MENTORS IN ORTHOPEDICS

THE KEY STEPS FOR OPTIMIZING TOTAL KNEE ARTHROPLASTY

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SUMMARY

Background: Total knee arthroplasty (TKA) is an established intervention for end-stage osteoarthritis; however, approximately 20% of patients report postoperative dissatisfaction. Improving clinical outcomes necessitates a multifaceted approach addressing patient selection, perioperative protocols, and surgical precision.

Objective: This review evaluates contemporary strategies to optimize TKA outcomes, focusing on patient risk stratification, multimodal perioperative management, and evolving philosophies in limb alignment and component positioning.

Key Points: Preoperative optimization involves rigorous risk stratification and the management of comorbidities such as diabetes and anemia. Patients with low-grade osteoarthritis (Kellgren-Lawrence Grade <3) are identified as having a higher risk for persistent pain. Perioperative enhancements include fast-track protocols, the administration of tranexamic acid to mitigate blood loss, and multimodal analgesia to facilitate early mobilization. Surgical technique remains centered on achieving stable joint spaces and accurate alignment. While mechanical alignment remains the conventional standard, alternative concepts such as kinematic and restricted kinematic alignment aim to restore native joint kinematics, though long-term comparative data are limited. Precise bone resection is critical, specifically regarding the tibial slope and the femoral valgus cut angle. Femoral rotation, managed via measured resection or gap balancing, significantly influences patellofemoral tracking and tibiofemoral stability. Furthermore, sequential soft tissue releases are required in cases of severe varus or valgus deformities to ensure symmetric flexion and extension gaps.

Conclusion: Achieving optimal TKA results requires a synthesis of careful patient selection, standardized surgical execution, and balanced soft tissue tension. Adherence to precise technical parameters and evidence-based perioperative care is essential for restoring stable, pain-free joint function.

KEYWORDS

Arthroplasty, Replacement, Knee; Osteoarthritis, Knee; Bone Alignment; Patient Selection; Postoperative Complications

Since more than thirty years Total Knee Arthroplasty (TKA) has proven its efficacy to treat end stage of osteoarthritis (OA) [1]. There has been a continuum in optimizing step by step the success of the procedure based on patient's indication, surgical technique, and quality of the material offered to the surgeon to restore patient knee function and relieve pain.

A better patient selection and preparation before the TKA will reduce the likehood of patient's related complications[2]. A standardized surgical technique with reliable instrumentation and adequate design will allow the surgery to be the most reproducible as possible and reduce the surgeon/implant related complications.

OPTIMIZING PATIENT JOURNEY

Selecting the indication and choosing the patient

Looking at the results of TKA over the last ten years there are still around 20% of patients who are not satisfied with their outcome[3]. The arthroplasty surgeon should resist when facing the so-called high demand patient with low grade of OA and high expectation. Patients undergoing TKA for less than Grade 3 or 4 OA should be informed that they may be at higher risk for persistent pain and dissatisfaction[4]. At the other end of the spectrum with an increased aging population and the growing number of TKA performed there is a need for consistent risk stratification based on the evaluation of comorbidities before the surgery in order to optimize patient preparation for the surgery[5]. Several actions might be necessary such weight loss program, muscular preparation or anemia/diabetes equilibrium.

Dealing with blood loss and thromboembolism prevention

In recent years, one of the major challenges of TKA has been to allow the fastest possible rehabilitation to reduce the average length of stay and facilitate the return to autonomy. Fast-track surgery is a concept aiming to give the patient the best available treatment today [6]. However, one of the main obstacles is blood loss, which is source of asthenia and transfusions. The introduction of intravenous (or oral) tranexamic acid (TXA) has reduced postoperative bleeding. As soon as the risk of transfusion is significantly reduced, without increasing Veinous Thrombo Embolism (VTE) complications, it is possible to integrate combined TXA and either one/two day(s) or no drain use in the context of fast-track knee arthroplasty.

Perioperative venous thromboembolism prophylaxis is part of the perioperative management for patients scheduled for TKA, and may vary according to country regulation or habits. Risk stratification is a key aspect for choosing the best program adapted to the patient with identification of well known risk factors such obesity, older age, congestive heart failure, pulmonary circulation disorders, renal failure, lymphoma, or cancer. The EU guidelines suggest to favor the use of aspirin for VTE prevention after total knee arthroplasty (considered as high risk orthopedic procedure) in patients without high VTE risk. For patients with high VTE risk the use of low molecular weight heparin is recommended [7].

