Technical Note
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Precise Calibration of Femoral Component Rotation Using the Posterior Condylar Axis as a Reference during Image-free Robot-assisted Total Knee Arthroplasty: A Technical Note

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Learning Point of the Article:

This manuscript describes a simple and useful technique with a broad scope of applications, for the calibration of femoral component rotation using the posterior condylar axis as the reference, during image-free robot-assisted total knee arthroplasty.

Abstract

Introduction: The use of image-free robotic systems for total knee arthroplasty (TKA) is gaining popularity. Although the surgical transepicondylar axis (sTEA) is considered the optimal femoral rotational reference during TKA, it is difficult to define intra-operatively. Conventional and image-free robot-assisted TKA (RA-TKA) therefore rely on the use of Whiteside's axis (WSA) or the posterior condylar axis (PCA) as surrogate references. The PCA is considered to be associated with less variability than the WSA. The authors present a simple technique to permit calibration of femoral component rotation (FCR) using the PCA as a reference for image-free robotic systems that do not permit this option.

Technique: The image-free robotic systems used by the authors (Navio and CORI, Smith and Nephew, Memphis, TN, USA) permit calibration of FCR only when the perpendicular to WSA is used as a reference. When the PCA is selected as a reference, a fixed 3° of external rotation is set by the robot. The technique proposed by the authors involves the use of the former setting, followed by internal rotation of the perpendicular to the WSA to co-align it with the PCA. The planning menu subsequently permits virtual surgical planning using the PCA as the femoral rotational reference and permits adjustments in rotational positioning of the femoral component while displaying the effect of rotation on bony resection and vice versa in real time. In addition, coaligning the perpendicular to the anatomic trans-epicondylar axis (aTEA) displays the internal rotation of the PCA with respect to the aTEA. This information can be used for setting rotational boundaries with respect to the PCA while using various alternate alignment strategies, like functional alignment, since the relation between the aTEA and sTEA is less likely to be affected by dyplasia and wear when compared with the PCA or WSA.

Conclusion: This simple technique permits optimally calibrated rotational positioning of the femoral component during image-free RA-TKA, using the PCA as a reference. It can be applied for optimizing surgery in knees with altered or outlier anatomy, as well as routinely, especially when alternate alignment strategies are used.

Keywords: Femoral component rotation, robot-assisted total knee arthroplasty, posterior condylar axis, trans-epicondylar axis, image-free robotics.

Introduction

Recent advances in surgical technology, including computer navigation, patient-specific cutting blocks, and robotic surgery, have led to an increase in the use of personalized alignment strategies during total knee arthroplasty (TKA) [1]. Robot-assisted TKA (RA-TKA) permits accurate planning of component positioning while providing real-time feedback on the precise effect of calibrated multi-planar alterations in bony

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Author's Photo Gallery


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Figure 1: The "use posterior condylar axis" option for "femur rotational axis" is shown as selected in the surgical preferences menu (marked by the red oval in the figure).

resection on the gap status [2]. This has led to a growing interest in alternate alignment strategies like functional and inverse kinematic alignment and permitted refinement of the existing options of mechanical, kinematic, and restricted kinematic alignment [1].

Robotic systems using pre-operative computed tomography scans permit the surgeon to base femoral rotational alignment on the surgical trans-epicondylar axis (sTEA). Image-free robots, however, continue to rely on the use of the posterior condylar axis (PCA) or Whiteside's axis (WSA), since they use intra-operative bone-mapping to generate a free-collection

