MENTORS IN ORTHOPEDICS

CONVENTIONAL NAVIGATION AND EXTENSION GAP FIRST TECHNIQUE FOR PROPER BONE CUTS IN TKA

https://doi.org/10.71165/8d2i-wimi

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SUMMARY

Background: Achieving optimal component alignment and soft tissue balance remains a primary challenge in total knee arthroplasty (TKA). Traditional techniques rely either on bony landmarks (measured resection) or soft tissue tension (gap balancing), both of which present specific limitations regarding femoral component rotation and joint line maintenance.

Objective: This study describes a "conventional navigation" protocol and an "extension gap first" technique to optimize bone resection and ligamentous balancing without computerized assistance. The study evaluates the clinical efficacy of this combined approach in 100 consecutive primary TKA cases.

Key Points: Preoperative planning utilized full-leg weight-bearing radiographs to determine the mechanical distal lateral femoral angle (LDFA) and medial proximal tibial angle (MPTA). Intraoperatively, distal femoral and proximal tibial cuts were verified using calipers and extramedullary rods. The "extension gap first" concept involved balancing the extension space through standardized soft tissue releases before determining femoral rotation. Axial femoral positioning integrated both the surgical transepicondylar axis and a flexion spacer to ensure gap symmetry. Results indicated that 94% of patients achieved frontal alignment within 3° of the neutral mechanical axis. The average femoral external rotation was 3.2° in varus knees and 5.1° in valgus knees. No cases required lateral retinacular release, and intraoperative trials confirmed balanced flexion and extension gaps in all patients.

Conclusion: The integration of conventional navigation and the extension gap first technique provides a reproducible framework for achieving precise component positioning. By combining bony landmarks with soft tissue assessment, this method identifies outliers and minimizes rotational malalignment, offering a cost-effective alternative to computer-assisted surgery.

KEYWORDS

Arthroplasty, Replacement, Knee; Bone Malalignment; Knee Joint; Anatomic Landmarks; Ligaments, Articular

INTRODUCTION

The challenge in total knee arthroplasty (TKA) is to achieve perfect alignment, rotational positioning, balancing and fixation of the implants without any additional risks or drawbacks [15]. Furthermore the success and longevity of TKA is predicated by correction of the individual deformity of the knee [17]. One of the challenges in TKA is to perform the proper bone cuts in the frontal, sagittal and axial plane to correct the underlying deformity [23]. The type and grades of soft tissue releases is determined by the two main factors of bone correction cuts and pre-existing soft tissue imbalances. Without proper bone cuts soft tissue balancing of the knee is not possible in most of the cases.

In the frontal plane the bone cuts correct the varus- and valgus malalignment at the tibia and/ or femur. In the sagittal plane at the tibia they determine the posterior inclination (slope) and at the distal femur the flexion/ extension positioning of the implant. In the axial plane at the tibia the rotational positioning of the implant is the most important factor for proper patella tracking [8]. In the axial plane at the femur the anterior and posterior cuts determine the sizing, anterior-posterior and rotational positioning of the implant. These parameters are most important for a proper flexion gap [25]. Internal malrotation of the femur component is one of the most common causes for an early failure due to a chronic painful TKA [14].

At the femur two principal philosophies are available for making proper bone cuts in the axial plane. The measured resection technique (so called femur first) is based on bony landmarks only [17] and the balanced gap technique (so called tibia first) is based on soft tissue structures only [11],[31]. Both stand the test of time and have shown advantages and disadvantages (Table 1).

Measured resection	Balanced Gap
• Preferred by 80% of surgeons • Bone cuts independent from ligaments • 3 different landmarks possible • Difficult to find landmarks • Minimum 3° ER for all • Soft tissue control after all cuts only releases • May lead to recutting femur for: wrong size or rotation possible	• Preferred by 20° only • Cuts independent from bony landmark • Ligaments must be intact • Extension gap must be released perfect • Risk for internal malrotation does not work after extensive • Femur deformity has to be addressed • Uncontrolled change of joint line

Table 1: Comparison measured resection versus balanced gap technique.

“Tibia and femur first” are not the right terms to describe these two different surgical techniques, therefore they should not be further used. In this report the “extension gap first” concept will be described as a solid compromise to combine the advantages of both philosophies. This might prevent the problems for performing the proper rotational bone cuts at the femur in the axial plane. This technique is combined with the concept of “conventional navigation” without the use of a computer for planning and cut verification. This includes preoperative planning on a full leg weight bearing x-ray, intra-operative cut verification using conventional instruments and intraoperative planning and verification of bone cuts in the axial plane at the femur and tibia. The aim of this study was:

1. To describe in more detail the tips, tricks and pitfalls of the “conventional navigation” and “extension gap first” technique.

2. To prove the efficacy and practicability of the combined “conventional navigation” and “extension gap first” concept for performing proper bone cuts in the frontal, sagittal and axial planes.

PATIENT AND METHOD OF THE STUDY

100 consecutive patients (73 female and 27 male) with an median age of 71 years (range 54-83) planned for primary TKA were included in this prospective study. Only patients with severe decompensated deformities requiring a more constrained implant (condylar constraint) were excluded. There were 83 varus (Ø 8° range 1 - 21°) and 17 valgus (Ø 7° range 4-17°) deformities. In varus knees and noncontract valgus knees up to 10° deformity a medial Mini-Midvastus MIS approach [23] was used. In all other contract valgus knees a lateral Mini-Midvastus MIS approach [16] was performed. All patients received a cemented posterior stabilized fix bearing implant (NexGen LPS Flex Fixed®, Zimmer, Warsaw) with patellar replacement. For planning and making the proper bone cuts “conventional navigation” without the help of a computer was used for all patients. This included planning on a standardized frontal full leg weight bearing x-ray, intraoperative cut verification using conventional instruments and intraoperative planning and cut verification for the rotational cuts and positioning in the axial plane at the tibia and femur [16]. For the axial alignment at the femur the “extension gap first” concept was used to intraoperative control the individual posterior condylar angle (angle between posterior condylar and surgical transepicondylar axis) for rotational positioning of the femoral component. The balanced flexion/extension gaps and proper patella tracking was tested intraoperatively by a clinical trial run. The balanced gaps were analysed with varus and valgus stress manoeuvres in full extension, 60 and 90° of flexion. Post operative on day 5-7 all patients received a full leg weight bearing and short lateral x-ray for post-operative alignment control in the frontal and sagittal plane. For didactical reasons the detailed description of the surgical technique is separated in the two concepts of “conventional navigation” and “extension gap first” technique.

