

FROM VISION TO REALITY: THE CLINICAL EXPERIENCE AND FUTURE OF KNEE ROBOTIC SURGERY

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SUMMARY

Background: Robotic-assisted surgery represents an evolution in computer-assisted orthopedic procedures, aiming to enhance the precision and reproducibility of bone preparation in lower limb arthroplasty. While traditional robotic systems often require preoperative computed tomography and bulky equipment, image-free systems utilizing bone-morphing technology have emerged to streamline the surgical workflow and eliminate preoperative radiation exposure.

Objective: This article describes the clinical application, technical implementation, and surgical outcomes of the Navio® image-free robotic-assisted system across various knee arthroplasty indications.

Key Points: The system utilizes an infrared camera, tracking arrays, and a handheld robotic bur with automatic feedback to ensure bone resection remains within planned boundaries. The workflow integrates dynamic ligament balancing and 3D anatomical mapping to optimize implant positioning in unicompartmental (UKA), patellofemoral (PFA), and total knee arthroplasty (TKA). Clinical data indicate that robotic assistance achieves superior joint line restoration and more accurate radiological positioning compared to conventional techniques. Furthermore, studies report a lower revision rate for lateral UKA and a significantly faster return to sporting activities, such as cycling and skiing, following robotic-assisted procedures. The technology also facilitates complex indications, including bicruciate-retaining TKA and combined UKA with anterior cruciate ligament reconstruction, by providing precise control over tibial slope and gap symmetry.

Conclusion: Image-free robotic assistance provides a highly accurate, reproducible method for knee arthroplasty that improves component alignment and soft tissue balancing. These technical advantages translate into enhanced functional recovery and reduced complication rates without the need for preoperative imaging.

KEYWORDS

Arthroplasty, Replacement, Knee; Robotic Surgical Procedures; Surgery, Computer-Assisted; Osteoarthritis, Knee; Recovery of Function

I - INTRODUCTION

The rise in robotic surgery is a natural progression from computer-assisted surgery, which has been used for lower limb arthroplasties for over 20 years. The main benefit offered by robotics, whatever system is used, is accurate and reproducible bone preparation thanks to a robotic interface.[1] The aim is not to replace the surgeon, but to improve their performance.

Many published articles[2, 3][4, 5] report on the increasing popularity of systems comprising an articulated robotic arm programmed with preoperative scan data. The drawbacks are the cumbersome equipment and the need for a preoperative scan, as well as additional staff for every operation. However, thanks to a simultaneous evolution in robotic surgery comprising a bone-morphing phase during the procedure using the Navio® system (Smith & Nephew)[4, 5], preoperative imaging studies are no longer needed.

Having used this system for the past 5 years, we wanted to report on our experience and describe how this smart tool has altered our practice.

II - HISTORY

The Navio® surgical system was launched in Europe in 2012 and in the USA in 2013 (Fig. 1).

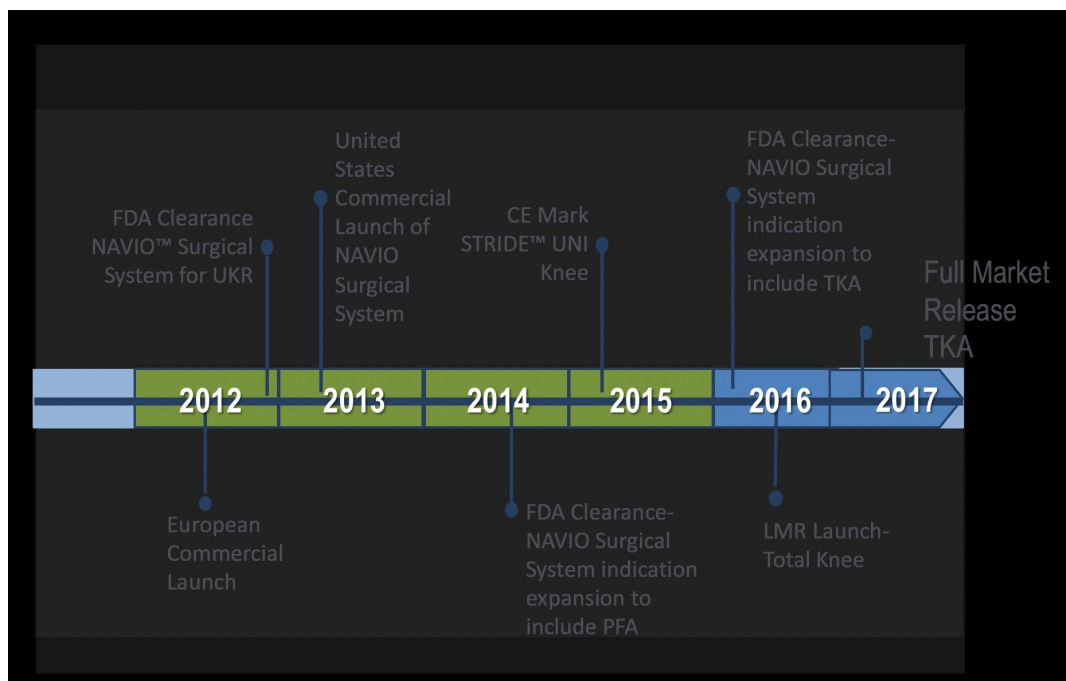


Figure 1. Chronology of the Navio® surgical system (Smith & Nephew)

The first published cadaveric studies demonstrated the superior accuracy of this system over conventional techniques in all aspects. It was initially only available for unicompartmental knee arthroplasty (UKA), which explains why the initial articles and discussions focus on partial replacement surgery. The patellofemoral joint replacement version was released in 2014, ahead of the total knee arthroplasty (TKA) system in 2016.

Since then, the system has undergone numerous upgrades, and the current version (Navio® 7) will be available for the Journey® TKA (Smith & Nephew).

III - THE SYSTEM AND TIPS FOR CORRECT INSTALLATION ---

The introduction of a new technology can be very disruptive for a surgical team. Although relatively compact, it is important to set up the Navio® system correctly to ensure optimum use in the surgical setting. In particular, the system and its accessories must be accurately positioned to ensure the operation can progress smoothly.

The patient is placed in the supine position, with one lateral and one distal positioner to hold the knee at 90°. The surgeon may also wish to apply a pneumatic tourniquet at the top of the thigh.

There is no need to train a multitude of assistants in the Navio® system. Usually, one instrument technician and one surgical assistant are enough, and they should stand so as to avoid blocking the camera, which must be able to see the femoral and tibial tracking arrays across the whole joint range of motion. We prefer stationing both the surgeon and assistants on the side of the operated knee, with the Navio® system on the opposite side.

There is no need for a plethora of instruments because the bone can be prepared using only the robotic-assisted handpiece. A saw may be helpful for TKA but is not usually necessary for partial replacements.

