MENTORS IN ORTHOPEDICS

TECHNOLOGY-ASSISTED REVISION TOTAL KNEE ARTHROPLASTY: CURRENT STATE, SURGICAL TECHNIQUE AND FUTURE PERSPECTIVES

https://doi.org/10.71165/qeit-p1ky

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SUMMARY

Background: Revision total knee arthroplasty (revTKA) presents significant technical challenges, including substantial bone loss, compromised anatomical landmarks, and ligamentous insufficiency. Traditional manual techniques often rely on intramedullary canal geometry for component alignment, which may result in suboptimal positioning when metaphyseal and diaphyseal centers are misaligned.

Objective: This article reviews the clinical rationale for technology-assisted revTKA, evaluates evidence-based outcomes regarding radiographic accuracy and clinical efficacy, and describes a standardized surgical technique utilizing an image-free robotic platform.

Key Points: Systematic reviews indicate that technology-assisted revTKA significantly reduces radiographic outliers in hip-knee-ankle alignment and component positioning compared to conventional methods. A fundamental paradigm shift is occurring from canal-dictated reconstruction to joint line-based restoration. This approach prioritizes anatomical joint line height and position, often utilizing short cemented stems to bypass diaphyseal constraints. The described robotic workflow employs image-free smart mapping, real-time gap balancing, and precision milling. Key technical steps include defining a "Homebase" reference before implant removal and utilizing specialized digital registration for intraoperative bone defect assessment. While radiographic precision is enhanced, current literature demonstrates comparable complication rates and patient-reported outcomes between robotic and manual techniques. Operative time remains higher for technology-assisted procedures, though the penalty decreases with advanced platforms and surgeon experience.

Conclusion: Technology-assisted platforms provide superior technical precision and facilitate anatomical joint line restoration in complex revision scenarios. Although long-term clinical superiority remains to be established, these systems offer a data-driven framework for addressing bone loss and soft tissue imbalance in revTKA.

KEYWORDS

Arthroplasty, Replacement, Knee; Reoperation; Robotic Surgical Procedures; Surgery, Computer-Assisted; Knee Prosthesis

STATE OF THE ART: TECHNOLOGICAL EVOLUTION AND CLINICAL RATIONALE

Adult knee reconstruction surgery has undergone a paradigmatic transformation with the emergence of technology-assisted surgical platforms, representing a fundamental shift from conventional manual instrumentation toward precision-guided interventions [1]. This evolution increasingly has been addressing the inherent complexities of revision total knee arthroplasty (revTKA) as well, as surgeons must face substantial bone loss, compromised anatomical landmarks, and ligamentous insufficiency [2],[3]. The theoretical foundation underlying technology-assisted revision knee arthroplasty rests on the principle that enhanced precision in component positioning and alignment restoration can potentially translate into improved long-term outcomes, reduced complication rates, and enhanced implant survivorship [4],[5].

The technological progression in this field demonstrates a fascinating chronological evolution, beginning with rudimentary first-generation navigation systems such as Navitrack and PRAXIM in the early 2000s, advancing through sophisticated computer-assisted platforms like Vector Vision and Orthopilot in the 2010s, and culminating in contemporary robotic-assisted systems including MAKO and CORI [6]. This technological maturation reflects not merely incremental improvements but fundamental advances in real-time data processing, three-dimensional spatial awareness, and intraoperative feedback mechanisms [7]. The underlying hypothesis driving this technological adoption is that revision total knee arthroplasty (revTKA) may benefit disproportionately from technological assistance, given that anatomical landmarks are often compromised in revision cases, unlike in primary procedures where they typically remain intact.

The clinical rationale for technology-assisted revision surgery emerges from the recognition that traditional manual techniques, while effective, are inherently limited by the surgeon's ability to process multiple variables simultaneously while maintaining optimal precision [2],[8]. In revision scenarios, the absence of normal bony landmarks necessitates alternative reference systems for achieving proper alignment and component positioning. Technology-assisted platforms theoretically address these limitations by providing objective, real-time feedback regarding critical parameters including the hip-knee-ankle angle, lateral distal femoral angle, and medial proximal tibial angle [6]. Furthermore, these systems offer the potential for enhanced soft tissue assessment and ligament balancing, crucial considerations in revision surgery where achieving appropriate constraint selection and stability becomes paramount.

Current regulatory perspectives reflect the evolving acceptance of these technologies, with the FDA's recent 510(k) clearance of the CORI Surgical System for revision total knee arthroplasty marking a significant milestone in the field. This regulatory endorsement acknowledges the unique challenges posed by revision surgery and recognizes the potential benefits of purpose-built technological solutions. However, it is crucial to note that many existing platforms were originally designed for primary arthroplasty and are currently utilized off-label for revision procedures, highlighting the need for continued technological refinement specifically addressing revision-specific challenges.

CLINICAL AND RADIOLOGICAL ACCURACY: EVIDENCE-BASED OUTCOMES

The evidence regarding technology-assisted revTKA presents a nuanced picture of improved radiographic outcomes, but inconsistent clinical benefits. A recent systematic review of 795 cases revealed evidence for enhanced alignment accuracy, with technology-assisted procedures demonstrating significantly fewer outliers in critical radiographic parameters compared to conventional techniques [6]. The most important finding related to overall limb alignment, where technology-assisted revTKA achieved a 12.8% reduction in hip-knee-ankle angle outliers, representing a clinically relevant improvement in achieving neutral mechanical alignment.

Component positioning accuracy demonstrates consistent superiority with technology-assisted approaches, particularly evident in coronal plane femoral and tibial component placement. For lateral distal femoral angle measurements, technology-assisted procedures achieved optimal positioning within ±3° of neutral in 88.4% of cases compared to 79.7% with conventional techniques, while medial proximal tibial angle accuracy reached 91.2% versus 82.6% respectively. These improvements in component positioning accuracy extend to joint line restoration, a critical parameter for achieving optimal knee kinematics, where technology-assisted procedures demonstrated superior outcomes with 79.5% achieving excellent joint line restoration (within 4mm elevation) compared to 58.3% with conventional methods. The magnitude of these improvements suggests that technology-assisted platforms provide meaningful advantages in achieving technical objectives that are fundamental to successful revision arthroplasty.

The temporal analysis of surgical efficiency revealed interesting trends that reflect the learning curve associated with technology adoption. While technology-assisted procedures consistently required additional operative time, ranging from 15-24 minutes for revision total knee arthroplasty, more recent studies utilizing advanced robotic platforms demonstrate markedly reduced time penalties compared to earlier navigation-based approaches. This temporal improvement suggests that technological refinement and surgeon familiarity contribute to enhanced surgical efficiency, potentially mitigating one of the primary concerns regarding technology adoption in revision surgery.

However, the clinical translation of these radiographic improvements presents a more complex picture. Despite consistent evidence of enhanced alignment accuracy and component positioning, most of the included studies failed to demonstrate statistically significant improvements in patient-reported outcomes, functional scores, or complication rates. This disparity between radiographic precision and clinical outcomes mirrors findings in primary total knee arthroplasty literature and raises important questions about the clinical relevance of achieving perfect alignment parameters. The absence of improved clinical outcomes may reflect the multifactorial nature of revision surgery success, where factors such as bone quality, soft tissue condition, and diagnosis may overshadow the benefits of enhanced alignment accuracy, as well as the need for standardized studies allowing for accurate comparison between technology-assisted and conventional approaches.

Complication profiles between the two approaches appeared largely comparable, with no evidence of increased adverse events associated with technological assistance [10]. While specific complications such as pin tract infections may occur with navigation-based systems, the overall safety profile remains acceptable [11]. The lack of increased complication rates despite longer operative times suggests that the additional surgical duration does not translate into meaningful clinical risks, supporting the safety of these technological approaches [12].

Cost-effectiveness considerations remains largely unexplored in the current literature, representing a significant knowledge gap given the substantial capital investment required for robotic and navigation systems [13]. The absence of comprehensive economic analyses limits the ability to make evidence-based recommendations

regarding technology adoption, particularly in healthcare systems with resource constraints. Future research must address this critical gap to inform rational decision-making regarding technology integration in revision knee arthroplasty practice.

The evolving evidence suggests that technology-assisted revTKA represents a promising advancement with demonstrated benefits in achieving excellent radiographic outcomes, though the clinical translation of these improvements remains incompletely understood. The consistent findings of enhanced alignment accuracy and component positioning provide a foundation for continued technology development and refinement, while the absence of clear clinical benefits highlights the need for longer-term studies and more sophisticated outcome measures that may better capture the potential advantages of improved technical precision.

THE PARADIGM SHIFT: FROM CANAL-DICTATED TO JOINT LINE-BASED RECONSTRUCTION

The increasing clinical burden of revision TKA, with an anticipated 78-182% increase in procedures between 2014 and 2030 and approximately 5% of primary TKAs requiring revision within ten years, has necessitated a fundamental rethinking of surgical approach [14],[15],[16]. Traditional revision TKA has historically operated under the principle of "building the knee from the diaphysis," where canal anatomy dictates implant alignment—a strategy borrowed from hip arthroplasty principles.

