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Quantitative, Comparative Assessment of Gait Between Single-Radius and Multi-Radius Total Knee Arthroplasty Designs

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ABSTRACT

Gait of single-radius (SR, n = 16) and multi-radius (MR, n = 16) posterior stabilized total knee arthroplasties was compared, along with controls (n = 16), pre-op and 1 year post-op. Computer navigation and standard order sets controlled confounding variables. Post-operatively, SR knees did not differ from controls while MR knees continued to differ in important knee kinetic and kinematic properties. MR knees remained more extended ($P = 0.019$) and had decreased power absorption ($P = 0.0001$) during weight acceptance compared to the SR knees. Both surgical groups had similar KSS for Knee Scores ($P = 0.22$) and Function Scores ($P = 0.58$). The significant biomechanical differences are likely influenced by patella–femoral moment arm geometry and changing ligament laxity throughout the active range of motion.

By the year 2030 the number of primary total knee arthroplasties (TKA) performed in the United States is projected to approach 3.48 million with revision rates of 7.2% [1]. To help meet this demand, while improving patient outcomes, new designs in prostheses, and new techniques in reconstructive surgeries, such as computer-navigation and patient specific jigs, have been developed in attempt to influence implant performance and surgical outcomes. Along with these developments, certain surgeons have moved toward non-anatomic alignment in an attempt to better simulate the kinetics and kinematics of the knee post-arthroplasty. These potential advances have ushered in a keen interest in analysis and study of the precise location of the axes relative to rotation about the knee.

Theories regarding the location and orientation of axis/axes of the knee date back to 1836 [Weber (German) as reviewed in: 2–4] when the study of cadaveric distal femora and ink on paper suggested a single flexion/extension axis and a single radius of curvature about the knee during functional flexion. The 'radius' is generally defined as 'the distance from the flexion/extension axis to the contact point between the femoral and tibial components of the implant' [4]. Around the turn of the 20th century, studies incorporating new imaging and measurement techniques suggested that flexion/extension was described by multi-radius curves with a shifting center of rotation [as reported in: 2–4].

These competing theories have, independently, been incorporated into the design of some modern-era knee implants which date back to 1970 [5]. The multi-radius (MR) designs have at least two instantaneous centers of rotation within the functional knee range of motion, which is driven by the changing radius of curvature of the femoral component. Fig. 1 shows an exemplary MR knee design and highlights how the radii change throughout the active flexion portion (~10°–110°) of the bearing surface. The more posterior aspects of the implant, which are employed during increasing knee flexion, show decreasing radii of curvature. Many designs have four or more radii at different points in the functional flexion–extension arc of motion, which may lead to differing soft tissue tensions and muscle moment arms throughout the range of motion. Comparatively, implants with a single-radius (SR) design (Fig. 2) have a single radius throughout the functional flexion arc and a single flexion/extension axis fixed about the femur, which is generally located more posterior to those of the MR design [6–8]. The SR should create consistent collateral ligament tension and muscle moment arms throughout the functional range of motion. By overlaying the two designs and their center(s) of rotation (Fig. 3), it is apparent that the center of rotation must translate during flexion–extension in the MR design and remains relatively fixed in the SR design.

Motion analysis is a well-established technique by which to evaluate TKA outcomes and compare prosthetic designs [7,12–24]. For example, quantitative motion analysis studies specific to single-radius and multi-radius designs have shown statistical differences in sit-to-stand activities, with MR designs showing increased compensatory mechanisms during the task [4,8,11]. More demanding tasks, such as sit-to-stand, tend to amplify small differences in performance.

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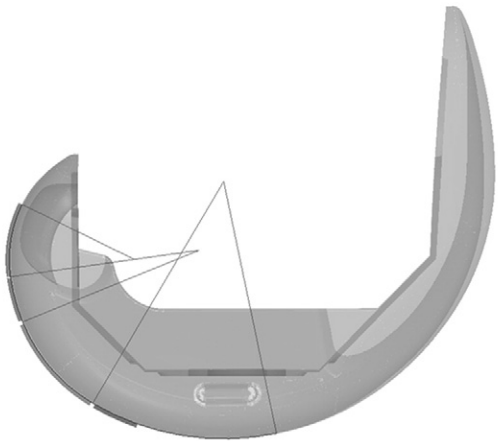

Fig. 1. A representative multi-radius total knee design showing decreasing radii of curvature on the higher flexion surface.

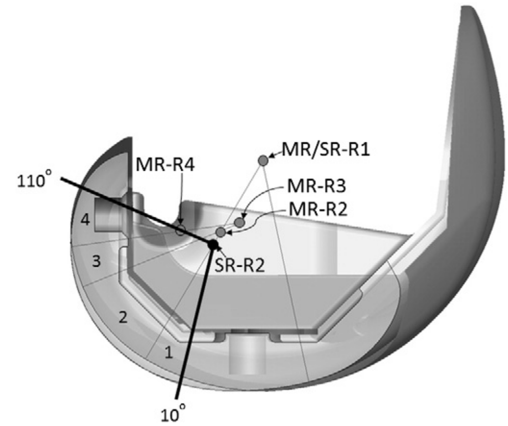

Fig. 3. Overlay of the single and multi-radius knee designs highlighting the shifting center of rotation (red dots) in the multi-radius design as the knee moves into increasing flexion. In contrast, the single black dot for the single radius design does not translate with increasing flexion.