There are three parts to the Navio® PFS console:

- * an infrared camera (like that used for traditional surgical navigation), which must be positioned approximately 1 metre from the surgical site, facing the surgeon so the femoral and tibial trackers are visible at all times;
- * a touchscreen monitor with sterile drapes. The monitor should be within easy reach of the surgeon and is usually placed by the hip opposite the knee to be operated;
- * a computer for controlling the robotic bur and irrigation during burring. The handpiece can be held in one hand and is connected to the computer by a cable and an irrigation tube (Fig. 2).



Figure 2. The Navio® robotic-assisted handpiece

The only preoperative imaging required is a standard radiography assessment.

The first stage is to position the femoral and tibial tracking arrays (for a patellofemoral arthroplasty, only the femoral tracker is needed), which are usually placed percutaneously onto the tibia (Fig. 3) and onto the femur via a minimal subvastus portal or through the quadriceps. The trackers must remain visible throughout the procedure, including at both ends of the knee range of motion.



Figure 3. Patient set-up with the femoral and tibial tracking arrays on the medial aspect of the leg. The surgeon sits alongside the knee so that the trackers remain in sight at all times.

IV - CURRENT PRACTICE

a. Convention

The typical indications are partial and TKA (cruciate-retaining and bicruciate substituting).

1. UKA

The incision is parapatellar (lateral or medial), and extends for about 10 cm, usually from the superior pole of the patella to approximately 1 cm from the joint space (Fig. 4). Osteophytes must be removed before using the joint balancing system.

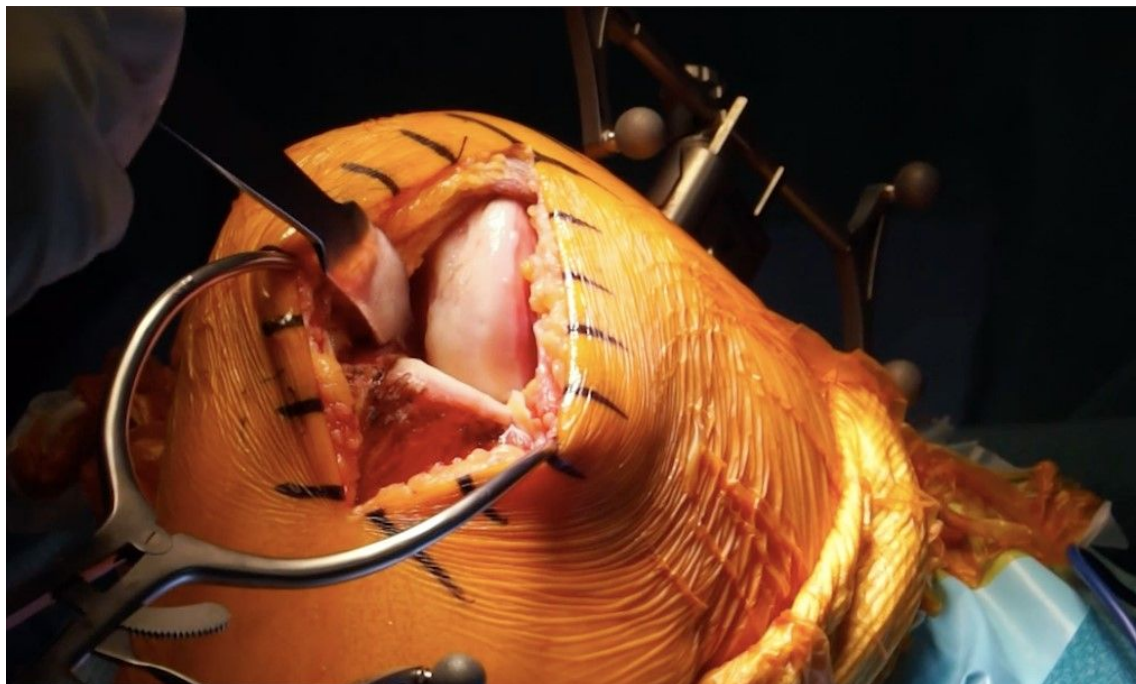


Figure 4. Subvastus approach with a Gelpi and Hohmann retractor

To ensure that the tracking arrays remain stable throughout the procedure, checkpoints are identified on the tibia and femur. The point probe can then be used at any time to determine if either tracker array has moved.

The hip centre is calculated through repeated circular movements, and the medial and lateral ankle centres are acquired using the point probe directly over the malleoli. The knee flexion angle is then recorded by flexing and extending the joint fully without any varus/valgus stress. The same flexion-extension movement is then used while applying a valgus stress (or a varus stress for a lateral UKA) to determine the amount by which the defect can be reduced across the full range of joint motion. This dynamic data acquisition is a crucial step which allows the system to account for any ligament laxity during the gap planning stage. The femoral condyle and tibial plateau are then mapped (Fig. 5).

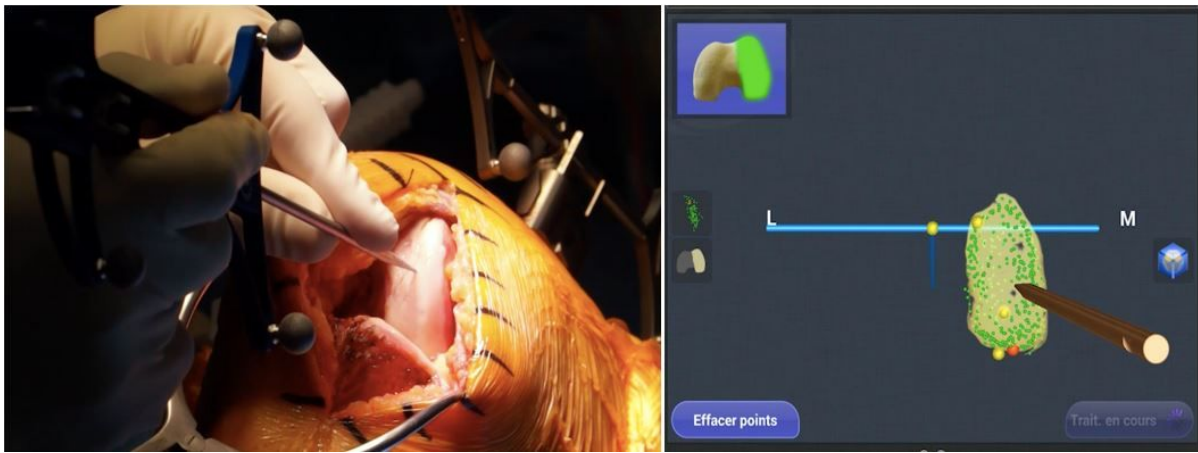


Figure 5. Bone mapping the femoral condyle

Planning is one of the most important stages of this robotic system because it produces a real dynamic map of the joint, taking into account the size of the gap. The first step is to select the size of the femoral component, although this can be changed at any time during planning. Next, the surgeon determines the desired placement of the femoral component in all three planes of view. The monitor displays four primary viewscreens to show the exact positioning of the component against the shape of the femoral condyle recorded in the previous stage. Using the touchscreen, the surgeon can manipulate a three-dimensional (3D) view of the condyle and the proposed component, to visualise the exact final position. The angles of the femoral component can be seen at all times: varus/valgus, flexion, rotation (Fig. 6). The goal is to cover as much of the bone surface as possible while retaining the height of the joint space and avoiding any major impingement of the tibial spines.

