EFFECT OF COMPONENT ALIGNMENT AND LIGAMENT BALANCING ON THE PASSIVE STABILITY OF A REPLACED KNEE

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ABSTRACT

Initial stability of the knee joint is essential if long-term survivorship is to be achieved. At the time of operation the surgeon can assess the stability of the joint by carrying out simple passive stability tests, assessing the integrity of the joint and the laxity of the ligaments. A fully mechanical model of a replaced knee has been developed to simulate this passive stability testing, which is capable of altering parameters such as component positioning and ligament tensions simply and accurately. Internal/external rotational stability of a posterior cruciate-retaining rotating platform knee was assessed under a variety of different knee conditions.

Increasing the strains equally in both collateral ligaments increased the axial stability of the knee, with lax ligaments causing the stability to decrease. Varus or valgus malrotation of the femoral component did not significantly affect the femoral rotations of the knee, however the interaction between the femoral and tibial components was significantly altered. A lax medial collateral ligament combined with valgus malrotation of the femoral component caused pivoting to occur on the lateral side of the knee, producing zero internal rotation. This indicates that 100% of the load passes through the lateral side of the knee. The opposite was seen in the varus knee with a slack lateral collateral ligament.

INTRODUCTION

The type of implant, component positioning and the tensions in the soft tissue structures (e.g. ligaments) around the knee are all factors that contribute to the performance and survivorship of the replaced knee. A surgeon performs passive (unloaded knee) stability tests during total knee arthroplasty (TKA) to check the integrity of the joint, with instability likely to jeopardize its long-term performance, possibly resulting in the need for revision surgery.

Many studies have been performed to evaluate the performance of the knee after TKA, including *in vivo studies* [1], cadaveric studies [2], computer simulations [3] and mechanical wear testing [4]. A review of the literature has indicated that a fully mechanical model of a replaced knee, used to assess the interaction of component positioning and ligamentous balancing on knee stability, is not currently available.

METHODS

A mechanical rig was developed (figure 1), allowing passive stability testing to be performed on total knee replacements. This rig has the capacity to test different knee designs as well as allowing the alignment of the femoral component and the strains within the primary ligaments of the knee (medial collateral ligament (MCL), lateral collateral ligament (LCL), posterior cruciate ligament) to be altered. A posterior cruciate-retaining rotating platform knee (PFC Σ-RP, DePuy, Leeds, UK) was tested in this study, assessing its internal/external rotational stability by recording the rotations of the femoral and tibial components during torque-controlled tests. The test machine recorded femoral motions while a linear potentiometric displacement transducer (LPDT) was setup to record the tibial insert rotations. The femoral component was rigidly fixed to the test actuator arm, rotating in the internal/external direction only. The tibial component is free to move in the anterior/posterior & medial/lateral translation, and varus/valgus & internal/external rotational directions.

The knee was tested in the neutral alignment position, that is with the femoral component parallel to the tibial component, and the tibial component at 90° to the shaft axis of the tibia. Testing was also carried out with the femoral component rotated into either 3° of valgus or 3° of varus. At each of these alignment positions the initial strains in the collateral ligaments were altered, with 0% strain representing the normal ligament strain, 4% strain representing a tight ligament and –4% strain representing a lax ligament. Table 1 shows the test conditions assessed in this study. The posterior cruciate ligament was not attached during testing. A constant 100N compressive load was applied through the femoral component in each test, chosen since it is relatively small and could be maintained accurately.

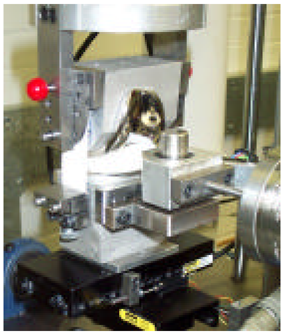

Figure 1. Test Rig

Knee Position	MCL	LCL
Neutral	Tight	Tight
	Normal	Normal
	Slack	Slack
	Tight	Normal
	Normal	Tight
	Normal	Slack
	Slack	Normal
3° Valgus	Normal	Normal
	Slack	Normal
	Normal	Slack
3° Varus	Normal	Normal
	Slack	Normal
	Normal	Slack

Table 1. Test conditions assessed

The collateral ligaments were represented by a rubber material possessing stiffness values similar to anatomic knee ligaments [5]. The knee was tested at 0° (full extension), 30° and 90° flexion for each test condition. A positive 3Nm torque was applied to the knee via the femoral component, the knee was returned to its zero rotation position and the torque zeroed before a negative 3Nm torque was applied.

