MENTORS IN ORTHOPEDICS

PATIENT SPECIFIC ALIGNMENT AND BALANCING WITH COMPUTER ASSISTED SURGERY IN TOTAL KNEE ARTHROPLASTY

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SUMMARY

Background: Achieving optimal outcomes in total knee arthroplasty (TKA) remains challenging due to the complex interplay between patient anatomy, implant design, and surgical technique. While neutral mechanical alignment was traditionally considered the gold standard for implant survivorship, recent evidence suggests that restoring constitutional alignment may improve functional scores and "forgotten knee" outcomes without compromising long-term stability.

Objective: This article describes a computer-assisted surgical strategy aimed at achieving patient-specific alignment and ligament balancing, utilizing a gap-balancing technique to restore native kinematics.

Key Points: The methodology employs navigation software to model knee laxity and plan bone cuts that accommodate the patient's pre-osteoarthritic axis. By adjusting the obliquity of tibial and distal femoral cuts within a ±3° range and modifying femoral rotation between 8° external and 2° internal, surgeons can achieve symmetric flexion and extension gaps without extensive soft tissue release. In a series of 199 primary TKAs using this technique, 79.9% of patients achieved neutral alignment (±3°), while 18% retained a constitutional deformity of 4–5°. Only 2% of cases were outliers exceeding 5°. Soft tissue releases were required in only 5% of the cohort, and no patellar dislocations were observed at three months postoperatively.

Conclusion: Navigation-assisted TKA allows for precise, individualized alignment targets that replicate native joint physiology. This approach facilitates excellent ligament balance and reduces the necessity for invasive peripheral releases, potentially improving postoperative functional recovery by respecting the patient's unique constitutional anatomy.

KEYWORDS

Arthroplasty, Replacement, Knee; Surgery, Computer-Assisted; Bone Malalignment; Range of Motion, Articular; Knee Joint

INTRODUCTION

A successful knee replacement depends on a complex equation incorporating numerous variables, some relating to the patient, some to the implant, and others to the surgical technique. Surgeons have yet to fully master all of these variables,[1,2] which is most certainly the reason why there is still room for improvement when it comes to unsatisfied patient outcomes.

Traditionally, neutral alignment (hip knee angle (HKA) 177°–183°) was the target for good functional outcome, in particular of improved survivorship. Technically, the only way this goal could be achieved was by making distal femur and proximal tibia cuts perpendicular to the mechanical axis and using ligament releases to maintain satisfactory stability and compensate for the unnatural changes to the native knee anatomy.

In recent years, the debate surrounding this dogma of neutral alignment has been heating up because long-term analysis has in fact revealed no difference in terms of implant survival and functional outcomes between implants that were normally aligned and those that were outside the normal range (outliers > 3°).[1,3,4] At the same time, numerous different alignment strategies have emerged (adjusted mechanical, functional and kinematic)[5], which are personalized and leave a non-neutral tibiofemoral axis.

Navigated procedures, which first appeared two decades ago, have now been compared to mechanical techniques for restoring a neutral axis. Although this goal was achieved more often with computer-assisted navigation (91% vs. 68%)[6], the functional outcomes were lastingly comparable between the two techniques.[7] An improvement in digital tools, and the use of modern computer-assisted navigation to control ligament balance are without doubt the reason why recent meta-analyses show an improvement in functional scores,[8,9] and, in the Australian Registry[10], an improvement in long-term survivorship in patients less 65 years old. This was also the conclusion of a multi-centre study by the French Society of Hip and Knee Surgery of patients with a preoperative deformity > 10°.[11]

Computer-assisted total knee arthroplasty has for many years been the gold standard for some surgeons because the software can plan the cut and predict the outcome in terms of axis and stability. Furthermore during the actual surgery it can monitor the quality of the procedure, the axis and the ligament balance. Modern navigation tools remove the need for a rigid workflow and can be adapted to individual set the axis and stability goals determined by the surgeon. The procedure can therefore be fully customised to suit the patient’s features and the surgeon's goals.