Since demanding functional tasks seem to be required to highlight differences between knee prosthetic designs, the clinical scores traditionally used in orthopedic outcome studies may not be sensitive enough to elucidate outcome differences in implant designs. Gomez-Barrena [25] and Mahoney [8] reported statistical differences in isokinetic muscle testing and ability to rise from a chair, respectively, but no statistical differences in clinical scores between subjects receiving either SR or MR designed TKAs.

Since level ground walking is the most common, and perhaps most important, activity of daily living performed by total knee recipients, the paucity of information comparing this task between SR and MR knee designs should be addressed. The purpose of this study was to use quantitative motion analysis techniques to evaluate the impact of a SR versus MR knee design on the kinematics and kinetics of the knee during level ground walking 1-year after surgery. We hypothesize that the SR knee design will function more similarly to a group of age matched controls in sagittal plane kinematics and kinetics of the knee joint.

Methods

Subjects

IRB approval was obtained to retrospectively compare 3 cohorts of prospectively collected biomechanical data generated from a motion analysis laboratory during level walking. The groups consisted of subjects who had undergone computer-navigated TKA with a representative SR (Stryker Triathlon Total Knee Replacement System) design, a representative MR designed implant (Biomet Vanguard Complete Knee System), and a group of age-matched healthy control subjects. The TKA groups were each a consecutive series of patients, enrolled in 2 parallel studies being conducted in the same community by the same practice. All patients were diagnosed with advanced knee osteoarthritis and scheduled to undergo TKA before being consented to participate in a study. Control subjects were drawn from a large database of controls, also from the same community, with no reported gait or lower extremity disorders at the time of gait analysis. A random sample, of equal size to the test groups, was repeatedly drawn and demographics were statistically compared to the treatment groups until a match in age, weight, height, and gender was obtained.

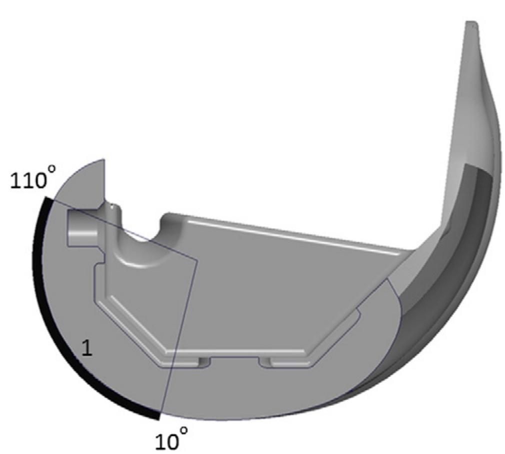

Fig. 2. A representative single radius knee design showing consistent radius of curvature on the flexion surface.

All implant procedures were performed by three different fellowship-trained arthroplasty surgeons from one orthopedic practice. Knee alignment was controlled using computer navigation with a target of neutral varus–valgus with respect to the mechanical axis. Postoperative alignment, as determined by the computer navigation system, was within $\pm 3°$ for all patients at the end of the surgical case. The patella was resurfaced in all cases. Both representative TKA designs were posterior cruciate ligament substituting implants. All patients were treated with identical standardized order sets and clinical protocols. All surgical subjects received similar pre-operative, peri-operative, and post-operative care based on the standard order sets. Surgical subjects and controls were excluded from comparison if significant diseases (e.g., rheumatoid arthritis, psoriatic arthritis, painful osteoarthritis, neuropathies, etc.) affecting other joints of the lower extremities, movement disorders (e.g. Parkinson's disease, Multiple Sclerosis), and/or arthrodesis were present.

The SR group consisted of 16 subjects ($n = 8$ male, $n = 8$ female) with an average age (at 1-year) of 71.6 ± 6.1 years, weight of 82.6 ± 13.1 kg, height of 1.67 ± 0.07 m, and BMI of 29.5 ± 5.0 kg/m^2. The MR group consisted of 16 subjects ($n = 8$ male, $n = 8$ female) with an average age (at 1-year) of 70.9 ± 8.4 years, weight of 85.5 ± 15.5 kg, height of 1.69 ± 0.08 m, and BMI of 29.6 ± 3.4 kg/m^2. The control group consisted of 16 subjects ($n = 9$ male, $n = 7$ female) with an average age of 69.2 ± 6.2 years, weight of 82.1 ± 11.6 kg, height of 1.67 ± 0.09 m, and BMI of 29.2 ± 3.3 kg/m^2.

Biomechanical Data

Position and force data (pre-operatively and 1-year post-operatively) were collected using ten Eagle-4 digital IR cameras (Motion Analysis Corp., Santa Rosa, CA) sampling at 120 Hz. Subjects wore