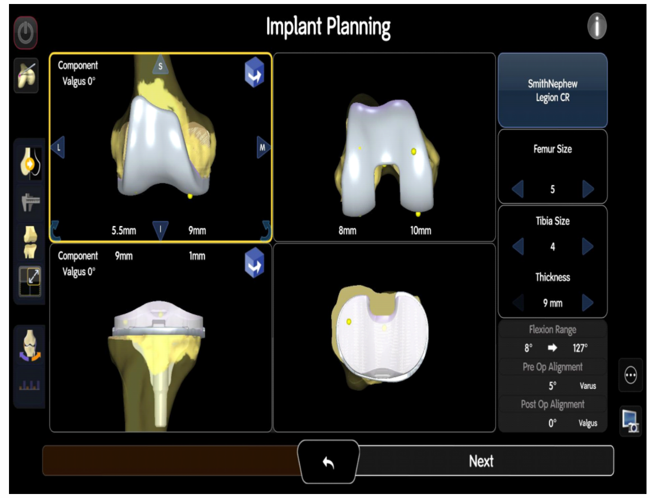

Figure 2: When the "use posterior condylar axis" option is selected, the surgical planning menu does not display the amount of femoral component rotation for calibration; a fixed value of 3° of external rotation is used instead ("M," "L," "S" and "I" refer to medial, lateral, superior and inferior aspects of the joint, respectively; the projected bony resection from the distal femur, posterior femur and proximal tibia are presented in millimeters).

mesh on which surgical planning is based. Image-free RA-TKA is gaining in popularity since it avoids exposure to radiation while providing comparable surgical accuracy [3].

The authors have used the Navio (Smith and Nephew, Memphis, TN, USA) and CORI (Smith and Nephew, Memphis, TN, USA) robotic systems extensively in their practice. These systems present two options for defining the femoral rotational axis: (a) a line at 3° of external rotation from the system-generated, mesh-derived PCA and (b) the perpendicular to a user-defined femoral anteroposterior axis. Though both options permit subsequent calibration of bony

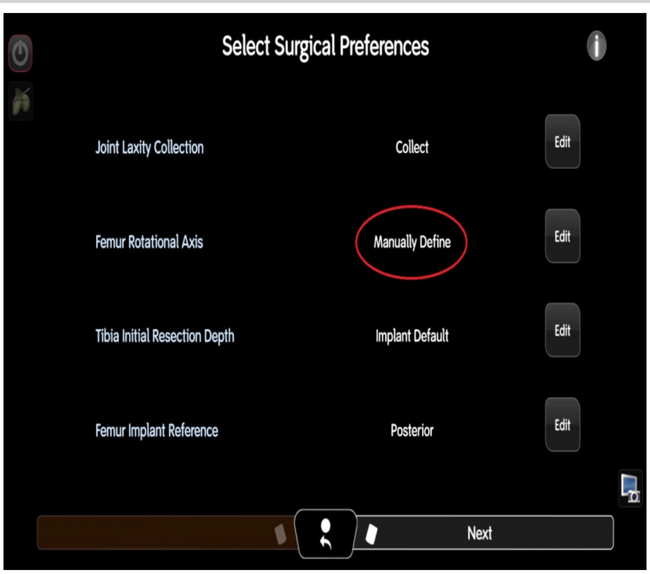

Figure 3: The "manually define" option for "femur rotational axis" is shown as selected in the surgical preferences menu (marked by the red oval in the figure); this permits the user to manually define Whiteside's axis using the pointer probe.

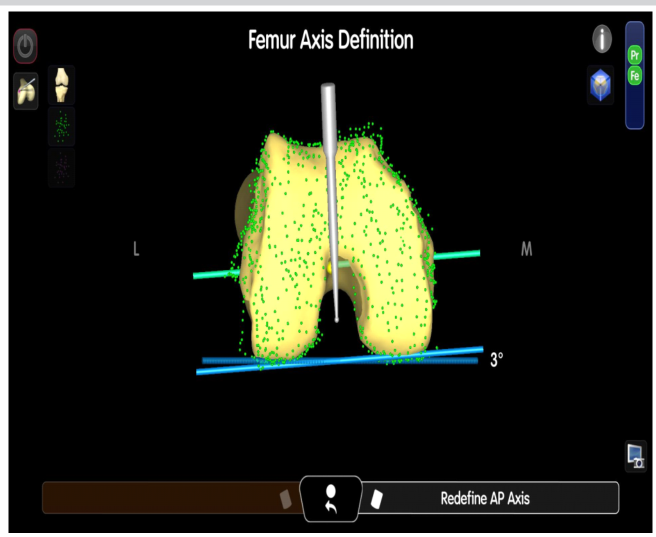

Figure 4: When the "manually define" option is selected, an additional step appears in the workflow, for definition of Whiteside's axis (WSA) ("M" and "L" represent the medial and lateral aspects of the femur, respectively; the green line represents WSA-P, the horizontal dark blue line represents the native posterior condylar axis (PCA), the oblique light blue line represents PCA-R; green dots represent anatomic registration points as captured by the pointer probe).