This article describes our own axis and stability goals, the planning, and the stages of the surgery, ending with our preliminary results for axis restoration. We use the Attune posterior-stabilized fixed-bearing implant (Depuy Synthes) and the Kick navigation platform and Knee3 Motion software (Brainlab).

TARGET AXIS AND STABILITY GOALS

‘Forgotten knees’ represent the new target and the neutral axis has been repressed from the top priority spot. Achieving perfect stability in both flexion and extension independent from the mechanical axis are the most stable joints post-surgery with high forgotten knee scores [12].

In principle, the aim is to fit the implant in a given ligament envelope without the need for release, because the effect on stability in flexion is hard to control and it creates a risk for subsequent recovery, similar to that experienced following ligament sprain. Ligament balance is obtained using the gap balancing technique; the nature of the bone cut, in terms of thickness and obliquity, is determined based on the nature of the other bone cuts and the subsequent effect on ligament balance.

The goal for the tibiofemoral axis is to restore patient's pre-osteoarthritic axis in order to reposition the leg in line with the native kinematics and joint, muscle and ligament physiology. This pre-osteoarthrititic axis can be determined by considering the axis of the other knee, if healthy, but the simplest way is with a deformity reduction test which accounts for any laxity due to wear. This measurement can be easily taken at the start of the procedure (Fig. 1) and distinguishes frontal deformity due to wear from any constitutional deformity. The result of the reducibility test will determine the target axis.

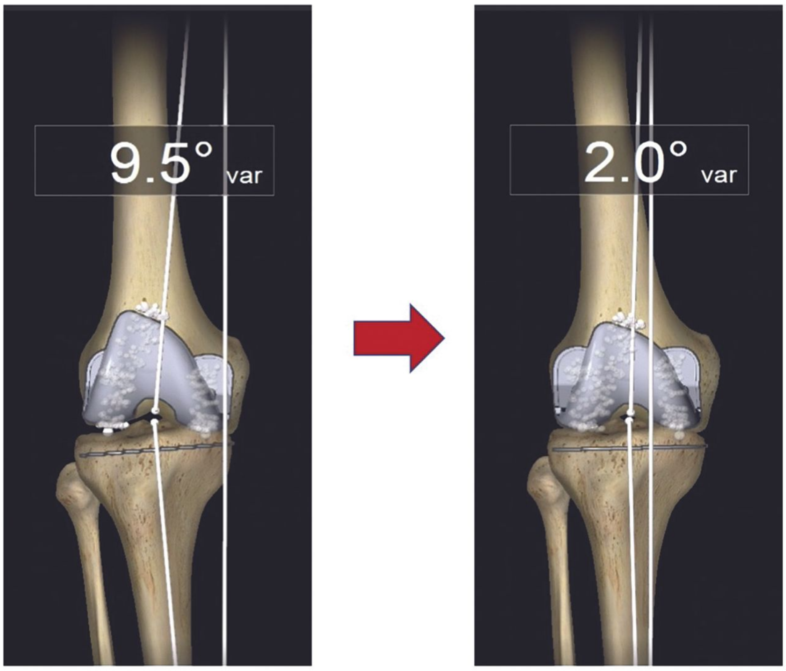

Figure 1 : Knee reduction test. The varus stress view determines the weight-bearing axis, here a varus angle of 9.5°. The valgus stress view corrects the laxity due to wear of the medial compartment and indicates a residual varus of 2°; this is therefore the target axis i.e. a normally-aligned knee.

We predict that with this technique, deformities of less than 10° will be realigned at 0–3°, and those over 10° will be realigned at 0–5°. Preoperative varus should result in a postoperative HKA < 180°. Preoperative valgus should result in a postoperative HKA > 180° (Fig. 2).

