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THE ACCURACY OF A ROBOTICALLY-CONTROLLED FREEHAND SCULPTING TOOL FOR UNICONDYLAR KNEE REPLACEMENT.

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SUMMARY

Surgical robotics with navigation has the potential to improve the accuracy of unicondylar knee replacement. Precision freehand sculpting tools allow the surgeon to accurately execute their surgical plan. A controlled study comparing the planned and final placement of uni compartmental knee replacement implants in nine cadavers. A quantitative assessment analysed the translation and rotational differences between the positions of the implants. The maximum femoral implant rotational error was 3.7^o with a maximum RMS angular error of 2^o. The maximum femoral implant translational error was 2.6mm and the RMS translational error across all directions was up to 1.1mm. The maximum tibial implant rotational error was 4.1 with a maximum RMS angular error was 2.6^o. The maximum translational error was 2.7mm and the RMS translational error across all directions was up to 2.0mm. The freehand sculpting tool was shown to produce accurate implant placement with small errors which are comparable to those reported by other robotic assistive devices on the market for unicondylar knee replacement.

INTRODUCTION

Total knee arthroplasty is a standard treatment for severe osteoarthritis of the knee. However, in cases were only one compartment of the knee joint has been affected by osteoarthritis, there may be a clinical and functional benefit to the patient in preserving bone and ligaments by offering a unicondylar knee arthroplasty (UKA) instead of a total knee arthroplasty (TKA). The popularity in UKA grew in the 1980s but due to high revision rates[1-2] the usage decreased. A high incidence of implant malalignment[3] has been reported when using manual instrumentation. Computer assisted techniques in orthopaedics have been shown to improve the radiological outcomes in TKA. Surgical robotics with navigation has the potential to improve the accuracy and precision of UKA. The introduction of precision freehand sculpting tools may allow the surgeon to accurately execute their surgical plan. The aim of this study was to quantify the differences between the planned and achieved cuts.

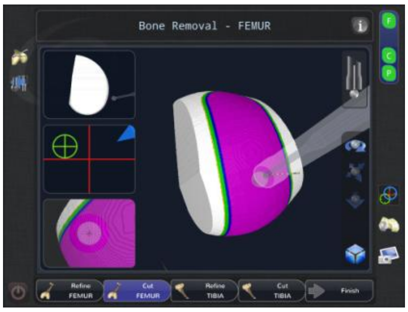
METHODS

Nine fresh frozen cadaveric lower limbs (hip to toe) were used (8 males, 1 females, mean age 71.7 (SD 13.3)). The UKA was carried out using an imageless navigation system - the Navio Precision Freehand Sculpting system (Blue Belt Technologies Inc, Pittsburgh, USA) – with a medical Uni Knee Tornier implant (Tornier, Montbonnot Saint Martin, France). Two users (consultant orthopaedic surgeon and post doctorial research associate) who had been trained on the system prior to the cadaveric study carried out 4 and 5 implants respectively.

The lower limb was registered using a tracked probe to locate knee and ankle landmarks as well as the hip centre. Once this was complete and the software had generated the limb axes the bone surfaces were generated by tracing the medial distal femur and medial proximal tibia. The software gave a visual representation of the bone and from this information the position and size of the implant was planned in all three planes. The robotic cutting burr was then used to prepare the bone surfaces. The software gave feedback on the amount of bone to be cut using a colour scale indicating the depth of bone remaining above the target surface (figure 1). The burr had two control modes; the 'speed' mode, where the burr only runs when it is within the 'planned' cutting zone, and the 'exposure' mode, where the burr retracts into a guard when it is outside the 'planned' cutting zone. Exposure mode was used to ream out both femur and tibia. Once the surfaces were prepared the implant was placed without cement. Trial implants were used which contained highly accurate location divots. These were used to record the final implant location using a ball point probe in the registration reference frame so that it could be compare to the plan.

The registration data were imported into AccuCut software for analysis. A 3D image of the implant position was calculated and overlaid on the planned implant image. The errors between the 'actual' and the planned implant placement were calculated in three planes and the three rotations.

(A)



(B)

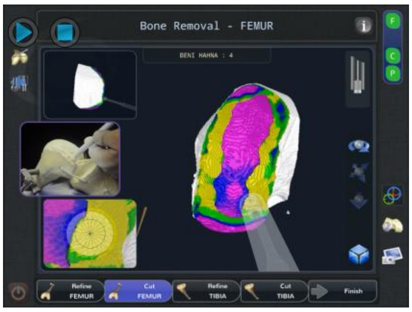


Figure 1: Visual representation of the femur and tibia cutting screen (A) Femur cutting screen prior to cutting (B) Femur cutting screen mid cutting.

RESULTS AND DISCUSSION

The results are given in table 1. The maximum femoral implant rotational error was 3.7^{o} with a maximum RMS angular error of 2^{o}. The maximum femoral implant translational error was 2.6mm and the RMS translational error across all directions was up to 1.1mm. The maximum tibial implant rotational error was 4.1^{o} with a maximum RMS angular error was 2.6^{o}. The maximum translational error was 2.7mm and the RMS translational error across all directions was up to 2.0mm.

CONCLUSIONS

Unicompartmental knee arthroplasty (UKA) is a challenging surgery. Despite accurate patient selection, the use of more modern conventional surgical instrumentations have not prevented significantly high rate revision in UKA surgery. Several factors can explain this high rate of UKA revision such as the lack of visibility in minimally invasive procedure usually use in this procedure or the difficulty to accurately and precisely position both femur and tibial implants which have been identified in UKA failure. Inaccurate leg alignment and unbalanced gaps are both responsible for enduring knee pain and unsatisfied patients who will need to be ultimately converted to TKA and unfortunately earlier than they should.

Recent improvements have been made to get round difficulties and help the surgeon to improve his work: dynamic laminar spreader and more recently navigation and robotic. The Navio Precision Freehand Sculpting system combines the advantages of gap measuring technique and measured resection technique. Indeed a gap planning using navigation measurements seem to offer optimal position and size of implants and the freehand sculpting tool was shown to produce accurate implant placement with small errors. Those are comparable to those reported by other robotic assistive devices on the market for UKA and make this instrumentation attractive to users. However, this technology still needs clinical assessment to confirm these promising results.

REFERENCES

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Table 1: Errors of implant positioning in six degrees of freedom, RMS error [range of errors]

Degree of freedom		Femoral component	Tibial component
	flexion / extension	1.02 (-2.06 - 0.40)	2.43 (-4.11 - 0.44)
	varus / valgus	2.02 (-1.73 - 3.69)	2.57 (-3.77 - 2.90)
Rotations (°)	internal / external	1.97 (-0.67 - 3.38)	1.63 (-0.71 - 2.81)
	lateral / medial	1.14 (-0.45 - 2.64)	0.88 (-0.79 - 1.43)
	anterior / posterior	0.53 (-0.10 - 0.95)	1.97 (-1.28 - 2.66)
Translations (mm)	inferior / superior	0.92 (-1.33 - 1.00)	0.63 (-1.06 - 0.70)

NOTE: External rotation, valgus rotation and extension were positive. Anterior/posterior translation was positive in the posterior direction, lateral/medial was positive in the medial direction and inferior/superior was positive in the superior direction.