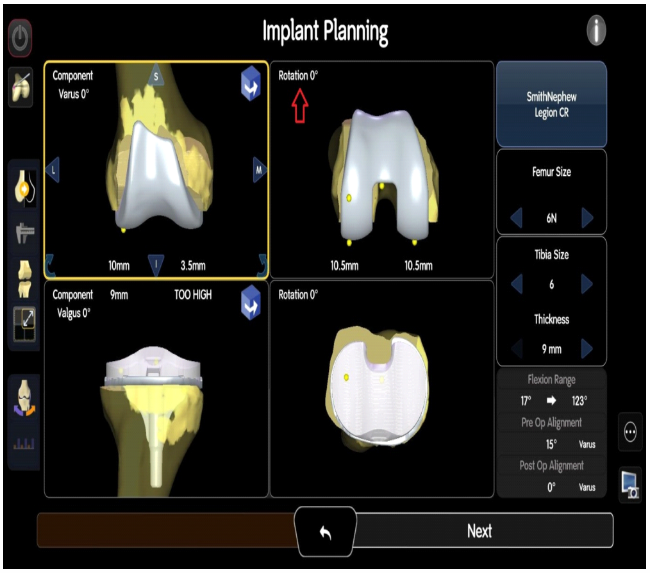

Figure 5: When the "manually define option is selected, the surgical planning menu displays the value of femoral component rotation (marked by the red arrow in the figure) and permits alterations of the same ("M," "L," "S" and "I" refer to medial, lateral, superior and inferior aspects of the joint, respectively; the projected bony resection from the distal femur, posterior femur and proximal tibia are presented in millimeters).

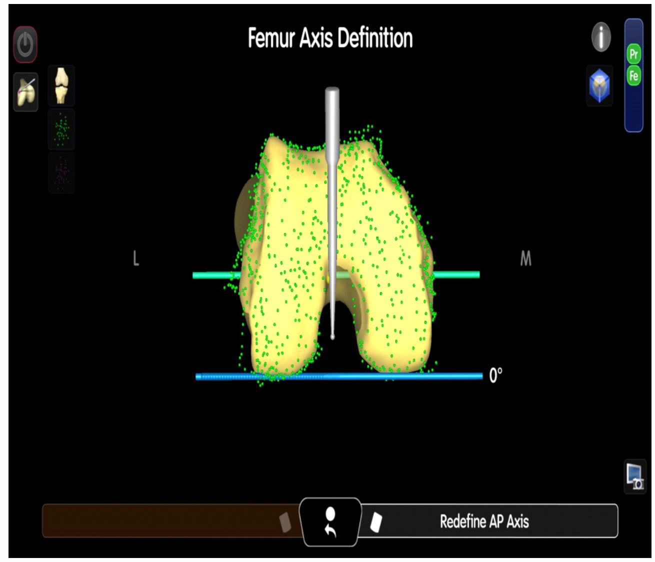

Figure 6: The pointer probe is internally rotated to co-align the posterior condylar axis (PCA) with PCA-R, to display a rotational value of 0° ("M" and "L" represent the medial and lateral aspects of the femur, respectively; the green line represents Whiteside's axis-P, the blue line represents the native PCA; green dots represent anatomic registration points as captured by the pointer probe).

resection, at the time of preparing this manuscript, the former precluded an assessment of its effect on femoral component rotation (FCR) and patient-specific calibration of FCR using the PCA as a reference. This led to the development of a simple but useful technique by the authors to circumvent this limitation. This technique is applicable for both Navio and CORI robotic systems (Smith and Nephew, Memphis, TN, USA).

Technique

The routine preliminary steps of RA-TKA are carried out.