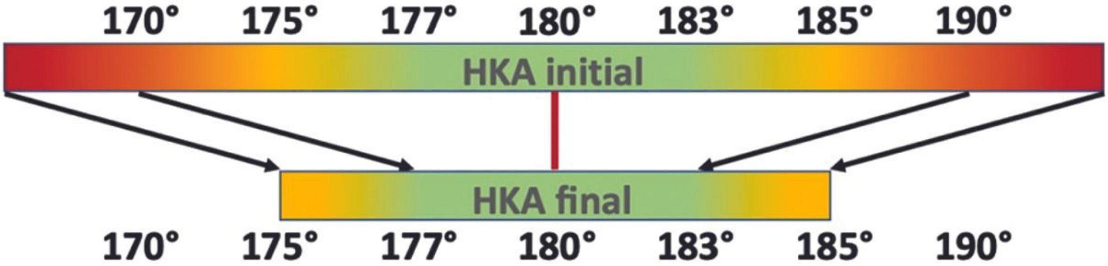

Figure 2: Target axis

IMPLANT PLANNING

All surgical approaches are compatible with computer-assisted surgery. Once surgically exposed, any osteophytes are removed completely but no other peripheral release is performed during the procedure, other than posterior release to treat a flexion contracture.

The knee is digitally modelled using standard navigation landmarks. Laxity is then measured by placing a forced valgus and varus stress on the joint, from maximum extension through to maximum flexion, as for a physical examination. The extent of the laxity is then used to determine the size of the peripheral ligament gaps between the tibial cut and the planned femoral condyles of the implant (Fig. 3).

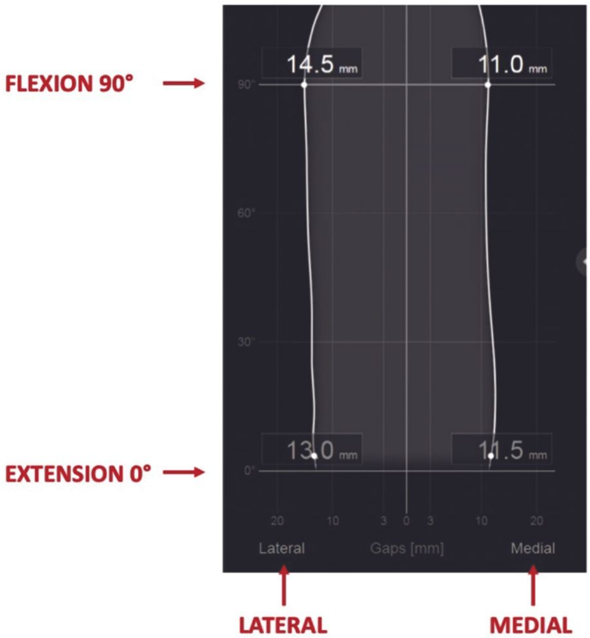

Figure 3 : Knee laxity. In this pre-planning example, there is 1.5mm lateral laxity in extension (13 vs. 11.5mm) and 3.5mm lateral laxity in flexion (15.4 vs. 11mm).

Implant planning can then take place. The computer is used to visualize all planned cuts as well as the anteroposterior position of the femoral implant. As a starting point we use for the frontal alignment the classical mechanical 90° cuts for the tibia and femur. In the sagittal plane 3° slope for the tibia and 5° of flexion for the femur component. For the axial plane we start with 3° of external rotation for the femur component and for the tibia 0° of rotation to the AP line. The functional targets are balanced and symmetric flexion – extension gaps.

Adjusting any of these parameters will affect the laxity and will allow to achieve an equal balance in medial and lateral flexion and extension gaps (Fig 4).

