MENTORS IN ORTHOPEDICS

PATIENTS SPECIFIC CUTTING GUIDES ARE HELPFUL TOOLS FROM SIMPLE TO COMPLEX INTRA-ARTICULAR HIGH TIBIAL OSTEOTOMIES

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SUMMARY

Background: Medial opening-wedge high tibial osteotomy (OW-HTO) is a standard procedure for treating medial compartment knee overload by correcting varus malalignment. Achieving precise correction in three spatial planes remains a significant surgical challenge, as conventional two-dimensional planning and manual execution may lead to suboptimal clinical outcomes or hinge fractures.

Objective: This article describes the technical implementation, 3D planning principles, and clinical experience associated with the use of patient-specific cutting guides (PSCG) in both routine and complex OW-HTO.

Key Points: The PSCG workflow utilizes CT-based 3D virtual planning to determine the optimal cutting plane angulation, hinge position, and wedge orientation. Technical execution involves a modified medial approach to facilitate guide seating and the use of protective K-wires to prevent lateral hinge fractures. In a cohort of over 300 cases, the system demonstrated high precision, with coronal and sagittal corrections within 1° of the preoperative plan. Furthermore, the technology allows for single-stage management of complex cases, including combined ligament reconstructions and intra-articular L-inverted osteotomies for post-traumatic or congenital deformities. Operative efficiency improved after a 10-case learning curve, resulting in reduced surgical time and decreased intraoperative fluoroscopy requirements.

Conclusion: The integration of 3D planning and PSCG technology enhances the accuracy of frontal and sagittal plane corrections in OW-HTO. While associated with modest additional costs, the technique offers a reproducible method for managing complex lower-limb deformities and may improve the long-term survivorship of the correction.

KEYWORDS

Osteotomy, Tibia; Surgery, Computer-Assisted; Imaging, Three-Dimensional; Genu Varum; Bone Plates

INTRODUCTION

The aim of medial opening-wedge and lateral closing tibial osteotomies is to correct varus alignment in the lower limb to treat overload in the medial compartment of the knee joint [1,2]. In the last decade, medial opening-wedge high tibial osteotomy (OW-HTO) has gained increasing popularity, as more and more studies continue to report good post-operative outcomes with fewer complications [2]. Accurate correction in all three spatial planes is a pivotal factor to obtain good clinical outcomes [3]. To achieve the ideal planned correction, various planning methods, surgical techniques using different instrumentations have been developed. This includes conventional methods (with various intraoperative techniques to assess lower-limb alignment), computer-assisted surgery [4,5] and recently the use of patient-specific cutting guides (PSCG) [6–8]. We started using PSCG in 2015 [9] and recently published 2 years results of our 100 first patients [10], as well as our learning curve using this philosophy in regular OW-HTO [11].

Our experience drove us to a better understanding of Maths and Biomechanical basis of osteotomies thanks to the extensive 3D planning and virtual osteotomy prior to the surgery. Thus, we challenged ourselves to perform more and more complex surgeries using these new tools with 3D virtual planning and PSCG to perform proper bone cuts and fixation of the plates. The aim of this paper is to describe our experience and share some practical tips and tricks for these new technologies for OW-HTO.

BASICS CORRECTION OSTEOTOMIES

Indication

In the vast majority of cases knee osteotomy aims to correct an extra-articular deformity by shifting the mechanical axis from the overloaded femoro-tibial compartment to the contralateral side to unload cartilage and subchondral bone [12]. By correcting a pre-existing tibial or femoral metaphyseal abnormality the natural evolution of knee arthritis might be slowed down. The Hip-Knee-Ankle (HKA) angle is usually used to estimate the overall alignment of the lower limb. This angle represents the result of three components: the bony alignment of the femur and tibia as well as the intra-articular deformity resulting from articular surface wear at the concave and soft-tissue laxity on the convex side of the deformity. To allow proper planning of the bony correction the deformity analysis, introduced by D. Paley long time ago, is mandatory[13]. This includes the Lateral Distal Femoral Angle (LDFA), the Medial Proximal Tibia Angle (MPTA) as well as the Joint Line Convergence Angle (JLCA). The LDFA is defined by the angle between the femoral mechanical axis and the articular surface of the distal femur. The MPTA is defined by the angle between the tibial mechanical axis and the articular surface of the proximal tibia. The JLCA best reflects cartilage wear, meniscus loss and soft-tissue laxity of the contralateral side. (Figure 1 A-B-C)

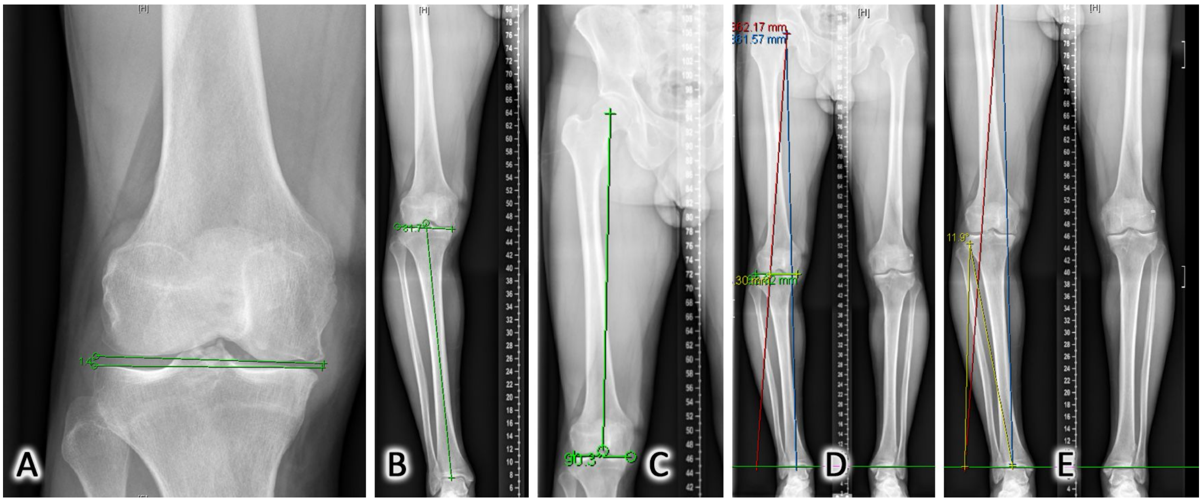


Figure 1 : Measurement of anglesA and B: Joint Line Congruency Angle (JLCA 3.3 mm) and Medial Proximal Tibia Angle (MPTA 82°) C: Lateral Distal Femoral Angle (LDFA 90°)D and E: Calculation of correction using the Miniaci Method: First draw the lower limb weight bearing blue line (line passing from the center of the hip to the center of the ankle. Second draw correction red line (connecting the hip center, passing through the selected "Fujisawa" point and down to the ankle level)Third draw a crossing green line (parallel to the ground passing through the center of the ankle)Forth draw the two-connection yellow lines (First line connecting the future lateral tibial hinge point and the center of the ankle joint. Second line connecting the tibial hinge with the intersection of the correction red line with the green crossing line)The angle formed between those two yellow lines represents the predicted correction angle (angle ɑ).