OPERATIVE TECHNIQUE

Conventional Navigation

This technique includes the five different steps of radiographic analysis, preoperative planning, intraoperative control before cuts, cut verification and intraoperative planning of rotational bone cuts.

Radiographic analysis

Standard anterior-posterior weight bearing and lateral non-weight bearing radiographs were used to estimate the severity of arthritis, osteophytes and bony defects. Templating the size of the implants was performed in exceptional cases only. A standardized frontal full leg weight bearing x-ray (Figure 1) was used for deformity analysis and planning of the intramedullary correction angle (IM-angle) at the femur [22]. In patients with clinical suspicion of patella maltracking a special weight bearing patella axial view was performed additional [10].

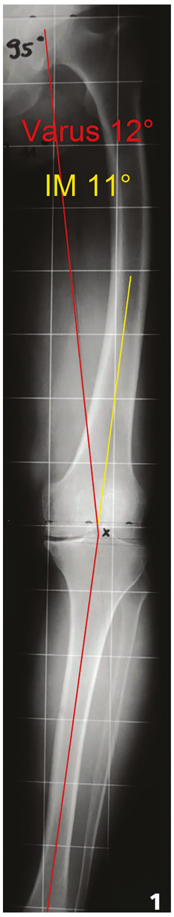

Figure 1: Standardized full leg weight bearing x-ray with mechanical axis femur and tibia, medial proximal tibia angle (MPTA), lateral distal femur angle (LDFA), varus deformity of 12° and IM-correction angle of 11°.

Pre-operative planning

The planning in the frontal plane was performed on the full leg x-ray and included deformity analysis according to Paley [21]. The mechanical axis of femur, tibia and baselines of distal femur and proximal tibia are drawn on the radiograph (Figure 1 and 2). The varus or valgus malalignment, the mechanical distal lateral femur angle (LDFA - normal 88°, range 85-90) and mechanical medial proximal tibia angle (MPTA - normal 87°, range 85-90) were calculated (Figure 2). Furthermore the individual IM-angle between the mechanical and the anatomical axis of the femur was analyzed. With these four numbers the severity and location of the frontal bony deformity as well as the individual IM-angle could be identified before surgery. Depending on the necessary correction cuts for neutral alignment (LDFA and MPTA 90°), the need for additional soft tissue releases could be estimated also. In the case of figure 1 for example with a contract varus deformity of 12° the valgus correction cuts of 5 mm each on the femur and tibia (1° ~ 1mm) will end up with an further 10 mm increase in the trapezoidal extension gap. Together with the already contract medial soft tissue structures this will need extensive medial releases to correct this contract varus deformity.

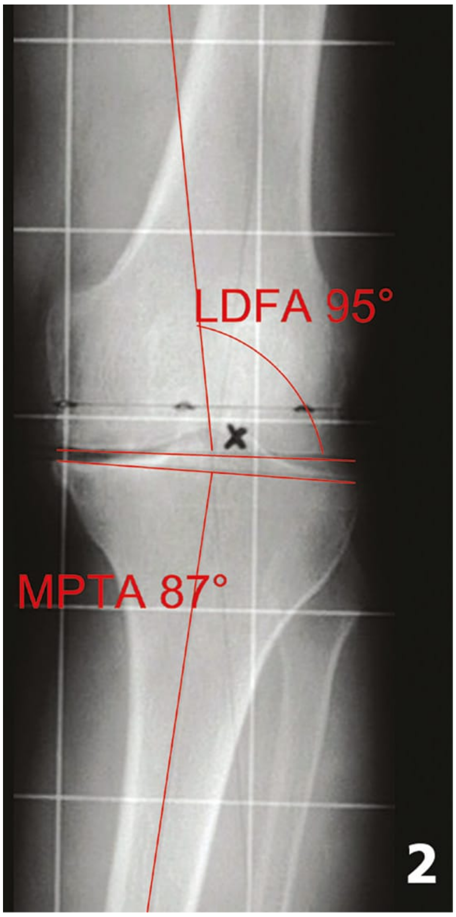

Figure 2: Detail of fig. 1 with deformity analysis: LDFA 95° and MPTA 85°, note that the tibia is normal and the varus deformity is at the femur only.

The analysis of the sagittal deformity was made on a short lateral radiograph. A full leg length lateral radiograph was performed in cases with complex extraarticular deformities only. Planning in the sagital plane included evaluation of the natural slope at the tibia and the posterior offset and the anterior trochlea thickness at the femur. For the NexGen LPS Flex Fixed® prosthesis a slope of 7° was planned for all patients independent from the natural slope. Furthermore anterior and posterior osteophytes, which might cause a flexion contracture or limited full flexion, were indentified.

Intraoperative controls before bone cuts

The frontal correction bone cuts were determined by the individual LDFA and MPTA only (Table 2). After using the conventional intramedullary instruments for preliminary placement at the femur, the cutting block position to the distal femur condyles was controlled by the LDFA as the "golden standard". In the case of figure 1 for example the distal cutting block must be flush on the lateral condyle and has to show a 5 mm lift off on the medial side (1 mm ~ 1°) (Figure 3). This will guarantee a 5° valgus correction cut at the distal femur. If necessary the IM correction angle of the instrument was changed to adjust the cutting block positioning according to the LDFA. At the tibia the individual tibial intramedullary entry point was planned on the full leg x-ray and an intramedullary alignment with a combined extramedullary control rod was used for the frontal correction cuts in all cases except of 6 severe bowed tibias where an extra medullary system could be used only. The landmarks for the frontal extramedullary control were the anterior tibia crest, centre of the ankle (5 mm medial to the midline of both malleolus) and lateral to the tibialis anterior tendon. The second tarsal toe was not used due to lack of save forefoot torsion control. The placement of the cutting block was then double checked by the MPTA. In the case of figure 1 for example the proximal cutting block should cut 5 mm more lateral than medial to guarantee a 5° valgus correction cut.

