Biomimetic Total Knee Arthroplasty with Anterior Cruciate Ligament Preservation Restores Normal Kinematics and Reduces Implant Wear

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Introduction: Anterior Cruciate Ligament (ACL) retaining Total Knee Arthroplasty (TKA) provides more normal kinematics than ACL sacrificing (CR) TKA. However, in the native knee the ACL and the asymmetric shape of the tibial articular surface with a convex lateral plateau are responsible for the differential medial/lateral femoral rollback (medial pivot). Therefore, the first hypothesis of this study was that an asymmetric biomimetic articular surface together with ACL preservation would better restore native knee kinematics than retention of the ACL alone. The second hypothesis of this study was that a biomimetic articular surface manufactured from a novel vitamin-E stabilized highly cross-linked UHMWPE would yield superior wear performance compared to contemporary TKA with conventional UHMWPE articular surface.

Methods: A biomimetic Bi-Cruciate Retaining (BCR) implant was designed through a novel process that directly used in vivo kinematics of healthy knees obtained via bi-planar fluoroscopy. This was achieved by moving the femoral component through the healthy knee kinematics and sequentially removing material from a tibial template.

Kinematic performance of the biomimetic BCR implant (asymmetric tibia with convex lateral surface), a contemporary BCR (symmetric shallow dished tibia) and a contemporary CR (symmetric dished tibia) implant during simulated deep knee bend and chair sit was analyzed using LifeModeler KneeSIM software. Components were mounted on an average bone model created from Magnetic Resonance Imaging (MRI) data of 40 normal knees. The soft-tissue insertions were obtained from the average knee model and the mechanical properties were obtained from literature. Femoral condyle center motions relative to the tibia were used to compare different implant designs. In vivo knee kinematics of healthy subjects from published literature was used for reference.

The wear performance of the biomimetic BCR and a contemporary CR implant were compared using knee simulator wear tests. The biomimetic BCR tibial inserts were machined from a 0.1 wt. % vitamin-E blended GUR1020 UHMWPE that was irradiated to 100 kGy, mechanically annealed to a compression ratio of 2, and thermally annealed to activate the shape memory property of UHMWPE. The contemporary CR tibial inserts were machined from compression molded GUR1020 UHMWPE. Both sets of tibial bearings were then EtO sterilized twice and subjected to ASTM F2003 accelerated aging prior to testing on an AMTI 6-station displacement controlled knee simulator for 5×106 cycles of simulated gait at a rate of 1.0 Hz. The simulations were conducted according to ISO 14243-3 with an amplified compressive peak load of 3200N.

Results: During simulated deep knee bend, the ACL sacrificing contemporary CR implant showed initial posterior femoral subluxation due to the absent ACL, followed by paradoxical anterior sliding until 90° flexion, and no medial pivot rotation. Retention of the ACL in the contemporary BCR implant reduced the initial posterior shift of the femur in extension. However, medial pivot rotation and steady posterior rollback could not be achieved. In contrast, the biomimetic BCR implant showed knee motion very similar to that reported for healthy knees in vivo, with medial pivot rotation and greater, consistent rollback of the lateral femoral condyle than the medial condyle (11 mm medial vs. 16 mm lateral, Fig. 1 and Fig. 2). Similar trends were seen for all implants and the native knee during simulated chair sit.

The wear data showed an average incremental wear rate of 14.23 +/-0.87 mg/Million Cycles (MC) for the biomimetic BCR implant compared to 84.89 +/-13.68 mg/MC for the conventional CR implant (Fig. 3). T-test statistical analysis showed that the biomimetic BCR wear was significantly less (83.2%) compared to the conventional CR implant (p<0.0001).

Discussion: An ACL preserving biomimetic TKA implant was able to restore normal knee kinematics unlike contemporary ACL retaining and ACL sacrificing implants, during the simulated activities. This confirmed the hypothesis that a biomimetic articular surface together with ACL preservation is required to restore normal knee kinematics. Additionally, the wear tests showed that the biomimetic BCR insert manufactured from a novel highly cross-linked vitamin-E stabilized UHMWPE has a significantly lower wear rate (83.2%) compared to a contemporary CR insert manufactured from conventional UHMWPE. Therefore, the novel biomimetic BCR implant could provide more normal knee kinematics, together with significant increase in implant longevity.
compared to contemporary TKA implants.

**Significance:** The novel biomimetic BCR implant is the first ACL retaining TKA implant with an anatomic tibial articular surface. The anatomic design of this implant together with the retention of the ACL may be the key to provide patients with a normally feeling and long lasting knee following TKA surgery.

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**References:**

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