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Technique and Accuracy Assessment of a Novel Image-Free Handheld Robot for Knee Arthroplasty in Bi-Cruciate Retaining Total Knee Replacement

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Abstract

Bi-cruciate retaining knee implants are anatomically designed for use in early surgical intervention, for patients with less severe arthritic disease. Patient satisfaction after total knee replacement is directly related to knee stability and proprioception, particularly for high-demand, active patients. While preservation of all intact and healthy ligaments may be the key to achieving such results of satisfaction, balancing four ligaments in a bi-cruciate procedure is more technically challenging then a conventional total knee replacement. Robotics-assisted arthroplasty has been gaining popularity as a tool to increase accuracy and precision of implant positioning. Robotics-assisted systems can provide surgeons with virtual tools to make informed decisions for knee replacement, specific to the needs of the patient. Here, we are introducing a semiautonomous handheld robotic system support for a bi-cruciate retaining knee implant design. The system supports image-free anatomic data collection and streamlined intraoperative surgical planning with dynamic gap balancing before any bone preparation. In this study, we evaluate the surgical technique and accuracy of implant placement in synthetic bone and cadaver experiments.

1 Introduction

Modern-day arthritis patients want to be able to return to high-level functional activities. Bi-cruciate retaining knee implant designs that are anatomically designed for use in early intervention surgical procedures, allow surgeons to indicate and operate on patients with less severe arthritic disease. Patient satisfaction after total knee replacement is directly related to knee stability and proprioception, particularly for high-demand, active patients[1,2] . While preservation of all intact and healthy ligaments may be the key to achieving such results of satisfaction, balancing four ligaments in a bi-cruciate retaining total knee is more technically challenging then balancing two ligaments in a posterior stabilized or BCS total knee[3]. At the same time, patients are also expecting to achieve a full and normal range of motion with flexion more than just 120-130°.

Robotics-assisted arthroplasty has been gaining popularity as orthopedic surgeons aim to increase accuracy and precision of implant positioning. Based on planned implant position and soft tissue considerations, robotics-assisted systems can provide surgeons with virtual tools to make informed decisions for knee replacement, specific to the needs of the patient. Here, we are introducing a semiautonomous handheld robotic system for total knee arthroplasty (Navio, Smith and Nephew) that supports a bi-cruciate retaining knee implant design (JOURNEY II XR, Smith and Nephew). The system supports image-free anatomic data collection and streamlined intraoperative surgical planning with dynamic gap balancing before any bone preparation. Navio utilizes intelligence of handheld robotics with a combination of burs and saws for accuracy and precision in bone preparation, to ultimately achieve the planned resection. Optimal planning will replicate the joint line, and achieve balanced range of motion outcome, specific to the patient's need.

2 Methods

In this study, we compared the planned and final implant placement in a total of 24 cadaveric femurs, 8 synthetic femur bones, 2 cadaveric tibias and 10 synthetic tibia bones using the bi-cruciate retaining knee implant design Journey II XR (Smith and Nephew), implanted with the Navio surgical system.

Final implant position was measured and compared to the surgical plan using a separate position tracking camera and analysis software. To document implant position, conical divots were drilled at known positions on all the implants used in this study. These divot positions were later used to measure the errors in the actual implant positions as compared to the planned implant positions. A quantitative analysis was performed to determine the translational, angular, and rotational differences between the planned and achieved positions of the implants.

Figure 1a. Ligament balance planning with the virtual components in place, before the bone cuts are performed.

Figure 1b. User interface showing medial tibia preparation of a bi-cruciate retaining knee using the speed control mode.

3 Results

The root mean square (RMS) errors of femoral varus/valgus, rotation and distal resection, were 0.7°, 0.7° and 0.86 mm; respectively. The RMS errors of tibial posterior slope, varus/valgus and resection depth were 0.88°, 0.69° and 0.68 mm, respectively. The image-free handheld robotic tool achieved accurate implementation of the surgical plan with small errors in implant placement.

Error type	Total error (Mean ± St.Dev)		Root Mean Square error (RMS)	
	Femoral implant	Tibial implant	Femoral implant	Tibial implant
ML error (mm)	*	0.1±1.3	*	1.29
AP error (mm)	0.1±1.5	0.5±0.6	1.46	0.79
SI error (mm)	0.0±0.9	-0.5±0.5	0.86	0.68
Flexion/extension error (°)	-1.7±1.4	-0.5±0.7	2.18	0.88
Varus/Valgus error (°)	-0.2±0.7	0.0±0.7	0.71	0.69
Rotation error (°)	-0.1±0.7	-0.5±2.2	0.69	2.21

4 Conclusions

As robotics continue to grow in the space of joint orthopedics, the flexibility and scalability of a system which eliminates the need of advanced imaging, and provides the same tools and workflow for unicompartmental, bi-compartmental and total knee surgery is going to be crucial for improving the efficiency and economic value of robotics-assisted knee arthroplasty[4]. The Navio robotic system brings some unique features that help enhance the surgical planning and execution. A bi-cruciate preserving implant design has a potential to better address the needs of more active patients with preserved cruciate ligaments[5]. For a bi-cruciate knee replacement the NAVIO system utilizes a hybrid approach for the femur with the use of burs and saws. For preparation of the tibia, the system uses the handheld robotic-assisted bur for entire bone preparation, preserving the ACL and the eminence bone island. In addition to image-free planning that takes into account the role of all four main ligaments in the knee, and the improved accuracy of bone preparation, the handheld robotics also allows a more ergonomic bone preparation and improves access to the lateral compartment. Future studies will focus on determining how well the accurate implant placement translates into a clinical and functional benefit for the patient.

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