Securing pain control

Immediate pain control following the surgery represents one of the greatest advances in the past ten years allowing rapid mobilization of the knee joint, lowering patient apprehension and allowing quick hospital discharge. Modern peri-operative pain management includes both multimodal and preventive analgesia. Multimodal analgesia, the combination of more than one class of analgesic drugs, improves analgesia and has an opioid-sparing effect. The ultimate multimodal pain treatment combines oral medication and local anesthetics reducing the need for parenteral drugs and preventing peripheral sensitization by neurogenic blockade [6].

The Modern Operative course

The type of anesthesia will typically include a non-narcotic, short-acting analgesic spinal, an adductor canal block and partial sciatic nerve block are also frequently used. This may limit the density and duration of the block but it rarely interferes with patient mobility and physical therapy postoperatively [6,8]. Spinal anesthesia combined with sedation is considered a safe alternative, allowing appropriate anesthesia as well as reducing the noise experienced by the patient without having to give a general anesthetic. In order to reduce the use of sedative medication with its incidence of side effects, the use of virtual reality (VR) has been developed to be used in anesthesia for patient's distraction by immersion (Figure 1). In a preliminary study exploring the interest of VR distraction during surgery in TKA under spinal anesthesia, we found reassuring results regarding patient anxiety, and encouraging ones regarding sedation requirement and adverse event with significant differences when using VR [9].

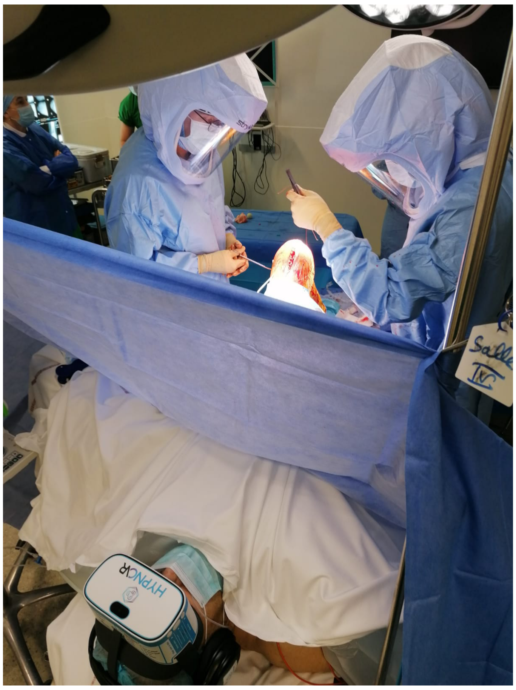


Figure 1: The use of virtual reality used in spinal anesthesia for patient's distraction by immersion during TKA

The Surgical Approach

The two most important structures to preserve when performing a TKA are the skin and the extensor mechanism, especially the patellar tendon. The midline skin incision, slightly translated to the lateral border to reduce the consequence of discomfort when kneeling remains the gold standard. In case of previous surgery it is recommended to use the most lateral one in order to preserve the subcutaneous blood supply, and if too lateral the rule of four fingers between two skin incisions represent a reproducible fashion to avoid skin necrosis. In case of previous hardware on the lateral proximal tibia (previous osteotomy or trauma) we are using a two stage protocol with previous hardware removal by the lateral incision followed a few months later by secondary TKA. Minimally invasive surgery (MIS) and gentle handling of the soft tissues should be promoted in order to minimize soft tissue trauma, reduce post-operative pain and favor short length of stay.

However long MIS procedures with hard pulling on the retractors may lead to readmission or increased pain [10], and we must probably target reproducible surgical technique and not ones that only a selected limited group can truly accomplish. The classical medial parapatellar approach remains the most commonly used. Its less invasive variants with mid- or sub-vastus approach has gained popularity over the last ten years but evidence is still lacking concerning the best surgical approach to the knee joint for patients undergoing primary total knee arthroplasty [11, 12].