Figure 7: Example case; anteroposterior and lateral knee radiographs of a 58-year-old lady who presented with osteoarthritis of the right knee, and underwent robot-assisted-total knee arthroplasty.

Following appropriate anesthesia, the patient is placed supine. The lower limb is painted and draped over a tourniquet. Surgical preferences including the chosen method of defining the femoral rotational axis are entered into the robotic system interface. An anterior midline approach is used. The preferred arthrotomy and surgical exposure of the joint are performed. Registration of bony landmarks and the centers of rotation of the hip, knee and ankle are carried out. The distal femur and proximal tibia are three-dimensionally mapped using a pointer probe and trackers, to generate a free-collection mesh, which shall be used for surgical planning.

When the "use PCA" option for defining the femoral rotational axis is selected (Fig. 1), a fixed value of 3° of external rotation from the mesh-generated PCA is employed by the system. The surgical planning menu subsequently does not provide the value of FCR in real-time while performing alterations in component positioning (Fig. 2), since this rotation is considered appropriate by the system. Although 3° of external rotation from the PCA might be adequate for most patients, its universal application would result in flexion gap imbalance in a large proportion of patients. Lack of the ability to titrate bony resection while assessing the impact on the gap status would be a suboptimal usage of the robot.

On the other hand, when the "manually define" option for setting the femoral rotational axis (Fig. 3) is chosen, an additional step needs to be performed in the work-flow, following mesh generation. The axial view of the mapped distal femur is presented to the surgeon, to manually define the