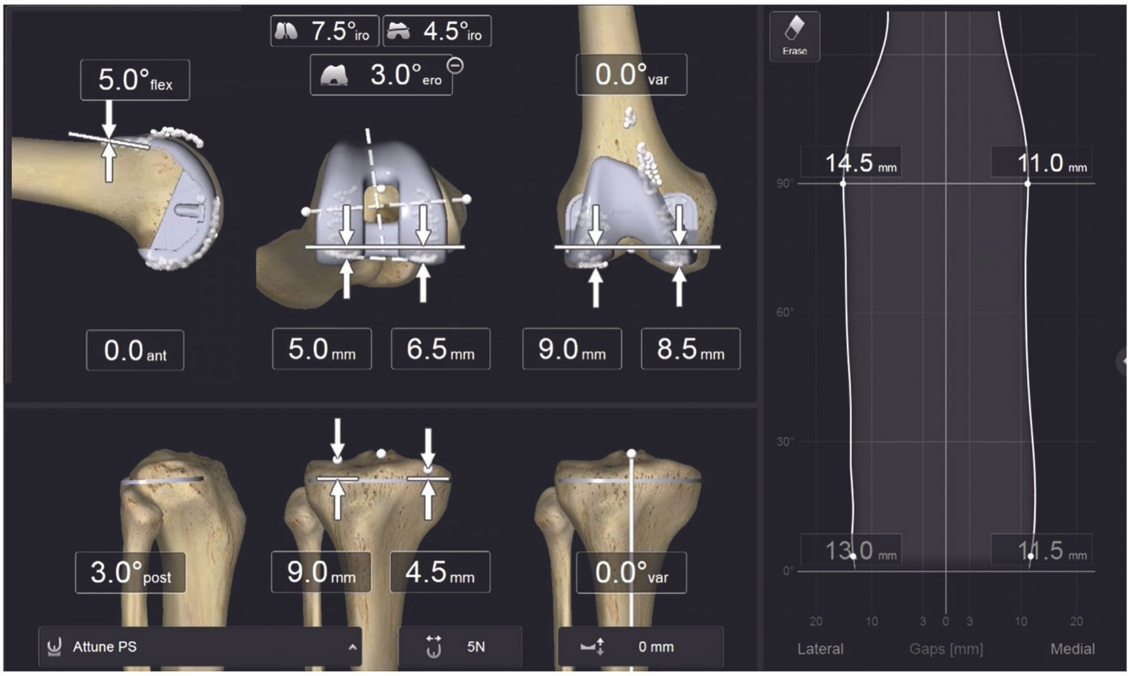

Figure 4 : Implant planning pre-adjustment. In this example of genu varum, there is lateral laxity in extension and in flexion if the distal femoral and proximal tibial cuts are made perpendicular to the mechanical axis, and external rotation set at 3° to the posterior condyles.

Stage 1: Mediolateral balancing in extension

To balance the gap in extension, the obliquity of the tibial and/or distal femoral cut must be modified in the frontal plane. We use the preoperative deformity analysis to determine the mechanical medial proximal tibial angle (mMPTA) and the mechanical lateral distal femoral angle (mLDFA) to locate the site of the constitutional varus- or valgus-producing deformity and transfer the findings into the planning software in order to replicate the knee native anatomy.

Some tips:

- Adding 2° of varus to the distal femoral cut is equivalent to the mechanical technique of selecting an intramedullary anatomical correction angle of 5° instead of 7°.
- Adding varus to the tibial cut reduces the degree of external rotation needed to balance the knee in flexion. For genu varum, the medial epiphyseal cut is typically made in less dense bone, which improves the quality of fixation.
- Excess varus applied to the distal femoral cut increases the risk of lateral overhang of the proximal trochlea of the implant as well as increased stress to the lateral patellofemoral joint in flexion.
- The navigation system can measure the mechanical distal femoral angle (mLDFA) by placing the mechanical cutting guide over the most distal points of the condyles, which allows to skip radiographic measurements.

Our limits:

- Tibial cut: obliquity between 3° valgus and 3° varus
- Distal femoral cut: obliquity between 3° valgus and 3° varus

Stage 2: Mediolateral balancing in flexion

The flexion gap is balanced by adjusting the obliquity of the posterior femoral cut, which in turn alters the rotation of the femoral component. External rotation can be determined in relation to Whiteside's line, the surgical transepicondylar axis or the posterior bicondylar line. We use the latter because we think it is more reliable and reproducible, although all three values are recorded and can be used by the system. Increasing the external rotation of the femoral implant reduces lateral laxity and increases medial laxity in flexion. External rotation further improves patellar kinematics, but external over-rotation increases the risk of notching in the anterior lateral femoral cut.

Our limits:

- Femoral rotation between 8° external and 2° internal rotation.

Stage 3: Extension-flexion balancing

The final stage of planning involves making the flexion and extension gaps equal by adjusting the thickness of the tibial or distal femoral cuts, the flexion of the femoral component or its anteroposterior position.