OPTIMIZING LIMB ALIGNMENT

Classical mechanical alignment MA

For optimizing the functional and survival results of TKA proper leg alignment with a hip-knee-ankle (HKA) angle close to 0° and femur and tibial components being parallel in the frontal plane and perpendicular to the mechanical axis. This mechanical alignment (MA) concept is in opposition with the anatomical alignment where the components are implanted in 3° varus considering the joint line obliquity to be more normal maintaining the leg alignment to be neutral. Due to the difficulty in making an accurate inclined bone cut, the anatomical alignment concept has not been used by many surgeons. This systemic approach placing every knee in neutral alignment has been a tenet for the last 40 years in TKA surgery but it is currently under debate.

Alternative alignment concepts

Over the last years the kinematic alignment (KA) concept has gained many proponents. In KA the principle of restoring the natural joint surface is based on a patient individual positioning, where the component is set along the articular surfaces and no soft tissue releases are necessary [27]. However, there are different types of KA published and it might be confusing for many surgeons. One principal difference exists by deciding how the tibial cutting should be performed. In classical KA the femur is purely resurfaced with compensation for the cartilage wear, and the tibia cut is adapted to the soft tissue frame. In inverse KA the tibia cut made by pure resurfacing and the femur cut is adapted to the soft tissue frame [29]. In order to avoid excessive coronal varus/valgus malalignment with reported outliers, the so-called restricted alignment (rKA) has been presented as an improved concept for restoring native knee kinematics with a similar bone cut performed within a safe range (< 5° varus) or at a defined angle. With the broader use of computer assistance functional alignment allows the tibial cut along with the femoral cutting surface to be based on the intraoperative information regarding alignment and gap tension.

Personalized alignment debate

The aim of personalizing alignment is to restore native knee kinematics and improve functional outcomes after TKA30. However objective improvements in soft tissue balance using KA have not been shown to result in improvements in patient-reported outcomes measures [31,32]. There is no doubt that these types of alignment have gained in popularity, but further confusion about their exact meaning often leaves the surgeon starting his TKA practice with uncertainty. There is controversy in finding the native joint line and whether if this joint line should be considered as acceptable or should be restricted to avoid outliers in alignment. There is controversy in choosing the starting point of the technique either by replicating the original articular surface, either starting from the soft tissue balance, or with controlling the alignment in the restricted approach. Finally there is controversy in using manual intraoperative or computer assistance for obtaining adequate information during surgery to decide both bone cut angles, soft-tissue balance and component position. In regards to this uncertainty and these various controversies with “alternative” alignment concepts the proponents of a systematic approach in which the knee is mechanically aligned remain numerous, at least as a starting point, waiting for long term survival data comparing alignment and clinical results on one side and the technique enabling the surgeon to reduce outliers and allow reproducibility on the other side.

OPTIMIZING BONE CUTS

The tibial cut

Analysis of alignment leading to OA is crucial in total knee arthroplasty to restore frontal plane neutral mechanical axis. Therefore full-leg hip to ankle preoperative X-rays have always been part of our routine radiological analysis before performing TKA, beside standard AP/lateral, stress and patellofemoral views of the knee. In the OA varus knee it has been shown that the radiological major contributor to varus knee alignment is related to proximal tibia deformity. During performing TKA, the majority of the attention should be focused on the tibial cut to achieve correction of the deformity [13].

In the frontal plane using classical instrumentation a 90° angle regarding the anatomical/mechanical axis of the tibia is recommended for the tibia cut, however in so-called personalized alignment a cut more parallel to the natural tibia jointline inclination is promoted for providing better functional outcomes14. Joint line orientation plays a role in TKA, but it remains still controversial which tibia alignment will be the best in TKA. However a recent biomechanical study has shown that these adapted tibia cuts for constitutional varus knees in TKA with a 3° and 6° varus tibia cut had the greatest varus deviation to the native knee while, knees with a 0° tibia cut were most similar to the constitutional varus knee joint. The same study concluded also that mechanical alignment seems to result in more balanced load distribution and kinematics more closely resembling the native knee [15].

