Patient Specific Instrumentation in Knee Osteotomies

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Abstract

Knee osteotomy is a successful operation which allow restoration of function, the preoperative planning and the achievement of the target correction during the surgery constitute critical steps which may affect the clinical results. With conventional techniques, the target correction may be difficult to obtain with substantial under- or overcorrection, then the preoperative planning should not only take into account the global alignment but also the segmental deformities with the proximal tibial deformity, the distal femoral deformity and the intra-articular deformity requiring an individualised approach to obtain the intended correction. The recent introduction of patient-specific cutting guides (PSCGs) based on preoperative CT-scan templating now offers the possibility of providing an instrumentation specific to each patient allowing to control exactly the correction in the different planes. The recent expansion in the use of PSCGs within the surgical community allows us to explore all its fields of application, from the simplest cases to the most complex cases. The accuracy of these guides allows in practice a great reliability for which the clinical impact must be known. However, we must keep in mind that the surgeon makes the final decision on target correction and this, whatever the level of accuracy of the tool used which involves that errors can occur in the event of poor preoperative analysis. The advantages and disadvantages of PSCGs require special consideration to justify their use.

Keywords: Knee osteotomy, Patient-specific cutting guide, Accuracy, Individualised approach, Correction

Introduction

Knee osteotomy (KO) is a successful operation requiring an individualised approach.

The choice of intended correction, preoperative planning and per-operative achievement of target correction are primordial steps following knee osteotomy.

Using conventional techniques, the target correction may be difficult to obtain with substantial under- or over-correction [31]. Newer technologies such as navigation have shown a more accurate and reproducible correction of the deformity in both frontal and sagittal plane [15].

Computer-assisted osteotomy is a real-time aid using a navigation system, anatomical landmarks are registered intraoperatively by using a pointer after image acquisition and attaching dynamic reference bases to the femur and the tibia. Navigation had shown by some studies to be more accurate than conventional methods [12, 13, 15], thus Bae et al showed a success rate of 86% in patients assisted by computer navigation against only 50% in the conventional group [2] but its use is not widespread among orthopedic surgeons, conversely Schröter et al found no difference and argues that equivalent surgical accuracy does not justify the increased expense and surgical time associated with navigated OW-HTO [27].

As the pin trackers of the navigation system cannot be implanted in each segment of the tibia (proximal to the osteotomy) to control of the opening performed and the exact correction in the frontal and sagittal planes is available. Furthermore, the navigation system requires a significant capital investment and the system might be cumbersome to use in the OR [5, 25].

The recent introduction of patient-specific cutting guides (PSCGs) based on pre-operative CT-scan templating now offers the possibility of providing an instrumentation specific to each patient allowing the exact control of the correction during the procedure for both the frontal and the sagittal plan [1, 20]. The accuracy of these systems have been verified in different in vivo and in vitro studies. Recent

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Rappel Bon de Commande (Mesures préopératoires et cibles postopératoires)

	Préopératoire	Postopératoire (cibles)	Corrections
HKA Frontal	NA	NA	7°
Pente tibiale	NA	NA	0°
Flexum	Non ☒ Oui ☐ Valeur :	Non ☒ Oui ☐ Valeur :	
Recurvatum	Non ☒ Oui ☐ Valeur :	Non ☒ Oui ☐ Valeur :	

Figure 1: Depicting an example of required correction (MPTA 7° PPTA 0°)

studies using PSCGs have also shown a decrease in operative time and a reduction in the number of fluoroscopic images per intervention compared with conventional techniques [1, 9, 20]. As for each and every new technology, the system of PSCGs might have a learning curve which seems important to properly assess for opening wedge high tibial osteotomies [8, 18, 30].