Conventional planning

When dealing with a misaligned lower limb, the first step is to analyze if the deformity is located at the Tibia, Femur or both, which will influence where the osteotomy has to be performed. Not all varus knees have the deformity on the tibia only. 10-15% will need a femur or a combined femur and tibia osteotomy for correction, otherwise the jointline will be significantly malorientated. The next step is to decide for the proper postoperative frontal alignment and therefore to plan the desired correction. The planning must be performed on standardized full leg weight bearing X-rays [14]. Traditionally the new weight-bearing line should be within the "Fujisawa" point, which is 62% and 65% of the tibial plateau (with the medial side set at 0% and the outermost lateral aspect at 100%) [15]. Based on this point it is then possible to calculate the amount of correction needed in the frontal plane. One of the most common used technique for this correction angle ɑ calculation is the Miniaci method [16] (Fig 1 D-E). Any existing soft tissue laxity on the concave side of the deformity (JLCA > 2 mm) has to be included in this bony correction angle calculation, otherwise the leg might be overcorrected.

3D PLANNING

The described conventional planning is focusing on the frontal plane only. PSCG includes the option of a much more sophisticated 3D planning procedure (Figure 1F).

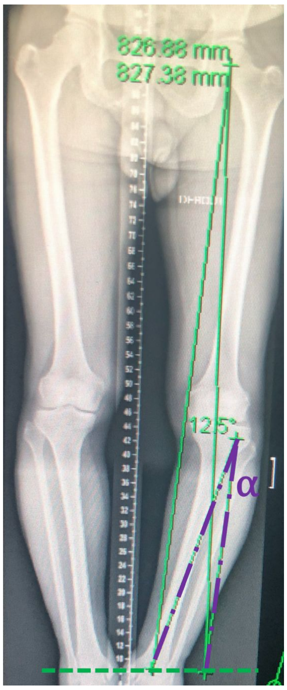


Figure 1F : Example of a predicted correction angle (angle ɑ). following the Miniaci Methhod

This allows in more complex cases, osteotomies to be used for correction of ligament insufficiencies, treat intra-articular deformities or correct lower-limb torsional malalignments. In those cases, additional measurements are needed (Figure 2A-B).

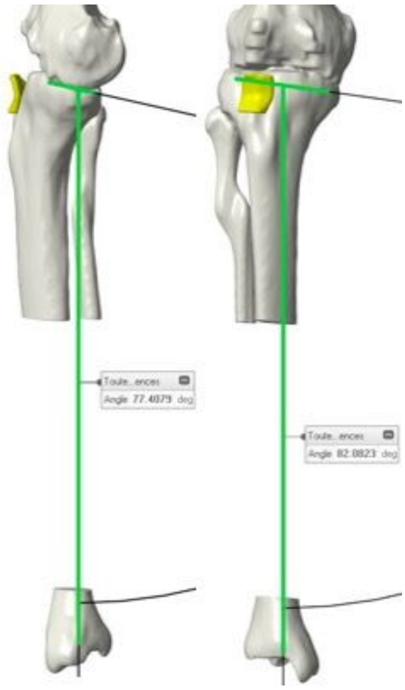


Figure 2 A-B : Example of a 3D planning of complex osteotomy which needs a correction of a pathological slope with 13°

For example, sagittal evaluation of the proximal tibia is mandatory to plan a slope modifying osteotomy in case of chronic cruciate ligaments insufficiencies or correction of sagittal bony deformity with a pathological slope. For ACL insufficiencies we reduce and for PCL insufficiencies we increase the natural slope. The aim of pathological slope correction is to end up with a normal value close to 7° [17]. Regarding varus deformities we usually aim for a correction of the Mikulicz line reaching a Fujizawa point between 55 to 65% based on cartilage and meniscus status. The CT scan included in the PSCG technique will also help surgeons to define quality and position of previous bone tunnels. For combined ACL reconstructions with OW-HTO the tunnel placement in reference to the screws can be planned also.

VIRTUAL OSTEOTOMY

This is one of the main advantages of the PSCG technique which allows a more sophisticated 3D planning.

Osteotomy correction depend on three connected parameters:

- Cutting plane angulation: This represents the angulation of the cutting plane with frontal and sagittal tibial mechanical axes (Figure 3). Every displacement of the sawing plane angulation away from a perfect perpendicular angle with the tibial mechanical axis and perfect parallel to the tibial plateau plane will influence frontal and sagittal correction.

- Hinge positions: A more posterior hinge will decrease the tibial slope and a more anterior one will increase the tibial slope as compared to more central positions (Figure 4)

- Wedge positions: A more posterior wedge will decrease the tibial slope and a more anterior wedge will increase the tibial slope as compared to more central positions.

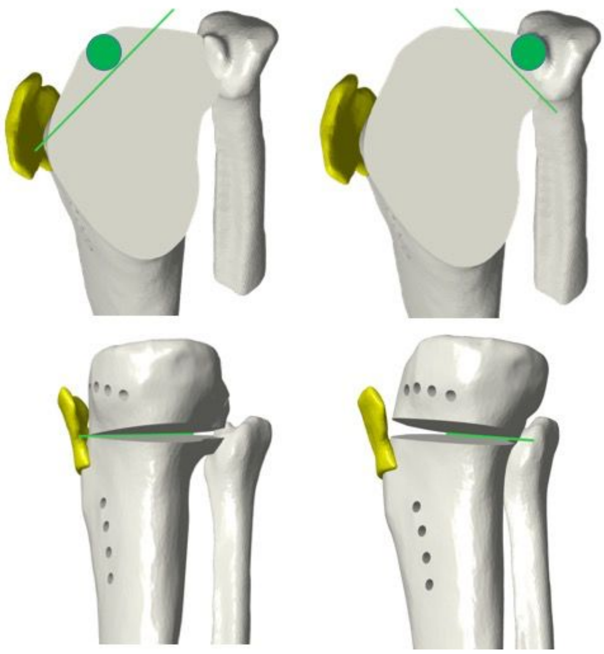


Figure 3: 3D planning of the cutting plane Every displacement of the sawing plane angulation away from a perfect perpendicular angle with the tibial mechanical axis and perfect parallel plane with the tibial plateau influence sagittal and frontal correction.