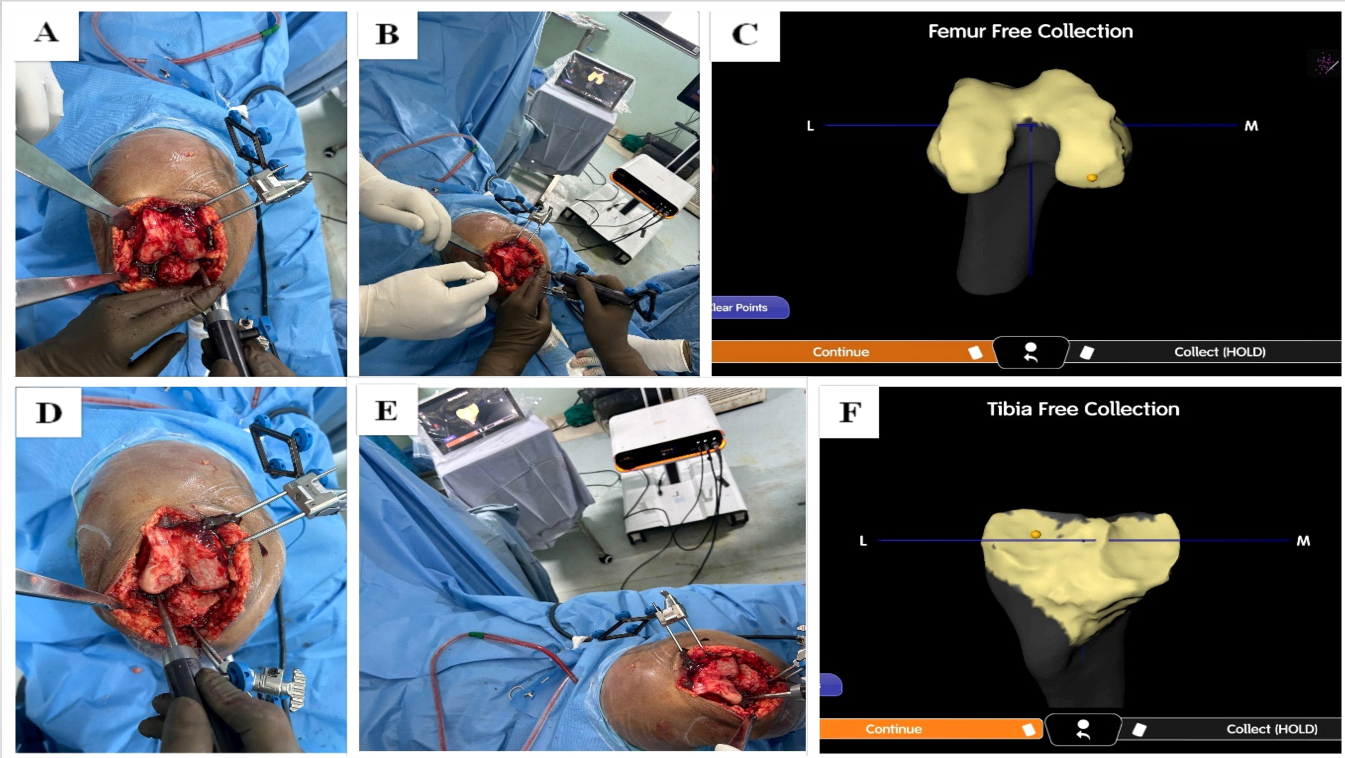

Figure 8: Example case; three-dimensional mapping of the distal femur and proximal tibia prior to surgery is depicted. (A) The surgeon is seen using a pointer-probe for mapping the femur. (B) As the surgeon maps the femur using the pointer-probe, the robot generates a free-collection mesh of the femur, as seen on the monitor in the background. (C) A screenshot is obtained at the end of femoral mapping, depicting the free-collection mesh. (D) The surgeon is seen using the pointer-probe for mapping the tibia. (E) As the surgeon maps the tibia using the pointer-probe, the robot generates a free-collection mesh of the tibia, as seen on the monitor in the background. (F) A screenshot is obtained at the end of tibial mapping, depicting the free-collection mesh ("M" and "L" in the screenshots represent the medial and lateral aspects of the femur or tibia, respectively).

anteroposterior axis of the femur (WSA), between the deepest point of the trochlear groove and the Center of the inter-condylar notch (Fig. 4). A system-generated perpendicular axis to the WSA is depicted on the interface (WSA-P), representing the resultant rotational orientation. Two posterior axes are also depicted, representing the mesh-derived PCA, and an axis parallel to WSA-P representing rotational deviation from the PCA (PCA-R). The angle between the PCA and the PCA-R is presented in real-time, and is indicative of the rotation of the WSA-P with respect to the PCA. The surgical planning menu now displays the value of FCR in relation to the WSA-P (Fig. 5).

The authors modified the technique of the "manually define" option, resulting in a third method for defining the femoral rotational axis that not only uses the PCA as a reference but also permits the surgeon to calibrate FCR for a given knee and observe the effect of alterations in bony resection on FCR and vice versa. This technique involves manual positioning of the pointer probe in a manner such that the PCA-R co-aligns with the PCA, thereby presenting a rotational angle of 0° (Fig. 6). The deliberate misrepresentation of WSA is inconsequential, as the planning menu now permits fine-tuning of FCR "unwittingly" using the PCA as the reference axis, despite the use of a setting meant for WSA-P-based referencing. Intra-operative pictures of an example case depicting the execution of the technique are depicted in Figs. 7, 8, 9.

An extended use of this technique involves preliminary coalignment of the WSA-P with the mesh-derived anatomic trans-epicondylar axis (aTEA) to derive the aTEA/PCA angle (Fig. 10), followed by execution of the remaining steps as mentioned above. This addition to the original technique is immensely relevant in the context of setting safe boundaries for FCR during functionally aligned RA-TKA. Rotational boundaries are defined with respect to the sTEA, which lies approximately 2° internally rotated from the aTEA [1, 4]. The aTEA/sTEA angle is relatively constant, as it is less likely to be affected by trochlear dysplasia, femoral condylar hypoplasia, posterior condylar wear, or posteromedial femoral condyle hypertrophy [5]. It can be used to indirectly assess the sTEA/PCA angle when the aTEA/PCA angle is known.