Traditional canal-dictated approach

Conventional revision TKA has relied heavily on long-stemmed implants to achieve proper alignment, with the intramedullary canal serving as the primary reference for component positioning [17],[18]. This approach utilizes long stems that engage the diaphyseal bone to establish coronal alignment, typically incorporating a 5-6° valgus taper to approximate normal knee alignment [19]. The femoral canal geometry determines sagittal positioning, with surgeons selecting the largest femur anteroposterior dimension and attempting to restore posterior condylar offset within the constraints imposed by the diaphyseal anatomy [20],[21],[22],[23].

While this method provides mechanical stability and reliable fixation, it presents significant limitations. The reliance on canal geometry can result in suboptimal component positioning when metaphyseal and diaphyseal centers are misaligned—a common occurrence given the natural anatomical variability among revision TKA scenarios [24]. The center of the metaphysis is frequently offset from the diaphyseal center [25]. This anatomical mismatch can lead to component overhang, compromised joint line restoration, and suboptimal ligament balancing.

The use of shorter cemented stems, while offering certain advantages, has been historically challenging due to the absence of reliable intramedullary landmarks for accurate component positioning perpendicular to mechanical axes [17],[26]. Without diaphyseal engagement for guidance, achieving optimal alignment becomes significantly more difficult using conventional instrumentation.

The robotic revolution: joint line-based reconstruction

The advent of robotic-assisted surgery has enabled a paradigmatic shift toward "building the knee from its original joint line." This approach prioritizes true joint reconstruction by restoring the anatomical joint line height and position as the primary reference, liberating surgeons from the constraints imposed by diaphyseal canal

anatomy. Rather than allowing canal geometry to dictate component placement, robotic systems enable precise restoration of the original joint line within defined physiological parameters.

This transformation is particularly significant given the main goals of revision TKA: correcting limb alignment with proper rotation and joint line restoration, achieving balanced flexion/extension spaces, ensuring central patellar tracking with appropriate patella height, and maintaining adequate range of motion. The joint line-based approach directly addresses these objectives by prioritizing anatomical reconstruction over canal-dependent positioning.

Robotic assistance facilitates this paradigm shift by providing real-time feedback on joint line position, enabling precise component sizing and alignment while maintaining surgeon control over the surgical procedure[27]. The technology allows for optimal component placement based on anatomical landmarks and planned joint line restoration rather than being constrained by the often-compromised diaphyseal anatomy encountered in revision scenarios.

Clinical implications and future directions

This paradigmatic evolution from canal-dictated to joint line-based reconstruction represents more than a technical advancement—it fundamentally changes the surgical philosophy of revision TKA. By prioritizing anatomical restoration over mechanical convenience, this approach has the potential to improve clinical outcomes through better joint line restoration, enhanced ligament balancing, and more physiological component positioning.

In this context, robotic technology—which allows for precise reconstruction of the native joint line independently of the anatomical constraints of the femoral and tibial diaphyseal canals—pairs particularly well with the use of short cemented stems, as it facilitates accurate joint line restoration while ensuring adequate fixation. Indeed, in revision TKA, short cemented stems provide greater freedom in restoring the joint line in both the coronal and sagittal planes without being limited by intramedullary cortical boundaries.

This combination could reduce the complexity and the biological burden associated with longer stems while achieving superior anatomical restoration compared to traditional canal-dependent techniques.

As robotic systems continue to evolve with dedicated revision software and enhanced planning capabilities, the shift toward joint line-based reconstruction is likely to become increasingly prevalent, potentially establishing a new standard of care for revision TKA that prioritizes anatomical restoration and functional optimization over purely mechanical considerations.

CORI SURGICAL SYSTEM WITH RI.KNEE ROBOTICS SOFTWARE FOR REVISION KNEE ARTHROPLASTY : SURGICAL TECHNIQUE

System overview and capabilities

The CORI Surgical System and RI.KNEE ROBOTICS Software for Revision Knee Arthroplasty surgical workflow demonstrate versatility through its support of multiple implant families and augmentation systems. Currently, this is the only robotic platform approved in both the US and Europe for performing TKA revision procedures.

With this indication, CORI and RI.KNEE ROBOTICS Software for Revision Knee Arthroplasty surgical workflow support preoperative planning and bone preparation for the currently supported Smith & Nephew TKA implant

families, including LEGION augments and the LEGION RK femoral and tibial components. When using the LEGION RK system, the platform is currently approved for use with short cemented stems (120 mm), which represents the most significant advancement in revision technique standardization.

The system's technological foundation rests on three primary pillars: image-free smart mapping, personalized planning, and precision milling capabilities.

The Image-Free Smart Mapping eliminates the traditional requirement for preoperative imaging such as X-rays, CT scans, or MRI studies. Instead, the system generates real-time three-dimensional models of implant surfaces and visualizes bony defects during the surgical procedure. This capability is particularly valuable in revision surgery where preoperative imaging may not adequately capture the full extent of bone loss or anatomical distortion following primary implant removal. The personalized planning enables surgeons to visualize and restore the native joint line, measure defects for accurate augment sizing, and optimize gap/ligament balance planning throughout the full range of motion. This level of customization is critical in revision cases where restoring proper kinematics and joint mechanics is paramount to achieving successful outcomes. Finally, the precision milling preserves healthy bone stock while providing handheld robotic accuracy for bone preparation. The system supports bone preparation for augments and comprehensive defect management, ensuring optimal interface preparation for component fixation.

Surgical workflow and technique

The RI.KNEE ROBOTICS Software for Revision Knee Arthroplasty surgical workflow follows a systematic five-phase approach: preoperative work-up and case set-up, image-free registration and ligament assessment, implant planning and gap balancing, defect mapping and management, and final assessment with trials in and/or post-implantation.

Phase 1: preoperative work-up and case set-up

The preoperative assessment must address the primary indications for revision surgery, including PJI, aseptic loosening, instability, stiffness, and malposition, as these factors will influence the surgical approach and system utilization strategy [28],[29].

The initial surgical phase involves the patient in a supine position with the leg freely movable on the operating table, followed by surgical exposure and debridement. A critical technical consideration during this phase is markers placement and checkpoint insertion, with specific attention to ensuring that pins closest to the joint are positioned 10-20mm beyond the intended stem length or femoral fixation features. This positioning is crucial for maintaining system accuracy throughout the procedure while avoiding interference with planned implant placement. Please note that off-label variations in pin placement can be considered for both tibial and femoral array fixation (Figure 1A-B). For instance, in the femur, a commonly adopted configuration involves placing the array fixation pins within the joint, in the meta-epiphyseal region of the medial femoral condyle, while taking care to avoid fractures and to prevent interference with the planned implant positioning. Similarly, in the tibia, a choice can be made between the mid-tibial pin placements and use of the Adjustable Tibia Cut Guide fixation technique (Figure 1C). An advantage of the Adjustable Tibia Cut Guide system is that it eliminates the need for separate pin tracks; however, a notable drawback is that it makes the use of the digital tensioner more challenging. Moreover, it may also be considered to perform a definitive alignment and balancing check with the trial component, and subsequently opt for removing the pins and complete the procedure by implanting short cemented stems if the marker pins obstruct the procedure.

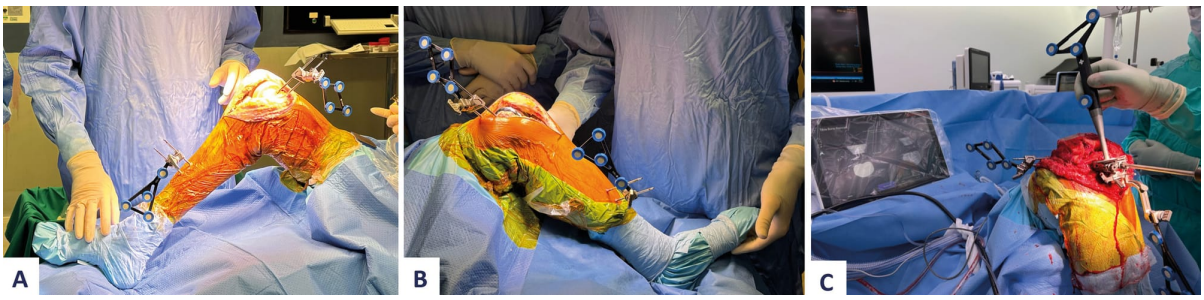

Figure 1: A. Standard configuration in the tibia, Intra-articular pin placement in the femur - B. Same 1A but with the arrays oriented upside-down. This configuration is useful in patients with a short leg or tibia and allows for improved visualization of the femoral arrays - C. “Shark-Bite” configuration in the tibia

Phase 2: image-free registration and ligament assessment

This phase represents one of the most innovative aspects of the surgical workflow with RI.KNEE ROBOTICS Software for Revision Knee Arthroplasty.

The image-free registration process involves mechanical axis and kinematic collections through range of motion assessment, followed by image-free smart mapping of the current prosthesis to be revised and rotational reference definition (Figure 2A-B). Precise matching of the current prosthesis with the polyethylene is required, along with the identification of bony landmarks such as the anterior medial and lateral cortices. This is essential to accurately delineate the borders of the bone.

