Restoration of knee function after total knee arthroplasty (TKA) often entails a balance between regaining the original kinematics of the native knee and providing the inherent stability necessary to perform demanding activities with confidence. In theory, knee designs that require normal ligament function may perform well in young active individuals. However, in patients with some loss of musculo-skeletal function, designs that provide more inherent stability have proven extremely popular despite loss of “normal knee biomechanics”. One type of knee design that typifies stability over kinematics is the ultra-congruent (UC) knee design in which the “deep-dish” geometry of the tibial insert closely conforms to the geometry of the mating femoral component in extension. The increased conformity of this articulation and its elevated features is intended to substitute for the posterior cruciate ligament in providing AP stability in activities traditionally causing anterior femoral subluxation. In this study we examine the kinematics of an ultra-congruent knee design in comparison with conventional articulations (PCL-retaining designs (CR) and PCL-substituting design (PS)) and the intact knee to answer the questions:

1. Do UC implants allow normal posterior roll-back with flexion or does the conforming insert convert the knee into a sliding hinge joint?
2. Do UC knees undergo normal coupled rotation with flexion?
3. Is there any resemblance between the kinematics of the normal knee and conventional knee prostheses and the UC design?

Methods: Six fresh frozen cadaveric human knees with functioning cruciates were prepared for this study. Reflective marker arrays were placed on the tibia and femur of each specimen allowing the tracking of each bone in 3D space. Prior to all testing, a CT of each specimen with the marker arrays were obtained using a helical scanner with a slice thickness of 0.625mm. The 3D tibio-femoral kinematics of the specimens were tested during loaded simulation of squatting in a computer-controlled knee testing rig. During this testing maneuver, loads of 150N, 100N, 75N, and 60N respectively (total: 385N) were applied to the rectus femoris and vastus intermedius, vastus lateralis, vastus medialis, and hamstring muscles respectively. The 3D positions of the knee were recorded using the marker arrays and a high resolution 12 camera motion analysis system (Motion Analysis). Testing was performed on the intact knee, and after implanting a standard design of total knee prosthesis with the posterior cruciate ligament intact (CR-TKA), resected using a PCL-substituting insert (PS-TKA), and a UC insert (UC-TKA group). Following testing, the 3D locations of the bones and CT models were imported into specialized software (Rapidform). Reference geometries were created from the tibial anatomical axis, the trans-tibial plateau axis, and the femoral transcondylar axis. A coordinate system aligned to the trans-tibial plateau axis and tibial anatomical axis were created for each specimen. Using projections of
the femoral transcondylar axis onto the tibial coordinate system, translations and rotations of the tibia and femur were calculated.

**Results:** Knee Kinematics

After TKA with a UC insert, the transcondylar axis of the femur remained within 4mm of its position in extension, translating slightly anterior between 30 and 75 degrees of flexion. During the same interval, the same knees in the intact state translated posteriorly an average of 8mm from their initial position in extension. In deeper flexion (90-120 degrees), the UC group exhibited slight rollback ranging from 2.2-5.6mm compared to 10.4 to 16.3mm for the intact knees (p<0.001). During knee flexion, the UC-TKA group underwent significant internal tibial rotation which averaged 10.7 degrees which was not significantly different from the same knees intact (11.5 degrees). However, the UC-TKR group underwent slight paradoxical external rotation from 0-30 degrees of flexion (mean: -1.8° (SD: 2.0; range: -5.2-1.2)). In comparison, the intact knees rotated internally an average of 8.4° (SD: 2.6; range: 4.2-11.1). Beyond 30 degrees of flexion, the intact knees rolled posteriorly without rotating internally until 105 degrees when internal rotation resumed. In contrast, the UC-TKR group rotated continuously from -3 degrees to 9 degrees of internal rotation when flexed from 30-120 degrees.

The PS and CR TKRs displayed approximately 50% more rollback than the UC-TKR group. For the first 90 degrees of flexion, all 3 groups remained within 5mm of their initial position in extension. Beyond 90 degrees, both the PS and CR TKR groups rolled back 7-9mm, in contrast to an average of 5.6mm for the same knees with a UC insert. The pattern of rotation with flexion was the same for all three TKR designs all reaching the same rotational position in deep flexion (120 degrees). In the first 30 degrees of flexion the PS TKR group displayed approximately half the paradoxical external rotation of both the CR and UC groups.

**Discussion:** This study demonstrates that, despite its extreme conformity in extension, the Ultra-congruent knee design does undergo some, though limited, posterior roll-back with flexion which is approximately one-third that seen in the intact knee at 120 degrees. Surprisingly, during the squatting maneuver studied, the ultracongruent knees underwent the same amount of internal rotation with flexion as the intact knees. In comparison with the conventional TKR designs (CR and PS), the UC knees displayed slightly less roll-back with flexion but a similar pattern of internal rotation.

These findings suggest that normal kinematics matching those of the ligament-intact knee may not be necessary to provide a TKR matching the functional requirements of many patients provided that AP stability comes with the freedom to allow rotation with flexion.

**Significance:** The Ultracongruent insert TKA employs a deep-dish geometry on the tibial insert for stabilization instead of retaining or substituting the PCL. This study explores the kinematics of this design.
Figure 1. The tibial internal rotation in the intact knee group, CR-TKA group, UC TKA group and PS-TKA group.

Figure 2. Midpoint translation of tibia through dynamic knee squat.