INTRODUCTION: During activities of daily living, such as walking and stair ascent, varus moments are experienced in the knee, which can result in liftoff of the lateral femoral condyle from the tibial plateau. However, it is not clear how much frontal plane rotation would actually be achieved due to this varus moment with a total knee replacement (TKR) where the posterior cruciate ligament (PCL) has been sacrificed. An understanding of this frontal plane rotation is valuable as it could potentially lead to contact between the femoral component and the polyethylene post. In addition, it would allow for an understanding of knee kinematics following such a procedure. This would be of particular interest for a device with increased stability than a standard PS TKR, to determine how this increased stability impacts frontal plane rotation.

Therefore, the purpose of this study was to assess how much frontal plane rotation was achieved due to varus moments imposed on a total stabilized TKR from activities of daily living, namely walking and stair ascent. In addition, we sought to determine whether the total stabilized TKR could withstand the contact stresses imposed by the varus loading for 1 million cycles without the post fracturing or plastically deforming.

METHODS: The TKR components tested included a standard PS femoral component (Triathlon PS, Stryker Orthopaedics, Mahwah, NJ) paired with a total stabilized polyethylene insert and tibial baseplate (Triathlon TS, Stryker Orthopaedics, Mahwah, NJ). The main design aspects which differentiate the total stabilized insert from the standard PS insert are a taller and wider polyethylene post and a stabilizing pin which is inserted into the post and engages with the tibial baseplate. There are several design differences between the PS femoral component and the total stabilized femoral component. However, the PS box geometry is identical with both devices. As this was the main aspect of the femoral component engaging with the post during testing, the PS femoral component was considered suitable for this study.

In order to evaluate the frontal plane rotation of the total stabilized device due to an imposed varus moment, a multi-axis testing system (MTS Systems Corp., Eden Prairie, MN) was used. The size 1 PS femoral component was first cemented to a femoral fixture and aligned to 60 degrees of flexion. This angle of flexion was chosen to ensure cam-post engagement at the start of testing. In addition, it represented an angle of flexion where peak varus moments were induced during stair ascent, as per data from OrthoLoad.com [1]. The femoral fixture, with size 1 PS femoral component, was then placed in a vise attached to a linear motion table, which allowed free motion in the Medial-Lateral (ML) direction, located at the base of the testing system. The corresponding size 1 tibial baseplate was cemented to a tibial fixture and a size 1 total stabilized 9 mm polyethylene insert was seated into the tray with its own locking mechanism. This fixture was then attached to the main system actuator located above the femoral fixture. It should be noted that the ML width of the PS box of the femoral component and the post of the total stabilized polyethylene insert remains the same for all size components. Therefore, with size 1 components, to achieve the same moment, higher reactive forces would be generated at the post; thereby representing a worst-case testing scenario. With the fixtures in place, the tibial component was aligned such that the polyethylene post was centered in the ML direction, the femoral condyles were in contact with the polyethylene bearing surface and there was cam-post engagement (Figure 1).

To determine the varus moment to be applied, the instrumented knee data from OrthoLoad.com was used. The peak varus moment during both walking and stair ascent for a 100kg patient was reported to be 39Nm [1, 2]. This moment was then scaled up for a 136.1 kg patient, representing 3 standard deviations from the average TKR patient body weight of 88kg, and the varus moment determined to be 54.5Nm. The loads were applied for 1 million cycles to represent the number of cycles of stair ascent experienced over 20 years, based on data from Morlock et al. [3].