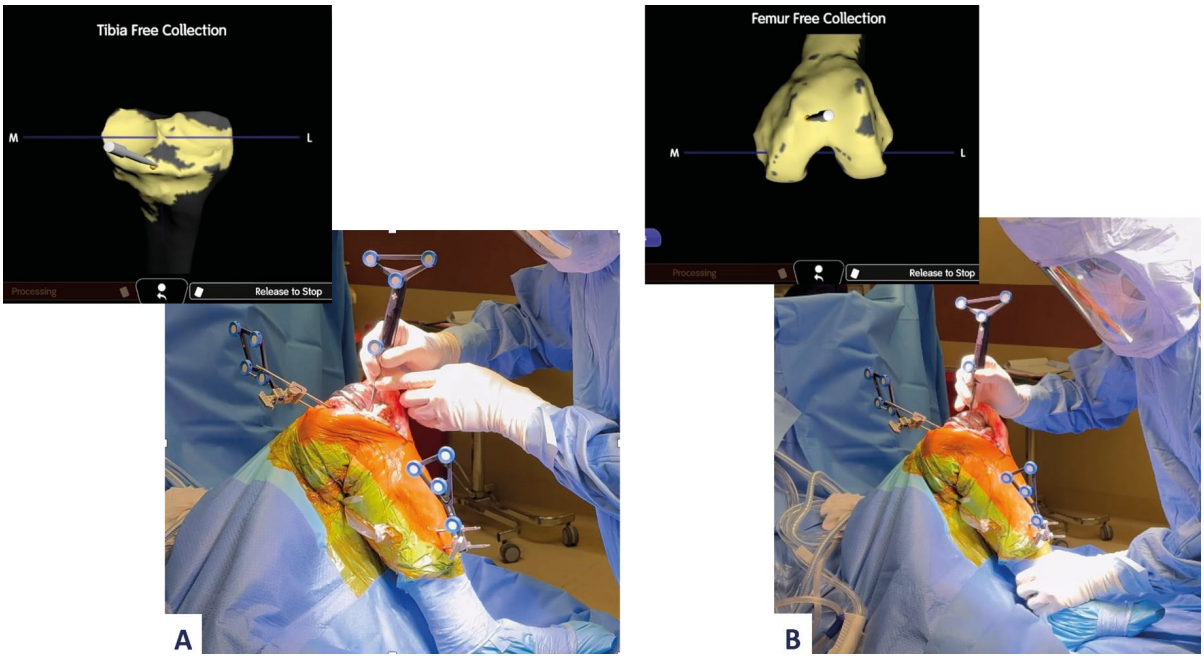

Figure 2: Image-free registration (mapping) of the femoral component (A) and the tibial component (B)

The system then proceeds with ligament laxity collection, providing comprehensive data on soft tissue balance and constraint requirements.

Advanced checkpoint definition and specialized femoral and tibial point acquisition enable the system to create detailed three-dimensional models of the existing anatomy.

At this stage, using the “Add Special Points” function, the system allows the surgeon to register specific anatomical landmarks that may serve as useful intraoperative references (e.g., the maximum mediolateral width of the femur, the epicondyles, or the ideal joint line height) (Figure 3A-B).

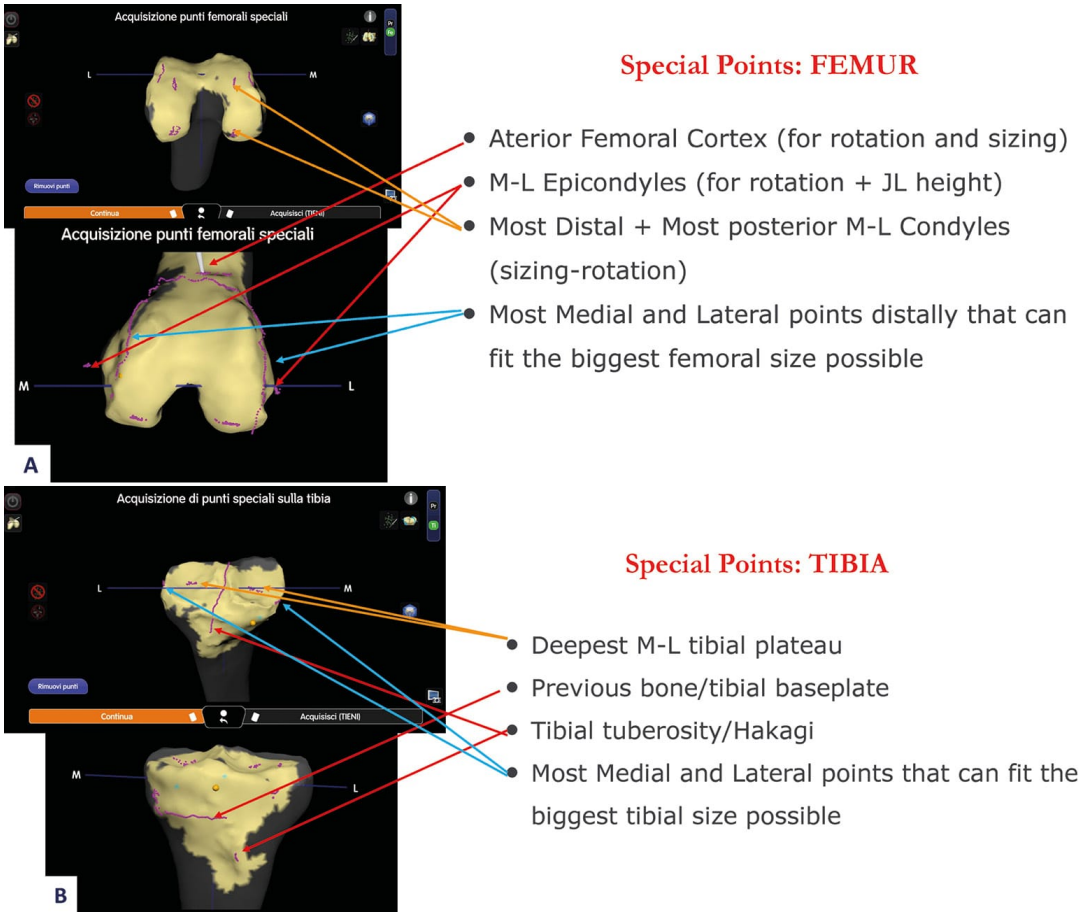

Figure 3: The “Add Special Points” feature enables the identification and registration of key anatomical landmarks that may be used as reference points during surgery. - A. Examples of usefull special points in the Femur. B. Examples of usefull special points in the Tibia

These points can also be used to assess patellar tracking and anteroposterior stability (Figures 4A-D; 5A-B).

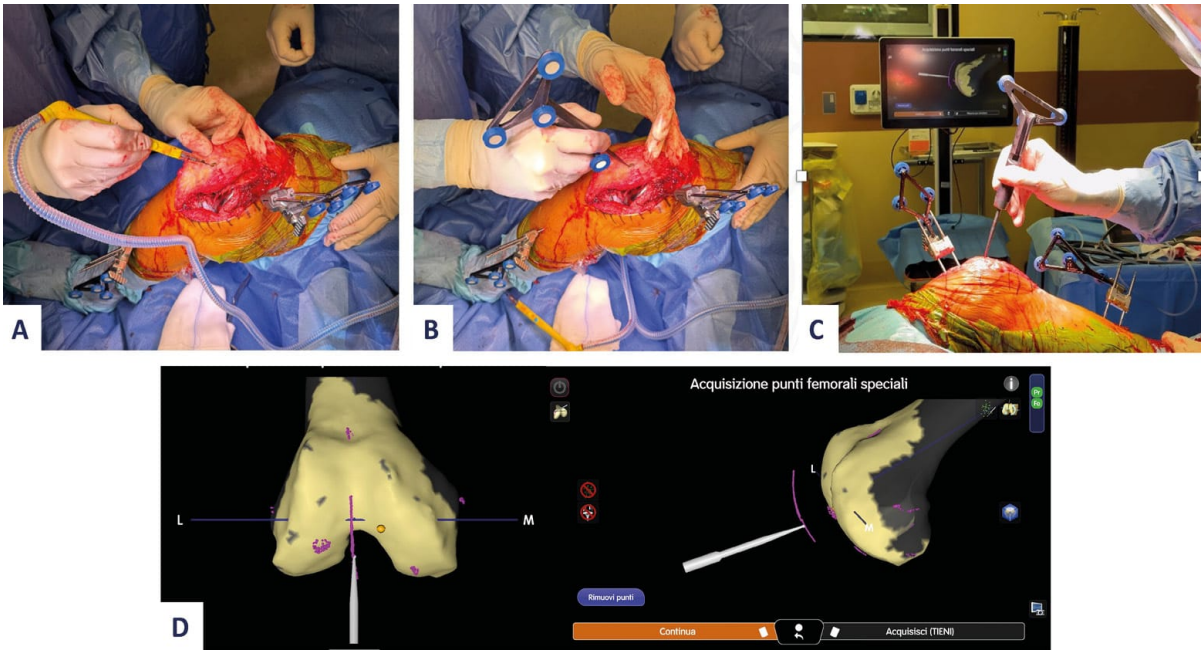

Figure 4: Patella Tracking Evaluation. - A. mark a spot in the patella. - B. use the pointer on femoral registration «special points» - C. dynamic patella tracking registration - D. Coronal (left image) and sagittal (right image) view of patella tracking on CORI screen