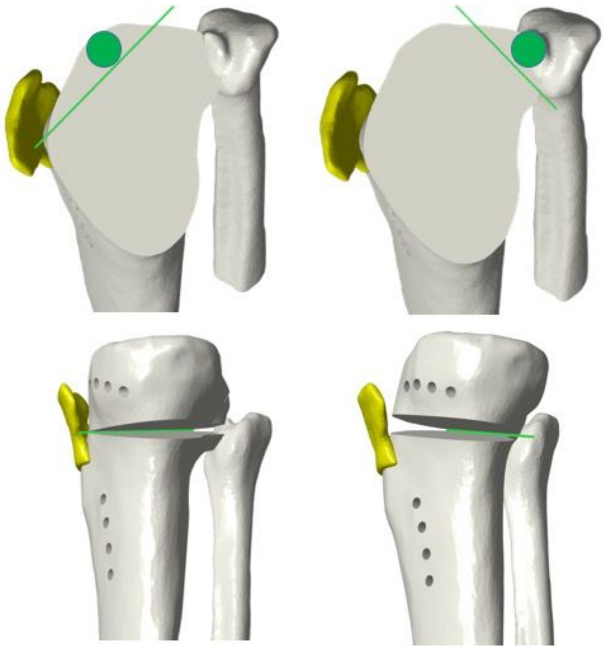


Figure 4: 3D Planning of the lateral hinge position The example shows the impact of the hinge position on the the tibial slope. A more posterior hinge increases the tibial slope and a more anterior one decreases the tibial slope as compared to more central positions

Those three elements are used in the 3D preoperative planning to obtain the desired correction (Figure 5) and to modify intentionally MPTA and slope when needed.

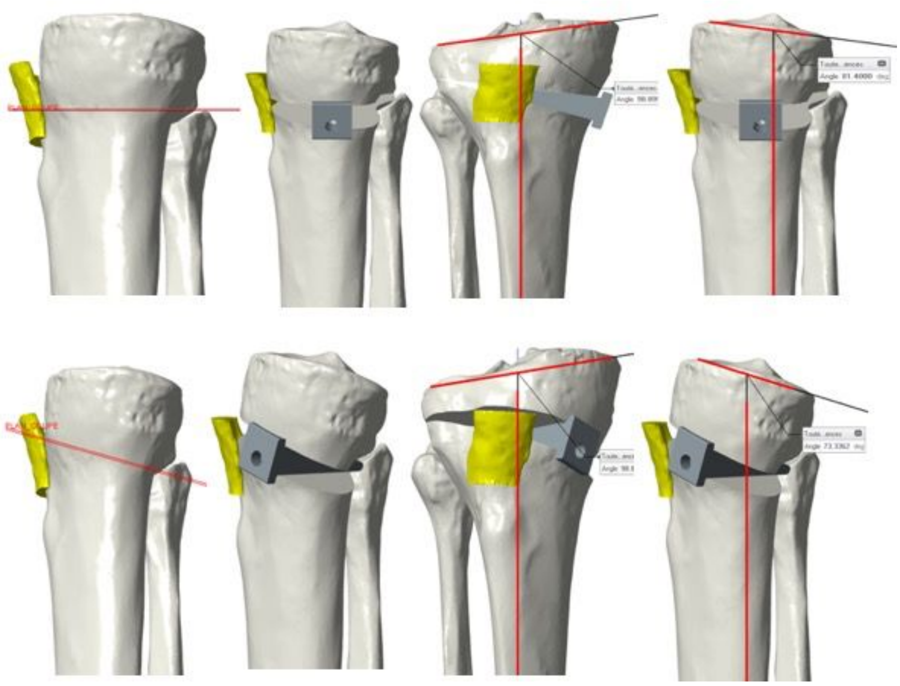


Figure 5: Influence of hinge position and cutting plane on MPTA and slopeThe two 3D planning examples (upper and lower line) with a modification of the hinge position and the cutting plane angulation show their influences on the MPTA and slope.

TECHNICAL CONCEPT PSCG

The global idea behind the PSCG is based on three crucial points:

- Positing two k-wires to verify PSCG position and secure Tibia's hinge from sawing (Figure 6)

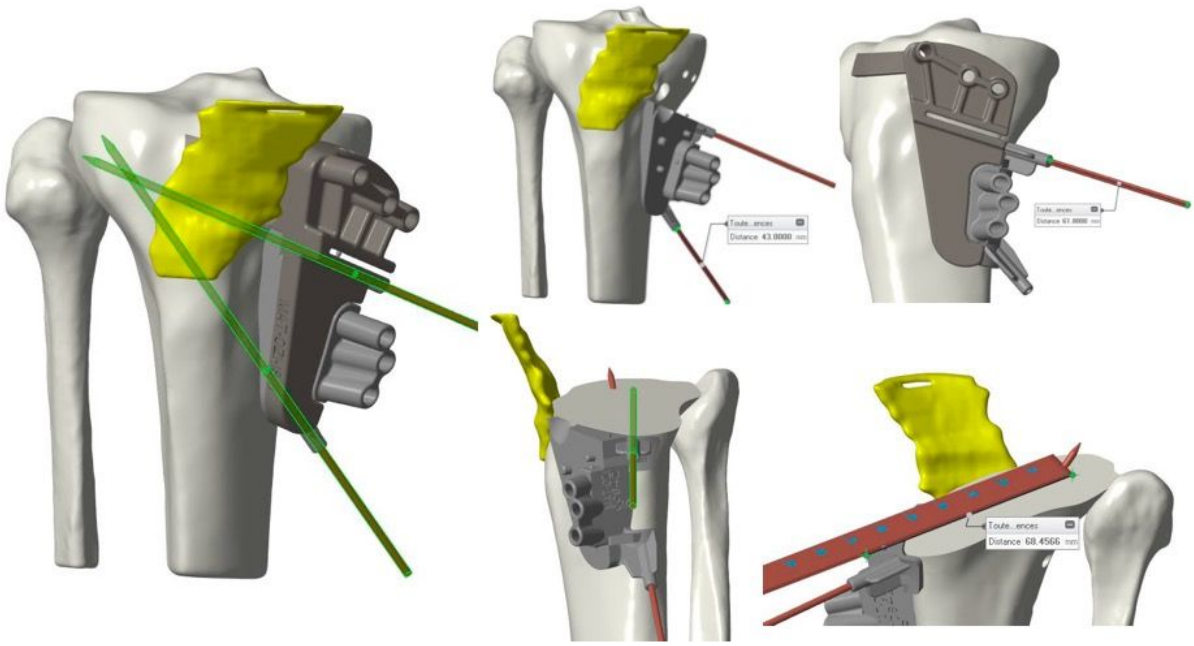


Figure 6: Temporary PSCG fixation - Example shows the 3D fixation with the two k-wires

- Saw blade guidance to allow very accurate angulation relatively to tibial morphological parameters (Figure 7)