RESULTS AND DISCUSSION

It was noted that the rotations tended to be slightly larger at 90° flexion than at full extension, most likely due to the altered conformity and ligament function at different flexion angles. Axial stability increased as both collateral ligaments were equally tightened, and the stability decreased with lax collateral ligaments (Figure 2). Tibial insert rotations were always lower than the femoral rotations due to sliding of the femoral component over the insert. The conformity of the two components was greatest at full extension, reducing through the flexion range causing the insert rotations to decrease even though the femoral rotations increased (Figure 3).

The overall stability reduced as one of the collateral ligaments was slackened, with no significant difference whether the MCL or the LCL was slack. With one tight collateral ligament the stability was not significantly altered, however the load distribution across the knee may have been affected; this effect will be investigated in future studies.

Malrotation of the femoral component into either 3° of valgus or 3° of varus did not significantly alter the internal/external rotations of the femoral component. The interaction of the femoral component and tibial insert was significantly altered due to malrotation, particularly with unbalanced collateral ligaments. External tibial insert rotations tended to be affected to a lesser extent than internal rotations, with the main effects noted when the knee was in the fully extended position (Figures 4 & 5 show the internal rotation findings). Valgus alignment combined with a slack MCL produced no recorded tibial insert rotation, with visible pivoting on the lateral side of the knee during both internal and external rotation. This indicates that most, if not the entire axial load was passing through the lateral side of the knee. Varus alignment combined with a slack LCL caused pivoting on the medial side of the knee, again with no internal insert rotation at full extension.

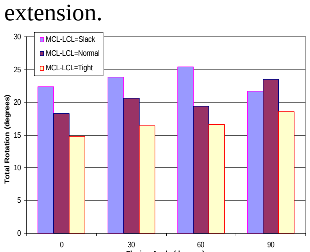

Figure 2. Femoral rotations with varying ligament strains

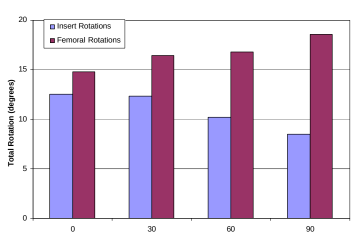

Figure 3. Tibial and femoral rotations over the flexion range

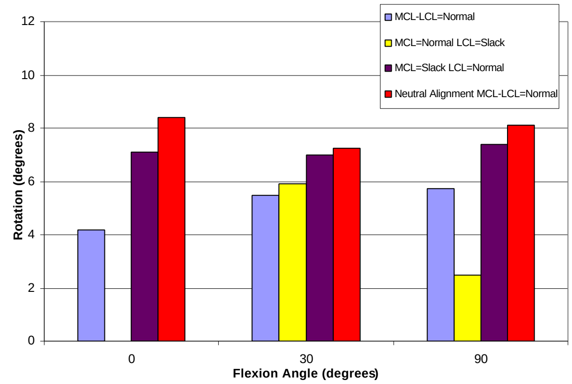

Figure 4. Effect of varus alignment on internal tibial insert rotations

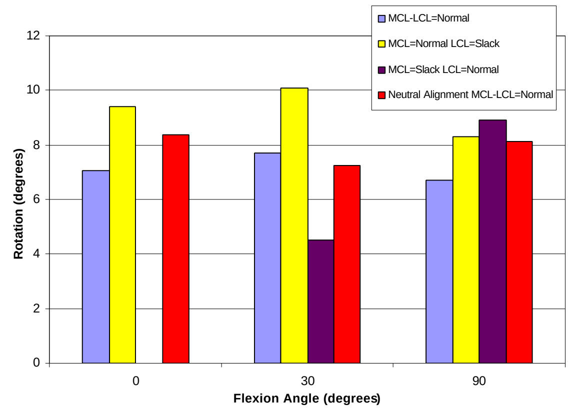

Figure 5. Effect of valgus alignment on internal tibial insert rotations

CONCLUSIONS

The importance of initial knee alignment and ligament strains towards the stability and performance of the knee is highlighted in this study. Slight alignment variations are likely to occur during TKA, and it is shown that this places increased emphasis on accurately achieving balanced ligaments. The knee may appear stable when assessing the femoral rotations, however it is shown that the interaction of the femoral and tibial components is altered under certain knee conditions. The MCL is seen to be particularly important in the valgus knee, and the LCL in the varus knee.

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