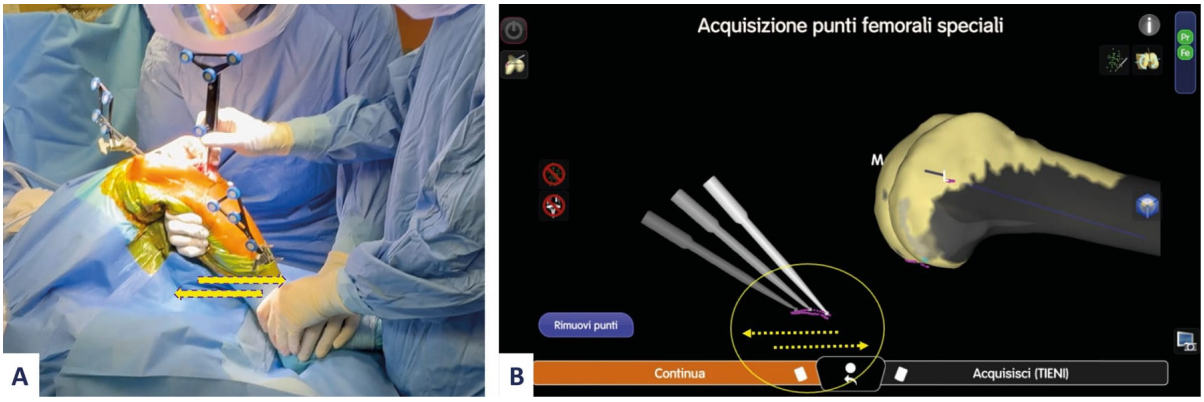

Figure 5: Acquisition of femoral special points is performed with the pointer positioned on the tibia while applying an anteroposterior drawer test. - A. Intra-op Antero-Posterior drawer test - B. CORI sagittal view of antero-posterior laxity (pink dots)

Phase 3: Implant planning and gap balancing

The implant planning phase utilizes the collected anatomical data to optimize component positioning and sizing. The current system was initially developed for primary arthroplasty, and its functionality reflects this original design intent. As such, it currently utilizes primary tibial baseplates measuring 2.3 mm, whereas revision baseplates measure 5.5 mm, resulting in a discrepancy/delta of 3.2 mm, which is equivalent to 13mm of polyethylene insert (or 7 clicks of adjustment) when using the primary settings (Figure 6).

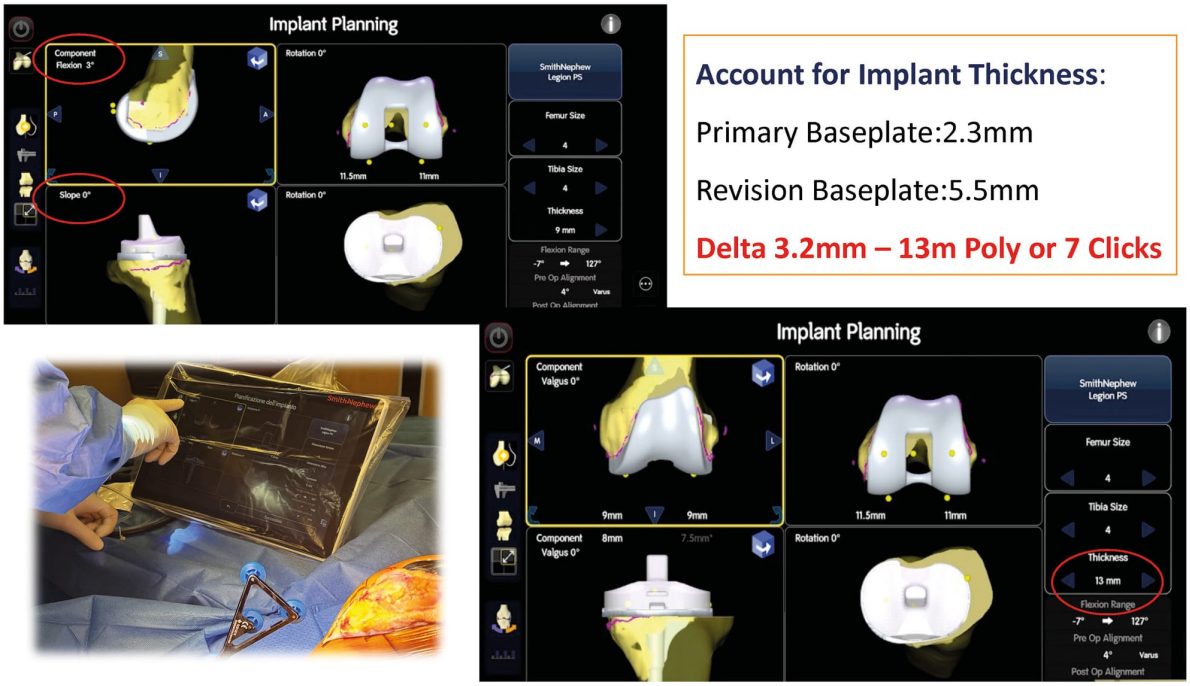

Figure 6: Digital conversion from LEGION Primary to LEGION Revision is performed by adding 4 mm of polyethylene thickness in the digital plan, to account for the difference in tibial baseplate thickness between the primary and revision systems. No adjustment is required on the femoral side...

Gap assessment technology provides real-time feedback on flexion and extension gaps, with the system capable of analyzing gap balance throughout the range of motion. The planning software establishes boundaries for optimal alignment, including femoral flexion ≤3°, varus/valgus ≤2° for the femur, posterior slope 0-1° for the tibia, and varus/valgus ≤1° for the tibial component.

Once the implant has been positioned within the boundaries allowed by the system—specifically in the case of a LEGION RK implant—a varus-valgus stress test is performed throughout the entire range of motion to generate a ligament balancing curve with the implant in its digital position (Figure 7). The CORI Digital Tensioner may be used to quantify joint laxity prior to bone resections within a robotic surgical system, providing objective gap data through automated collection using surgeon-defined force settings (Figure 8). The device communicates directly with the CORI Surgical System to deliver consistent varus and valgus stress during gap assessment throughout the full range of motion, utilizing adjustable force settings that support optimal ligament tension while eliminating the subjective variability inherent in manual tensioning techniques. This technological integration enables surgeons to achieve repeatable joint balancing and alignment through standardized stress application, thereby reducing both intra- and inter-surgeon variability in gap assessment and component positioning decisions.

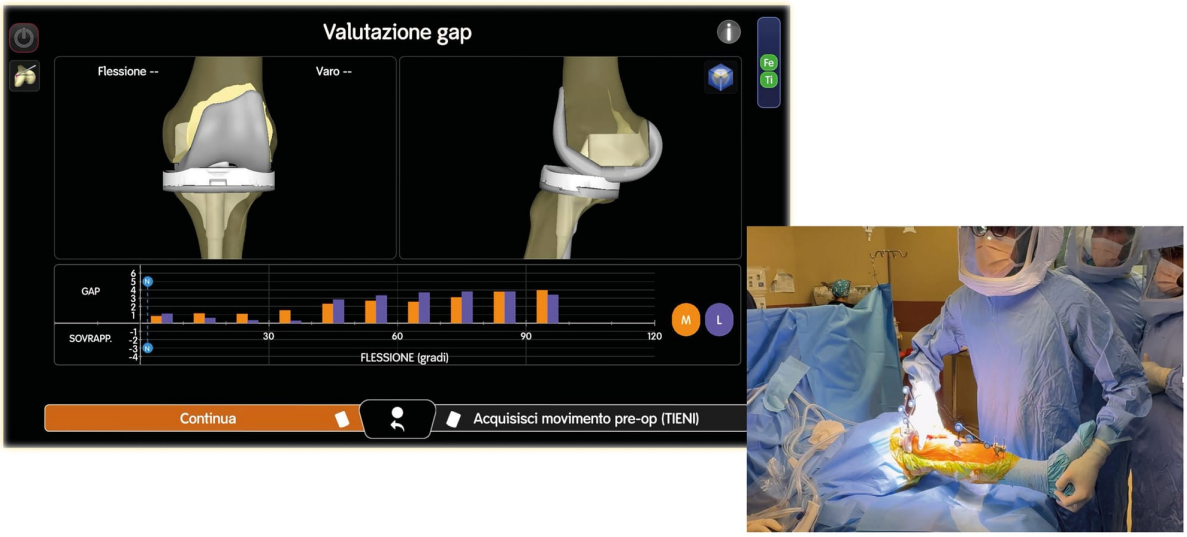

Figure 7: Initial varus-valgus stress test during the whole ROM to assess baseline ligament balance with the previous prosthesis still in place

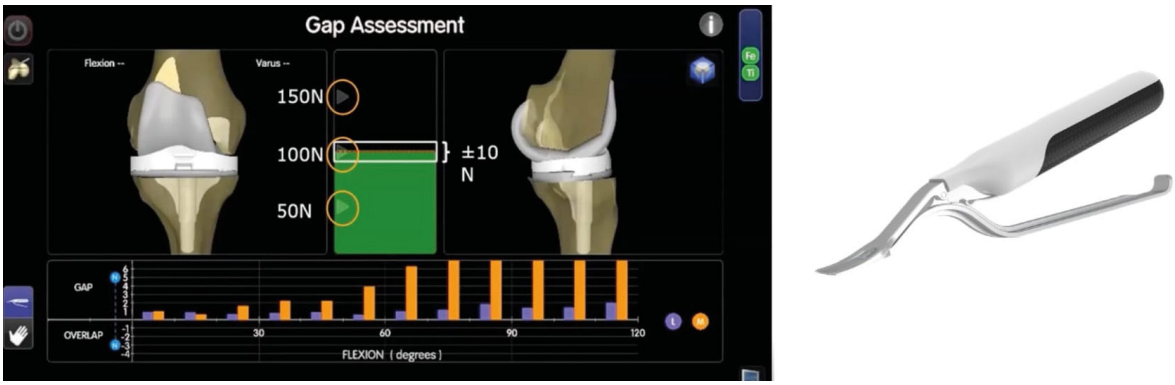

Figure 8: The tensioner assists in quantifying joint laxity prior to bony resections when using a robotic system. It provides objective gap measurements through automatic gap balance collection, based on a surgeon-defined force setting (50, 100, or 150 N). Consistent joint laxity assessments are achieved throughout the full range of motion. Note: Use of tensioner as described in primary TKA could also be used in RTKA although in large bone defects it might be more difficult to have a reliable gap measurement.