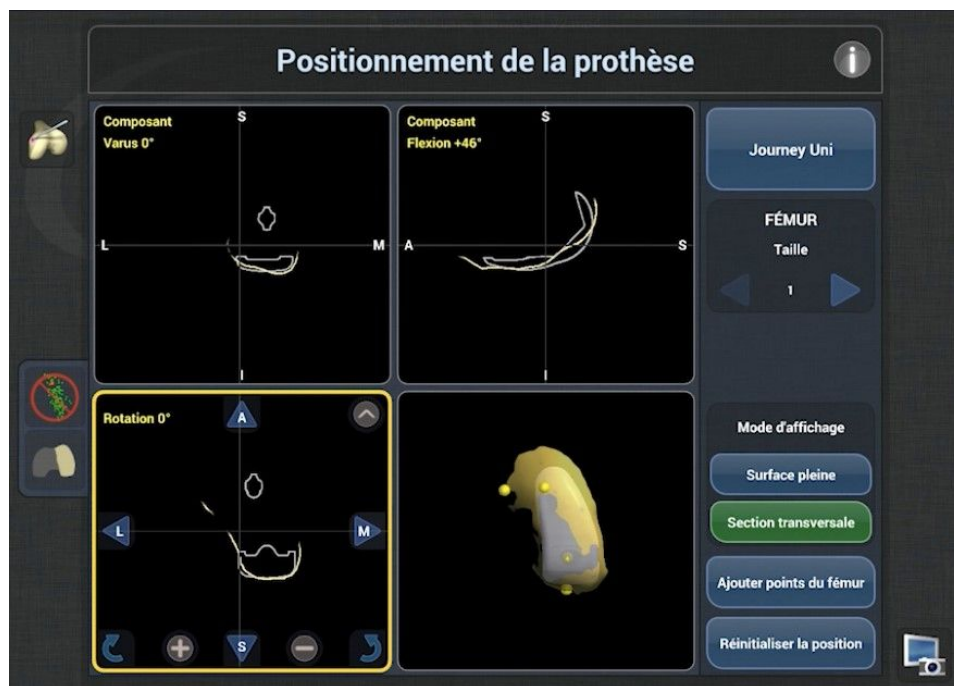


Figure 6. Tibial component planning: 0° varus, 0° rotation and 45° flexion

These steps are then repeated for the tibial component. First, select the implant size and polyethylene thickness. Next, select the varus/valgus rotation (a few degrees of varus may be retained in cases of constitutional anatomical tibial varus), tibial slope, and the rotation and position of the implant compared to the tibial spines. Again, the touchscreen can be used to rotate the 3D images and visualise the exact position of the implant in all three planes. As with all unicompartmental knee replacements, the tibial bone cut should be minimal.

Next, we visualise the outcome of the planning in terms of angular correction (preoperative vs. postoperative) between 0° and 120° flexion. At this point, we can adjust the positioning of both the tibial component (varus/valgus, slope, rotation, cut height) and the femoral component (varus/valgus, flexion, rotation, cut height) and generate an instant simulation of how the adjustments will affect the final angular correction. This simulation is based on the static data collections as well as the initial dynamic data, providing the ability to balance the gap throughout flexion.

The final planning stage involves visualising the contact points between the two components during flexion, then making any necessary medial or lateral adjustments of the implants to better centre the contact points (Fig. 7).

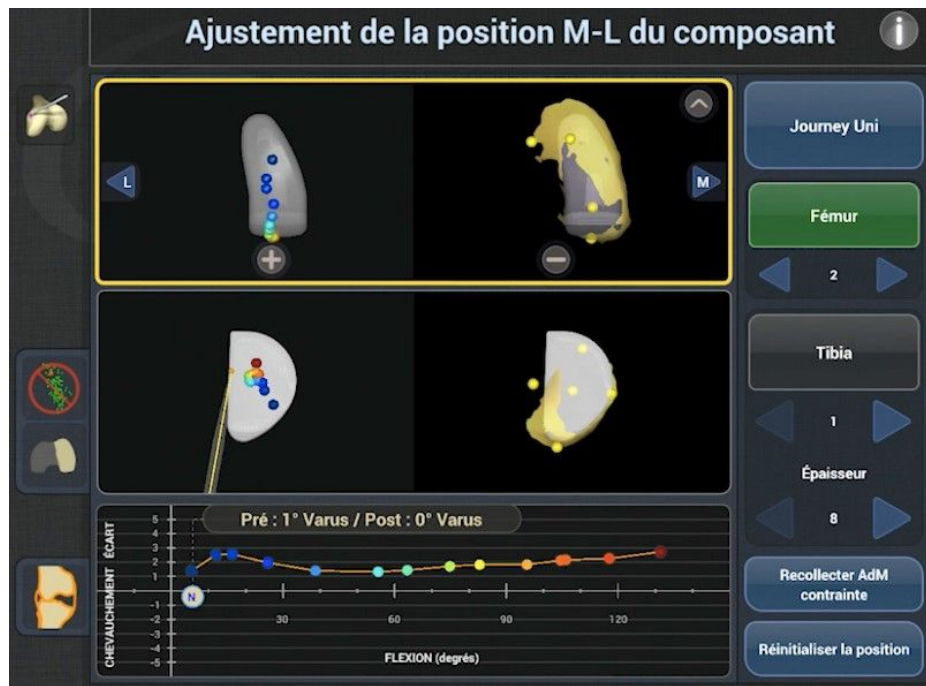


Figure 7. Component mediolateral position adjustment to centre the tibiofemoral contact point while checking ligament balance across the full range of motion

The surgeon can navigate between the various screens of the planning stage. Once the desired outcome is obtained, the final selection is validated.

Once the plan is validated, the bone surfaces can be prepared. We usually begin with the femur, which is easier to access. However, it is also possible to start with the tibia. The handpiece uses an automatic feedback system to prevent any burring outside the target area. The bur retracts if it exits this zone, making it impossible to remove any bone from elsewhere by mistake (Fig. 8).

