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Effects of surgical variables in balancing of total knee replacements using an instrumented tibial trial

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ABSTRACT

Background: In total knee surgery, typically the bone cuts are made first to produce the correct overall alignment. This is followed by balancing, often using spacer blocks to obtain equal parallel gaps in flexion and extension. Recently an electronically instrumented tibial trial has been introduced, which measures lateral and medial contact forces. The goal of our study was to determine the effect of different surgical variables; changing component sizes, modifying bone cuts, or ligament releases; on the contact forces, as a method to achieve balancing.
Methods: A special rig was designed to fit on a standard operating table, on which tests on 10 lower extremity specimens were carried out. After making bone cuts for a posterior cruciate retaining knee using a navigation system, tibial thickness was determined in extension using the Sag Test. Different Surgical Variables were then implemented, and the changes in the condylar forces were determined throughout flexion using the Heel Push Test.
Results: condylar forces were found to consist of gravity forces due to the weight of the leg plus forces due to pretension in the collateral ligaments. The pretension force averaged 145 N but there was considerable variation because of ligament stiffness properties. Balancing from an imbalanced state could be achieved with adjustments within only 2° or 2 mm.
Conclusion: The instrumented tibial trial provided force information which indicated which surgical correction options to carry out to achieve balancing. From an initial unbalanced state, relatively small changes could produce balancing, indicating the sensitivity of the procedure.
Clinical Relevance: Non-clinical. This study will assist in the balancing of the knee at total knee replacement surgery.

1. Introduction

Achieving the ideal alignment of bone cuts, together with ligament balancing, are important goals in total knee surgery. The accuracy of the various bone cuts is usually within 3° of target, with some studies showing that navigation produces more consistency [1,2]. However there is still uncertainty of the basis for the alignment in terms of achieving the optimal results [3–6] and differences between measured resection and gap balancing have been pointed out [7,8]. The complexities of soft tissue balancing have been described and evaluated by many authors, while other balancing options have been specified including adjusting bone cuts and component sizing [9–15]. Generally the emphasis is on achieving equal gaps at 0 and 90° of flexion, with the femoral rotation playing an important role [3,10,16–20]. However, other authors have proposed unequal lateral and medial balancing to better reproduce the normal anatomic situation [21,22].

Various methods have been introduced to improve and quantify the process of balancing, distractors being the most frequently used [23–26]. The concept of measuring the tibial plateau forces and contact locations at surgery was first demonstrated using pressure sensitive film [27,28]. Recently an electronically instrumented tibial trial component has been introduced, which measured and displayed in real time the forces on the lateral and medial compartments and their locations at all flexion angles [29]. Clinical studies have suggested that correct balancing can improve outcomes in various ways, including the avoidance of postoperative instability and improved flexion [11,12,30–33].

However, there have been few reports of the ideal values of distraction or contact forces in order to achieve 'correct balancing'. The first such data was provided from a series of cases using a distractor device, where having achieved ideal balancing empirically, average total femoral–tibial compressive forces of 120 N at both 0 and 90° flexion were reported [24]. Whatever the ideal balancing goals, the instrumented tibial trial concept does provide the possibility of reaching a defined goal in a methodical way. At surgery, balancing is usually attempted by 'surgical variables' such as ligament releases, changing component sizes, or modifying bone cuts. An instrumented tibial trial can then evaluate the effects of the different surgical variables.

Hence, the primary goal of this laboratory study was to determine the effect of the different surgical variables on the forces on the lateral and medial condyles over a full range of flexion. This would then provide guidelines for which surgical variable would be most effective in

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achieving balancing from an initial unbalanced state. An associated goal was to evaluate a specific surgical test that would provide the required force data.

2. Methods and materials

A test rig was developed for mounting lower body specimens to a standard operating table (Fig. 1). The pelvis was fixed to the base of the rig and a surgical boot was firmly strapped to the foot. A spherical bearing fixed to the heel of the boot was attached to a low friction carriage which advanced towards the hip along a slide rail, to flex and extend the knee with no constraints. To maintain the leg in a vertical plane, chocks were used to prevent foot rotation. For specific tests, fixtures on the rig allowed the leg segments to be supported at a required flexion angle, to maintain the thigh and lower leg in a vertical plane, to prevent axial rotation of the femur, and to be correctly positioned medio-laterally. A total of 10 leg specimens were tested, of which two were used for experimental development.