The thickness of the tibial cut affects the flexion and extension gaps equal. The tibia cut can be increased if there is major tibial bony defect due to wear which has to be compensated by using a thicker polyethylene component. The tibia cut can be reduced if the cut is too large (target value 9 mm bony cut on the healthy compartment) or if there in genu valgum (traditionally undercut of 7mm on the healthy medial side to compensate for the peripheral laxity).

The thickness of the distal femoral cut affects only the extension gap. We limit it to a range of ± 2mm because an insufficient distal cut increases the patellofemoral flexion stresses in flexion, and an overcut increases instability in mid-flexion. Any change to the joint space height is therefore detrimental.

Increasing flexion of the femoral component decreases the flexion gap and the risk of notching. Contrary to the femoral intramedullary guide used for the mechanical technique, which forces the femoral component into flexion due to the sagittal curvature of the femur, the navigation system calculates the flexion angle in relation to the sagittal mechanical axis. At least 3° flexion is recommended to reproduce the distal femoral curvature. We avoid exceeding 6° due to the risk of femoral metal notch impingement to the poly posterior-stabilizing cam in PS knees.

The anteroposterior position of the femoral implant can also be used to adjust the flexion gap. Anterior overstuffing should be avoided since this would affect the patellofemoral joint but also undercutting should be avoided to prevent any fracture risk.

The navigation system displays the thicknesses of every bone cut. This information can be used to determine the parameters of the cuts based on the patient's anatomy and the wear of the various compartments. Never forget that the navigation system is a tool for recording all values measured during initial data acquisition. If the navigation landmarks are not measured accurately this could skew the figures. Finally, there is no one-size-fits-all planning solution, and the parameters can be adapted to meet the goals set by the surgeon (Fig 5).

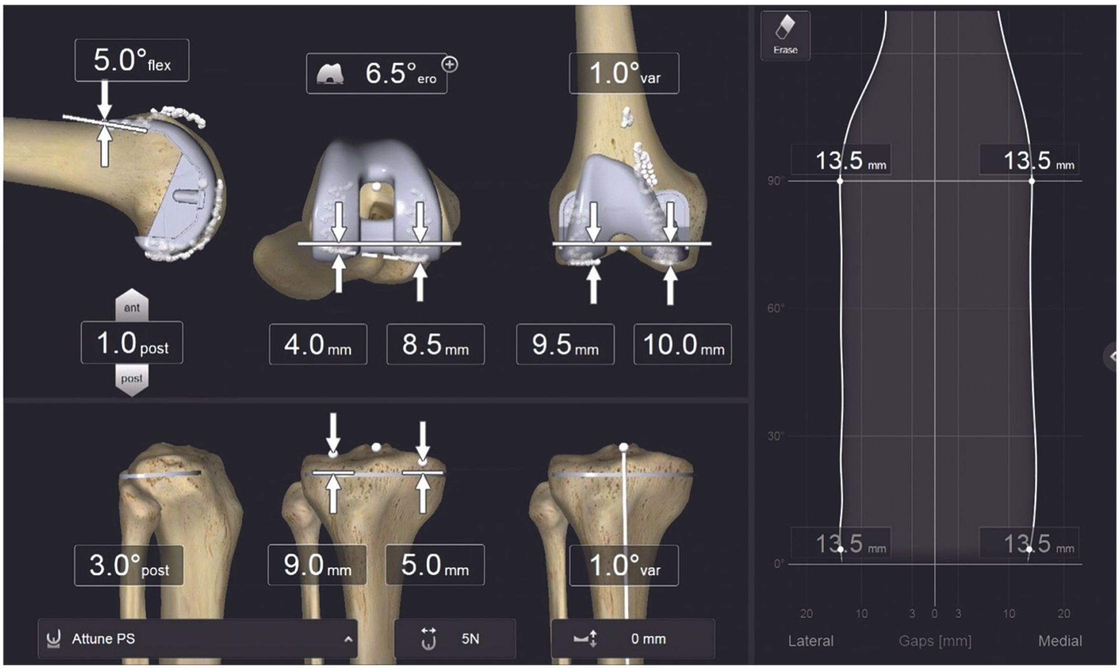

Figure 5 : Adjusting the planning to obtain a balanced knee. Compared to fig 4 the femur component is positioned 1 mm posterior, 6.5° of ER and in 1° varus. The tibia component is set in 1° varus. All these bony cut adjustments allow a perfect balanced and symmetric flexion-extension gap.