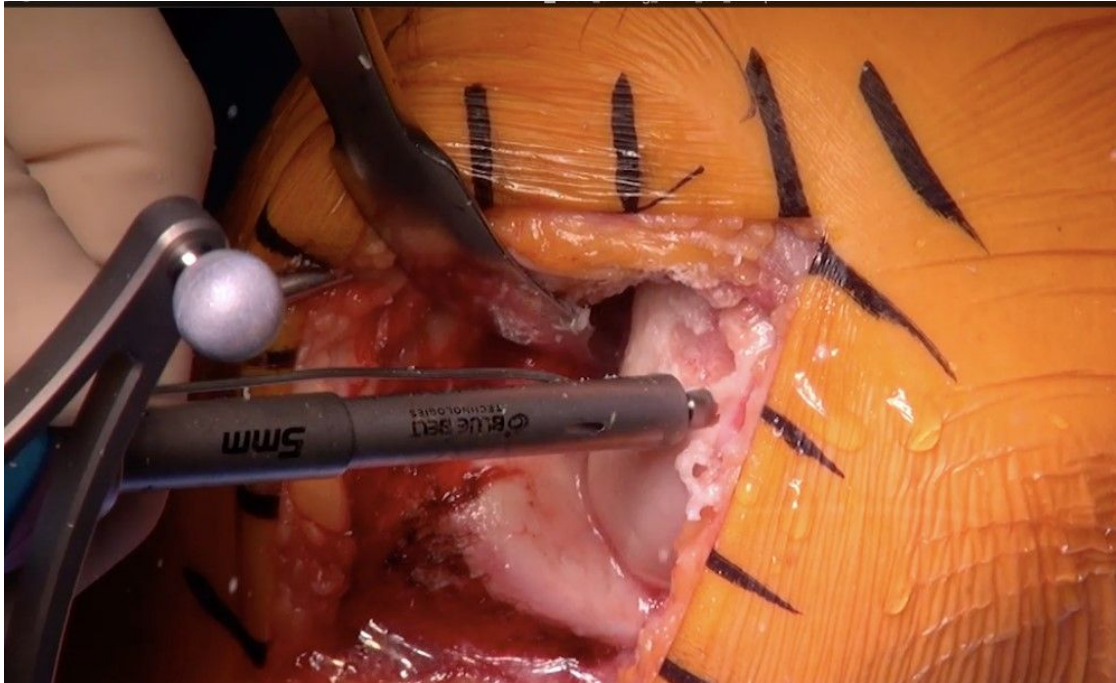


Figure 8. Burring the femoral condyle. The bur retracts automatically if it leaves the target area.

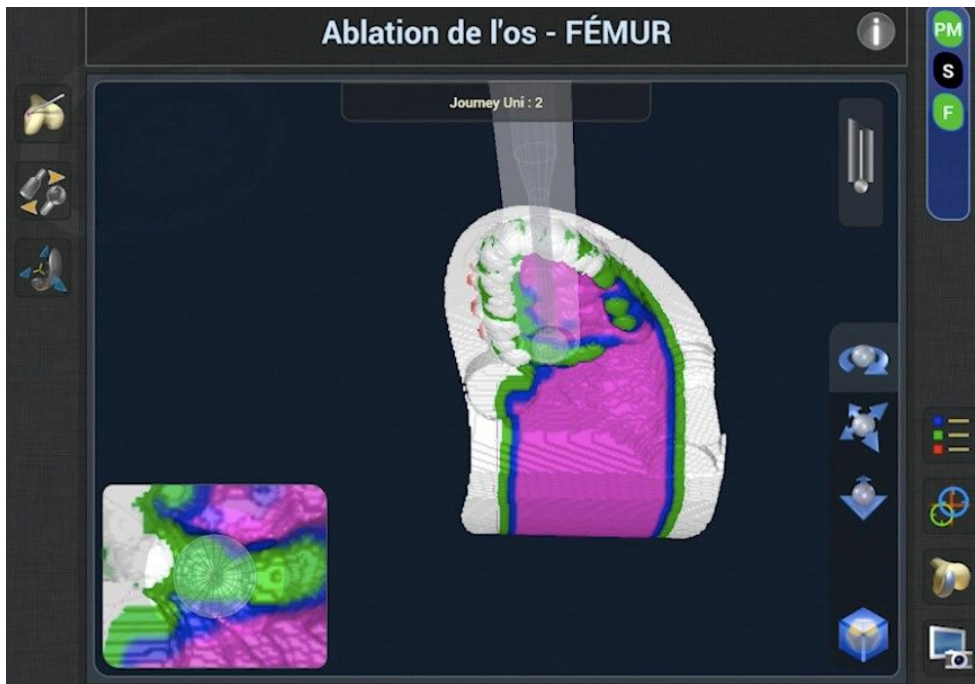


Figure 9. Screen view of the burred areas and remaining bone (9a: distal femur, 9b: tibia)

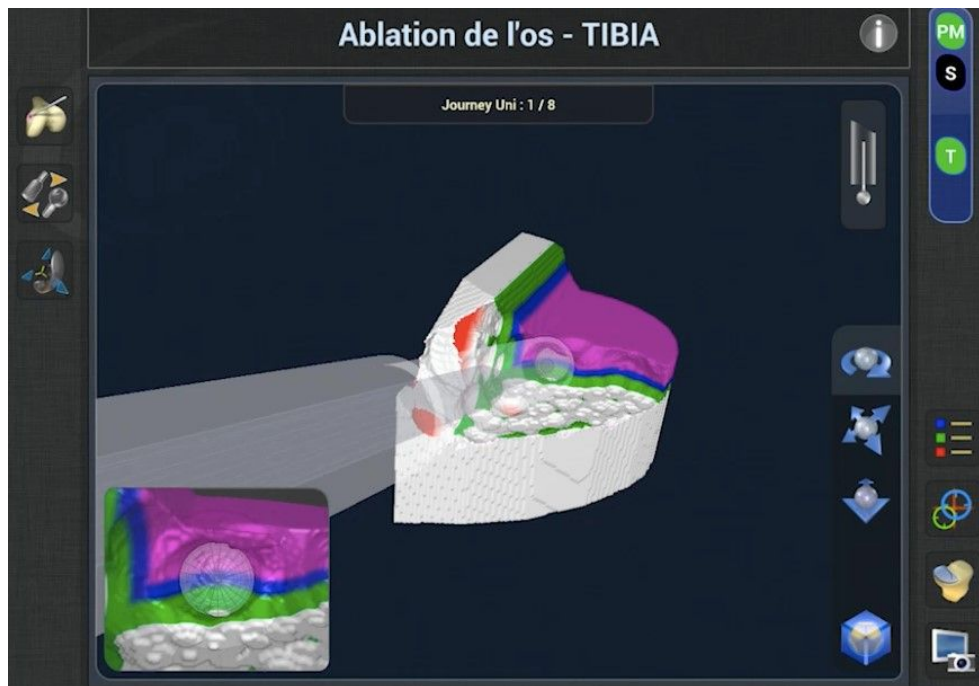


Figure 9. Screen view of the burred areas and remaining bone (9a: distal femur, 9b: tibia)

The surgeon has complete freedom of movement, and the robotic system only retracts if the bur moves outside the planned area. The knee should be gradually moved into hyperflexion to access the posterior most part of the femur. The cylindrical burs are quick and efficient, and are especially effective at accessing the posterior condyle.