In the example shown in Fig. 10, the aTEA/PCA angle is 8°, indicating a sum total of approximately 2° from the aTEA/sTEA angle and 6° from the sTEA/PCA angle. Therefore, to set

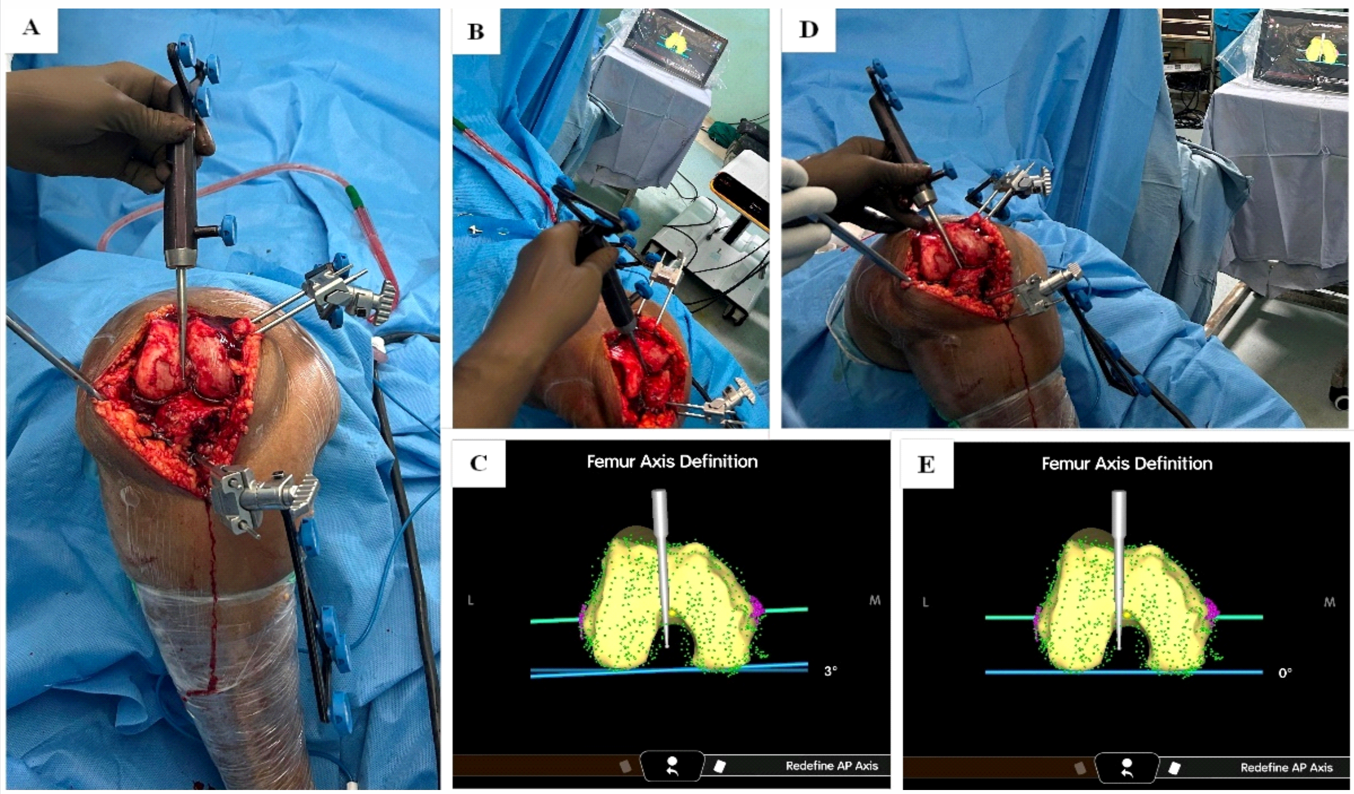

Figure 9: Example case; calibration of the femoral component rotation is depicted. The "manually define" option was selected in the planning menu. (a) The pointer-probe is held by the surgeon in a vertical orientation, to calibrate femoral component rotation. (B) When the probe is held parallel to Whiteside's axis, a rotational value of 3° is shown on the monitor in the background. (C) A screenshot taken at this time depicts 3° of external rotation of Whiteside's axis (WSA-P) from the posterior condylar axis (PCA). (D) The surgeon adjusts the position of the pointer-probe by internally rotating it by 3°; this results in the PCA-R co-aligning with the PCA, as shown in the monitor in the background. (E) A screenshot taken at this time depicts 0º of rotation of the WSA-P with respect to the PCA; using this setting, the surgeon can now accurately calibrate femoral component rotation using the PCA as a reference ("M" and "L" in the screenshots represent the medial and lateral aspects of the femur, respectively; the green line represents Whiteside's axis-P, the horizontal dark blue line represents the native PCA, the oblique light blue line represents PCA-R; green dots represent anatomic registration points as captured by the pointer probe; purple dots represent additional registration points collected for defining the epicondyles).

