave groups was 9.2 ± 0.6, 10.5 ± 0.9, and 12.1 ± 0.4mm respectively. The average relative insert displacement for the convex, flat, and concave groups was 9.2 ± 1.2, 12.3 ± 1.5, and 14.0 ± 1.3mm respectively. Grouping the specimens based on insert thickness showed that the 11mm insert decreased mean global tray displacements 8 out of 9 times.

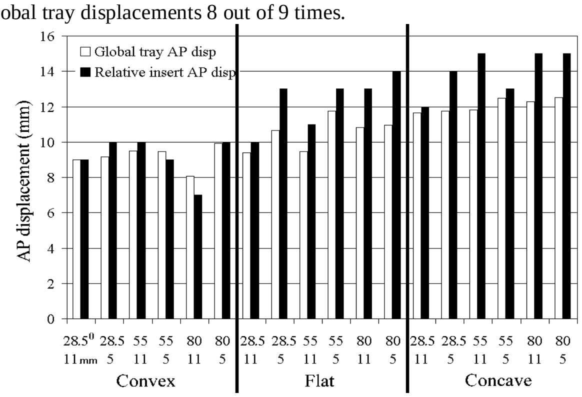


Figure 4. Kinematic results grouped by tray geometry

Of the 18 specimens run, the extent of global tray IE rotation measured from the simulator showed no dependence when comparing the convex, flat, and concave groups (17.6 ± 1.0, 18.0 ± 1.8, and 16.1 ± 1.2° respectively). Femoral component geometry did affect the insert rotation score with respect to the femoral component (Table 1). The designs incorporating a femoral component with θ = 80° showed the most frequent occurrence of ~0° of IE rotation score (5 out of 6 specimens). The greatest insert rotation (>40°) was observed once with the 55° design.

Table 1: IE rotation of inserts with respect to the femoral component

	~0°	0-20°	20-40°	>40°
θ = 28.5°	0	4	2	0
55°	1	2	2	1
80°	5	1	0	0

DISCUSSION

The results showed that the geometry of the articulating surfaces influences the kinematics of a prosthesis. The convex tray had the least global tray and relative insert AP displacement while the concave tray had the most. Increasing insert thickness reduced the mean global tray AP displacement. The 80° femoral component had the least insert global IE rotation, because at maximum gait flexion (58°) the femoral surface remains highly conforming with the insert. This high conformity resulted in a more rotationally constrained device which may transfer higher stresses to the bone-implant interface.[4] The 55° design had an IE rotation >40° which may have been attributed to the similarity between the flexion and medial-lateral radius (20 and 19mm respectively) resulting in a nearly spherical femoral surface similar to the Oxford design.[5]

Minimizing relative motions at both bearing surfaces has been shown to reduce the wear-track area and wear debris.[6,7,8] Minimal AP displacement of the tray may also expand indications to patients with a deficient ACL. Therefore, these factors suggest that the convex tray may be most appropriate. Numerical models and finite element analyses will be performed to examine soft tissue compatibility and bone-implant fixation. Determining how an orthopaedic implant behaves under a gait sequence helped to quantify how design influences joint kinematics.

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