Once the femur has been prepared, the same visual planning control is used for the tibia before burring can begin. Start with the most anterior part of the tibia and gradually move across the whole of the planned surface. After burring, a rasp can be used to refine the bone cuts, smooth any bumps and finalize the angles. The meniscus can now be accessed easily and should be removed completely. The final stage is to burr the anchor posts on the femoral implant using the visual planning guide on the screen.

The trial implants can then be positioned, and the screen used to visualise the angle of correction and joint balancing throughout flexion. The surgeon can then cement and fix the final implants using their usual method. Once again, the surgeon can use the screen to assess the angle and gap obtained with the final implants (Figs. 10 and 11).

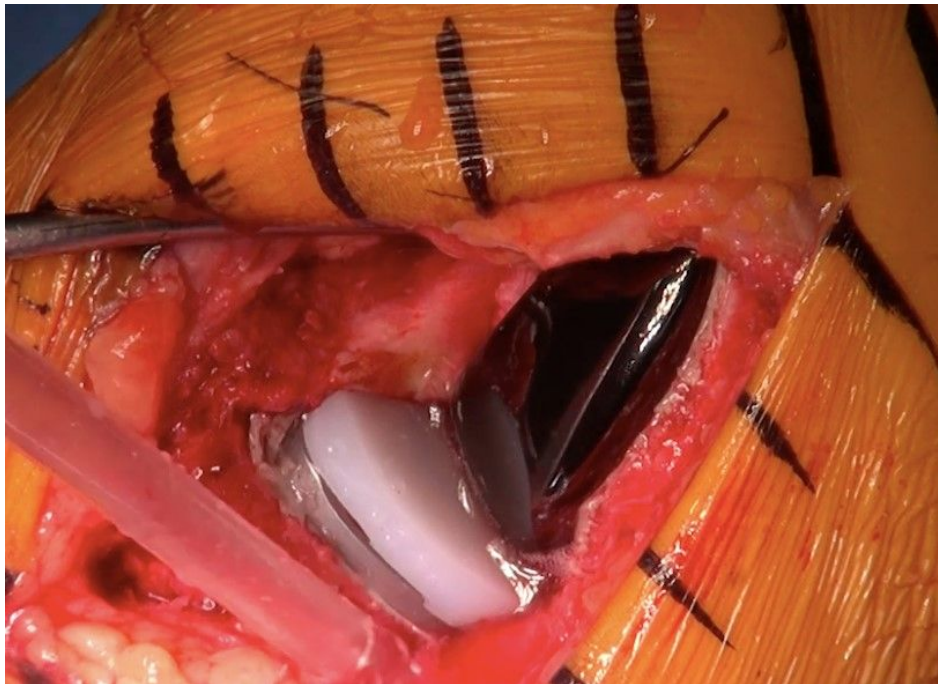


Figure 10. Trial components (10a) and gap assessment throughout the range of motion (10b)

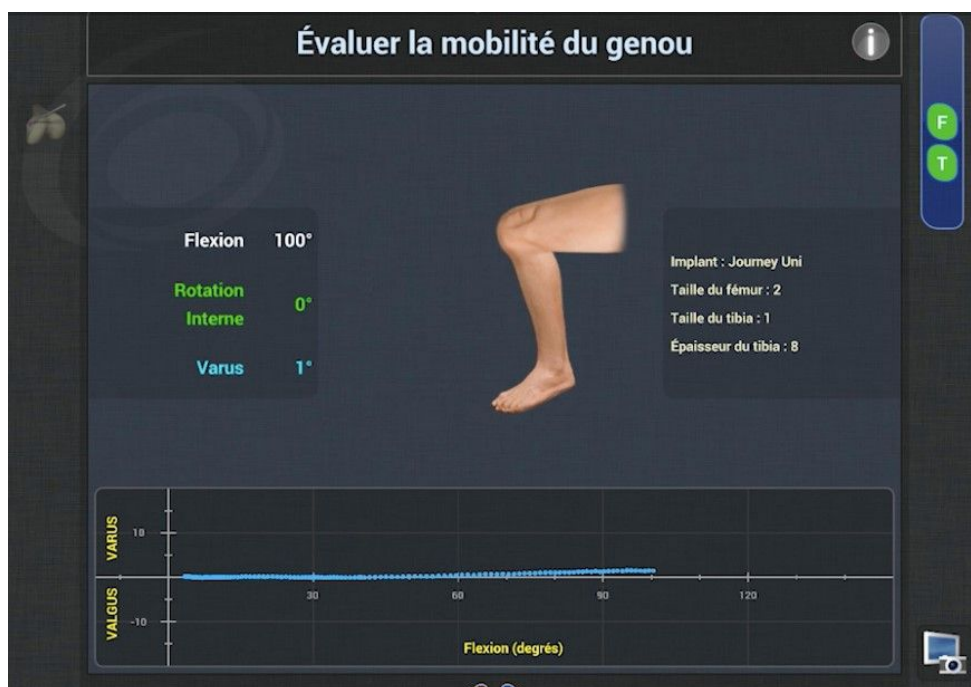


Figure 10. Trial components (10a) and gap assessment throughout the range of motion (10b)



Figure 11. Lateral unicompartmental knee arthroplasty. Note the medial rotation of the tibial component, anticipated using the Navio® system.

2. Patellofemoral replacement

There are different considerations when performing a patellofemoral arthroplasty. However, it is probably one of the best indications for robotic surgery since the ideal position can only be obtained through accurate mapping of the 3D anatomy of the distal femur. Bone preparation requires a bur, even when using conventional instruments. The 3D planning stage is now much easier thanks to the Navio® surgical system which produces a 3D model of the trochlea and records landmark points (medial and lateral epicondyle points, Whiteside's Line, femur mechanical axis mechanical femoral vagus) (Fig. 12).



Figure 12. Set-up for a patellofemoral replacement using the Navio® system

It displays a 3D simulation of the trochlear component placement and guarantees a perfect transition area between the femoral component and femoral condyle cartilage prior to the bone cut (Fig. 13).