rotational boundaries of ±3° from the sTEA, the surgeon would have to consider the boundaries of the FCR as 3° and 9° of external rotation from the PCA for implants that do not have an externally rotated design (like the Legion [Smith and Nephew, Memphis, TN, USA] system used by the authors). Where components with externally rotated designs (for example, the Genesis II system [Smith and Nephew, Memphis, TN, USA]) are used, the technique remains applicable, though appropriate boundary adjustments need to be made by the surgeon.

The rest of the surgery is performed customarily. Titrated bony resections to achieve optimal gap balance are planned and executed. Anteroposterior positioning of the femoral component can be adjusted during the planning process, for an appropriate posterior offset without anterior femoral notching. Soft-tissue releases are performed where necessary. Trial components are fixed in situ to assess the adequacy of the surgical procedure. Definitive implants are finally fixed.

Discussion

Application of the technique: general day-to-day use

Appropriate FCR during TKA is critical for healthy patello-femoral joint mechanics, tibio-femoral joint stability, and prosthetic longevity [6]. Optimal FCR has a strong positive correlation with clinical outcomes following TKA [7]. Malrotation of the femoral component could result in numerous patellofemoral complications such as maltracking, subluxation, dislocation, wear, anterior pain syndrome, or the need for lateral retinacular release. It could also affect tibiofemoral flexion gap balance adversely and result in stiffness, instability, post-cam impingement, asymmetric compartment loading, polyethylene wear, mid-flexion pain, component loosening, or prosthetic failure [8,9].

The sTEA is considered the most reliable reference for FCR but is difficult to define intra-operatively due to soft-tissue coverage [9, 10]. To overcome this impediment, the PCA and WSA are used as surrogate references for femoral rotational alignment [11]. Despite the possibility of errors with either of these references, the PCA has been shown to be associated with less variability than the WSA [11]. The use of a fixed 3° external rotation from the PCA, however, as was the general practice in