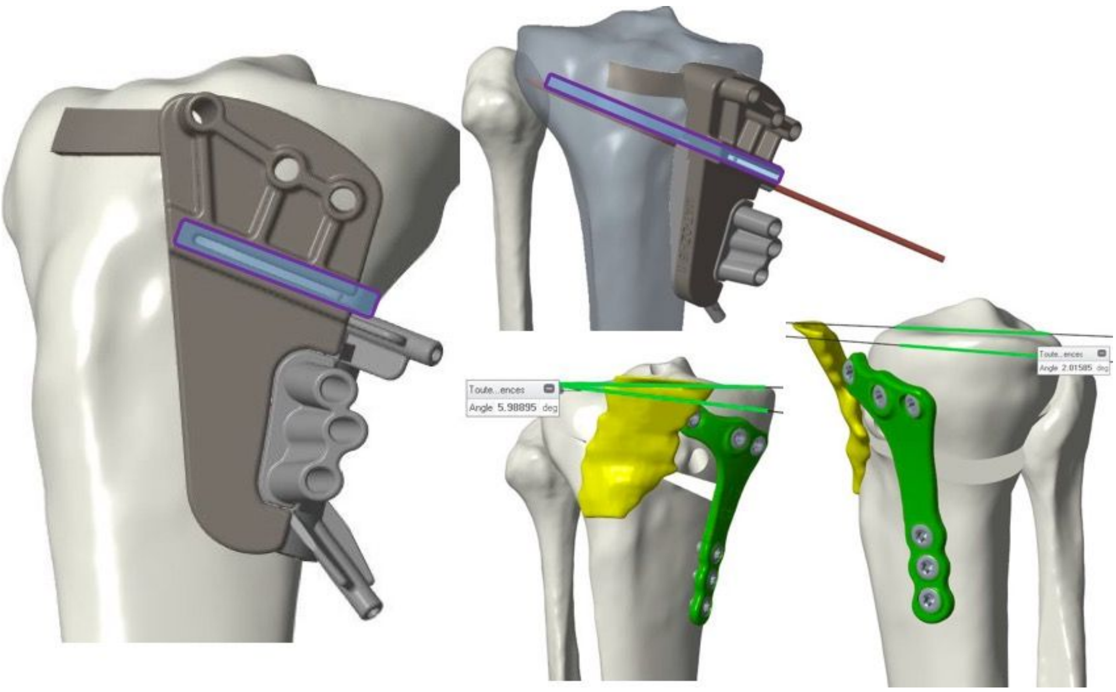


Figure 7: Saw blade guidance and final plate fittingExample shows the 3D representation of the saw blade guidance and fitting of the final blade

- Map of 6 to 8 screw holes to allow guided drilling for screw holes which will match to the screw position of the final plate after the correction (Figure 8)

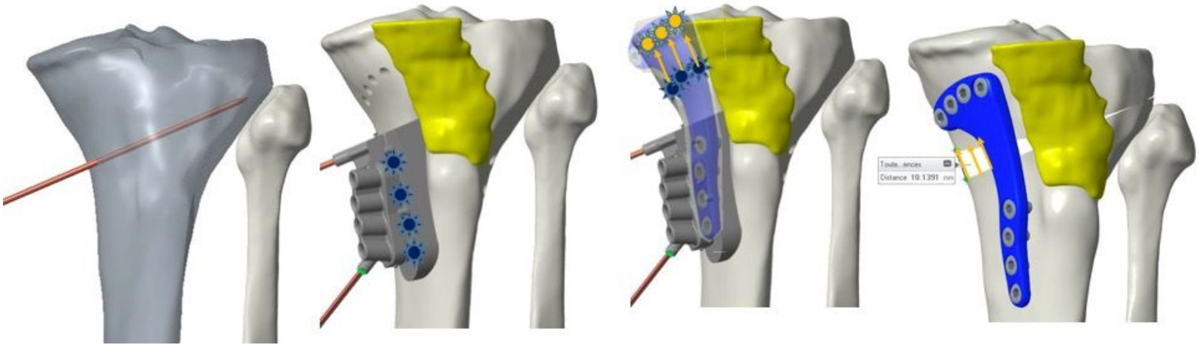


Figure 8: Fitting of pre-drilled holes to the final plateExample shows 3D fitting of the pre-drilled holes to the final holes and plate after the correction allowing stable fixation by screws

The PSCG concepts allows

- Deep surface mirroring of the tibial bone to easily find its adequate position

- Anterior and posterior legs to be placed below the patellar tendon and anterior to the released posterior oblique ligament.

- Two or more K-wires holes to fix temporary the guide on the tibia, verify its position using fluoroscopy and avoid saw blade to change direction or to cut the hinge unintentionally.

- A saw blade slot to insert the saw and perform mono or biplanar cuts.

- Secure the system onto the tibial bone for sawing using the 6 to 8 holes which are prepared for the future final screws position

- Option for additional slots such as Ligament or Meniscus Tunnel driller, articular cutting bloc, etc....

This PSCG is not protecting soft-tissues or posterior neuro-vascular structures during sawing by itself. Therefore, a modification of the traditional antero-medial or anterolateral approach is mandatory to achieve an optimal positioning and a safe procedure.

SURGICAL TIPS AND TRICKS

Approach, MCL, Pes anserinus and posterior Neurovascular structure management.

Medial Collateral Ligament (MCL) release and posterior neurovascular structures (NVS) protection during OW-HTO remain two stressful steps.

Approach:

A medial skin incision is performed starting 1cm below the femoro-tibial joint line and extending 8-10 cm toward the distal tibia, slightly more posterior than usual to get access the postero-medial corner. (Figure 9) A Blunt dissection allows to palpate and mark the Patellar tendon to prepare some space for PSCG anterior leg positioning.