LDFA	Femur	Correction cut	Medial condyle	Lateral condyle
90°	Neutral	Neutral	Equal	Equal
> 90°	Varus	Valgus	Less	More
< 90°	Valgus	Varus	More	Less
MPTA	**Tibia**	**Correction cut**	**Medial plateau**	**Lateral plateau**
90°	Neutral	Neutral	Equal	Equal
> 90°	Varus	Valgus	Less	More
< 90°	Valgus	Varus	More	Less

Table 2: Planning of bone resections according to LDFA and MPTA measurements.

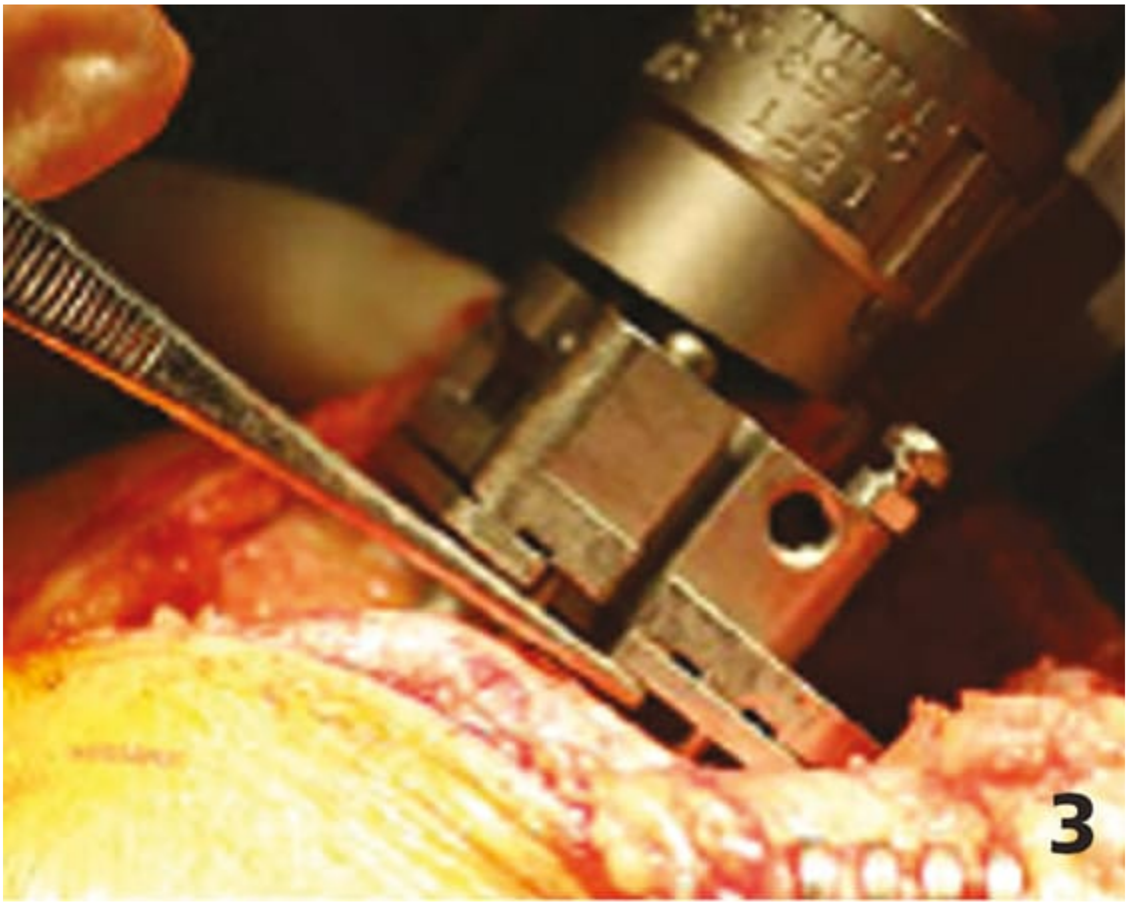

Figure 3: Pre cut control with cutting jig (LDFA 95°) with valgus correction cut of 5°, the distal plate is flush at the lateral condyle and off for 5 mm at the medial condyle (1 mm ~ 1°).

For the rotational alignment of the tibia cut a functional and anatomical landmark was used. The functional landmark was a modified Akagi line [2]using the mid-to medial third of the tibia tubercle to the centre of the posterior cruciate. In patients with proximal torsional deformities at the tibia where the tibia tubercle is external positioned to the anterior tibia crest (increased Q-angle), an in between compromise between the proximal tibial entry point of the mechanical axis and this functional landmark was used for rotational alignment. For the anatomical landmark the “curve on curve” concept of the anterior tibia cortex with the tibia baseplate was used [5]. The slope cut of 7° was built into the conventional intra- and extramedullary system. For the extramedullary slope control the 3° anterior deviation of the anterior tibia crest to the sagittal tibia axis was taken into account.

Cut verification

After the distal femur und proximal tibia cuts were done, the thickness of the distal medial and lateral bone resections at the femur and tibia were measured with a calibre to control the planned frontal correction cuts (cut verification: 1 mm ~ 1°).
For example in the case of figure 1 (the thickness of the distal metal of the NexGen LPS Flex Fixed® is 9 mm for all sizes) the lateral distal femur cut should be 9 and the medial 4 mm respectively (Figure 4). In varus deformities with varus femurs (the lateral condyle is the most distal contact point for the cutting block), the intact cartilage of the lateral distal condyle was taken into account. The same was done in a mirror wise fashion with valgus deformities and normal or valgus femurs.

