Using CT generated 3D models to measure the bony geometry and mechanical axes of the lower limb before and after performing a computer navigated opening wedge high tibial osteotomy

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INTRODUCTION

Obtaining exact information on the bony geometry and mechanical axes of a patient is crucial in pre-, intra-, and post-operative planning for orthopaedic procedures of the lower limb. Procedures such as high tibial osteotomies (HTO) alter the mechanical axis such that loads are moved away from an arthritic joint compartment[1,2]. Conventional calculations have been performed using 2D radiography or intra-operative fluoroscopy with diathermy, but have limitations[3]. Computer-assisted navigation requires the rigid fixation of optical markers to bone in order to provide the surgeon continuous visualization of mechanical axes during surgery. Unfortunately, landmarks can also be registered percutaneously which could affect the accuracy of these axes. For example, the intra-operative detection of the transepicondylar axis has shown poor repeatability[4]. In this study, pre-operative computed tomography (CT) data was converted into 3D computer bone models such that landmarks could be placed directly onto bone, thereby improving the accuracy of anatomic measurements[5].

The objective was to develop a novel process for identifying specific bony landmarks of 3D CT models of cadaveric lower limbs, and use them to measure their geometry and calculate their associated mechanical axes. An opening wedge HTO was also performed to examine changes in measurements. With the implantation of a 12.5mm tapered Puddu plate (Arthrex, FL) we would expect to see a 12.5° increase in valgus angle of the knee joint[6]. In addition, the orientation of the tibial plateau and leg length after HTO is not anticipated to change.

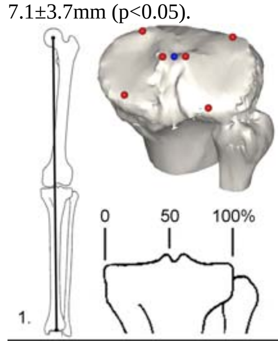
METHODS

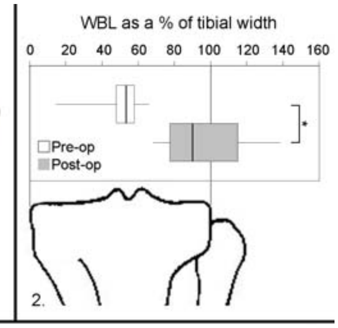
The lower extremities of 8 thawed cadavers (7 male, 1 female) were obtained, but 3 limbs were lost due to inadequate bone quality for plating. Therefore, a total of 13 limbs were analyzed. The average age was 68yrs (range 35-92). The feet were held in foam mold at approximately 15° hip flexion with full extension of the knee. Each limb was scanned before and after each HTO procedure. The osteotomy plane was established using VectorVision1.0 (BrainLAB, Munich/Germany) navigation system, and the plate was inserted and screwed medially into place. The cadavers were scanned using a GE LightSpeedVCT with scan spacing of 2.5mm at regions of interest: the hip, knee, and ankle. This CT data was converted into 3D computer models using Mimics10.11 (Materialize, Leuven/Belgium), and landmark points were placed directly onto the surface (Figure 1). Spherical landmark center points of the femoral head and postero-distal aspects of femoral condyles were calculated using GeoMagic Studio9 (GeoMagic, NC/USA). Pro/E Wildfire3.0 (PTC, MA/USA) was used to determine the location of the weight bearing line (WBL) with respect to the total width of the proximal tibia as a percentage from the most medial side (Figure 1)[7]. Other measurements recorded include the external rotation of the distal tibia with respect to the proximal tibia (tibial torsion), the posterior slope of the lateral and medial tibial plateaus (tibial slope), the varus-valgus and extension angle of the leg, the external rotation of the tibia with respect to the femur (femoral tibial rotation), and the length of the tibia.

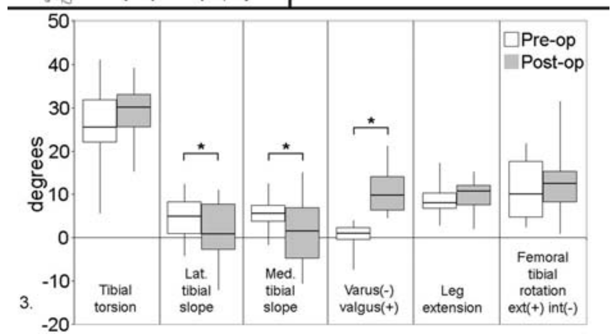
RESULTS

The average pre- and post-op tibial torsion were 26±10° and 28±7.3°, respectively. The average pre-op lateral and medial tibial slopes were 4.6±5.0° and 5.6±3.6°. A paired student t-test analysis showed that the post-op lateral and medial tibial slope were significantly different from pre-op ($p<0.05$) with and an average 3.7° and 4.6° increase in anterior tilt, respectively. The varus-valgus alignment was statistically different ($p<0.05$) between pre- and post-op groups due to the insertion of the tapered plate. The difference between their average change in valgus angulation was 11°±4.7°.(Figure 3)

The average pre-op location of the WBL as a percentage of tibial width was 49±14%, with neutral alignment being defined as 50%[8]. Post-op results significantly shifted the WBL laterally to a percentage of 96±25% ($p<0.05$), since the HTO creates a valgus correction.(Figure 2) The length of the tibia also increased by 7.1±3.7mm ($p<0.05$).







DISCUSSION

The results were comparable to another published cadaver study performed by Yoshioka et al.[9] which showed an average pre-op tibial torsion of 24±9.3°, lateral tibial slope of 8.0±3.8°, and medial tibial slope of 7.0±2.8° for 18 limbs (men and women). The Puddu plate did provide an average valgus correction close to the prescribed 12.5°, but the standard deviation was quite wide. The plate may not provide an accurate means of controlling correction in the coronal plane. In the sagittal plane, the average tibial slopes were lower post-op which may suggest that the taper on the plate provides an excessive anterior tilt of the tibial plateau. In addition, the opening wedge HTO caused an increase in length of the tibia which could alter the balance of the patient's gait.

The results showed that CT 3D models can be used to identify key bony landmarks, as well as examine spatial relationships from one bone to the next. Using CT data to obtain a patient's WBL can become an important pre- and post-op tool in evaluating surgical correction of the lower limb. Tibial slope can be calculated, which surgeons can use to address knee malalignments and instabilities, and to adjust contact pressure locations[2]. Applying this protocol to data obtained from a standing fluoroscopy machine will provide pre- and post-op information in a weight bearing environment.

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