I. How Does It Work?

Preoperatively, all patients undergo conventional radiographs (weight bearing long-leg, A/P and lateral views) and a CT scan using a dedicated protocol including the hip and the ankle. The targeted correction is defined by the surgeon based on the physical examination and the radiological analysis of the Hip-Knee-Ankle (HKA) angle, Medial Proximal Tibia Angle (MPTA), Posterior Proximal Tibia Angle (PPTA) and mechanical Lateral Distal Femoral Angle (mLDFA) including the location of the deformity which presupposes knowledge of the tibial and femoral normal angular values. An order form is then filled by the surgeon to transmit the requested targets to the engineers.

A. Virtual Templating

The CT scan protocol consists of acquiring images centered on the femoral head, the knee (allowing the distal femur and 15 cm of the proximal tibia to be captured), and one centered over the ankle. The slice thickness are 0.625 mm for the knee and 2 mm for the hip and ankle (GE Light Speed VCT64). The concept is then to create a 3D model of the bone using the CT scan images and to mimic the KO correction following the request of the surgeons concerning the degrees of correction both in the frontal and sagittal planes. CT-scan is performed on supine position, therefore it is our recommendation of having systematically weight bearing long-leg X-rays to assess the share of the intra-articular part which is dynamic [3].

After simulating the osteotomy on the 3D tibia/femurl model, the plate (Activmotion HTO/DFO plate, Newclip Technics®, Haute-Goulaine, France) is virtually positioned to perfectly stabilized the osteotomy. The screws placement and sizes are also calculated. Once the final construct has been virtually defined, the pre-osteotomy cutting jig is designed to guide the cut and to drill the final screws hole. Additionally, two k-wires are virtually positioned to protect the hinge during the cut and the opening-wedge.

Intra-operatively, the surgeon positioned the PSCG on the bone, drill the holes and do the cut, and perform the opening/closing wedge. The plate is positioned on the tibia/femur when the plate holes match the pre-drilled holes on the tibia, the correction is perfectly achieved both on the frontal and the sagittal plane and consecutively for the HKA angle, MPTA and PPTA (Figure 1).

B. Surgical technique

After performing the standard surgical approach, the PSCG is positioned on the one and secured to the tibia or femur using two k-wires. After controlling the position of the jig is then controlled using the fluoroscopy, the futures screws holes were pre-drilled using the jig and dedicated pins were inserted to secure the position of the jig on the tibia.

Using the dedicated slot of the jig, the saw blade is guided during the cut.

The upper part of the PSCG is then removed to finalized the cut and another slot of the jig is used to guide the bi-planar anterior cut below the ATT.

The osteotomy cut was then gradually opened/distracted using a lamina-spreader until having the holes of the plate aligned with the pre-drilled holes on the tibia. The screws were then inserted in the plate to secure the construct. As the screw length was measured on the virtual pre-operative planning, sizing the screws intra-operatively is no-longer required.

C. Accuracy of the system

Several studies compared the achieved correction using PSI with the planned correction. As the only way to analyze accurately the 3D correction is to use CT-scans. We evaluated our 100 first PSI-HTO