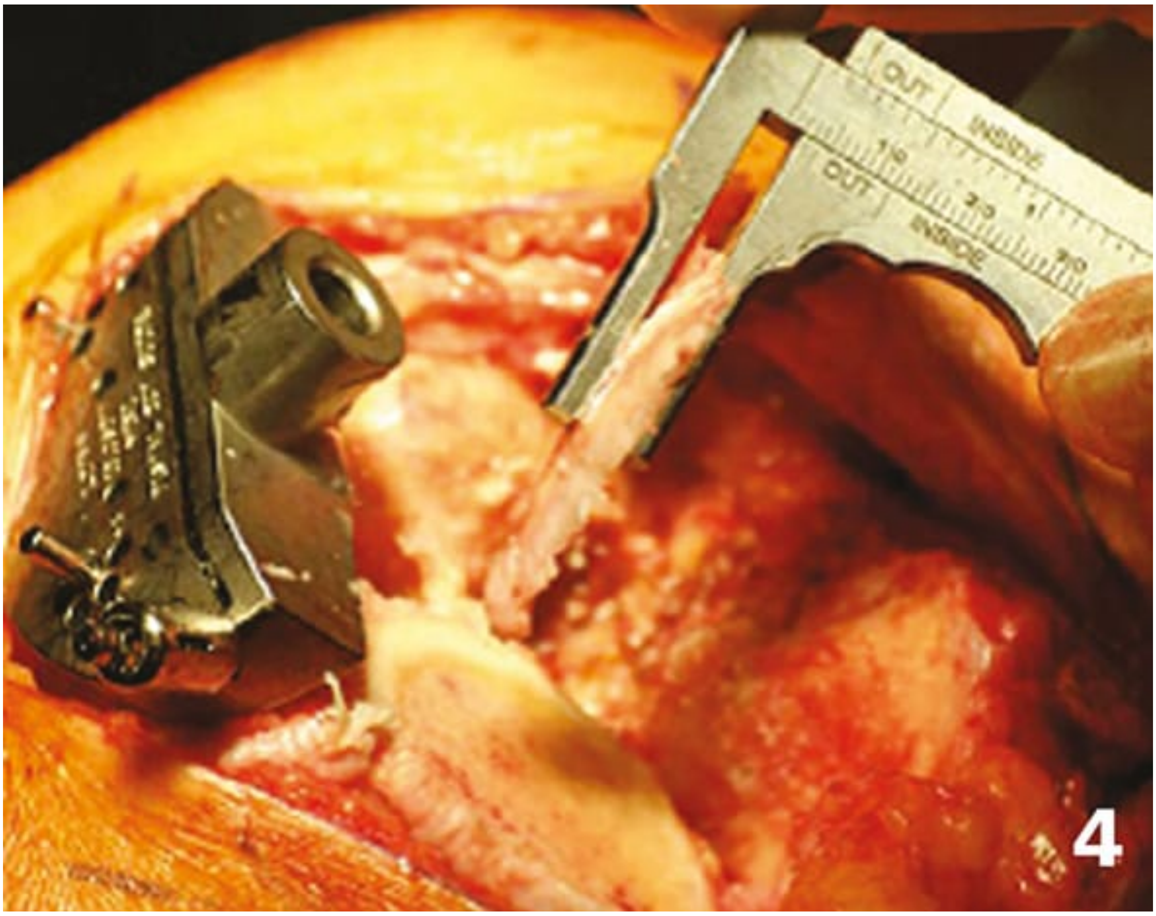

Figure 4: Cut verification of the distal bone resection with a calibre (case of fig. 1 medial 4 mm bone resection only).

Additional an extramedullary control rod in combination with a spacer block was used in extension for a further control of the frontal correction cuts at the femur and tibia after the bone cuts were performed. At the femur medial/lateral rod deviation for 1 cm to the proximal centre of the femoral head (2-3 cm medial to the anterior spine) indicates ~ 1° valgus/varus malalignment at the joint level. At the tibia medial/lateral rod deviation for 1 cm to the centre of the ankle indicates ~ 1.5° varus/valgus malalignment at the joint level. At this time any deviation of more than 2° from neutral mechanical alignment was immediately recutted using a varus or valgus correction cutting block. Controlling the slope was achieved by comparing the resected anterior – posterior bone wedge with the preoperative planning.

Intraoperative planning rotational bone cuts

At the femur the two bony landmarks (surgical epicondylar axis and AP-line) were drawn on the distal cut surface (Figure 5). With the combined instrument for anterior referenced sizing (Figure 6A) and rotational positioning (Figure 6B) these two lines were compared with the posterior condylar line. The individual posterior condylar angle (angle between posterior condylar line and surgical epicondylar axis) was identified. By using standard different rotational corrections blocks (0, 3, 4 and 7° of external rotation) the two rotation pins were then inserted parallel to the epicondylar line (Figure 6B).

