Robotically Assisted Unicompartmental Knee Arthroplasty with a Handheld Image-Free Sculpting Tool

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KEYWORDS

• Robotic • Unicompartmental knee arthroplasty • Treatment • Implant positioning
• Soft tissue balance

KEY POINTS

- Unicompartmental arthroplasty is a successful procedure for the treatment of focal arthritis or osteonecrosis of the medial or lateral compartments of the knee.
- This article reviews the next-generation robotic technology (an image-free handheld robotic sculpting tool), which offers an alternative method for optimizing implant positioning and soft tissue balance without the need for preoperative computed tomography (CT) scans and with price points that make it suitable for use in an outpatient surgery center.
- The Navio robotic sculpting system does not compromise precision or safety; it represents a considerable savings on multiple levels, including savings of time, inconvenience, and radiation exposure related to the elimination of the preoperative CT scan; savings on space requirements; and savings on capital and per-case costs.

INTRODUCTION

The popularity of unicompartmental knee arthroplasty (UKA) continues to grow, currently accounting for roughly 10% of all knee arthroplasty procedures; the percentage is anticipated to increase to more than 20% in the future.[1–3] The use of UKA increased between 1998 and 2005 at an average rate of 32.5% compared with the growth of 9.4% in the rate of total knee arthroplasty in the United States.[1] Interest in UKA continues to expand as an early intervention strategy and is viewed as a more conservative procedure than total knee arthroplasty, with better kinematics and functionability.[4,5] UKA is also a particularly relevant option when considering that our knee replacement patients today tend to be more active, younger, and often present with an earlier stage of arthritis than in years past.[6] Even without expanding the appropriate surgical indications, a growing interest in outpatient knee arthroplasty procedures and the emerging use of surgery centers for UKA will likely increase training and endorsement of these procedures by a growing volume of surgeons.

Successful results and durability of UKA are affected by a variety of factors, including appropriate surgical indications, implant design, component alignment and fixation, and soft tissue balance. Early mechanical failure has been shown to occur in the setting of excessive posterior tibial slope or varus of the tibial component or both.[7–9]

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Achieving consistently accurate alignment of the tibial component in UKA using conventional approaches is difficult.[7,10–12] Outliers beyond 2° of the desired alignment may occur in as many as 40% to 60% of cases using conventional methods[12,13]; the range of component alignment varies considerably, even in the hands of skilled knee surgeons.[7] The problem is compounded when using minimally invasive surgical approaches.[10,11,14] In a study analyzing the results of 221 consecutive UKAs performed through a minimally invasive approach, tibial component alignment had a mean of 6° (standard deviation ±4) of varus and a range from 18° varus to 6° valgus.[11]

Computer navigation was introduced in an effort to reduce the number of outliers and improve the accuracy of UKA. Even with computer navigation, the incidence of outliers (beyond 2° of the preoperatively planned implant position) may approach 15% resulting from imprecision with the use of standard cutting guides and conventional methods of bone preparation.[12] Semiautonomous robotic guidance was, therefore, introduced to not only capitalize on the improvements seen with computer navigation but also to further refine and enhance the accuracy of bone preparation, even with minimally invasive techniques, by better interfacing and integrating the planning and performance of bone preparation.[13,15–24] Although the emergence of robotics in knee and hip arthroplasty has been gradual, semiautonomous robotic technology is currently being used in more than 15% of the UKA cases performed in the United States.[25] Enhanced precision and optimized outcomes have raised substantially the interest in semiautonomous robotics for UKA (and increasingly other procedures), but the challenge facing the robotics sector is to produce technologies that are also efficient and economically feasible. Although first-generation semiautonomous robotic technology was found to significantly improve precision and reduce error of bone preparation and component positioning in UKA, broader adoption of robotic technology was impeded by several factors: the high capital and maintenance costs of the first-generation systems; soft tissue complications observed with an autonomous (active) robotic system used for a brief time by several centers for total hip and knee arthroplasty primarily in Asia and Europe; skepticism regarding the importance of optimizing precision in UKA; expense, inconvenience, and delays associated with having to obtain preoperative computed tomography (CT) scans for planning and mapping; and concern regarding the potential carcinogenic risk associated with radiation exposure with CT-based planning.[18,20,26,27]

The story of the evolution of robotics in knee arthroplasty is a study in the characteristic pattern that defines technological progress and innovation, in general, whereby exponential developments occur along with declining capital and maintenance costs, smaller space requirements, broadening access, and increased use.[28] A newer image-free semiautonomous robotic technology (Navio PFS [Precision Free-Hand Sculptor], Blue Belt Technologies, Plymouth, MN) is an alternative to the first-generation autonomous and semiautonomous CT-based systems, with data in the first 1000 cases showing optimization of accuracy and no compromise of safety. This technology is reviewed herein.

NAVIO PRECISION FREE-HAND SCULPTOR SYSTEM OVERVIEW

The Navio PFS robotic system is a handheld image-free open-platform sculpting device available worldwide for assistance in UKA and patellofemoral arthroplasty (PFA), having received initial CE Mark and US Food and Drug Administration (FDA) clearances in February and December 2012, respectively (Fig. 1). This lightweight robotic tool combines image-free intraoperative registration, planning, and navigation with precise bone preparation and dynamic soft tissue balancing. As a semiautonomous system, it augments the surgeon's movements, with safeguards in place to optimize both accuracy and safety. The system continuously tracks the position of the patients' lower limb as well as the handheld burr, so that the limb position and degree of knee flexion can be changed constantly during the surgical procedure to gain exposure to different parts of the knee during registration and bone preparation through a minimally invasive approach.[29]

After percutaneous insertion of bicortical partially threaded pins into the proximal tibia and distal femur and attachment of optical tracking arrays, mechanical and rotational axes of the limb are determined intraoperatively by establishing the hip and knee centers and the center of the ankle. The kinematic, anteroposterior (Whiteside), or transepicondylar axes of the knee are identified and selected to determine the rotational position of the femoral component (Fig. 2). Osteophytes are excised, and the condylar anatomy is mapped out by painting the surfaces with the optical probes (Fig. 3). A virtual model of the knee is created (see Fig. 3). In this way, intraoperative mapping supplants the predicate system that required a preoperative CT scan.

A dynamic soft tissue balancing algorithm is initiated. With an applied valgus stress to tension