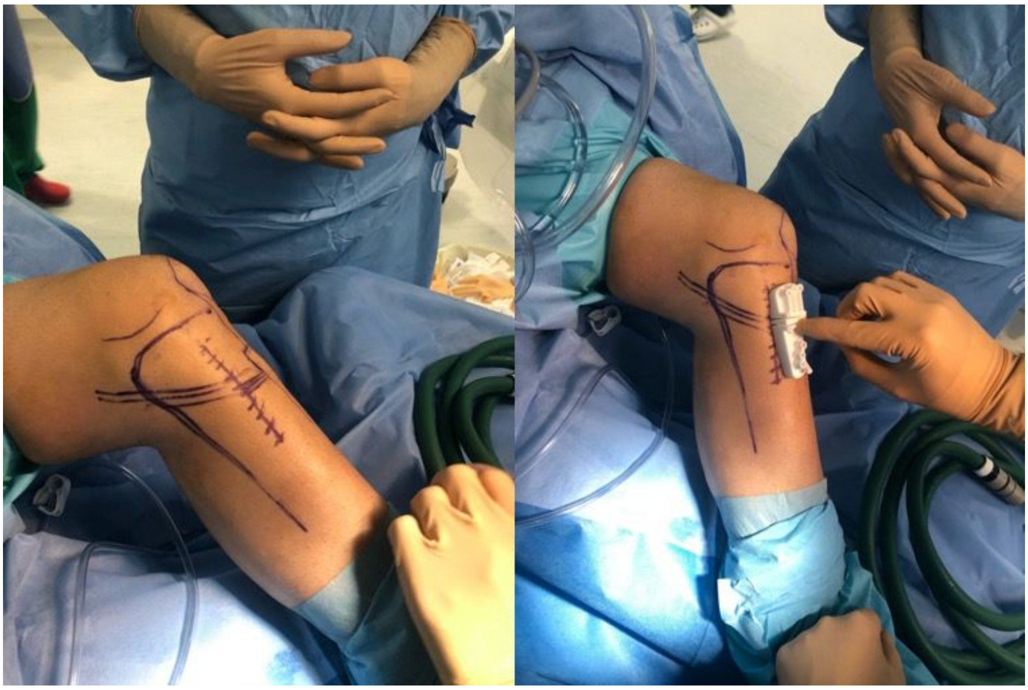


Figure 9: Skin incision for medial approach Starting 1cm below the femoro-tibial joint line and extending 8-10 cm toward the distal tibia

The pes anserinus is dissected and retracted posteriorly. Starting at the posterior aspect of the MCL a periosteal elevator is used to dissect the soft tissue until the posterior cortex of the tibia is reached and the popliteus muscle can be carefully released. This elevator is left in place to guide the posterior-tissue retractor (PTR) between the posterior cortex and the popliteus muscle (this step can be done in flexion to facilitate insertion). (Figure 10) The posterior Oblique Ligament (POL) is released carefully using a periosteal elevator. The two posterior legs of the PSCG will need a sufficient amount of POL release to allow posterior retractor to be inserted easily.

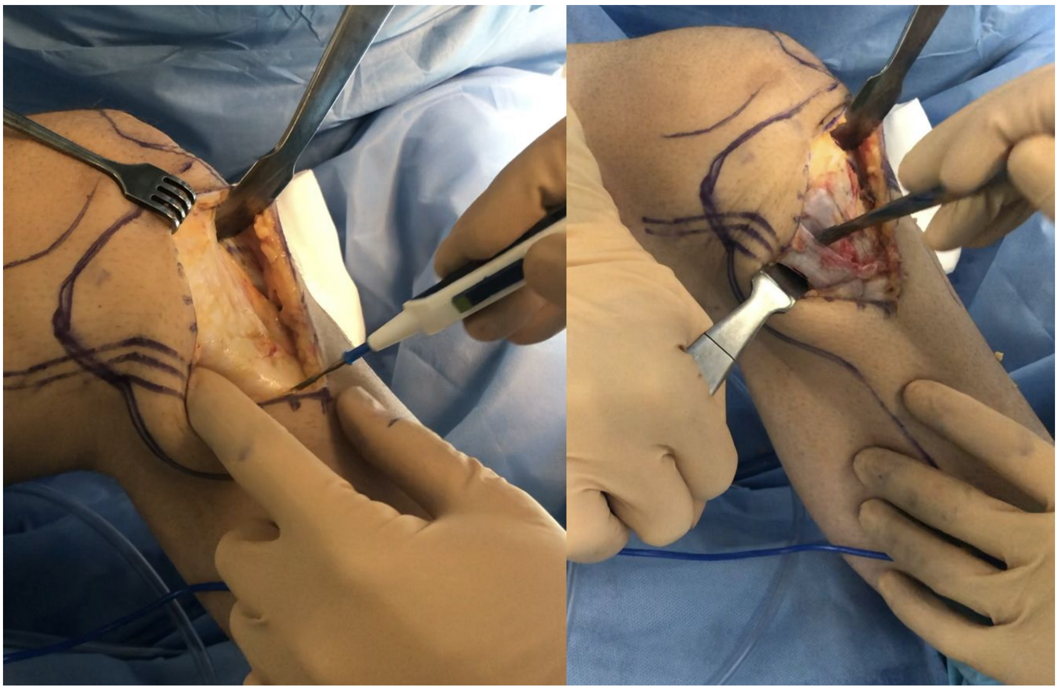


Figure 10: Medial approach for the osteotomy: The pes anserinus is dissected and retracted posteriorly. Starting at the posterior aspect of the MCL a periosteal elevator is used to dissect the soft tissue until the posterior cortex of the tibia is reached and the popliteus muscle carefully released. This elevator is left in place to guide the posterior-tissue retractor (PTR) between the posterior cortex and the popliteus muscle (this step can be done in flexion to facilitate insertion)

Positioning PSCG and Osteotomy:

Once the PSCG is inserted two K-wire are drilled in the dedicated holes, for temporary fixation. This should be carefully controlled by fluoroscopy (Figure 11) to confirm the optimal position of the Guide. Then the screw holes are drilled, and the guide is rigidly fixed on the tibia using six 4 mm Pins. During the sawing process a small Hohmann retractor is used to retract the MCL, to get good access to the cutting plane.

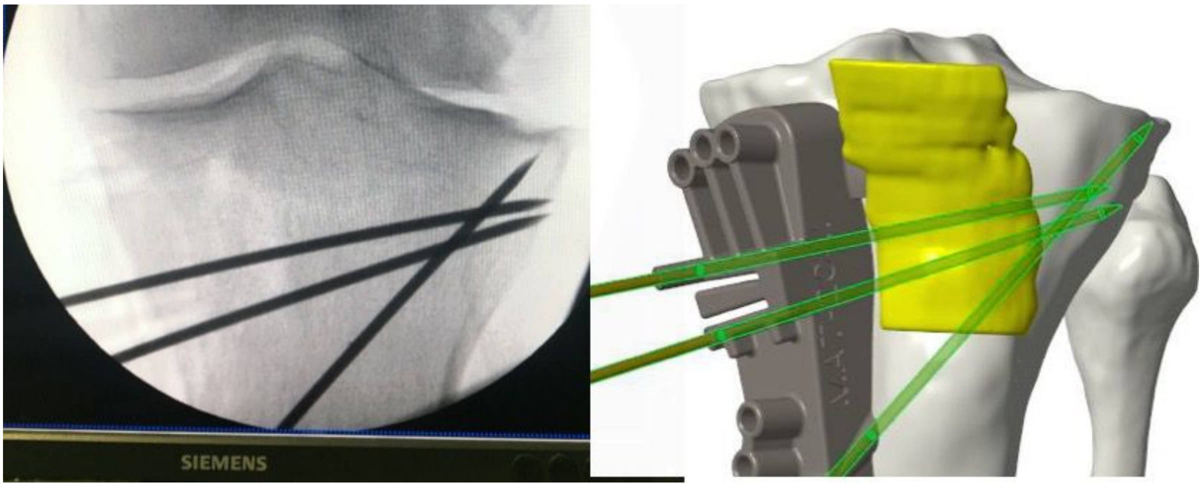


Figure 11: Fluoroscopic control of the optimal position of the PSCGNote the perfect correspondence of the fluoro to the planning picture

Once the Saw-cut has been done, the PSCG is removed leaving only the hinge K-wire inside the tibia. A metal ruler or chisel is used to confirm that all the posterior cortex has been completely cut, by felling a metal contact on the posterior retractor in place.