In the sagittal plane the target for the slope in TKA depends on the design of the prosthesis. The accuracy of the posterior tibial slope is often more difficult to achieve even using patient specific guides with a recommended target of 2°, a result which can land outside the target in nearly 30% of the cases with values ranging from 9° to -6° in this outlier group [16]. Furthermore, there is a wide variability of the slope in osteoarthritic knees and any change of this natural slope must be corrected with the femur posterior offset to balance the flexion gap.

The femoral cuts

The distal femoral cut, also called the valgus cut angle (VCA) of the distal femur, will decide the final alignment achieved in the coronal plane. Standard long leg X-rays are our choice to calculate the VCA since many individuals variations may occur according to patient morphology, especially the hip femoral offset, or ethnicity as shown in some countries [17,18]. Choosing a fixed VCA, set around 6°, may lead to a significant number of knees aligned outside the ideal 0- to 3-degree Hip Knee Ankle (HKA) angle. In constitutional varus knees with lateral distal femoral bowing slight variations of this rule might be beneficial for individuals in order to achieve a cut parallel to the proximal tibial cut. Identically in valgus knees with lateral femoral hypoplasia adaptation of the entry point of the intramedullary road and specific calculation of the mechanical lateral distal femoral angle (mLDFA) might be helpful to fall within the accepted HKA angle [19]. Surgeons using personalized alignment keep the distal femur cut parallel to femur anatomy (distal condylar line) to fit to the personalized cut at the tibia.

The Antero-Posterior (A/P) cuts will have influence on both sizing and rotation. Sizing the femur in the A/P plane can be done by anterior or posterior referencing and is an important step. Notching the anterior cortex with increased risk of supracondylar fracture or overstuffing the anterior compartment with limitations in range of motion may occur more often with posterior referencing. On the other hand, with anterior referencing a change in posterior offset can occur, which will have an influence on the flexion gap. For both techniques the femoral resection anterior cortex is a key landmark in the placement and sizing of the femoral component. Improper sizing, notching, undercutting, or overstuffing can occur based on selecting the highest or lowest cortex point [20]. We are using a "four hands technique" in which the operator secures the A/P femoral cutting guide on the distal femoral cut while the assistant is making sure the stylus is lying on the lateral anterior cortex (where the saw should exit), to optimize sizing and reduce notching (Figure 2).

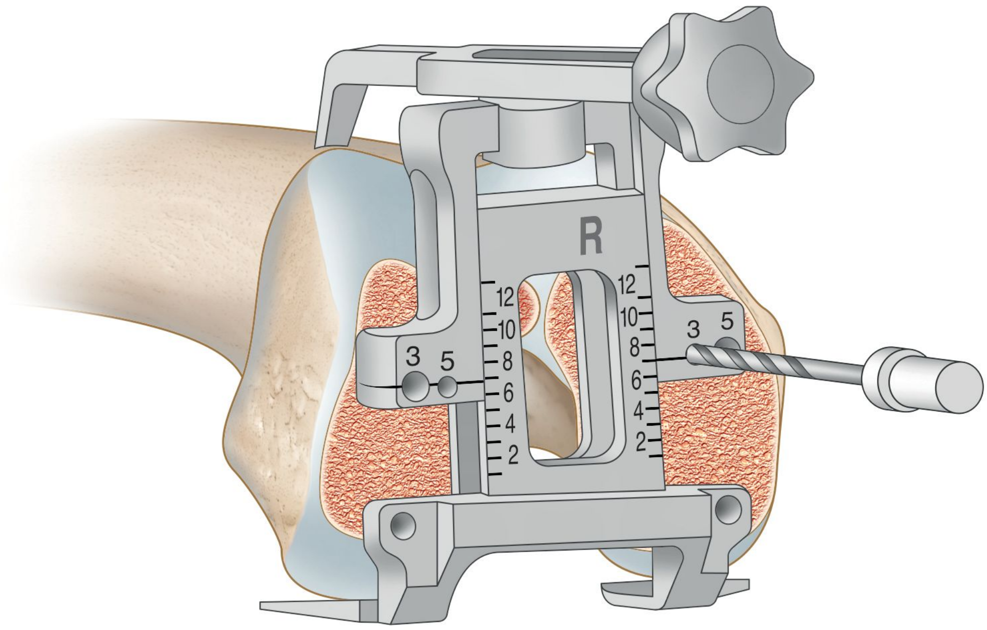
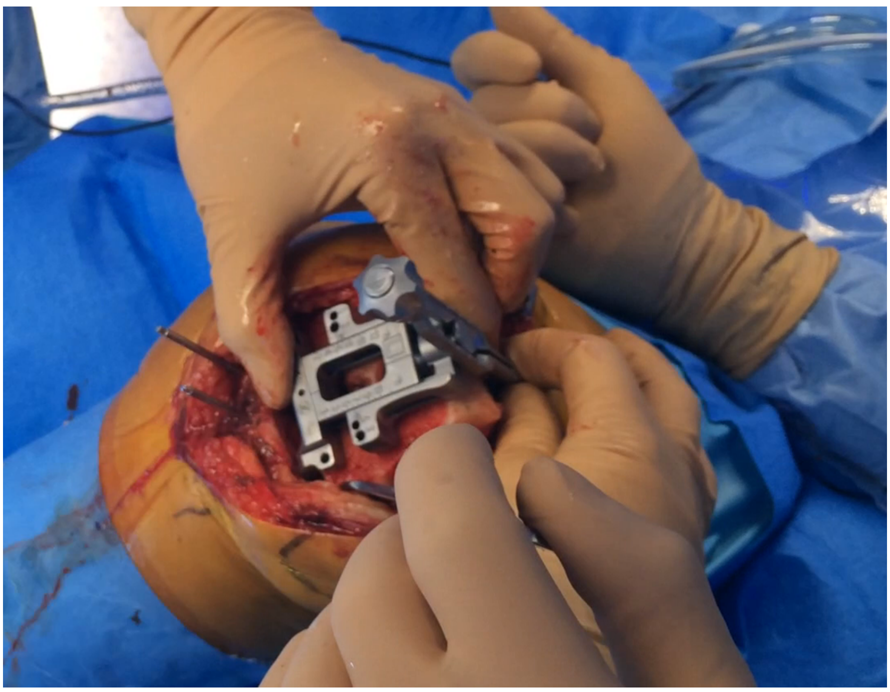