At this stage, to achieve optimal joint balance throughout the full range of motion, the implant position is fine-tuned functionally, while remaining within the system-defined boundaries.

Once ideal balance is obtained, the final digital position of the implant is registered and noted for future use as the initial articular position of the implant ("Homebase") . Noting the initial articular position of the implant ("Homebase") essentially consists of documenting -either by noting down it intraoperatively or capturing a screenshot- the hypothetical resection values in millimeters for the distal femur, the medial and lateral posterior condyles, and the medial and lateral proximal tibia (Figure 9 A-C). Defining and recording this initial articular position is critical for the subsequent steps, as it provides a reference point to evaluate and manage the extent of bone loss following implant removal. This documentation provides a reference point for surgical decision-making and ensures consistency throughout the procedure.

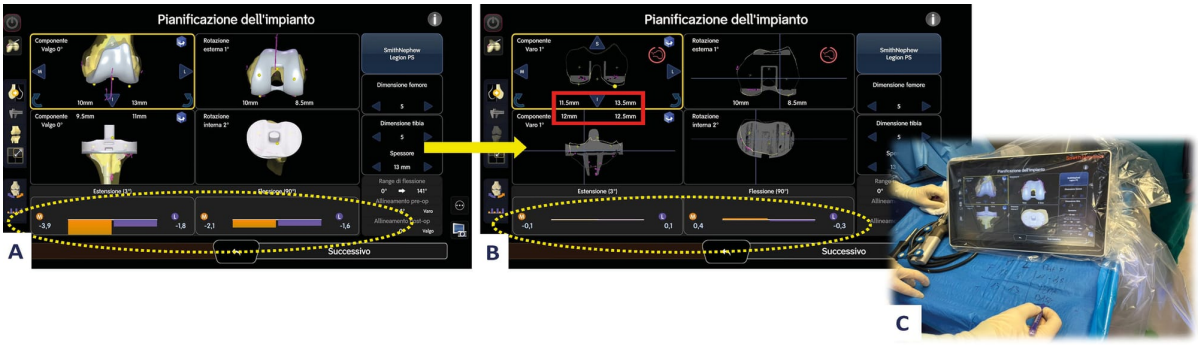

Figure 9 A-C: Defining the “Home Base” by functionally fine-tuning implant positioning in order to achieve optimal joint balance throughout the full range of motion (ROM). - A. Balancing curve after initial stress acquisition - B. Balancing curve after implant position fine-tuning and setting the definitive “Home Base” (red square) - C. Documenting the finalized “Home Base” position intraoperatively.

For cases in which we expect severe bone loss or instability, some tips and tricks of the system provides additional guidance through joint line height assessment, which becomes particularly important when considering the digital location of the joint line (Figure 10 A-C). This feature is crucial for restoring the joint line height, particularly in cases where severe instability precludes the creation of an ideal balancing profile and necessitates the use of a semi-constrained insert.

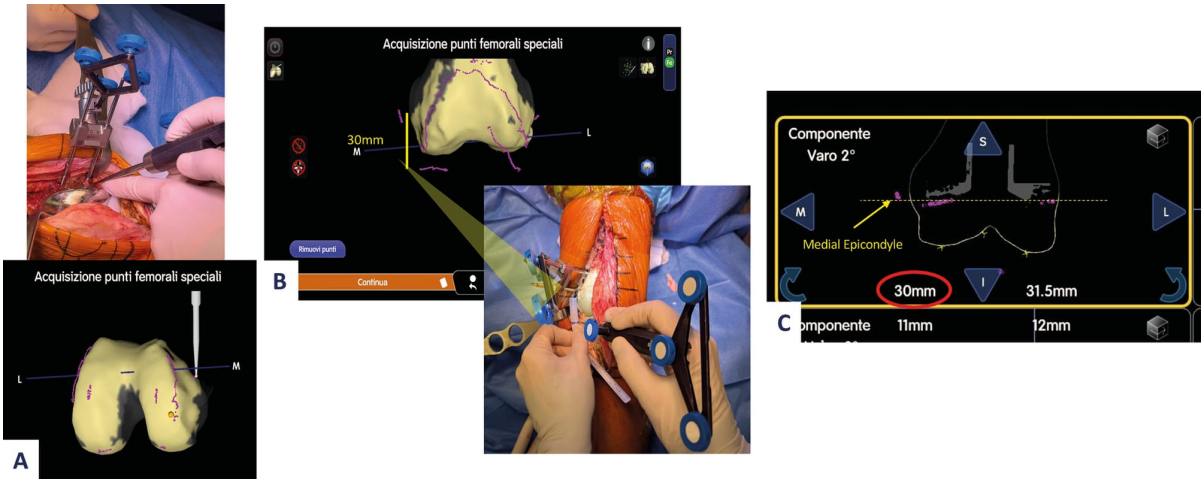

Figure 10: A. Identification of the medial epicondyle. - B. Marking the joint line level using a ruler and the CORI pointer to measure the distance from the medial epicondyle to the expected joint line based on preoperative planning. - C. Confirmation of the joint line level by digitally proximalizing the prosthesis until it aligns with the medial epicondyle special point (pink dots), indicating a distance of 30 mm in this case (highlighted by the red circle).

Phase 4: implant removal and bone defect management

Following completion of the preliminary phases, the surgical workflow proceeds to implant removal (Figure 11 A-C). Once the existing prosthesis has been explanted, the "Add Special Points" function is utilized to remap the exposed bone surface without the implant in situ. This function creates a new surface representation displayed in a distinct pink colour that overlays the previous anatomical mapping (Figure 12 A-C). The "Add Special Points" feature enables surgeons to systematically navigate between the established homebase reference and the newly exposed bone surface through dual-surface visualization.

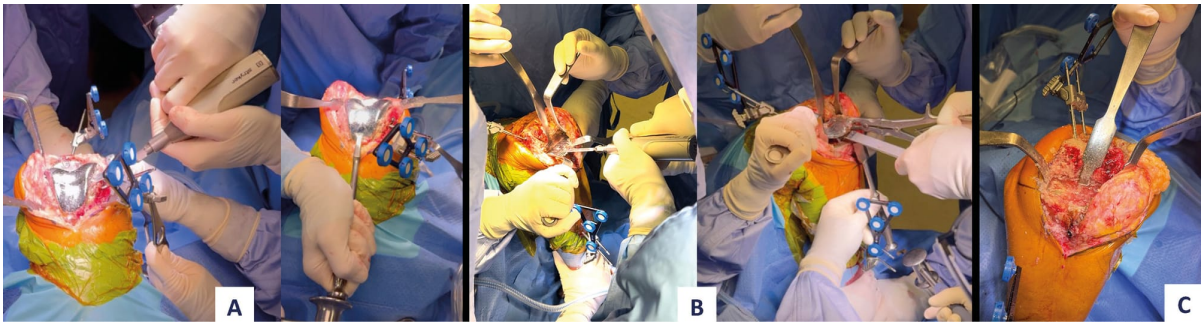

Figure 11: Implant removal following image-free registration of the failed components and ligament assessment. - A. Femoral removal - B. Tibial removal - C. Evaluation of residual bone stock after implant removal

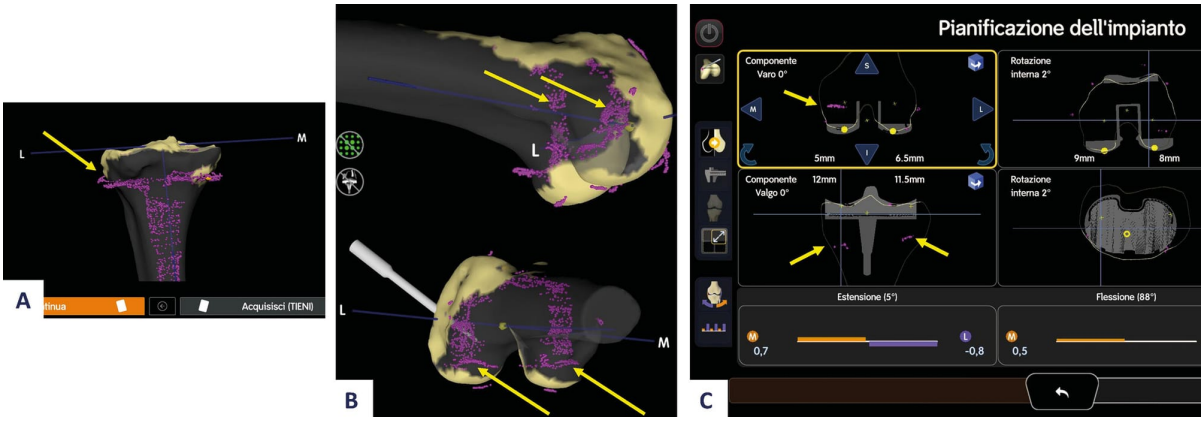

Figure 12: Evaluating tibiofemoral bone loss using the “Add Special Points” function to re-register the bone surface after implant removal. Assessment of the residual bone stock in the proximal tibia (A) and the distal/ posterior femur (B) (pink dots highlighted by yellow arrows). In the CORI "CT scan view” (C), pink dots (highlighted by yellow arrows) represent an estimate of the expected femorotibial bone loss from the digitally planned prosthesis.