In order to evaluate the frontal plane rotation achieved due to the varus moment with minimal influence from other loads, it was desired to apply the least possible joint compression that would allow testing to be completed. To determine this, a finite element analysis (FEA) was used. The physical testing setup described above was modeled in ANSYS 15.0 (ANSYS Inc., Canonsburg, PA). The model was meshed using 10-noded tetrahedral elements of 1mm edge length. All components were modeled as linearly elastic. Frictionless contact was modeled between the femoral component and the insert, between the insert and the tibial baseplate and between the distal end of the pin and the insert. The proximal end of the pin was bonded to the insert to account for the barbs that typically lock into the insert when impacted into it. The base of the tibial baseplate was fixed in all degrees of freedom. The 54.5Nm varus moment was applied and the joint compression increased in 250 N increments from 1500N until a stable testing construct was achieved, where the femoral component would remain properly aligned on the polyethylene insert as the moment was applied. In this fashion, the least possible joint compression that would allow testing to be completed was determined to be 2250N, which is approximately 50% of the joint compression reported to be induced at the time of the peak varus moment, per OrthoLoad.com. The FE analysis was also used to confirm the anticipated areas of contact between the femoral component and the polyethylene post prior to physical testing.

Given this, testing was completed with a constant joint compressive load of 2250 N while sinusoidally applying a varus moment from 5 Nm to 54.5 Nm for 1 million cycles, representative of a severe varus loading condition. The frontal plane rotation at each cycle was acquired from the system potentiometers and the maximum frontal plane rotation determined. Testing was completed with 3 sets of components to assess repeatability of the data. It should also be noted that to ensure this testing methodology was properly providing a varus moment and loading the polyethylene post as expected, a validation test was completed. The above test was completed with an additional set of components, where the polyethylene insert was notched 1/8" towards the center of the post at the medial distal aspect and lateral proximal aspect of the post. In this fashion, the least possible joint compression that would allow testing to be completed was determined to be 2250N, which is approximately 50% of the joint compression reported to be induced at the time of the peak varus moment, per OrthoLoad.com. The FE analysis was also used to confirm the anticipated areas of contact between the femoral component and the polyethylene post prior to physical testing.

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RESULTS: The maximum frontal plane rotation achieved for component set 1 was 7.48 degrees, for component set 2 was 7.05 degrees and for component set 3 was 7.82 degrees. The frontal plane rotation increased, on average, 0.76 degrees during the 1 million cycle test (i.e. frontal plane rotation at start was 6.30 degrees and 7.05 degrees at cycle 1 million for component set 3). Contact was noted between the femoral component and the polyethylene post at the medial distal aspect and lateral proximal aspect of the post, as demonstrated with the FE analysis prior to testing (Figure 2). At the completion of testing, all components were noted to be intact with no gross plastic deformation present.

DISCUSSION: The frontal plane rotation achieved due to the applied varus moment imposed on a total stabilized TKR from activities of daily living, namely walking and stair ascent, was determined to be 7.45 degrees, on average. The frontal plane rotation increase noted throughout testing was likely a result of local contact creep of the polyethylene. As a result of this frontal plane rotation, contact was noted between the femoral component and the polyethylene post at the medial distal aspect and lateral proximal aspect of the post. However, this did not result in gross plastic deformation of the components.

It should also be noted that the frontal plane rotation measured was induced by the varus moment with minimal influence from a joint compressive load. In the knee, the joint compression would be substantially higher and applied in combination with several other forces (i.e. Anterior-Posterior Shear), which would likely reduce the frontal plane rotation achieved. In addition, the collateral ligaments would be present to provide restraint from excessive frontal plane rotation. Given this, the data from this study is useful in determining the amount of restraint achieved by the components themselves and understanding the impact on knee kinematics following implantation with a total stabilized TKR.

SIGNIFICANCE: The frontal plane rotation achieved due to an applied varus moment imposed on a total stabilized total knee replacement from activities of daily living, namely walking and stair ascent was determined to be 7.45 degrees, on average. This was investigated with minimal influence from a joint compressive load and without the influence of the collateral ligaments. Given this, the data from this study is useful in determining the amount of restraint achieved by the components themselves and understanding the impact on knee kinematics following implantation with a total stabilized TKR.
REFERENCES:


IMAGES:

Figure 1. Test setup used to assess the frontal plane rotation achieved due to the applied varus moment imposed on a total stabilized TKR from activities of daily living, namely walking and stair ascent.

Figure 2. Contact pressure plots indicating contact points on the medial and lateral aspects of the total stabilized TKR.