Opening Wedge and Fixation

The opening is performed by placing the spreader posterior to the MCL. Depending of the amount of opening the MCL will be tensioned and need some release. The additional tension of the MCL can be sensed easily with the fingertip. We manage the necessary release of the MCL using the pie-crusting technique. For limited amount of corrections, a small release of the posterior fibers allows sufficient lengthening and maintain integrity of the MCL to cover the osteotomy plate. The correction is performed sufficiently when the previously drilled holes in the tibia bone are fitting to the selected holes in the plate. The plate is then finally fixed to the tibia bone by using all drilled screw holes to sufficiently hold the planned correction. (Figure 12)

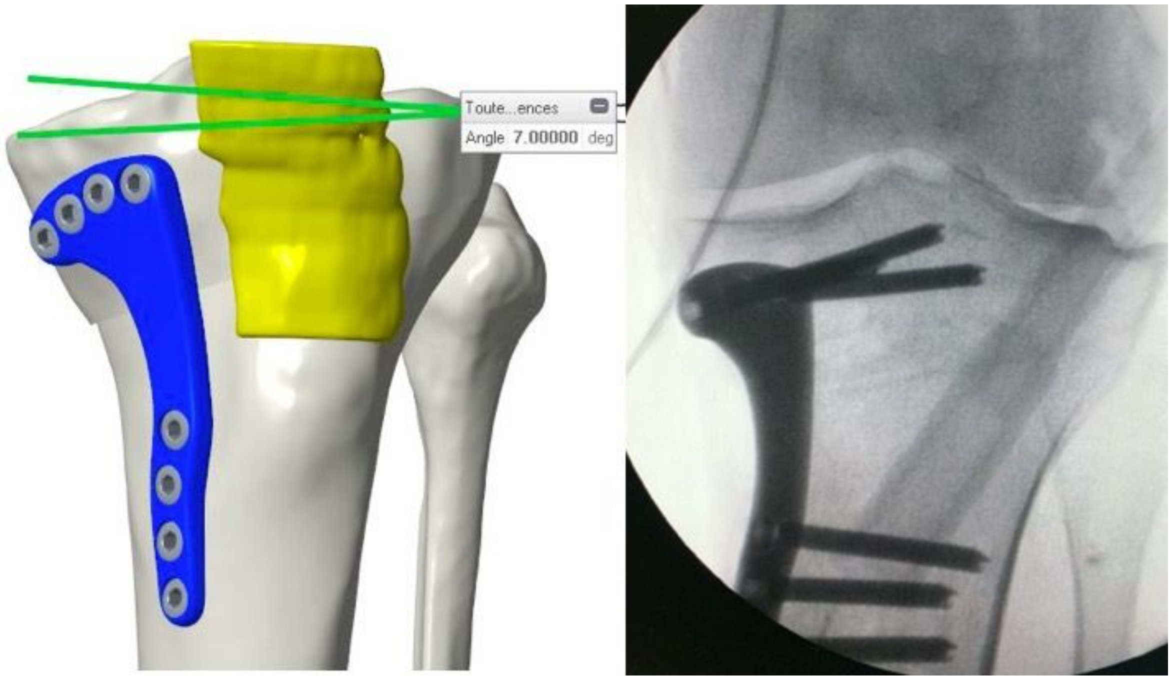


Figure 12: Fluoroscopic control of the final fixation

COMPLEX CASES

As PSCG are also "Surgeon Specific" and very versatile, progressive modifications have been done during the last years. This allows us to perform a more minimally invasive, Hinge Protective [18,19] and combined single stage surgery (ACL – PCL – Cartilage – Meniscus repair/reconstruction) in cases often requiring two or more staged procedures in the past.

For Example, combined ACL + OW-HTO are easily done using a dedicated tunnel driller implemented during 3D Planning. This modification of the PSCG ensure the surgeon not to hit the osteotomy screws when drilling the ACL or PCL tunnel. (Figure 13) Intra-articular osteotomies are recommended to correct either intra-articular deformities (such as post-traumatic malalignment) or severe metaphyseal varus (such as Blount Disease for example).

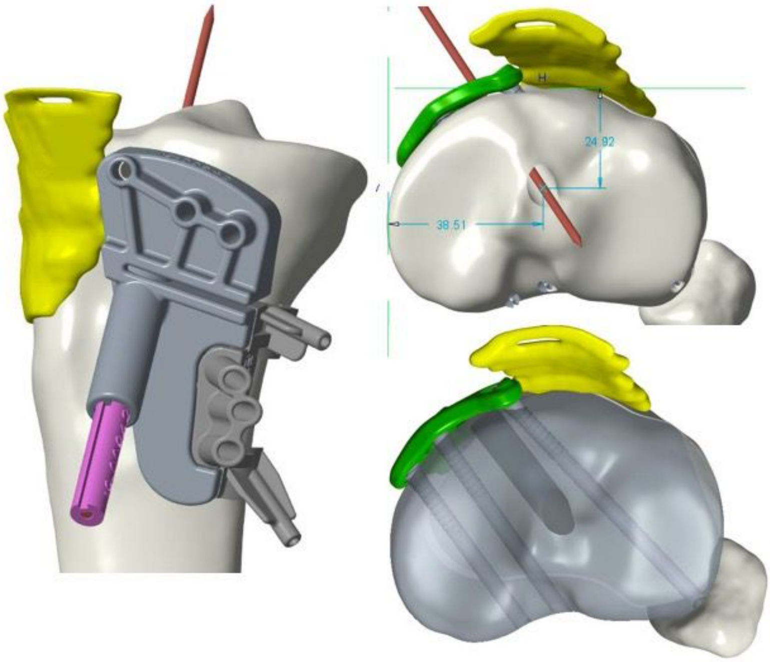


Figure 13: Combined ACL & OW-HTOExample shows the 3D planning of the tunnel placement for the combined ligament reconstruction using the cutting guide to perform the tibial tunnel

Chiba et al [20] described their L-inverted shape osteotomy to correct metaphyseal varus using an elevation of the medial or lateral tibial plateau alone in combination with a rotational correction to allow the upper tibial plateau to be perpendicular to the diaphysis (figure 14).