Figure 2: The A/P guide is positioned flush on the distal femoral cut (figure 2A) with the stylus positioned on the lateral anterior cortex of the femur using a "four hands technique" (figure 2B)



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The anterior femoral cut sets also femoral component rotation, which has effects on patellar tracking and gap balancing. There are basically two techniques for achieving a balanced flexion gap in TKA. In the balanced gap technique the surgeon will use tensioners or spreaders to establish equal tension to the medial and lateral ligaments at 90 degrees flexion. This allows to cut the posterior femur parallel to the tibial cut surfaces to gain a symmetric flexion gap. With this technique rotational alignment of the femur is performed by guidance of the soft tissues only. In the measured resection technique rotational femur alignment is guided by several landmarks only including posterior condylar line, the epicondylar line or the A/P (Whiteside) line. We are using on a routine basis the anteroposterior trochlea axis and then resecting bone to match implant thickness. In an vitro cadaveric study it was found that bone landmarks were more reliable to provide stability, patellar groove position, and load transfer compared to balanced gap technique which showed a shift into varus malalignment in flexion, a medial shift in flexion of the compressive stress, and a lateral shift of the patellar groove [21]. There is no consensus which of these two techniques is better and many surgeons are using the combined technique or extension gap first technique to combine bony landmarks and soft tissue frame for proper rotational alignment of the femur component. For personalized alignment the femur rotation is set parallel to the posterior femur line accepting an asymmetric flexion gap. However it is probably important for the orthopedic surgeon involved in TKA to have a good knowledge of the bone landmarks for setting femur rotation and then when getting experience to explore the possibilities of customizing ligament balancing through gap tensioners if suitable for his practice.

OPTIMIZING FLEXION/EXTENSION SPACE

A key step for achieving motion and stability in TKA is the ability to obtain equal spaces between flexion and extension as well as symmetry between the medial and the lateral compartments. Intraoperative checking of flexion/extension gaps and medial/lateral compartments can be achieved by using spacer blocks or the implant trials in which the experience of the surgeon plays a role, or using technological tools such navigation, sensors or robotics in which the quality of the information provided to the machine plays a role. Obtaining equality and symmetry of flexion and extension gaps involves balance of both bony and soft-tissue structures (Figure 3).