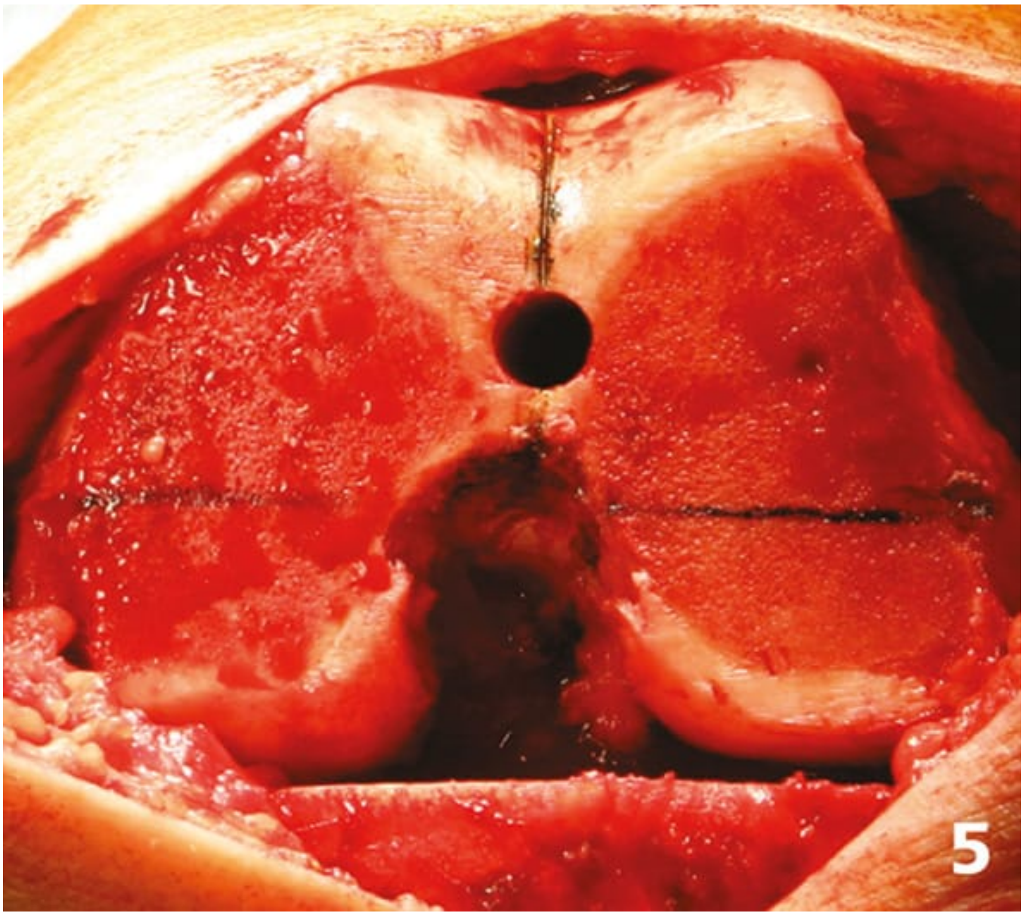

Fig. 5: Landmarks (surgical epicondylar line and AP- line) are drawn on the distal femur cut in a case with 3° of ER.

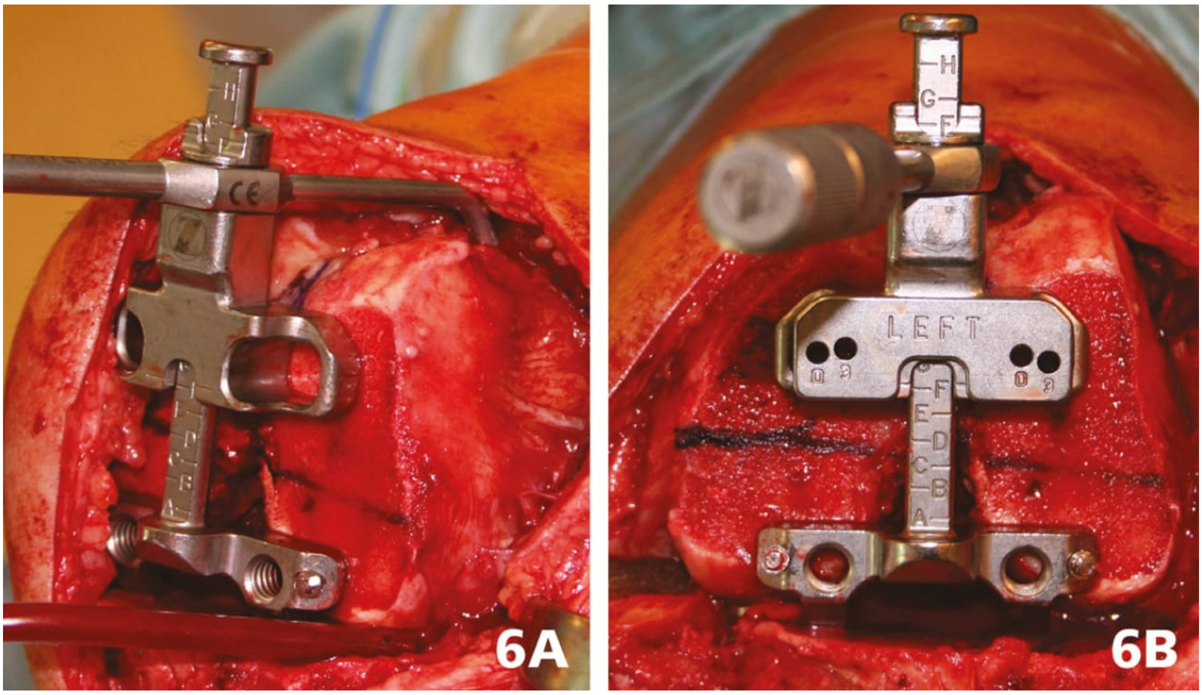

Fig. 6A-B: Combined MIS instrument for sizing (Fig. 6A) with anterior referencing and rotation (Fig. 6B) with posterior referencing.

After removing of the instrument the positioning of the two rotation pins parallel to the epicondylar line was controlled by eyeballing (Figure 7). Before cutting the anterior and posterior femur the rotation positioning and correct sizing and AP-positioning of the 4 in1 cutting block was controlled with the “extension gap first” technique in 90° of flexion (see later).