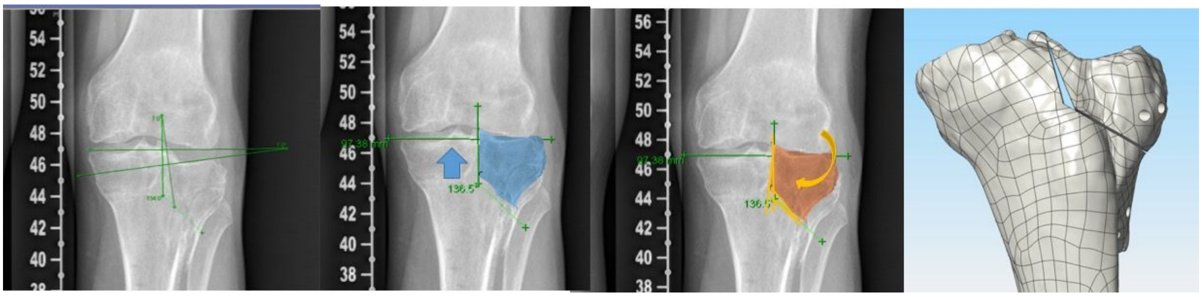


Figure 14: Lateral Hemi-ostotomy planningExample shows L-inverted shape osteotomy to correct metaphysal post-traumatic varus using an elevation of the lateral tibial hemi-plateau alone in combination with a rotational correction allowing the upper tibial plateau to be perpendicular to the diaphysis.

This represents a very complex surgery and requires two cuts: one horizontal and one vertical (inside of the joint) to completely separate the hemi-plateau from the tibia (Figure 15).

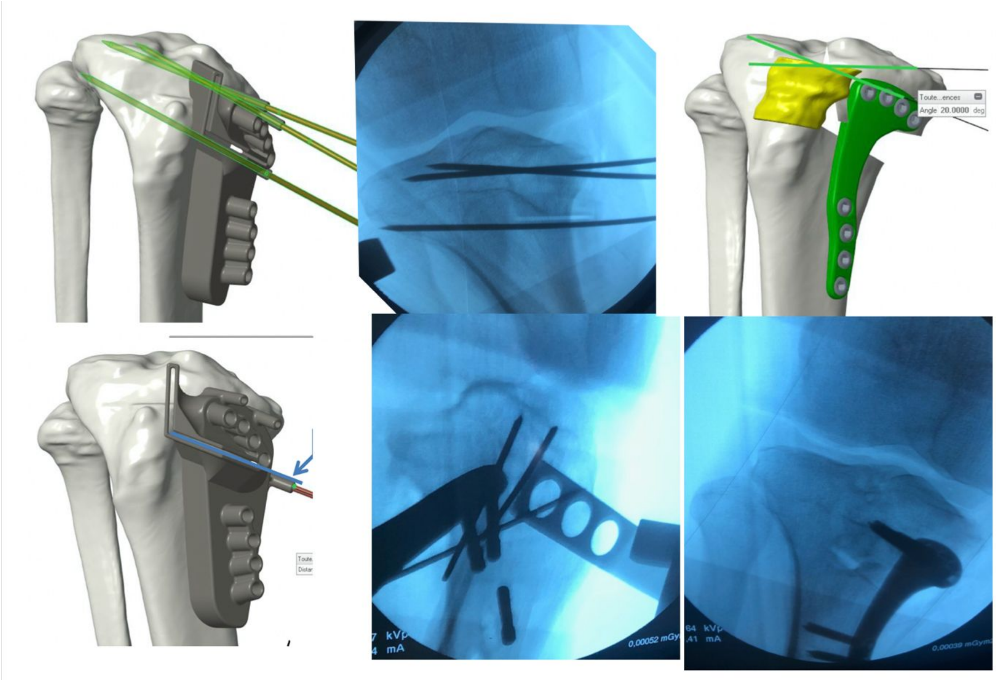


Figure 15: Planning & fluoro views of case from fig 14Example shows the L-inverted shape osteotomy using the cutting guide. The correction implies creation of two cuts : one horizontal and one vertical (inside of the joint) to completely separate the selected tibial plateau from the tibia

Once adapted PSCGs are fantastic tools to perform this complex intra-articular L-Inverted correction. We have been using it in abnormal tibial deformities (Figure 16) and after tibial plateau fractures with hemi-plateau impression. The protecting K-wires are multiplied to protect also the neurovascular bundles during the risky vertical cut. Specific 3D printed wedges can be prepared to position the hemi-plateau prior to final fixation. Furthermore, the PSCG represents sometimes a good option to prepare an ideal bone wedges from a femoral head allograft to ensure perfect gap filling.

Figure 16: Case of a bilateral Blount disease This deformity required a bilateral double L-inverted shape osteotomy using PSCG system

OWN PRELIMINARY RESULTS

We performed more than 300 PSCG osteotomy cases in the last 5 years, and we already published the accuracy of the correction obtained in both specimens [9], ten first [7] and hundred first HTO and DFO patients [10,21] as well as the learning curve of the system [11]. We also Investigated on several improvement such as the hinge protective K-wire [18,19] or the influence of saw-blade geometry [22]. Overall, the precision of the system in both coronal and sagittal plane was 1+/- 1° and after 10 cases the mean operative time dropped below 30 minutes with 6 intraoperative fluoroscopic images taken only [10,11]. The clinical results of our patients involved in impact sports showed better results compared with patients undergoing unicompartmental knee arthroplasty [23].

FUTURE FOR PSCG

We have been using PSCG for 5 years. Our understanding and performing of osteotomies has been drastically changed by 3D planning and Virtual Osteotomy. We have learned how much the ideal position of the hinge, direction of the cutting plane and insertion of the wedge influence OW-HTO's precision. The various modification that were incremented into our 3D planning now allow inclusion of Mikulicz line modification and will be converted into load changes on the medial and lateral tibial plateau (figure 17). For regular HTO, the PSCG devices have been adapted following surgeons' recommendation and desires. Most of us switch to smaller guides to minimize the size of the incision and the soft tissue release necessary for their positioning (FIGURE 18). For more complex cases, the only limit is probably imagination from surgeons and engineers. Several surgeons challenged this new PSCG philosophy with their "worse cases" (figure 19). We do believe that PSCG will have a bright future in regular and especially for more complex cases. The small additional costs (around 300 €) are compensated by the drastic reduction of operative time and will probably conduce to better function and longer survivorship of the osteotomies. But this cost-effectiveness has to be proven by further studies in the future.