By gradually aligning the planned prosthesis with the pink reference points, the surgeon can accurately assess the extent of bone loss and determine the optimal augmentation required to position the prosthesis according to the predefined home base target (Figures 13,14 A-C).

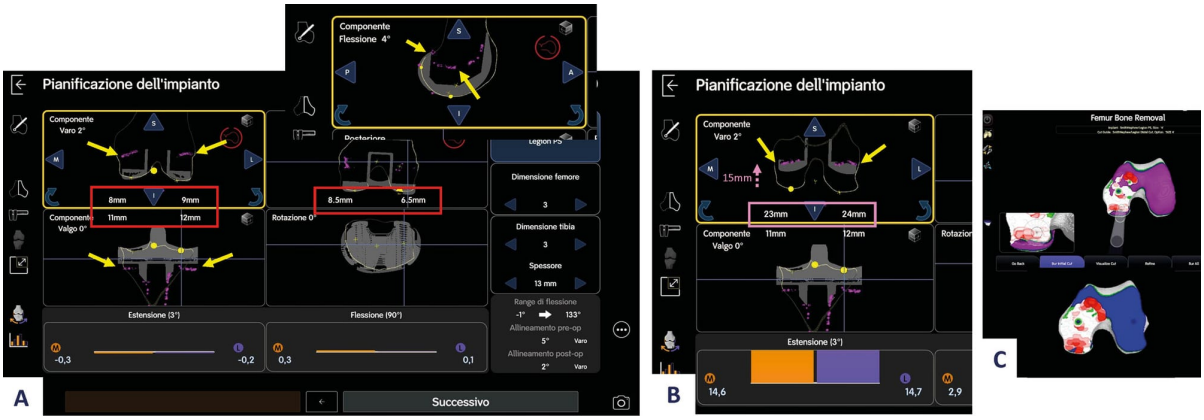

Figure 13: A. After defining the “Home Base” (red squares), begin identifying the pink dots that indicate the distal femoral bone stock following prosthesis removal (yellow arrows on the AP and sagittal CT scan views). - B. Gradually move the implant proximally by clicking upward until it reaches the level of the distal medial femoral bone stock. A useful tip is to adjust the implant in 5 mm increments, corresponding to the available augment sizes (5, 10, 15 mm). In the case shown, the implant is shifted medially from the 8 mm “Home Base” to 23 mm, indicating the need for a 15 mm medial augment. - C. Burr the distal-medial femur. White areas indicate that the target bone level has been reached with no residual bone loss; red areas indicate remaining bone loss; pink and blue zones represent uncut regions (in this case, the lateral femoral condyle). After completing the distal-medial cut, return the implant to the “Home Base” position and repeat the procedure for the lateral compartment and the posterior condyles.

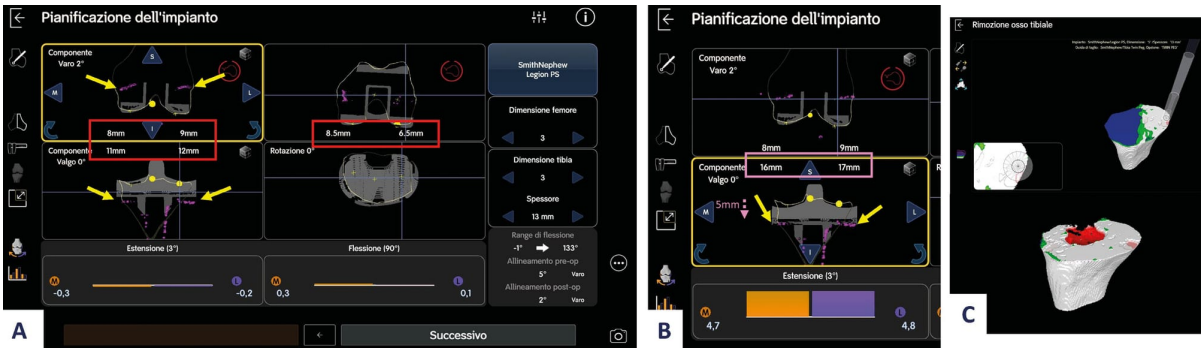

Figure 14: A. After returning to the “Home Base” (red squares), begin identifying the pink dots that indicate the proximal tibia bone stock following prosthesis removal (yellow arrows on the AP and sagittal CT scan views). - B. Gradually move the implant distally as described for the femur until it reaches the level of the proximal medial tibia bone stock. A useful tip is to adjust the implant in 5 mm increments; however, in the tibia, it is also possible to fine-tune the resection millimeter by millimeter, as tibial height can be modulated not only with metal augments but also through polyethylene thickness. In the case shown, the implant is shifted medially from the 11 mm “Home Base” to 16 mm, indicating the need for a 5 mm medial augment. In this particular case, a 5 mm lateral tibial augment was also required, allowing us to burr both the medial and lateral aspects of the proximal tibia simultaneously. - C. Burr the proximal tibia. White areas indicate that the target bone level has been reached with no residual bone loss; red areas indicate remaining bone loss; blue zones represent uncut regions.

This methodical approach utilizing the "Add Special Points" mode facilitates comprehensive evaluation of defect sites across the distal femur, posterior femur, and/or tibia, enabling decision-making regarding augment necessity, type selection, and precise placement strategy for each anatomical region (Figure 15).

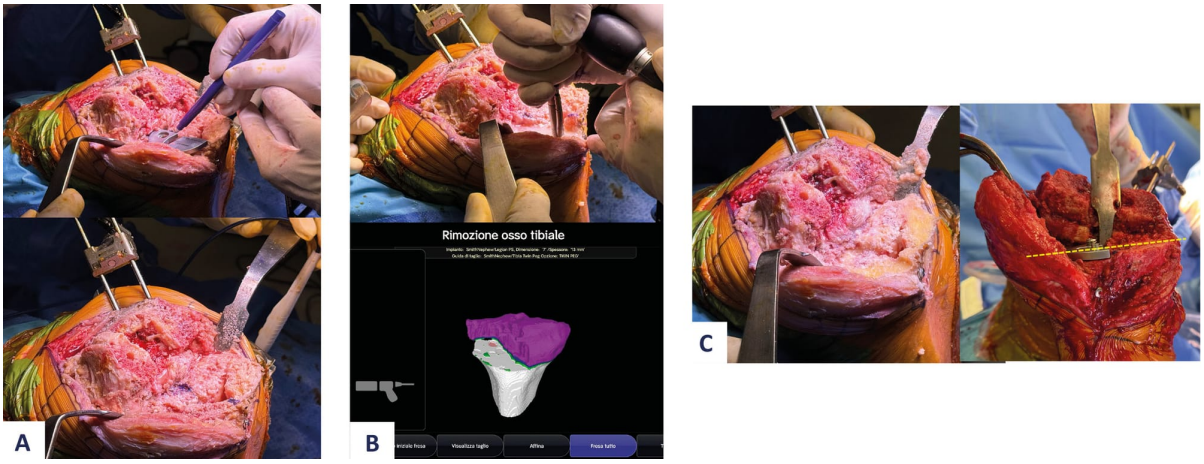

Figure 15: Tips and Tricks for Managing Hemi-Tibial Bone Loss and Preparing for Hemi-Wedge Implantation - A. Position the contralateral hemi-wedge upside down on the tibial surface and mark its borders on the bone. This serves as a visual guide to direct the burr during bone preparation, helping to avoid encroaching on the opposite tibial side, which may not require augmentation or may need a different one. - B. Shape the bone using the burr, carefully following the previously marked contour. - C. Final result after precise milling of the affected hemi-tibia (in this case, the lateral hemi-tibia).

Defect management represents perhaps the most challenging aspect of revision TKA, and the RI.KNEE ROBOTICS Software for Revision Knee Arthroplasty provides sophisticated tools for addressing bone loss. The system's bone refinement capabilities include comprehensive femoral bone removal planning with detailed visualization of bone loss patterns. It provides comprehensive guidance for distal femoral augment preparation through visual indication of defect depth to support planning, employing a systematic approach beginning with medial preparation, allowing surgeons to "return home" for reference, then proceed laterally (Figure 16).

Figure 16: Flowchart for Bone Loss Assessment and Preparation for potential Metal Augmentation

A key technical feature is the ability to move the implant position superiorly by 5-10-15mm specifically for distal-posterior femoral or medio-lateral tibial augment accommodation. The software utilizes a precise measurement protocol where every 1 click equals 0.5 mm of adjustment, providing fine-tuned control over component positioning.

The femur cut selection process allows for targeted bone removal, with specific capability for distal burr (distal cut) selection to target bone removal on the distal surface alone. This precision ensures optimal preparation of the defect site while preserving healthy bone stock (Figure 14 C).