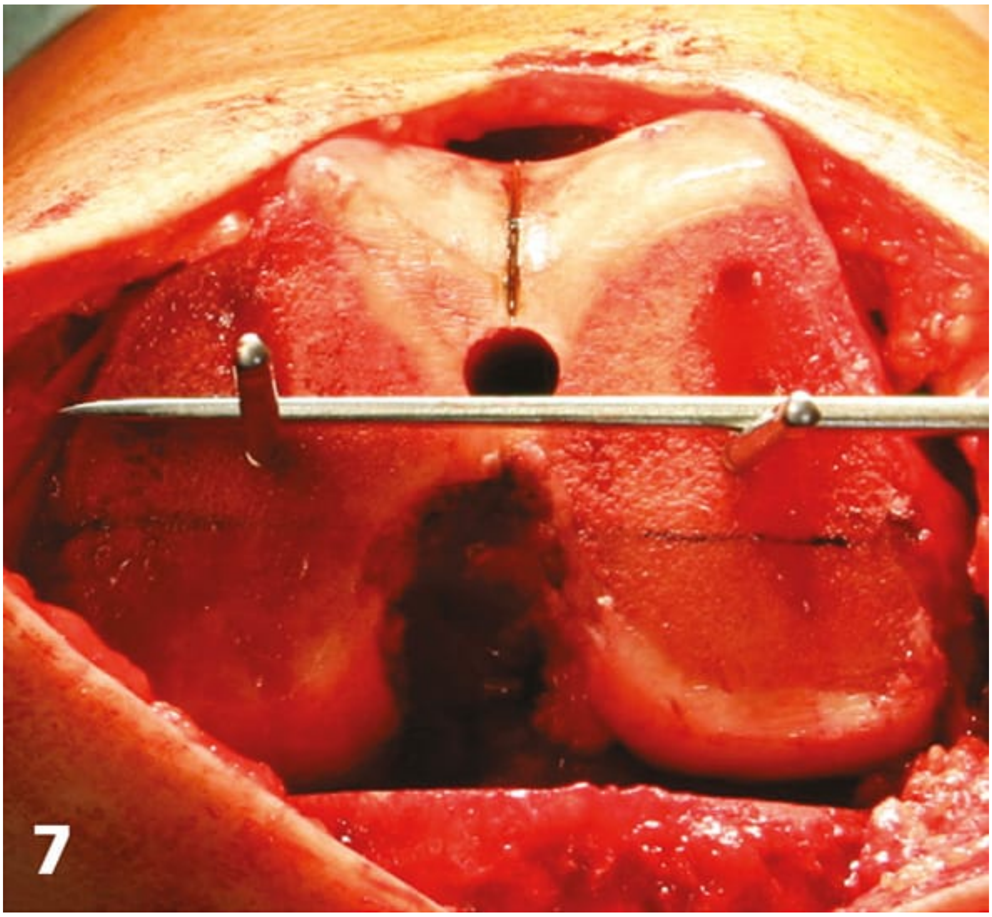

Fig. 7: Control of the rotation pins parallel to the surgical epicondylar line by eyeballing.

At the tibia the individual rotational positioning for the bone cuts and for rotational positing of the tibia baseblate a functional and anatomical landmark was used (see above). Proximal tibial malrotation of the tibia tubercle according to the anterior tibial crest (medial border of the tibia tubercle lateral to the anterior crest) was documented.

Extension gap first

This concept will be described in the three steps of extension gap cuts, balancing extension gap and axial femur bone cuts.

Extension gap cuts

The first step is the distal femur cut followed by the proximal tibia cut using intramedullary instruments and conventional navigation (see above). At the femur exact the thickness of the distal implant (9 mm for all sizes with NexGen LPS Flex Fixed®) was resected at the most distal condyle (lateral in varus and medial in valgus femurs). At the tibia the thickness of the cut was determined by four rules.

Balancing extension gap

After removing the osteophytes and the posterior cruciate ligament the soft tissue situation of the extension gap was controlled by using conventional spacer blocks or laminar spreaders. The tip of the index finger was used as a "biological" tensioner to control the tightness of the ligaments. Asymmetric extension gaps or too tight ligaments were not accepted. The contract side was then released by a standardized four step releasing technique to balance the contract medial or lateral side depending on the type of deformity (Table 3). After each step of releases the extension gap was controlled by spacer blocks or laminar spreaders again. Over releases were tried to prevent. At this stage not more than step 2 releases were performed because after grade 3 and 4 releases in the extension gap the contract side will significantly open in flexion. This will cause a relative instability in the flexion gap and then the ligaments can not be used for controlling the flexion gap anymore (see later). In these contract deformities the still remaining trapezoidal extension gap asymmetry was recognized in mm. This asymmetry was used later for the flexion gap control (see below). Furthermore in cases with dorsal osteophytes the final balancing of the extension gap could not be performed at this stage.

VARUS DEFORMITY	
Step 1	Deep medial MCL, posterior medial capsule and PCL
Step 2	Semimembranousus insertion
Step 3	Superficial MCL
Step 4	Medial condylar osteotomy (pes anserinus)
VALGUS DEFORMITY	
Step 1	Iliotibial band, posterior lateral capsule and PCL
Step 2	Lateral collateral ligament
Step 3	Popliteus tendon
Step 4	Long head biceps tendon

Table 3: Step by step soft tissue releases.

Axial femur bone cuts

After preparing the medial and lateral epicondylus (Figure 8), the surgical epicondylar- and AP-line were drawn on the distal femur. It was controlled that these two lines are rectangular (± 3°) to each other. If this was not the case, the landmarks were checked again. After drawing the rotational landmarks, the sizing of the femur was performed with an anterior referencing instrument (Figure 6A). For in between sizes in the AP dimension the clear closer size or primary the larger size were used. In the NexGen LPS Flex Fixed® design the posterior jump for the standard sizes is 4 mm. For clear in between sizes the anterior reference point was adapted for 1-2 mm anterior or posterior to partly correct the anterior referencing problem (modified posterior referencing). The goal was to resect the metal thickness at the posterior medial condyle as close as possible (11 mm for all sizes of NexGen LPS Flex Fixed®). For mismatches between AP and ML dimension "gender components" with smaller ML sizes were available. The 4in1 cutting block was then fixed with the two rotation pins parallel to the epicondylar line in 0-7° of external rotation to the posterior condylar line depending on the individual anatomy (see above). The degree of external rotation (posterior condylar angle) was documented.