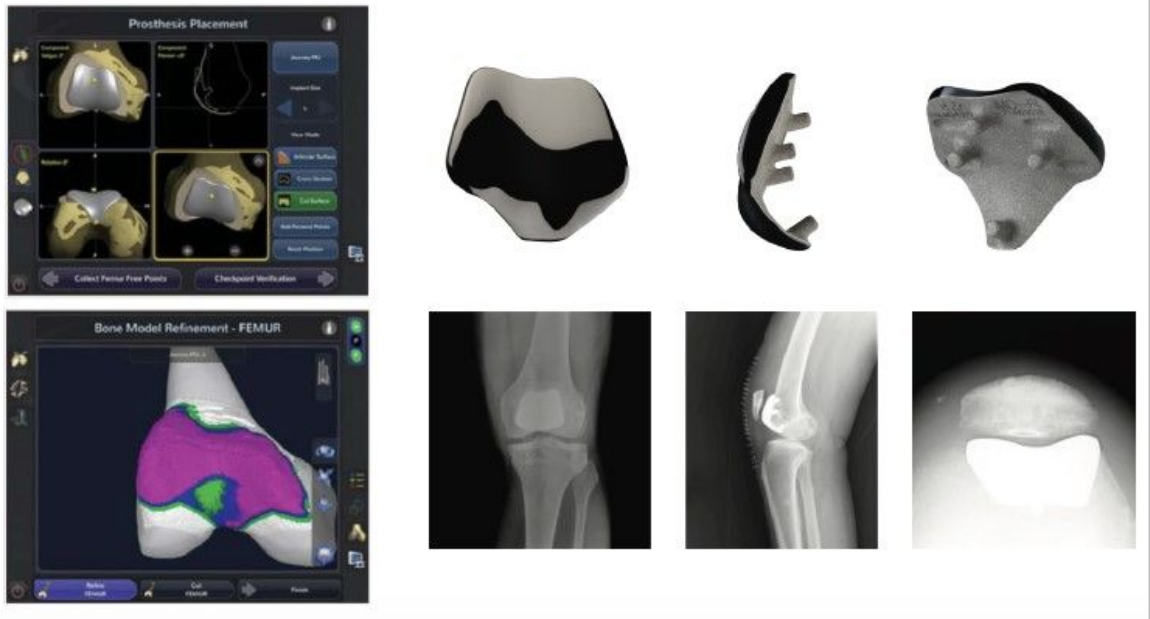


Figure 13. Robotic-assisted patellofemoral replacement

The preparation stage is made easier thanks to the controlled bone removal using a robotic handpiece that removes the residual cartilage and subchondral bone in line with the planning, obtaining a more consistent outcome than standard tools.

V - TKA

Other computer-assisted surgical systems help the surgeon place the cut blocks by collecting anatomical and gap balancing data. However, the Navio® 7 is a new generation system that uses more detailed anatomical data, especially from the soft tissues (Fig. 14).



Figure 14. TKA workflow using the Navio® 7 (in development)

Data are collected across the whole range of motion to position the femoral and tibial components for maximum stability at all angles, not just at 0 and 90° of flexion (Fig. 15).



Figure 15. Collection of gap planning data prior to the procedure, across the whole range of motion

Soft tissue balancing and release can be checked and refined during the data collection phase. Alignment and any ligament gap or retraction are measured across the whole range of motion.

The size of the components and their positions are determined before any bone cuts are made. This virtual planning allows the surgeon to select the correct size and position the implants to best suit the native anatomy and ligament balance (Figs. 16 and 17).



Figure 16. Implant positioning



Figure 17. Cut guide positioning

Once the plan is confirmed, the surgeon uses the robotic bur to prepare four fixation features in the distal femur and 2–4 in the proximal tibia (Fig. 18).



Figure 18. Placement planning for the femoral and tibial cutting guides using the robotic handpiece

The distal cut can be made entirely using the bur (Fig. 19) before the cut blocks are placed, using the fixation holes as guides, and fixed.



Figure 19. Distal burring mode

The surgeon can visualise virtual bone cuts on the screen before they are made by placing a tool in the cut slot. The same tool can be used to check the cuts once they are made (Fig. 20).



Figure 20. Completing the bone cuts and verification using the Navio® robotic system

The trial implants are put in place, and the gap balance is checked across the whole range of motion, cross-referencing with the initial planning, before cementing the final implants.

This type of planning is especially useful when using implants to recreate native knee kinematics. This outcome is achieved by using both bone and soft tissue markers to reproduce optimum joint kinematics between both the medial and lateral femur and tibia. The robotic assistant performs the final stage of this procedure by making the cuts with the necessary precision (Fig. 21).



Figure 21. Intraoperative gap assessment

VI - CLINICAL DATA

Several authors have published articles with interesting information about Navio® system outcomes.

a. No early onset complications caused by the robotic system

A 2019 article by Lonner and Kerr[6] concerning 572 unicompartmental knee arthroplasties using the Navio® system reports a low incidence of iatrogenic complications, and specifically no soft tissue or bone surface damage.

b. Better joint space restoration

One of the keys to the success of knee replacement surgery is restoration of the joint space.[7] Our published results from unicompartmental knee arthroplasties show that this parameter is highly manageable using this robotic system, with positive short- and mid-term clinical outcomes since 2013.[8]

c. Better functional outcomes after lateral and medial UKA

Since using the Navio® system, we have observed a significant improvement for both outcomes and implant positioning. One study comparing 80 'robotic' and 80 'traditional' UKAs found no early onset complications specific to the robotics, equivalent short-term functional outcomes, a lower rate of revision for the robotic group (for lateral UKAs) and better radiological positioning (for both lateral and medial UKAs).[9]

d. Resumption of sporting activities

There is currently a lot of debate over the patient's ability to resume sporting activities after joint replacement surgery. Several recent studies show faster recovery following robotic surgery; one investigated the resumption of sporting activities after lateral unicompartmental knee arthroplasty and found that patients could resume sports such as hiking, cycling and skiing twice as fast when the surgery was robotically assisted.[10]

VII - RECENT DEVELOPMENTS

a. Bicruciate-retaining arthroplasty

There is a long history of bicruciate-retaining total knee replacements (Fig. 22) with promising long-term results but a reputation as a technically demanding procedure. Robotics have provided considerable assistance for surgeons undertaking this type of arthroplasty, which requires a meticulous understanding of the difference in joint space between the lateral and medial compartments, as well as highly accurate bone preparation (Fig. 23). Protecting the tibial spines is also much easier when using a bur guided by a robotic handpiece.