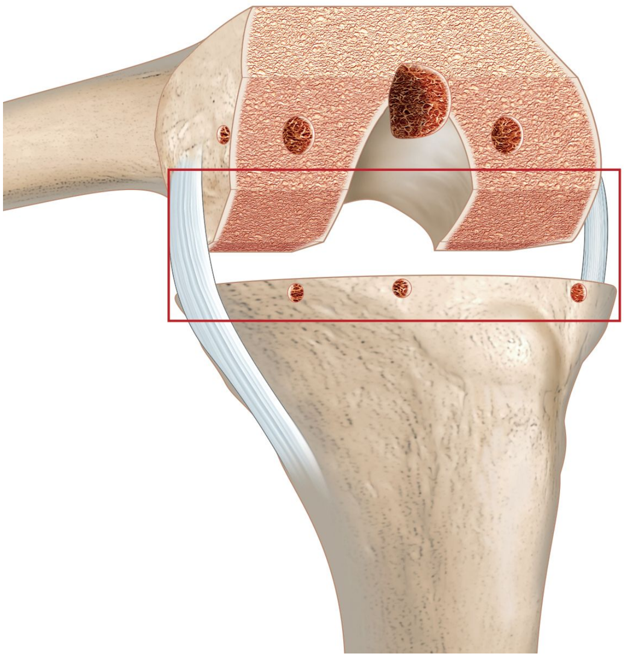

Figure 3: Obtaining equality and symmetry of flexion and extension gaps involves balance of both bony and soft-tissue structures

Femoral component rotation is an essential part of this process since non optimal position in rotation may lead to patellofemoral and tibiofemoral instability or reduced range of motion. Basically femoral component rotation can be set by using a measured resection technique or the balanced gap technique as described above [26]. Using a measured resection technique based on an average 3° external femoral rotation referring to the posterior condylar axis for all knees may underestimate individual variations between the posterior condylar and transepicondylar axis, and expose to more difficulty in case of posterior lateral femoral condyle hypoplasia in valgus knees or medial hyperplasia in varus knees.

On the other hand, the balancing gap technique will mainly rely on the precision of the proximal frontal tibia cut and the integrity of the collateral ligaments, exposing the knee to an internal rotation of the femoral component in case of varus tibial cut or superficial MCL deficiency with excessive medial flexion gap. The arthroplasty surgeon should keep in mind the potentials pitfalls of each technique and choose the one most reliable and reproducible in its own hands. Therefore, many surgeons use the combined or extension gap technique which allows to get rid of the disadvantages of both techniques. Using personalized alignment, the flexion and extension gaps will not be equal, like in the natural knee, but it is not clear how much lateral instability can be accepted in the flexion gap, which will also depend on the type of prosthesis used.

OPTIMIZING SOFT TISSUE TENSION

Optimal kinematics and subsequent function are achieved in TKA through achieving a symmetric balance in the medial and lateral compartment. Insufficient soft tissue release results in unsatisfactory deformity correction, whereas excessive release relatively increases the flexion-extension gap, which can eventually lead to instability of the knee. Performing classical mechanical alignment will require some kind of soft releases for most of the arthritic knees. During personalized TKA the bone cuts are adapted to the soft tissue frame, which allows to perform surgery without any releases, like in unikondylar knees. This concept will work in less deformed knees, but in severe varus or valgus deformities it will end up with severe residual varus or valgus malalignment and therefore many personalized knee surgeons accept restrictions in patient selection. Furthermore, in osteoarthritic knees with stretched out ligaments (varus or valgus thrust) personalized alignment has its further limitations.

The preoperative evaluation of the severe varus or valgus knee, including clinical examination and stress radiographs will have to establish two key factors for achieving a good result and choosing the appropriate method during surgery:

- Is the deformity correctible?
- Is there a lateral or medial laxity (thrust)?

The Varus knee

Varus osteoarthritis of the knee is the most common indication for TKA. Soft tissue release and bone resection in TKA are performed taking care to balance the flexion-extension gap as much as possible. Bone resection can precede sequential soft tissue releases or can be performed during the release procedures. The surgical approach itself opening the medial parapatellar joint and removing the medial osteophytes is able to correct most of the varus knees. This deformation is accompanied with contracture of the medial collateral ligament and other medial soft tissue structures. To obtain proper balance, release of the medial collateral ligament (MCL) is frequently required for correction of more severe varus [22].