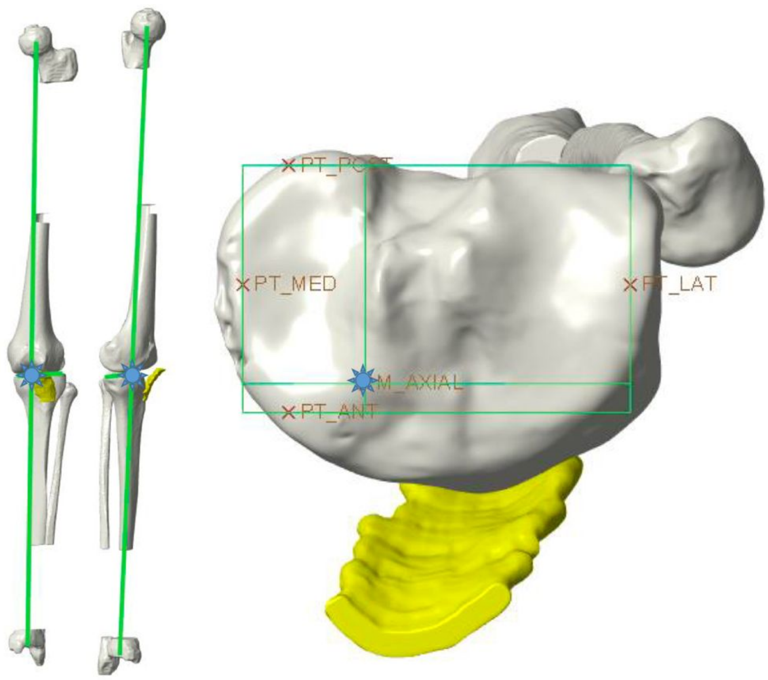


Figure 17: Virtual representation of the 3D Mikulicz line The example shows the maximal load point on the medial anterior Tibial Plateau before the correction

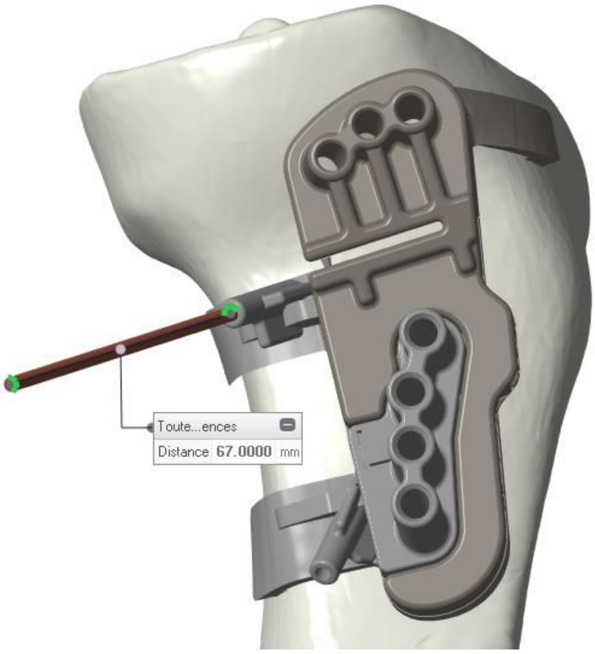
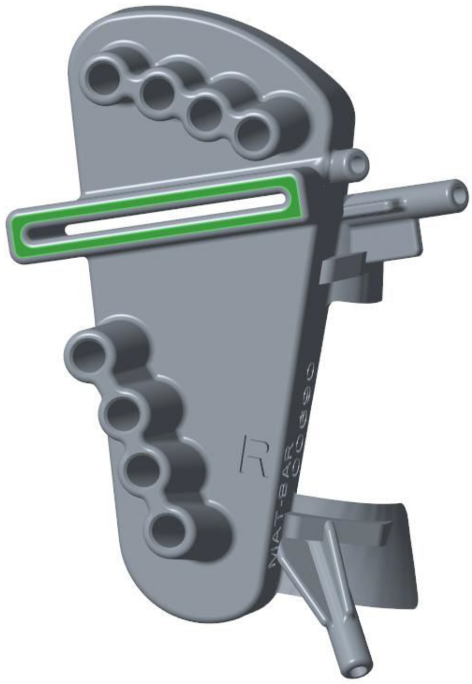


Figure 18. Evolution of PSCG's size A. Initial shape with 7-8 screw holes, one anterior and two posterior legB. Actual shape for derotation no anterior legC. Actual shape for OW-HTO no posterior leg and only two distal holes.



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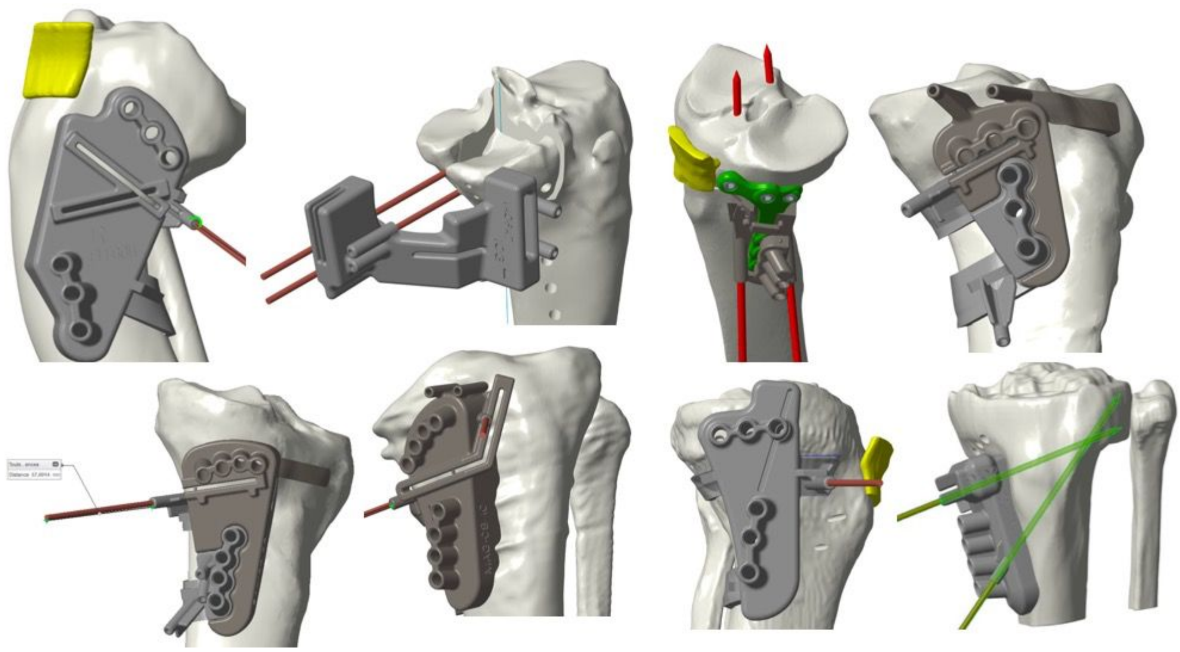

Figure 19: Virtual representation of different complex cases of osteotomyA : Congenital varus correction with slope deflexion osteotomyB : Post-traumatic Chiba osteotomyC : OW-HTO associated with meniscus allograft (the PSCG included meniscus transplants osseous tunnels).D : Post traumatic flexion osteotomyE: Congenital reverted slope correctionF: Chiba osteotomy for massive metaphyseal varus deformityG : intra-articular osteotomy for post-traumatic deformityH: OW-HTO for post-traumatic deformity

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