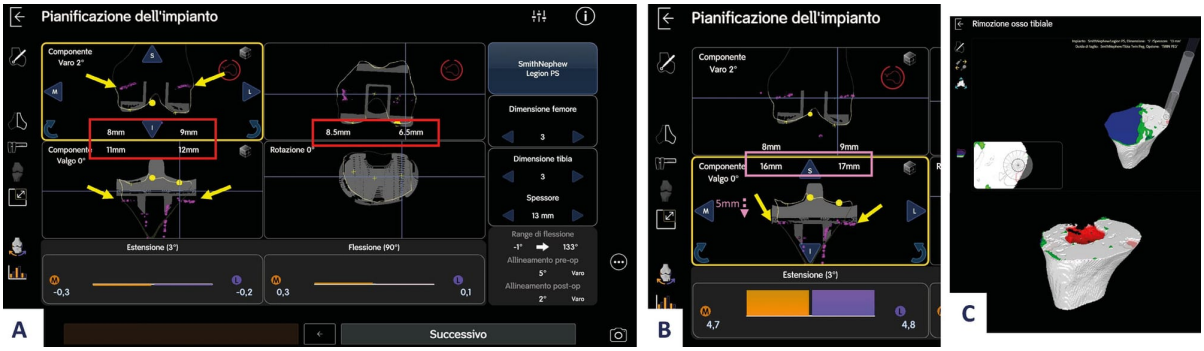

Figure 14: A. After returning to the “Home Base” (red squares), begin identifying the pink dots that indicate the proximal tibia bone stock following prosthesis removal (yellow arrows on the AP and sagittal CT scan views). - B. Gradually move the implant distally as described for the femur until it reaches the level of the proximal medial tibia bone stock. A useful tip is to adjust the implant in 5 mm increments; however, in the tibia, it is also possible to fine-tune the resection millimeter by millimeter, as tibial height can be modulated not only with metal augments but also through polyethylene thickness. In the case shown, the implant is shifted medially from the 11 mm “Home Base” to 16 mm, indicating the need for a 5 mm medial augment. In this particular case, a 5 mm lateral tibial augment was also required, allowing us to burr both the medial and lateral aspects of the proximal tibia simultaneously. - C. Burr the proximal tibia. White areas indicate that the target bone level has been reached with no residual bone loss; red areas indicate remaining bone loss; blue zones represent uncut regions.

For posterior femoral defects, the system requires moving the component anteriorly to prepare the posterior femur adequately. The cut selection interface allows for "Bur All" option for comprehensive posterior bone removal. This systematic approach ensures proper preparation of posterior defects, which are critical for achieving stable flexion gap balance and preventing posterior impingement.

The tibial preparation workflow incorporates sophisticated defect visualization and management capabilities. The system allows surgeons to "Add Special Points" to define bone loss precisely, enabling accurate quantification of tibial defects. The planning interface provides comprehensive gap analysis throughout the range of motion, with particular attention to adjusting tibial position relative to planned tibial augments versus adjustment of polyethylene thickness (Figure 17 A-E).

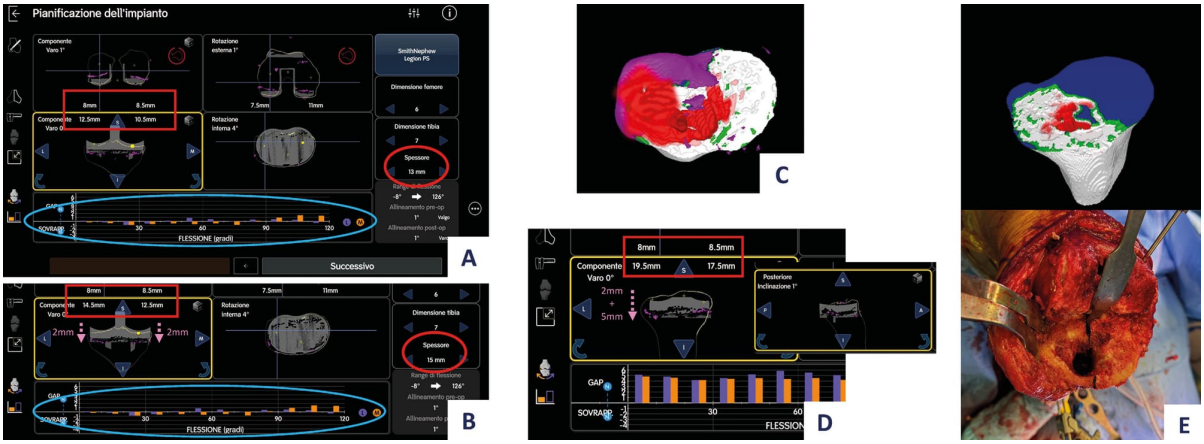

Figure 17: A. Starting from the defined Home Base, the implant was progressively moved distally until it reached the underlying bone. - B. In this case, the implant was advanced 2 mm distally, and the polyethylene insert thickness was increased from 13 mm to 15 mm (red circles) to maintain consistent gap balancing (light blue circle). C. Following tibial burring, the system indicated residual lateral bone loss. D. As a result, the implant was moved an additional 5 mm distally to accommodate a 5 mm lateral tibial augment. E. Final tibial surface preparation after burring for the 5 mm augment.to 15 mm (red circles) to maintain consistent gap balancing (light blue circle).

The tibial bone removal interface provides detailed three-dimensional visualization of bone loss patterns, with color-coded mapping to distinguish between healthy bone (shown in blue) and areas requiring removal (shown in green). The cut selection allows for "Bur All" option for comprehensive tibial bone removal, ensuring optimal preparation of the tibial surface for augment placement.

The defect management workflow incorporates special points collection on explant surfaces and defects, enabling precise characterization of bone loss patterns. The plane visualization tool provides quantitative assessment of defect dimensions, facilitating appropriate augment selection and sizing. Moreover, this tool can also serve as a verification method after the bone cut has been performed, to assess whether the planned target has been accurately achieved (Figure 18). The software can evaluate and visualize bone defects in real-time, allowing for adaptive surgical planning based on intraoperative findings.

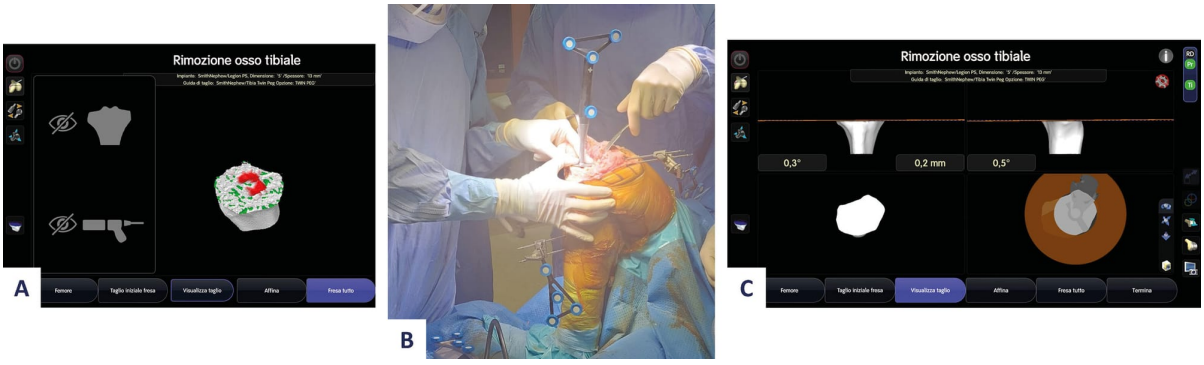

Figure 18: After performing the tibial cut (A), the pointer can be used in navigation mode by placing it on the burred tibial surface (B) to verify the achieved alignment using the “Plane Visualization” tool (C).

Phase 5: final assessment and implantation

The final phase consists of comprehensive component trialling, evaluation of residual laxity, and final prosthesis implantation. This phase represents the culmination of the robotic-assisted planning process, where the theoretical surgical plan is validated through actual component testing and biomechanical assessment.

The robotic platform provides sophisticated tools for final component assessment, including comprehensive laxity evaluation across multiple planes of motion. The final assessment interface displays detailed kinematic data, gap measurements, and stability parameters to ensure optimal joint mechanics have been achieved (Figure 19). This real-time feedback capability allows surgeons to make final adjustments to component positioning, polyethylene insert thickness, or constraint level before final implantation.

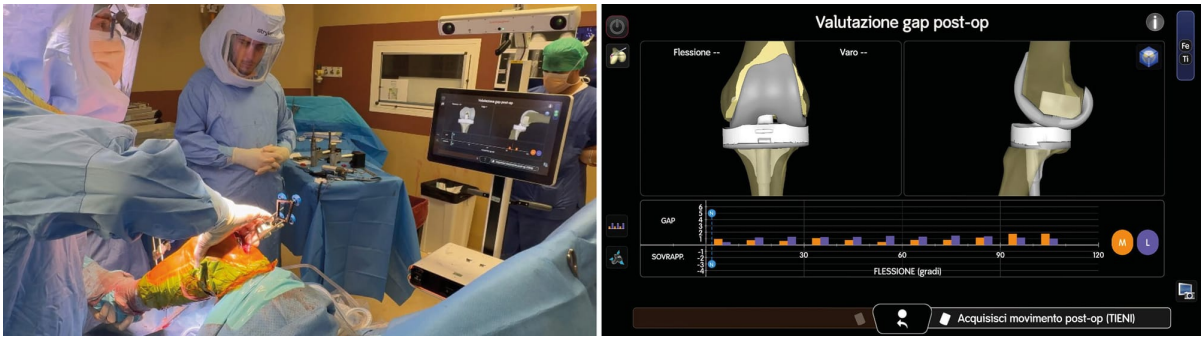

Figure 19: Final gap assessment performed through varus-valgus stress testing across the full range of motion, with trial or definitive implants in place.

