• A NAVIGATED DRILL GUIDE USING AN INSTRUMENTED LINKAGE FOR THE PLACEMENT OF CUTTING JIGS DURING TOTAL KNEE ARTHROPLASTY

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ABSTRACT INTRODUCTION:
Current total knee replacement surgery uses a set of instrumentation and jigs to make a sequence of cuts on the femur and tibia, together with adjustments to soft tissues, to achieve the required joint stability and overall alignment. Inaccuracies result from several of the steps such that final errors in excess of 3° arc are not uncommon (Stulberg, 2003). Computer-assisted surgery using optical navigation for the placement of the slotted cutting jigs has reduced the number of outliers and has provided other advantages (Victor & Hoste, 2004; Sparmann et al, 2003). However, such navigation systems are expensive and still retain much of the original instrumentation. The purpose of our study was to determine the accuracy of navigating pin placement as a method for slotted cutting guide positioning. The navigation system was comprised of an instrumented linkage with a drill guide attachment and a computer navigation interface. We tested the simplicity of the system and whether the results would be independent of the experience of the operator.

MATERIALS & METHODS:
The experimental plan was to navigate the placement of a slotted cutting guide onto a simulated tibia using the navigated drill guide, to perform a tibial resection using an oscillating saw, and to measure the cut accuracy. A 6 degree-of-freedom MicroScribe G2LX (Immersion Corp) instrumented linkage with a point accuracy of under 0.23 mm at the tip was used. This was rigidly anchored next to the foam plastic tibia (Sawbone) which has comparable mechanical properties to an actual tibia. The tibia was securely mounted in a holder providing reproducible position (Fig. 1). Points on the tibia holder and on the upper tibia were used to define the target resection plane 10mm below the tibial surface. A dual drill-guide with holes corresponding to those of the slotted saw guide was attached on the end of the linkage. PC-based software was written to determine the location of the tibia, to track the drill guide and to navigate the placement of the drill guide against the anterior tibia (Fig. 2). The task of the surgeon was to position the guide in order to align a set of circles on the computer screen, one for target hole position on the bone and another set representing the orientation. Once aligned, the surgeon drilled the first hole into the anterior tibia. The procedure was repeated for the second hole. Pins with 3 mm diameter were then tapped into the holes. The slotted saw guide was placed over the pins and the upper tibial resection made. The MicroScribe was then used to digitize a plate placed on the cut surface to measure the accuracy of the cut. Both the mean depth and the angle in frontal and sagittal planes were analyzed. The system was tested by a medical student, a resident trainee, and a senior total knee surgeon, each cutting 10 tibias. Each operator was allowed one trial cut to become familiar with the system.

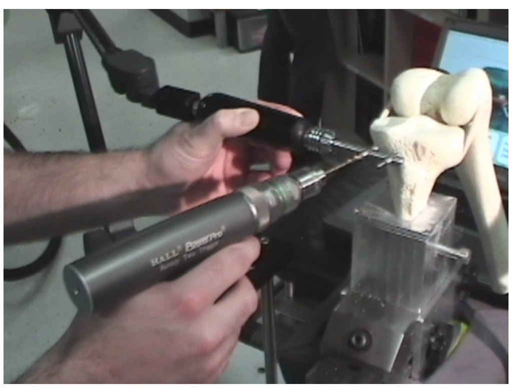

Figure 1. Experimental Setup.

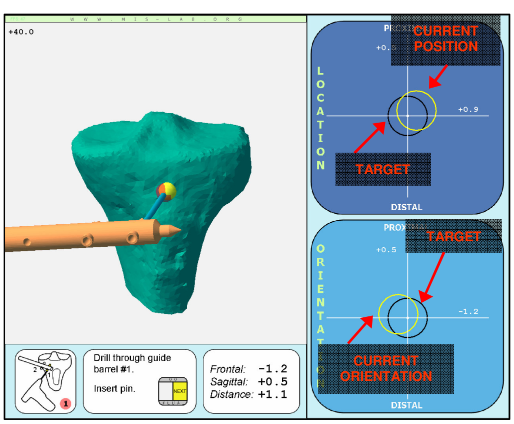

Figure 2. Graphical User Interface

RESULTS:
The mean results of all three operators were within 0.5 mm of the target depth and 1.2 degrees in both frontal and sagital planes (Fig. 3). The overall mean errors and standard deviation were as follows: the level of the cut surfaces was 0.19 ± 0.48 mm, the frontal plane angle was 0.66 ± 1.14 degrees and the sagittal plane angle was 0.88 ± 0.72 degrees.

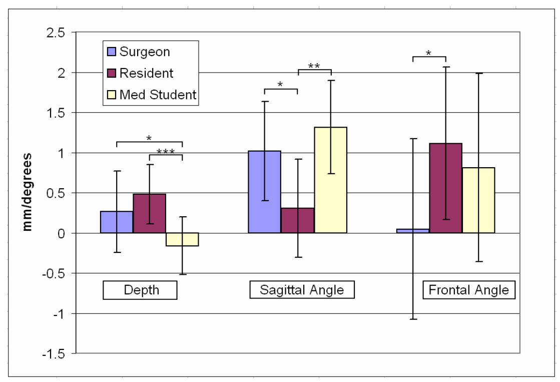

Figure 3. Results: Errors for three operators.'*' indicates statistical significance: * $p<0.05$, ** $p<0.001$, *** $p<0.0001$.

DISCUSSION:
The mean errors in depth of a cut and in the angles were small in the context of knee replacement. The error in the sagittal plane could be attributed mainly to motion of the cutting guide relative to the bone during cutting and the bending of the blade as it progressed across the tibia. Small proximal-distal inaccuracies in pin insertion were most likely a source of error for the frontal as well as sagittal planes. Although we did not compare the errors with a 'mechanical alignment' system, the accuracy appeared to be less than those under surgical condition (Mahaluxmivala et al, 2001). A further improvement in accuracy could be achieved by directly drilling the pins into the bone and using a third pin to further anchor the cutting guide. The simplicity of the system was demonstrated by the fact that each operator was comfortable after only one trial, because each step was easy to perform and the computer graphics intuitive. There was also no 'risk' involved with the drilling process even while glancing at the computer screen. No one operator was more accurate than any other, overall. This may have been because of the small inherent errors in the system, that it was difficult to produce errors of any significant magnitude.

Our next step is the incorporation of an instrumented linkage into a complete surgical procedure. Other applications using an instrumented linkage are also possible, including freehand navigation with a saw attachment (Walker et al, 2002, 2003), and navigated reaming in hip replacement (Cobb & Davies, 2005). The common factors are speed, accuracy, and simplicity achieved.

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