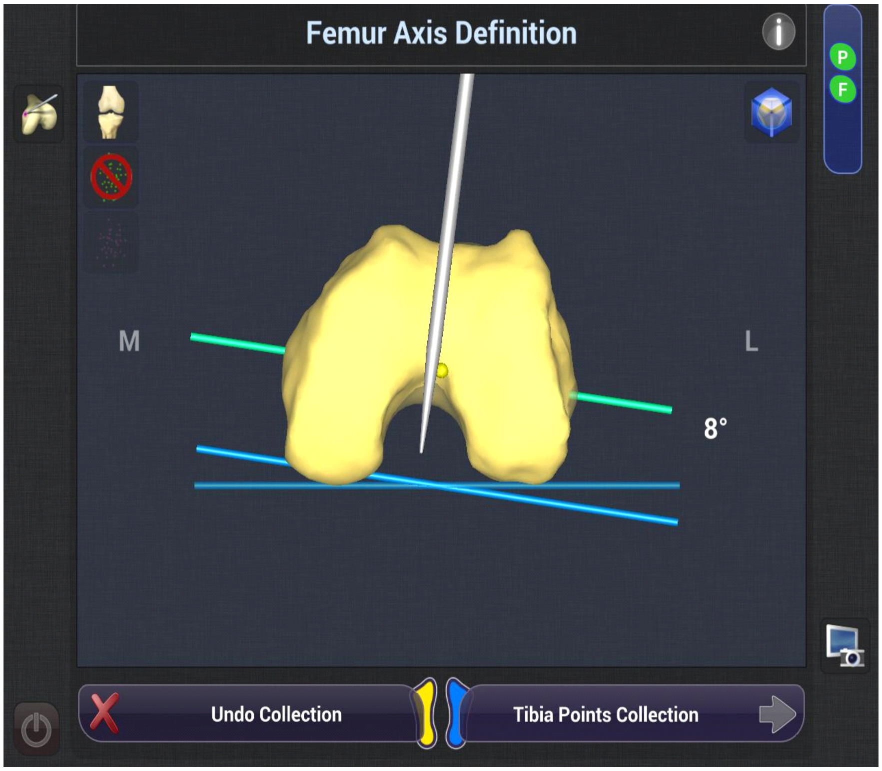

Figure 10: The pointer probe is positioned such that the green line is collinear with the anatomic trans-epicondylar axis (aTEA); this displays the amount of internal rotation of the posterior condylar axis (PCA) with respect to the aTEA ("M" and "L" represent the medial and lateral aspects of the femur respectively; the green line represents Whiteside's axis-P, the horizontal dark blue line represents the native PCA, the oblique light blue line represents PCA-R).

the past, has been questioned in recent times [10]. The technique presented herein is simple and finds application in multiple specific case scenarios, as outlined below, apart from having the potential for routine day-to-day use.

The application of this technique is primarily during the surgical steps associated with correcting mediolateral gap imbalances in flexion rather than extension, since alterations of the FCR affect the flexion gap. However, any residual extension-flexion gap mismatch following coronal plane balancing can be subsequently addressed in the planning stage through appropriate alterations of the distal femoral resection level, femoral component flexion, or posterior tibial slope. Moreover, the increased ease of obtaining flexion balance while remaining within acceptable boundaries of FCR could potentially obviate the need for posterior cruciate ligament recession or release in several patients.

Application of the technique: valgus knee deformity

Hypoplasia of the lateral femoral condyle in knees with valgus deformities is well documented in the literature [12]. It results in internal rotation of the femoral component when a fixed 3° of external rotation from the PCA is used to define the femoral rotational axis during TKA. Calibration of FCR through the use of appropriate boundaries would prevent implant mal-positioning among these knees.

Application of the technique: posterior medial femoral condyle hypertrophy

The increasing severity of knee varus deformities is associated with the incidence of posterior medial condyle hypertrophy of the femur, especially among knees with anterior cruciate ligament insufficiency [5]. Individualized titration of FCR on a case-by-case basis would prevent erroneous, internally rotated placement of the femoral component during TKA.

Application of the technique: various alignment strategies

Kinematic and restricted kinematic alignment aim to retain native femoral rotation, which varies from patient to patient [1]. Our technique results in 0° of rotation from the PCA as a starting point for performing alterations in component positioning, which would be the exact rotational alignment required in these strategies. Functional alignment uses alterations in femoral component positioning within pre-defined boundaries to attain improved gap balance [1]. The aforementioned strategies would permit the execution of functionally aligned RA-TKA.

Application of the technique: anatomic variations and outliers

The PCA is more internally rotated in relation to the sTEA among women than men [11]. The orientation of the PCA also varies across ethnic groups [13, 14]. The possibility of outliers with sub-optimal knee biomechanics also exists. Assessing the relationship between the various described rotational axes of the femur in each case rather than using empirical values and appropriately orienting component placement would prevent re-creation of inferior anatomy and could translate to superior clinical outcomes.

Conclusion

The technique presented by the authors is simple and finds application in specific case scenarios as well as routine use during

RA-TKA. The accuracy of image-free robotic systems in terms of alignment and component positioning is well established. However, execution of the manufacturer-recommended workflow using default settings presents a limitation in practical usage, leading to suboptimal utilization of the robot. While it could be possible to address this limitation in future software updates, the alternate strategy presented herein would help surgeons calibrate FCR using the PCA as a reference for improved gap balancing in the meanwhile.

Clinical Message

Though the sTEA is considered the most reliable reference for FCR during TKA, WSA, and the PCA continue to be used as surrogate references during conventional and image-free robot-assisted surgery. This manuscript describes a simple and useful technique with wide applicability for calibrating FCR using the posterior condylar axis as the reference during image-free RA-TKA.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Conflict of interest: Nil **Source of support:** None

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