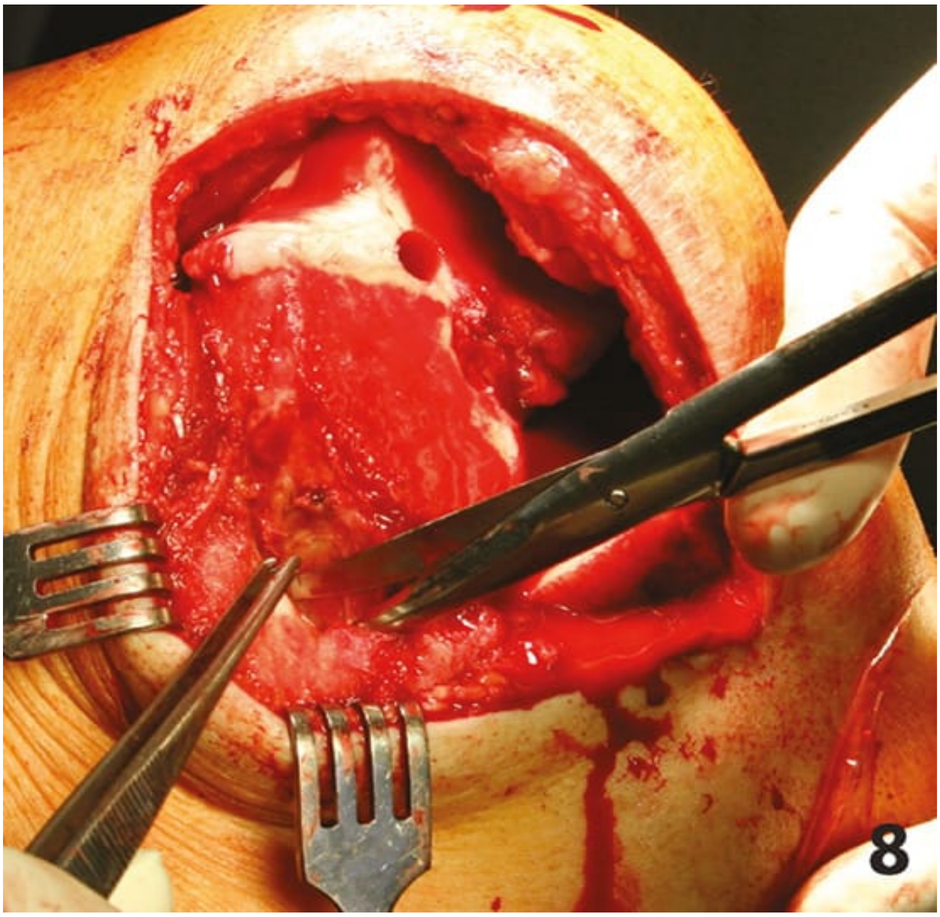

Fig. 8: Preparation of medial epicondyle and medial collateral ligament at femur.

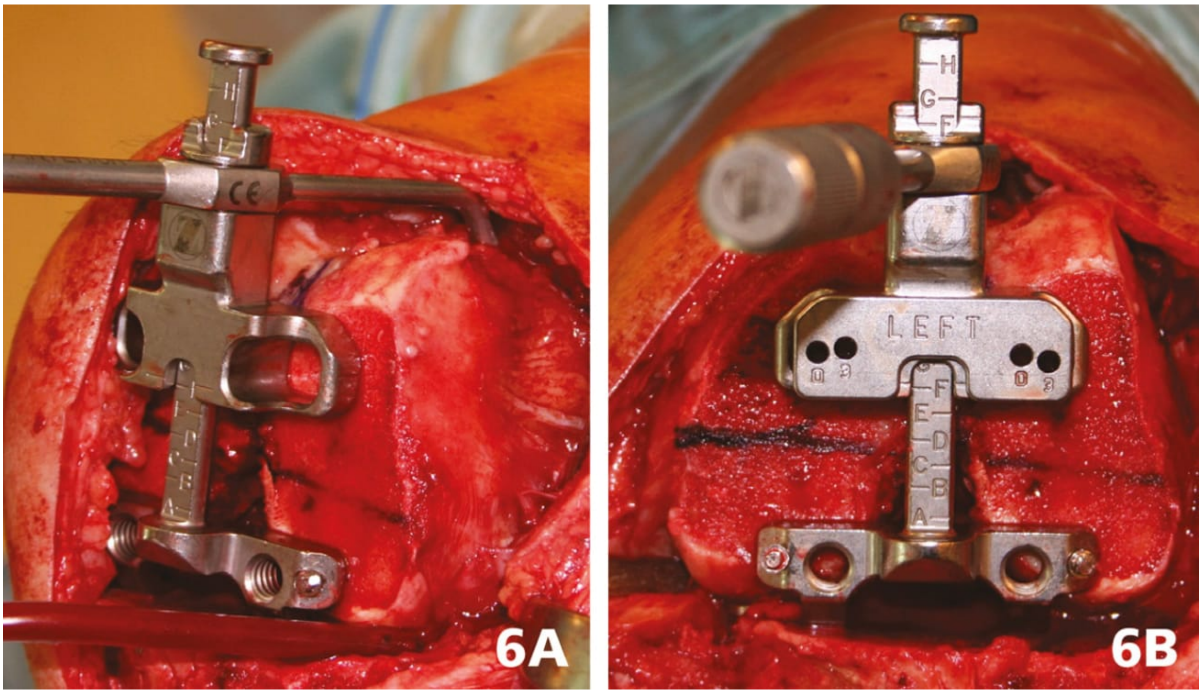

Fig. 6A-B: Combined MIS instrument for sizing (Fig. 6A) with anterior referencing and rotation (Fig. 6B) with posterior referencing.

Before performing the anterior and posterior femur cuts a rotation spacer block with the same thickness as in the extension gap (plus 2 mm with the NexGen high flex® component) was introduced in 90° of flexion to control the

proper rotational alignment and sizing of the femur (Figure 9A and B). A symmetric flexion/ extension gap mismatch of more than 2 mm was corrected by using a smaller femur size. An asymmetric flexion/extension gap mismatch of more than 2 mm
was not accepted. Rotational positioning of the 4in1 block, malalignment at the tibia or improper ligament balancing in the extension gap were controlled again and corrected if necessary. After the chamfer cuts extensive work at the posterior part of the knee was performed. This included removal of all residual posterior osteophytes and any soft tissue left in the medial and lateral dorsal capsular space. It was checked again, that the posterior cruciate was resected and/or released completely.