Figure 22. Journey XR bicruciate-retaining system

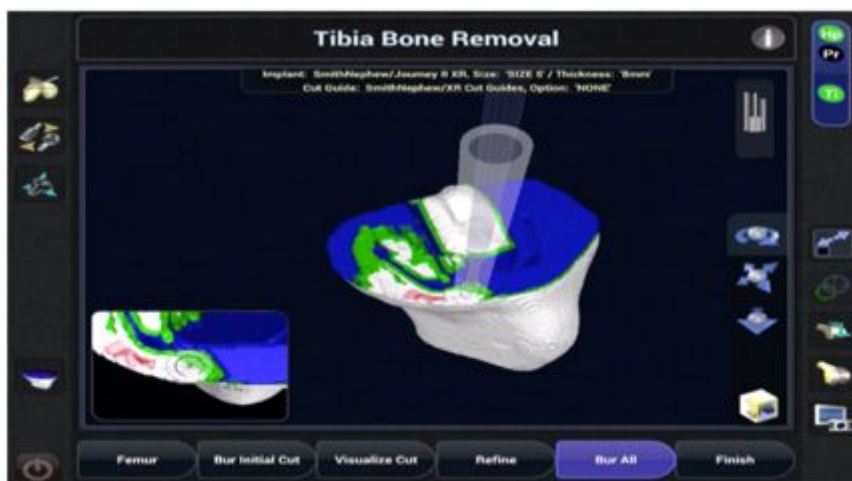


Figure 23. Femoral and tibial preparation using the Navio® system



Figure 23. Femoral and tibial preparation using the Navio® system

b. Additional indications

- Combined UKA and anterior cruciate ligament (ACL) reconstruction

ACL reconstruction combined with unicompartmental knee arthroplasty is a tempting solution for anyone keen on unicompartmental procedures. The Navio® system ensures accurate implant positioning (with tibial slope and overall alignment control in particular) but also allows the surgeon to visualize any residual gap before and after implant fixation (Fig. 24). Both implant position and the polyethylene thickness can be adjusted based on the dynamic data provided by the Navio® system.

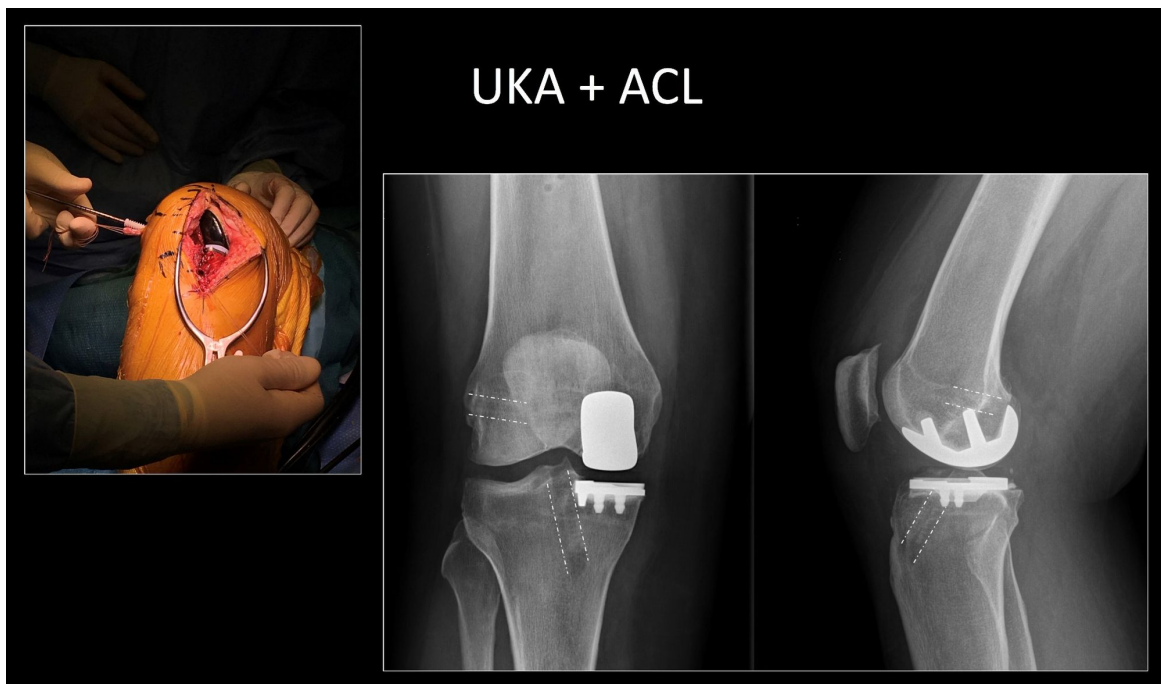


Figure 24. Intraoperative and radiographic images of combined medial UKA and ACL reconstruction surgery

- Bicompartamental arthroplasty

In some cases, if the patient is young and active with bicompartamental osteoarthritis, there may be an indication for two partial knee replacements (usually a medial unicompartmental arthroplasty and a patellofemoral replacement). Despite long-standing support for this surgery, in particular from Philippe Cartier, it is technically challenging. The Navio® system can be used to predict and adjust the relative position of the two implants, making this uncommon procedure more consistent (Fig. 25).



Figure 25. Intraoperative and radiographic images of a bicompartamental implant

c. Virtual reality: a new educational tool

Virtual reality tools are now being developed to offer a ‘life-size’ simulation of the Navio® system, not only for surgeons but also for their teams, so that they can improve their performance and gain experience in different scenarios without the constraints of an anatomy lab. These training sessions can be replayed and now form part of the curriculum to help students and reduce the learning curve imposed by any new technology (Fig. 26).