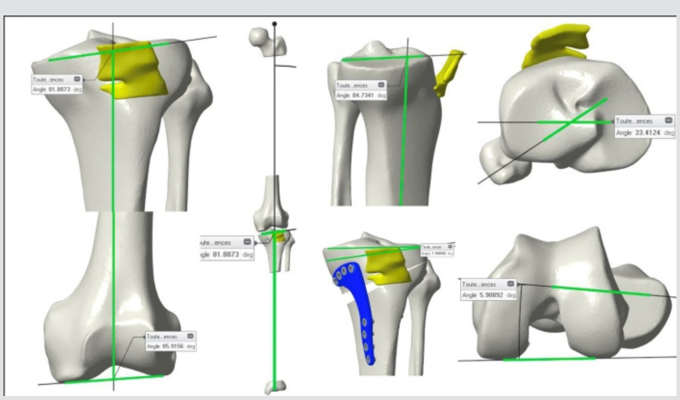

Figure 2: Illustrating a virtual osteotomy

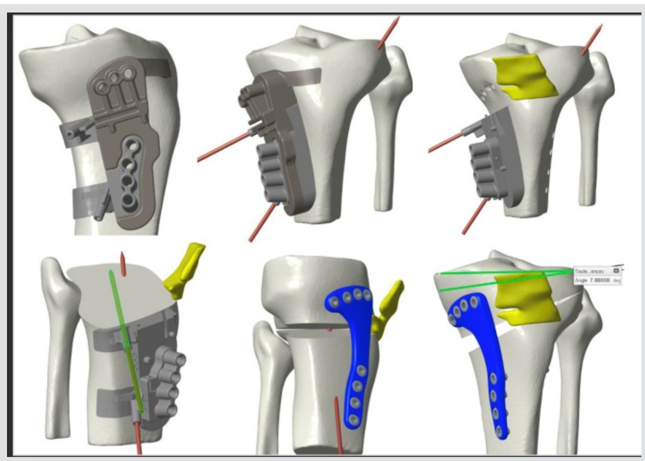

Figure 3: Preoperative 3D templating illustrating the operative technique of custom cutting guides.

using postoperative CT-scan reconstruction, formatting and measurements [7]. Patient-specific cutting guides for open-wedge high tibial osteotomy: safety and accuracy analysis of a hundred patients continuous cohort. We didn't observe any learning effect for the accuracy of the post-operative alignment. No difference in alignment accuracy was observed between the first 10 patients and the following 10 for each surgeon of our team [17]. The overall accuracy for coronal plane correction was around 0.5° for both MPTA and mLDFA target and around 1° for HKA.

Several other series have been published on the use of PSCGs for KO. Victor et al [32] reported accuracy of 1° in the frontal plane and 2° in the sagittal plane; however, the analysis was performed with radiographs only which can lead to measurement bias. Perez-Mananes et al [23] had similar results in the frontal plane with an accuracy of 2°, but the tibial slope was not measured. Munier et al [20] in their pilot study observed an accuracy measured on a CT-scan of less than 2° in the frontal and sagittal plane. Our findings in three different studies were similar in terms of accuracy of correction [7, 16].

The use of navigation is another established technique that theoretically improves the accuracy of postoperative limb alignment correction. Saragaglia et al [26] reported a rate of 96% for accuracy of a planned HKA angle at 184° ± 2° in their study with computer-assisted surgery. The results of our study are favorably comparable to those of Saragaglia. However, navigation seems to lengthen the operative time (average time of operative procedure: 82 ± 9.3 min for Hankemeier et al and 74.6 ± 11.4 min for Saragaglia et al [14, 26]). Published radiological results often point to an under-correction after HTO surgery with conventional techniques. The problem is particularly apparent with opening-wedge procedures as the under correction is about 2°more than with closing-wedge [6, 22]. Marti et al [19] reported a 50% accuracy between the correction achieved and the one planned after opening-wedge HTO with conventional methods while 31% showed an undercorrection and 19% an overcorrection. This results are vastly different from those using PSCGs which led to a reliable correction.

D. Specific complication

A recent study reported that the complication rate following medial OW-HTO ranged from 1.9% to 55% [29]. In our series, the overall complication rate was 32% up to 2 years post-operatively and the majority of the complications were classed as minor (28%). Major complications requiring procedure modification or additional surgery were found in 10% of patients in this series.

Recently, Han et al [11] reported a rate of complications at 29.7% after medial OW-HTO using locking plates, most of their complications were minor (21.1%). The most common complications were undisplaced lateral hinge fracture, whilst major complications requiring additional surgery were found in 8.6% of their patient population.

With our 100st PSI-HTO the incidence of lateral hinge fractures was 24% similar to other studies relating from 15.6% to 25.4% lateral hinge fractures [21, 29]. No other specific complication related to PSCG and intra-operative use was reported, no abandon of the guide to perform the surgery "free hand" was necessary.

E. Clinical Outcomes

In our series KOOS and UCLA activity scores, at a mean of 2 years follow-up showed a significant improvement, consistent with previous published studies [24, 28]. Concerning return to sport and work, PSCG have shown a great improvement as previously described [4, 10] but the superiority of the PSCG on the conventional methods for the clinical outcomes remains to be confirmed and if it exists, will provides a strong final argument favoring PSI.