STAGES OF NAVIGATION-ASSISTED SURGERY

The navigation system does not impose a strict workflow, and the surgeon is free to decide the order of the cuts because the computer is able to automatically identify the stage of the procedure based on the position of the arrays. The surgeon can therefore progress to the next step or even return to a previous stage, without the need to first validate any given element of the procedure. After making each cut, a verification plate is used to check the quality of the cut, and the computer instantly adjusts the laxity values based on any deviation from the pre-determined target. An imperfect cut can be revised, or the plan for the subsequent cuts can be adjusted accordingly.

We typically start with the tibial cut. Once completed and checked, a 9 mm spacer is placed in the tibial gap in order to check that the cut is wide enough (the spacer enters easily, with no increase in flexion). We also use it to check the flexion balance and whether there is any need to increase the lateral femoral rotation.

The distal femoral cut is then made and checked. An 18 mm spacer is placed in the extension gap in order to check the extension balancing, the final tibiofemoral axis and that the gap is wide enough (Fig. 6). With the spacer in place, residual flexion of up to 5° is typical because you are placing a square-edged spacer between two cuts angled at 3° on the tibial side and 3–6° on the side of the femur.

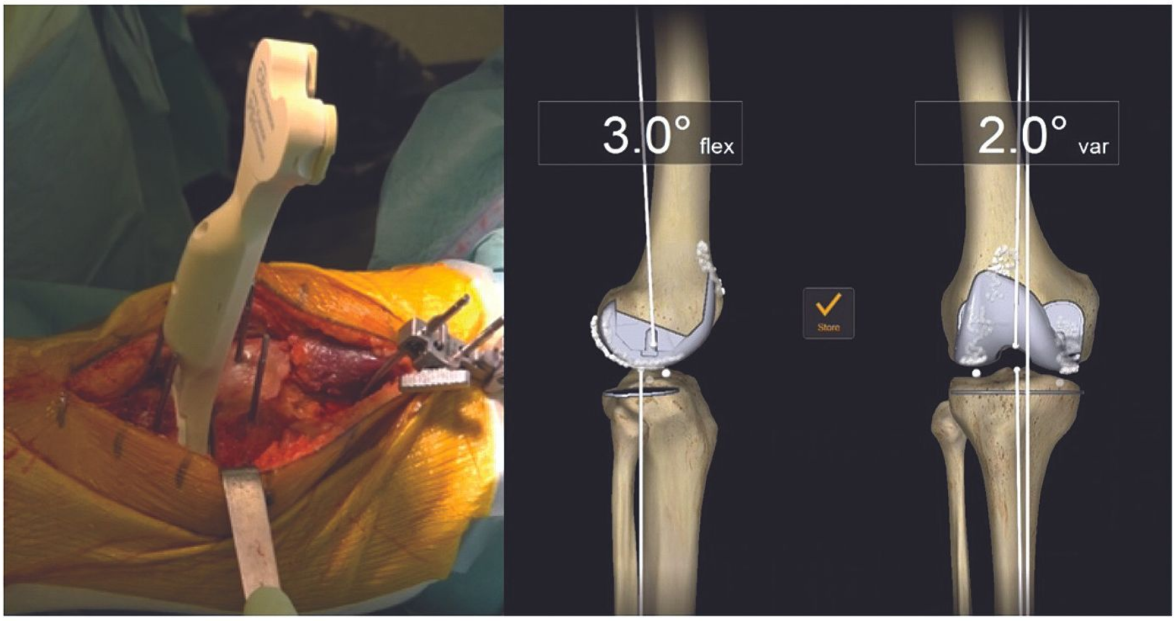

Figure 6 : Checking the extension gap and tibiofemoral axis.