Once the specimen was mounted, navigation trackers were fixed to the femur and tibia. A subvastus medial approach was then used for surgical exposure. The bone cuts were made for the insertion of a posterior cruciate retaining total knee (Triathlon, Stryker Orthopaedics, Mahwah, NJ) using an optical navigation system (Stryker Navigation, Kalamazoo, MI). The frontal plane cuts were perpendicular to the mechanical axes of the respective bones, while the tibia was cut at 5° posterior slope in the sagittal plane. The femoral rotation was 3 to 4° external to the epicondylar axis, verified by Whiteside's line and the posterior condylar line. The trial femoral component and tibial baseplate were inserted, the latter rotationally aligned initially to the medial third of the tibial tubercle.

The wireless instrumented tibial trial was then introduced (OrthoSensor Knee Balancer, OrthoSensor, Inc., Sunrise, FL), of a thickness so that the knee just reached full extension when the foot was lifted up from the table. This procedure was called the Sag Test. For this and all subsequent tests, the vastus medialis and medial arthrotomy incision were closed with towel clips. In order to assess the rotational position of the tibial component, the foot was oriented vertically, and was manually pushed along the horizontal rail such that the knee flexed from 0 to 120°, with the leg moving in a vertical plane. This procedure was termed the Heel Push Test. The anterior–posterior (AP) locations of the contact points were observed and the rotational position of the tibial component was adjusted if necessary to produce uniform locations of the contact points on the lateral and medial sides. The tibial baseplate was then pinned in place to define its position for all subsequent tests.

A surgical variable (Fig. 2) was selected based on the initial output data. For example if there was a consistently higher medial than lateral force during flexion, a two degree tibial varus angle was applied by stuffing the lateral side with a two millimeter wedge. The Heel Push Test was then repeated. The difference in the output data caused by the surgical variable (in this case, the two degree tibial varus) was then determined. This principle of differences was used throughout the sequential testing to determine the effect of each surgical variable. The order of applying the surgical variables was based mainly on the output data from the preceding test. The method was to move towards and away from a balanced state with each variable. All variables could not be applied to every knee due to situations when the contact forces became zero, or were excessive in certain flexion ranges.

3. Results

3.1. Analysis of Heel Push Test

The leg is represented in Fig. 3, where the hip is a fixed pivot, the foot slides horizontally along the slide rail, and a heel push force is applied. The forces between the femur and tibia are shown as a force JF down the axis of the tibia, which would be measured by the instrumented tibial trial, and a shear force. JF is the sum of the lateral and medial forces. The weights of the thigh and lower leg are WT and WS, acting at the distances shown.

This equation for the total joint force JF (Fig. 3) predicts that the forces will be small at higher flexion angles, but increase rapidly as the flexion angle becomes about 15°. The

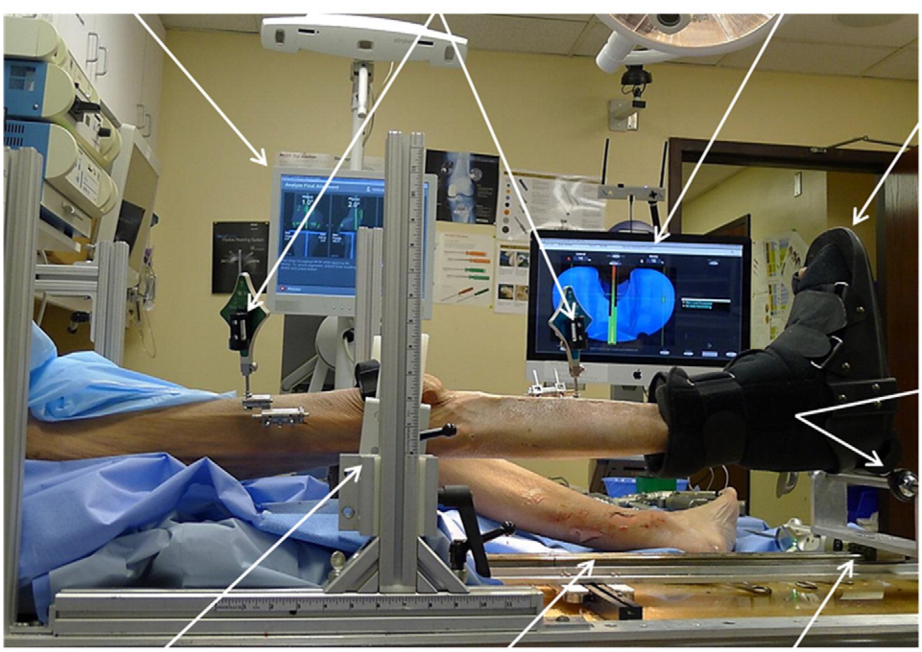

Fig. 1. The test set-up for carrying out the experiments on the lower limb. The custom-made rig was fixed to a standard operating table.