F. Complex cases versus simple cases

Despite being involved in the early design phase and have been using PSI in more than 500 KO, we recommend gaining experience with conventional techniques prior to adopting the use of PSI which may be a nice alternative technique to free hand methods. The adoption of PSI for basic medial OW-HTO or lateral CW-DFO is recommended for experienced surgeons who require familiarization prior to using the technique for more demanding cases.

Nuanced presentations with the existence of multiplanar deformity (especially including elements such as torsion and intra-articular malunion) are ideal situations for the PSI in the hands of an experienced surgeon who has ascended the learning curve in this technique.

More PSI can be adapted to associate procedure (ligament tunnels, arthroplastie) with specific elements that can be created specifically to avoid implants convergence and optimize different stage of the surgery.

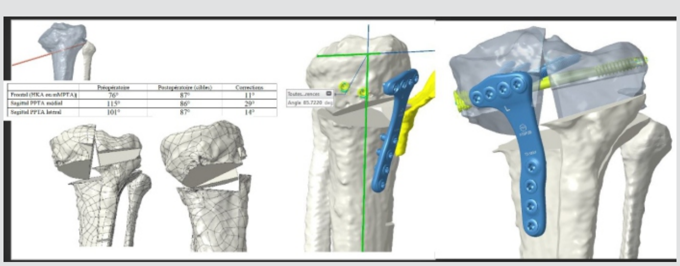

Figure 4: Extreme case with biplanar correction, separate double Chiba's osteotomy and anterior asymmetric opening wedge

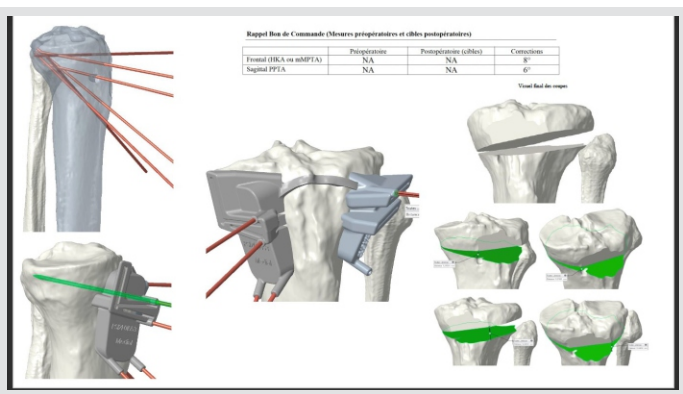

Figure 5: Example of a double patient specific cutting guide used for tibial tubercule sparing anterior closing wedge osteotomy.

G. Future perspective

The business model of PSCG or PSI is tackled by more "controlled" technologies such as augmented reality and robotic arms. However, those surgical helps seemed not to be ready for the prime time and their extensive use will be based upon the decrease of their cost and the demonstration of their superior precision.

During this time frame, PSCG will be advocated for complex cases such as anterior closing. Wedge osteotomy associated with chronic ACL deficient knees.

We recently imagined a "twin" PSCG to avoid tibial tubercule osteotomy in this special case, allowing optimization of surgical site morbidity. If the early results of our 10 first cases are promising, longer-terms outcomes will be needed to confirm the clinical advantage of this strategy.

Conclusion

Patient-specific cutting guides provide excellent accuracy, this use can serve for some surgeons less or more experienced to perform knee osteotomies and especially for more complex cases of knee deformity. His first interest concerns the possibility to perform an accurate preoperative planning which is allowed with the CT-scan carried out for PSCG creation. The second interest is related to the accuracy obtained of less than 2° in the coronal and sagittal plans. If the postoperative correction results are excellent, further studies should state the clinical benefit of this procedure compared to conventional techniques.

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

Conflict of Interest: NIL; **Source of Support:** NIL

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