The 4-in-1 posterior referenced anteroposterior cutting guide is then fixed on the distal femur cut in 90° of flexion, together with an anterior stylus to determine the proper femur AP size. If necessary, the flexion gap can be checked before making the posterior cut, using the 18mm spacer to confirm that the flexion-extension gaps will be equal.

Once the trial components are in place the patella is prepared. The final axis and joint stability are assessed. If full extension still cannot be achieved, which happens if there was a significant prior flexion contracture, the posterior capsule is released to finetune the extension gap.

PRELIMINARY RESULTS

Between January and November 2018, two surgeons performed a consecutive series of 200 Attune primary total knee arthroplasties. The preoperative and postoperative frontal alignment values were documented by the navigation system, along with the external rotation of the femoral component in the axial plane. One patient was excluded from the analysis due to missing data, leaving a sample of 199 implants.

Preoperative Alignment:

- 140 patients had a varus deformity, average 14° (0.5–20°), of which 30.7% had a deformity > 10°.
- 56 patients had a valgus deformity, average 8° (0.5–25.5°), of which 35.7% had a deformity > 10°.
- 3 patients had a 0° deformity.

Postoperative frontal axis

A total of 79.9% knees had a neutral postoperative axis +/- 3° by reaching the initial target. 18% of knees were borderline with residual deformity of 4-5° and only 2% of knees were outliers > 5° (highlighted in grey). There was a difference between knees without severe deformities (< 10°) compared to severe deformities (> 10°).

Postoperative external rotation and patella tracking

Average external rotation was 4.5°, ranging from 2° internal to 10° external. At 3 months post surgery, an analysis of patellofemoral views revealed no patellar dislocation, and only one patellar tilt in an obese patient with additional quadriceps snip approach.

Ligament release

Ten releases (5%) were performed across the whole series. Most used the pie-crusting technique, with one condylar sliding osteotomy for a valgus of 25.5°.

Preoperative axis	Number of patients	Postoperative axis			
		0 – 3°	4 – 5°	> 5°	Average
Varus < 10°	97	91 (93.8%)	5 (5.2%)	1 (1%)	1.9°
Varus > 10°	43	23 (53.5%)	19 (44.2%)	1 (2.3%)	
Valgus < 10°	36	35 (97.2%)	1 (2.8%)	0 (0%)	2.3°
Valgus > 10°	20	7 (35%)	11 (55%)	2 (10%)	
0°	3	3 (100%)	0 (0%)	0 (0%)	
Total	199	159 (79.9%)	36 (18.1%)	4 (2%)	

DISCUSSION AND CONCLUSION

This computer-guided 'patient-specific stabilization/alignment' technique for knee replacements makes it possible to balance knees whilst retaining an acceptable constitutional deformity with a low rate of releases. 79.9% of implants were neutrally aligned, 18 % with acceptable alignment (4-5° residual deformity) and only 2% of outliers with a residual deformity > 5°.

Our goals are like the alignment and stability targets for unicompartmental knee arthroplasty which have been used successfully for more than 40 years. This includes compensating for any laxity due to cartilage wear, restoring patient's native alignment and leaving the ligament envelope intact. Unicompartmental knee arthroplasty have proven to tolerate residual deformity outside the neutral axis, and there is no reason to believe that a total knee replacement will not behave likewise, a hypothesis which is supported by literature.[3,4]

Bellemans [13] showed that 32% of men and 17% of women without osteoarthritis have a constitutional varus of greater than 3°, and that a neutrally aligned implant in this population leads to major, unwanted anatomical deformity. We recorded degrees of residual deformity similar to this study, implying that we managed to replicate the patients' constitutional deformity. Further research is needed to determine whether this technique improves functional outcomes, although this is widely thought to be the case by many authors who report that a residual deformity of <6° is beneficial for varus [14] and neither beneficial nor detrimental for valgus.[15]

Each knee has its own specific constitutional deformity, and its own specific deformity due to cartilage wear and soft tissue laxity. Patient-specific targets should help improve the outcome of knee replacement surgery. Navigation systems are an ideal surgical tool for dynamic interoperative control to help meet these targets.

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