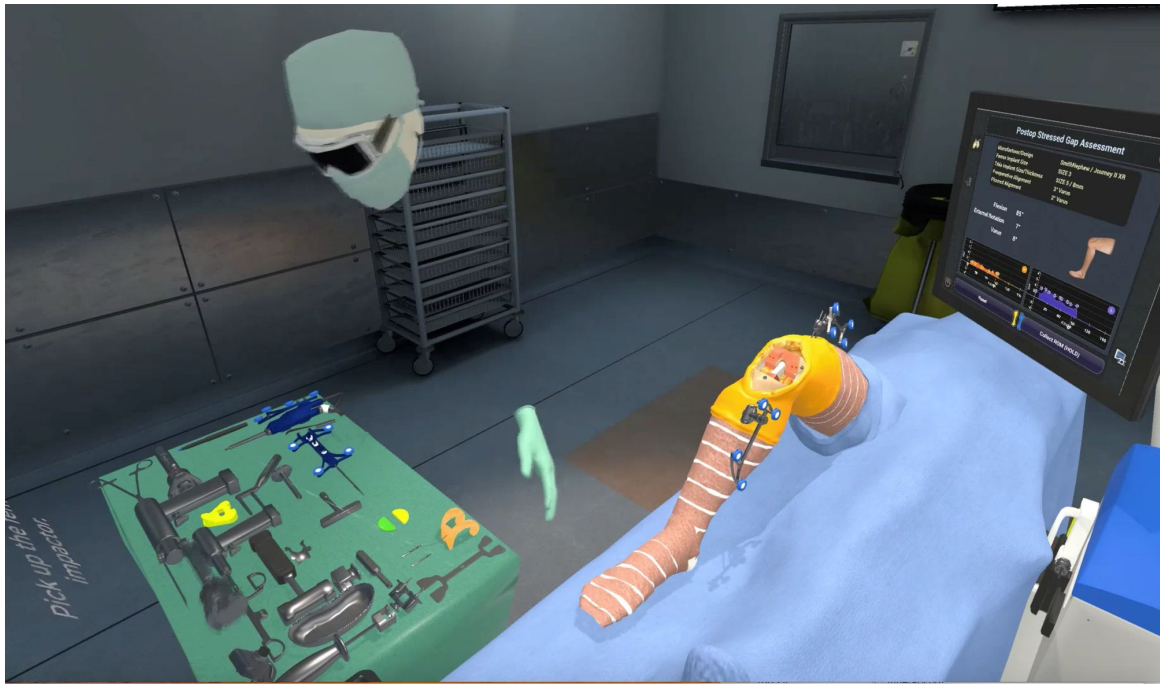


Figure 26. Virtual reality simulation of a total knee replacement using the Navio® system

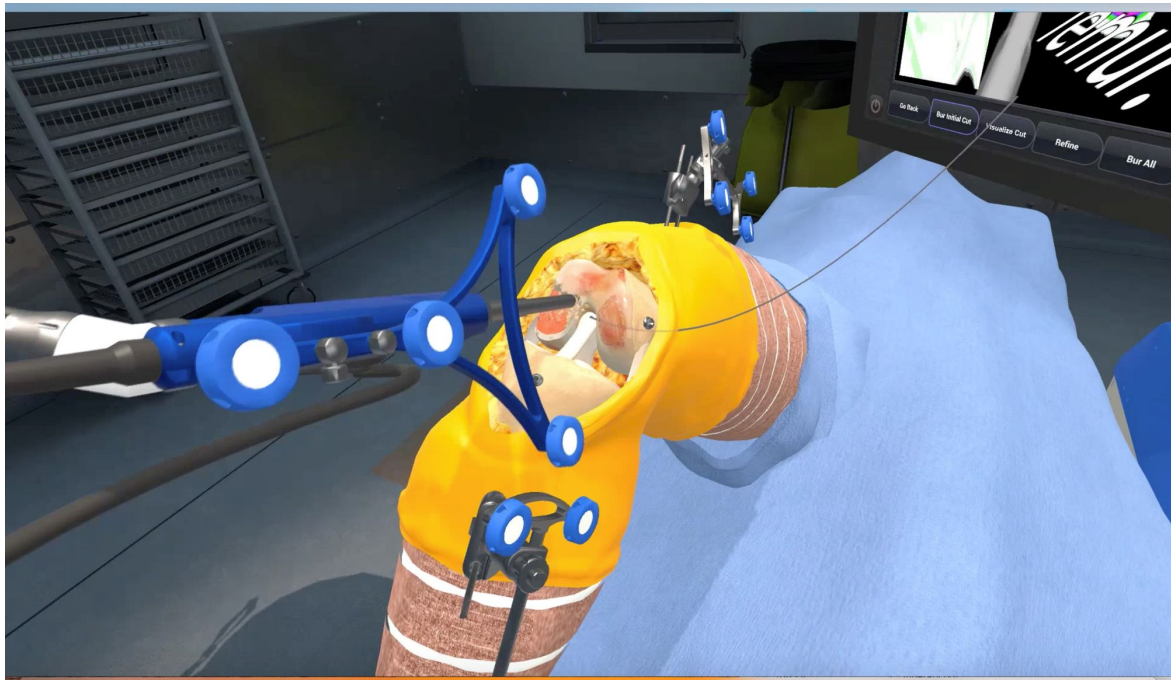


Figure 26. Virtual reality simulation of a total knee replacement using the Navio® system

VIII - EVEN MORE INDICATION

Given the success of robotic surgery systems, they are likely to become an ever more prominent feature of the operating theatre (Fig. 27).

Reconstruction

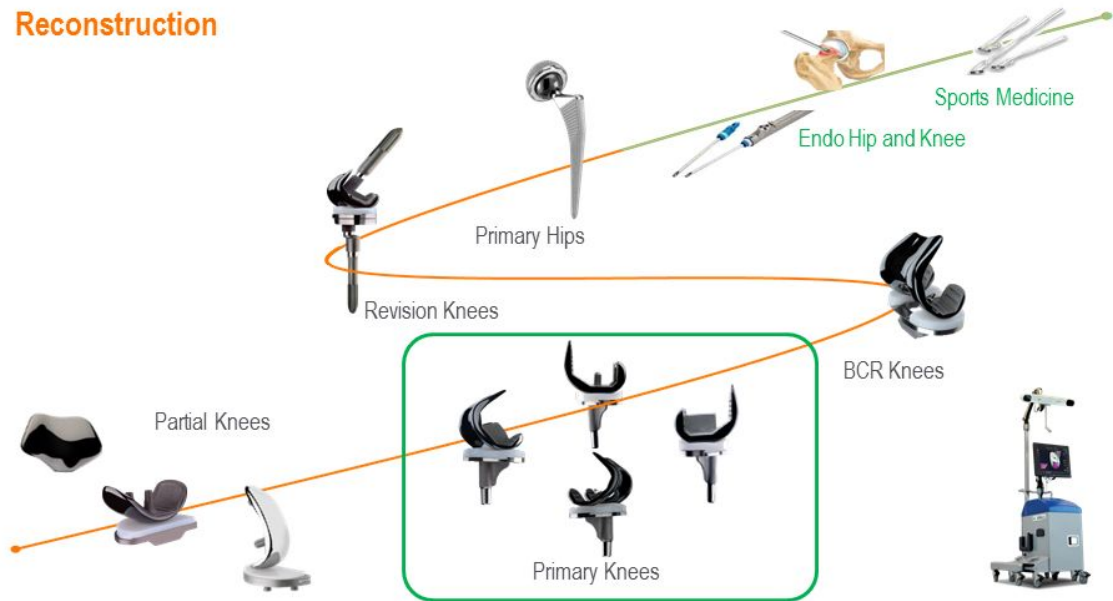


Figure 27. Current and future indication for Robotic system

Revision knee replacements are experiencing exponential growth and are also likely to benefit from robotics. Preparing the bone defects will allow for accurate adaptation of any wedges and cones, together with meticulous planning of the revision implant based on gap balancing data, before the primary implants are even removed.

Finally, there is every likelihood that robotic surgical tools will soon be developed for hip surgery (salvage and replacement) and all forms of sports surgery, bolstered by the excellent outcomes currently being obtained for knee arthroplasty.

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