The laxity assessment protocol evaluates both coronal and sagittal plane stability throughout the range of motion, providing objective data on joint stability that can guide final surgical decisions. This is particularly valuable in revision scenarios where soft tissue balance may be compromised and achieving appropriate constraint is critical for long-term success.

The robotic software provides final verification of component positioning and joint mechanics, ensuring that surgical objectives have been achieved before final implantation (Figure 20). This includes confirmation of appropriate gap balance, component alignment, and joint stability parameters established during the planning phase. Since reconstruction is now performed based on the joint line rather than diaphyseal landmarks, a short cemented stem is selected. This approach avoids being constrained by the boundaries of the cortex.

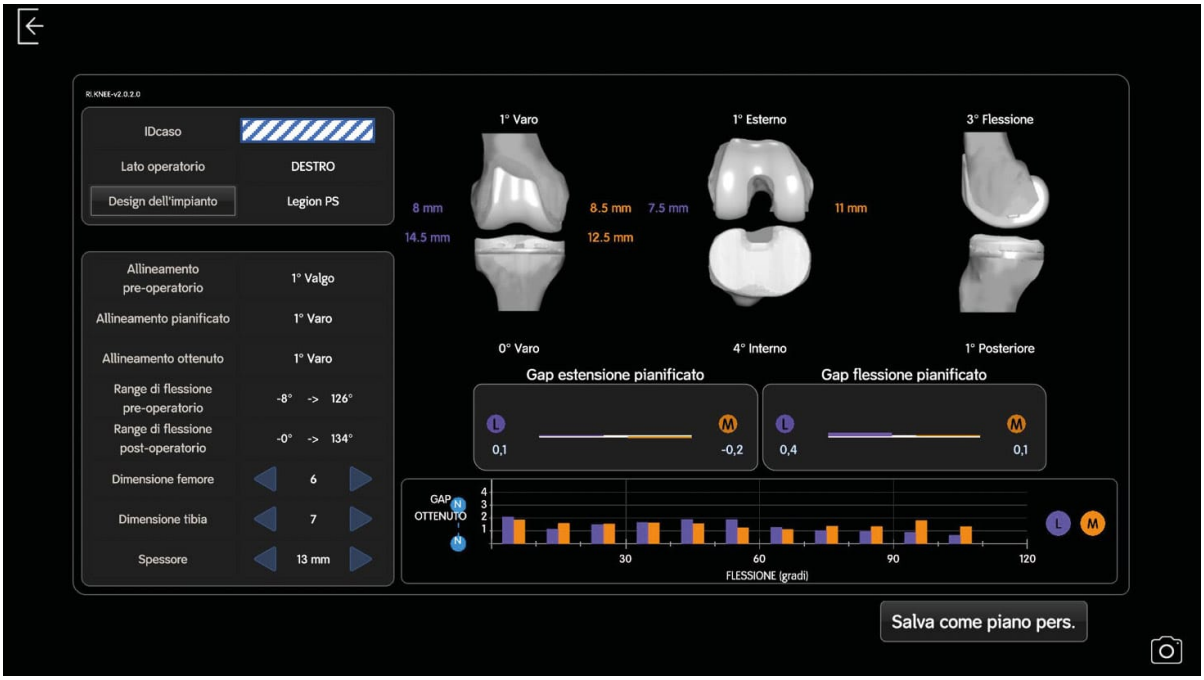

Figure 20: Final report with the planned to obtained alignment in both the coronal and sagittal view and also the pre-to post-op ROM and the final balancing curve.

CLINICAL APPLICATIONS AND ADVANTAGES

The CORI Surgical System and RI.KNEE ROBOTICS Software for Revision Knee Arthroplasty specifically address many of the traditional challenges encountered in revTKA. The elimination of preoperative imaging requirements streamlines the surgical workflow while providing superior intraoperative visualization of defects and anatomical variants. The real-time bone modelling capability is particularly valuable when dealing with complex bone loss patterns that may not be fully appreciated on static imaging studies.

The precision milling capability preserves healthy bone stock while ensuring optimal preparation of compromised surfaces for component fixation. This is particularly important in revision surgery where preservation of remaining bone stock is critical for long-term implant stability and potential future revision procedures.

Enhanced surgical decision-making

The system's comprehensive gap balancing and ligament assessment capabilities provide surgeons with objective data for surgical decision-making. The ability to assess joint stability and gap balance throughout the range of motion enables more precise soft tissue releases and constraint selection, potentially reducing the incidence of postoperative instability.

The real-time feedback on component positioning and joint mechanics allows for intraoperative adjustments to optimize outcomes. This is particularly valuable in revision cases where anatomical landmarks may be absent or distorted, making traditional alignment techniques less reliable.

Advanced augmentation planning and execution

The system's approach to augmentation planning represents a significant advancement in revision surgery technique. The ability to visualize defect depth and adjust component positioning with millimeter-level precision (every 1 click equals 0.5 mm) enables optimal augment sizing and placement. The systematic approach to both distal and posterior femoral augmentation, combined with precise tibial defect management, ensures comprehensive restoration of bone stock and joint mechanics.

The "Return Home" functionality provides surgeons with a consistent reference point throughout the procedure, enabling systematic progression through complex revision cases while maintaining spatial orientation. This is particularly valuable when managing multiple defects or when transitioning between different phases of bone preparation.

Precision in bone stock conservation

The selective bone removal capabilities, including options for distal-only cuts or comprehensive "Bur All" removal, demonstrate the system's commitment to bone conservation while ensuring adequate defect preparation. The three-dimensional visualization of bone loss with color-coded mapping provides unprecedented clarity in distinguishing between healthy bone that should be preserved and defective bone that requires removal.

Integration with LEGION implants

The system's compatibility with LEGION augmentation systems and specialized revision components provides surgeons with a comprehensive toolkit for addressing complex revision scenarios. The specific guidance for short cemented stems represents an important advancement in revision technique, as these components can provide adequate fixation while preserving bone stock for potential future revisions.

Future advancements are promising to facilitate the mapping of metaphyseal bone, thereby enabling the robotic system to account for compromised metaphyseal bone quality in the consideration of cones, as well as to integrate diaphyseal anatomy for optimal stem fixation and positioning.

INTERIM RESULTS FROM THE CURRENT CLINICAL PILOT TRIAL

The authors, at the time of the current review, conducted a prospective multicentric longitudinal study to evaluate the performance of imageless robotic-assisted revTKA using the CORI system. The investigation compared two distinct surgical approaches: one utilizing intra-articular pinning with stemless trials for range of motion and balancing assessment, and another employing extra-articular pinning with stem-in trials.

The interim analysis revealed that the robotic system demonstrated excellent accuracy in achieving planned implant positioning across multiple radiographic parameters. The system showed remarkable reliability between preoperative planning and actual surgical execution, with statistical validation confirming strong correlations between planned targets and achieved outcomes. The consistency extended across all phases of the surgical procedure, from intraoperative measurements to final postoperative radiographic assessments.

Both surgical techniques proved equally effective, demonstrating that the CORI system maintains consistent accuracy regardless of the specific pinning strategy employed. This flexibility validates the system's adaptability to different surgical preferences while preserving precision. The analysis revealed exceptional radiographic

outcomes, with all cases achieving optimal alignment targets without any outliers across critical parameters including overall limb alignment, component positioning, and joint line restoration.

When compared to conventional intramedullary instrumentation techniques, the robotic approach demonstrated clear superiority in achieving target alignment. The analysis suggested that traditional methods would have resulted in significantly more alignment outliers, highlighting the advantage of robotic assistance in revision scenarios where anatomical landmarks may be compromised.

The precise bone preparation and gap balancing achieved through robotic assistance appeared to reduce the complexity of implant selection, with most cases successfully managed using less constrained implant designs. The optimal polyethylene thickness distribution suggested appropriate joint line restoration without excessive soft tissue tension, indicating that the system effectively addresses the challenging balance between stability and mobility in revision arthroplasty.

These preliminary findings demonstrated that imageless robotic-assisted rev-TKA provides superior accuracy and precision compared to traditional approaches, effectively eliminating radiographic outliers while maintaining consistent implant positioning regardless of the specific surgical technique employed, whether intra-articular pinning with stemless trials or extra-articular pinning with stem-in trials.

CONCLUSIONS

Technology-assisted revision TKA represents a promising advancement in orthopaedic surgery, demonstrating clear improvements in radiographic parameters and surgical precision. While these benefits have not yet consistently translated into superior clinical outcomes, the evolution of technology platforms and integration of artificial intelligence may bridge this gap. The future of revision TKA likely lies in personalized, data-driven approaches that leverage advanced technologies to address the unique challenges of each revision scenario.

As the field advances, continued research focusing on long-term outcomes, cost-effectiveness, and the development of revision-specific platforms will be essential. The integration of AI, advanced imaging, and personalized surgical planning holds significant promise for improving both radiographic precision and clinical outcomes in this challenging surgical domain.

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