Deep MCL (dMCL) release is often the first step described in sequential releases, this step can be followed by a release of the posterior oblique ligament (POL), the superficial MCL (sMCL), the pes anserinus or semimembranosus tendon (SMT) in severely deformed knees. Theoretically, release of the anterior portion of the sMCL or the pes anserinus tendon are performed to increase the flexion gap, whereas POL or SMT release, as posteromedial structures, affects only the extension gap. But there is no consensus concerning the more accurate sequence for the soft tissue release in the severely deformed varus knee. As a second step (after dMCL) some authors release the distal portion of the sMCL, whereas other release the POL or the SMT [23].

The Valgus knee

The lateral soft-tissue structures involved in the deformity have different influence on the flexion or extension gap. The Lateral Collateral Ligament (LCL) running from the lateral condyle to the fibular head provides stability both in flexion and extension, whereas the popliteus tendon works as rotational stabilizer in flexion mainly. The stability in extension is provided by the posterior capsule and the Ilio-Tibial Band (ITB) with its very proximal origin and its distal insertion at Gerdy's tubercle . The sequential release of the lateral structures usually starts by the ITB from Gerdy's tubercle or using the pie-crusting technique, followed by the release of the structures from the lateral condyle and finally of the popliteus tendon keeping in mind the risk of postero-lateral instability [24]. The lateral releases can be performed either using a conventional medial approach with an "inside-out" technique , which is our choice, or by using a lateral approach which allows an "outside-in" technique25. The main question in balancing valgus knees is the presence or not of medial laxity which raises the problem of further instability. Increasing the TKA constraint in case of severe valgus deformity involving medial laxity should be balanced with the risk of postoperative instability, especially in patients over 70's.

OPTIMIZING IMPLANT POSITION

The patellofemoral joint

There is a continuous controversy about resurfacing or not of the patella in TKA as illustrated by ten meta-analysis over the last ten years. A greater Knee Society score was found in only two of them in the resurfacing group with a lower risk of anterior knee pain in four of them and a lower risk of revision in six of them [33]. It is true to say that nowadays the rate of complications related to the patellofemoral joint has dramatically decreased since the nineties with greater attention paid to avoid femoral component malrotation, optimize tibial position in rotation, and prevent overstuffing of the patellofemoral joint. Indeed restoration of both patellar thickness and normal patellar height while avoiding patellar facet impingement can improve patellar tracking and minimize patellofemoral instability following TKA. Modern implants with patella friendly trochlear grooves may accommodate both resurfacing or not the patella with satisfactory functional results. The surgeon should consider conformity of the groove to match anatomy when selecting the implant combined to stability especially for optimizing lateral tracking in extension and flexion. The surgeon should also check patellofemoral tracking intraoperatively at the time of implant trials, and decide in some cases to perform a lateral retinacular release [34]. Some situations have been identified as higher risk of patellar complications such valgus deformity, obesity, history of patellar subluxation [35].

The tibiofemoral joint

The position of the tibial component in medio-lateral and rotation can be a source of compromise since an error in the rotational positioning of the tibial tray can lead to stiffness, patellofemoral pain or posterolateral conflict with the soft tissues in case of posterior overhang, or early loosening in case of insufficient cortical support (Figure 4).

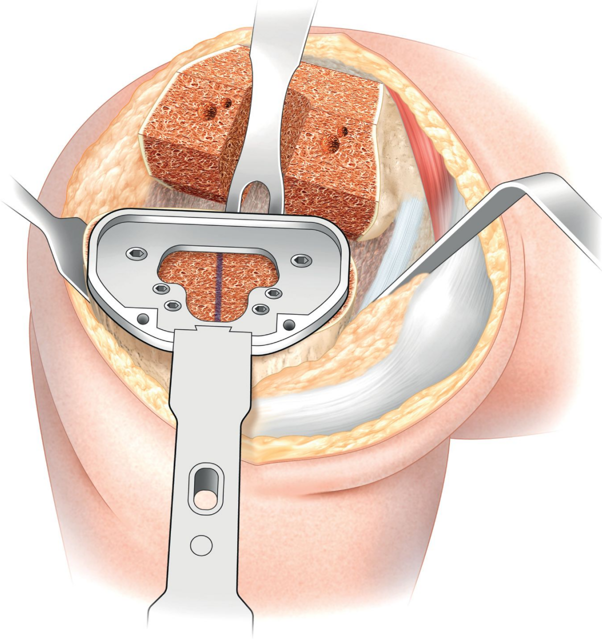

Figure 4: The position of the tibial component is a source of compromise since correct rotational positioning may be a source of overhang (figure 4A). This can be prevented by either choosing a smaller symmetric or an asymmetric tibia baseplate. For proper rotational alignment no compromise will be allowed (figure 4B).

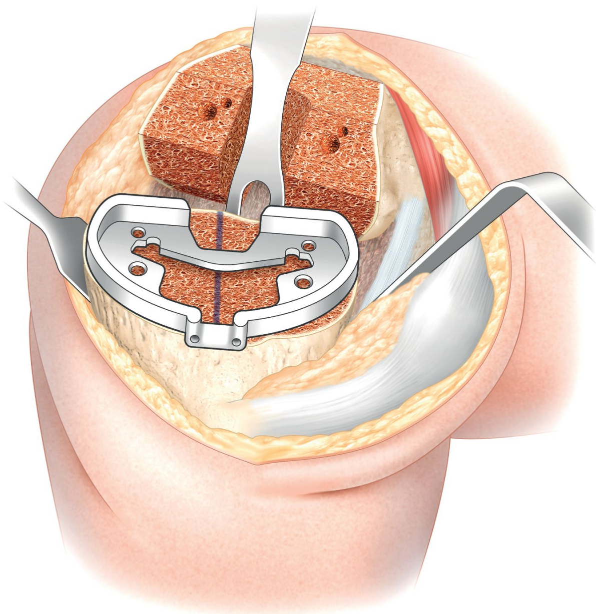

Figure 4: The position of the tibial component is a source of compromise since correct rotational positioning may be a source of overhang (figure 4A). This can be prevented by either choosing a smaller symmetric or an asymmetric tibia baseplate. For proper rotational alignment no compromise will be allowed (figure 4B).

To optimize rotational-coverage ratios and limit the potential conflicts with the soft-tissues, new designs of tibial implants have been designed to adapt both the morphology and the dimensions of the proximal tibial plateau and reduce intraoperative compromise [36]. The sagittal position, as currently qualified as tibial slope, may have impact on range of motion and stability since impacting ligament tension. According to implant systems, specific recommendations on the degree of posterior tibial slope for a cruciate-retaining or posterior-stabilized TKA are provided and deviations from this can have an impact on knee kinematics. With the achievement of technologyassisted TKA improved precision in component alignment is expected, even if referencing differences between systems may lead to a posterior tibial slope variation averaging 2° on the tibial component [37].

The position of the femoral component, as previously exposed, may have consequences for patellofemoral tracking in the rotation plane as well as for tibiofemoral (TF) stability by modification of the extension space with the proximal/distal position and the flexion space with the anterior/posterior position. Important variations in sagittal femoral component position may occur during the course of conventional instrumented TKA [38], and the attention paid to the entry point of the intramedullary rod should be reinforced as well as the sagittal position of the rod in regards to the femoral diaphysis. The sagittal position of the femoral component has an impact on the flexion gap space but may also have a role on tibiofemoral kinematics and the degree of femoral component flexion may not only modify TF kinematics, but impact also patellofemoral contact force during patient knee-bending activities.

CONCLUSION

Despite several key steps that can be highlighted in order to optimize Total Knee Arthroplasty, it is our challenge for the coming years to reduce this ratio of one fourth of our patients not fully satisfied with the result of the procedure, reinforcing the importance of not scheduling patients with mild radiographic arthritic changes and of better evaluating patient's expectations before planning the surgery [39, 40]. When careful patient selection is realized, perioperative management well conducted, bone cuts and soft tissue balance appropriately executed, stable joint spaces and reproducible alignment achieved by implant position TKA is able to positively change the life of our osteoarthritic patients providing them a pain-free, mobile and stable knee.

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