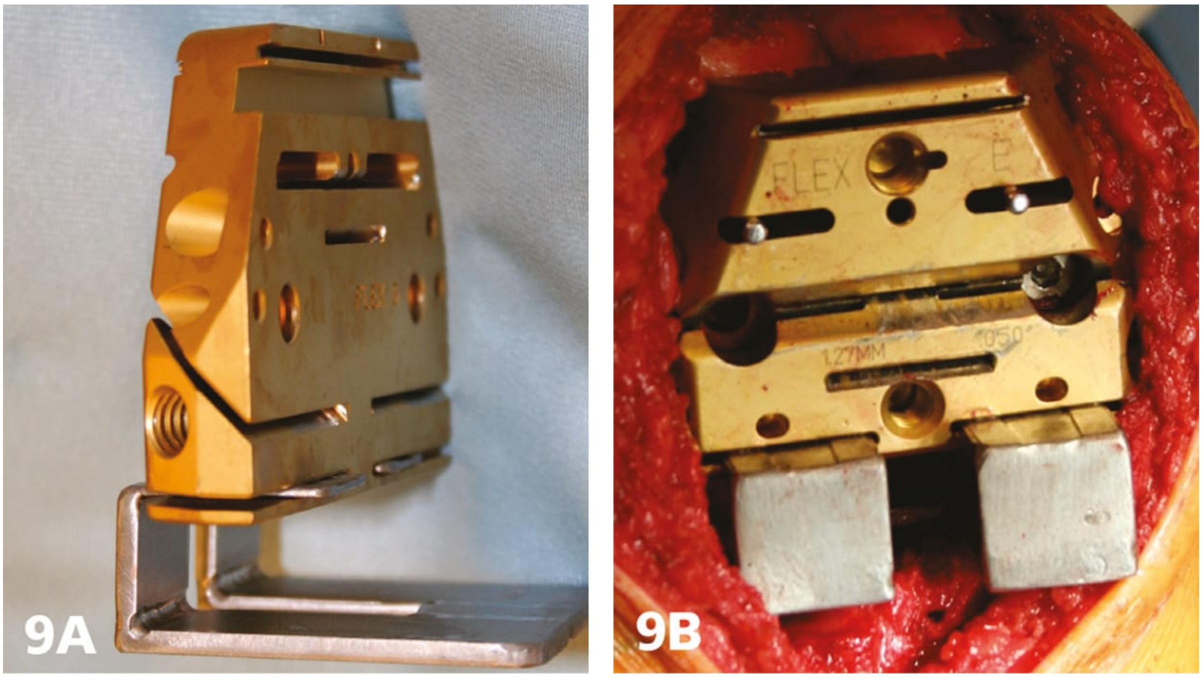

Figure 9A-B: Rotation spacer to control rotational positioning and sizing of 4in1 cutting block before anterior - posterior bone cuts (A side view and B intra operative).

Finally the symmetry of the extension and flexion gaps was controlled by spacer blocks or laminar spreaders and the biological tensioner. In very contract deformities where a step 2 release had been performed in the extension gap only, the persisting trapezoidal extension gap has to shown now the same asymmetry in the flexion gap (symmetric medial asymmetry for varus or lateral for valgus deformities). If this was the case finally the trapezoidal gaps were balanced with further releases of step 3 or 4 until they were symmetric.

RESULTS

Preoperative deformity analysis of the varus knees showed in 48% the deformity at the femur only (LDFA > 90°) and the tibia was normal (MPTA > 84°). In 35% of the valgus knees the valgus deformity was at the tibia only (MPTA > 90°) and the femur was normal (LDFA > 84°). In further 47% the valgus deformity was both at the femur and tibia. In 8 cases with preoperative flexion contractures of more 15° the deformity analysis had to be performed on two long films for the femur and tibia sepa- rate to compensate for the flexion contracture. The preoperative planned IM valgus correction angle was on average 6.2° (range 2-11°). In 8% of the cases the preoperative IM valgus angle had to be corrected during surgery according to the planned LDFA.

An intraoperative AP to ML mismatch at the femur, which was solved with a "gender com- ponent", was found in 22% of females and 4% of males. Changing the primary chosen size at the femur after controlling the flexion gap with the extension gap first technique was necessary in 8% of the cases. The external rotation correction for the femoral component to the posterior condylar line (posterior condylar angle) was on average 3.2° (0-7°) in the varus knees and 5.1° (3-9°) in the valgus knees. None of the cases showed an internal rotation correction (negative posterior condylar angle). In all cases the rotational alignment control with the extension gap first technique showed a correlation between the landmarks and the soft tissues within ± 2°. The symmetry of the flexion and extension gaps could be verified in all patients by an intraoperative trial run with varus and valgus stress tests. None of the cases needed recutting for rotational malalignment of the femur due to an asymmetric flexion gap > 3 mm. In 24% of the cases the tibia showed a proximal torsional deformity with external positioning of the tibia tubercle according to the anterior tibial crest. These cases required a "comprise" internal rotational positioning. In none of the cases an internal positioning of the tibia tubercle to the anterior tibia crest could be observed. Proper patella tracking with the "no thumb test" could be verified in all patients. In none of the patient a lateral retinaculum release was necessary to compensate for improper patella tracking.

Postoperative alignment evaluation on the full leg weight bearing radiographs showed in 94 knees (94%) a normal frontal alignment (0-3° within the neutral mechanical axis) with an average LDFA of 89,1° (range 85-93) and MPTA 89,4° (87-92). 4 knees showed varus (4-7°) and 2 knees a valgus malalignment (4 and 6°). The overall average frontal alignment was 0,7° Valgus (Varus knees) and 1.4° Valgus (Valgus knees). The average sagittal alignment at the tibia was 5,6° slope (3-10°) and 2,8° (1-7) flexion positioning at the femur.

DISCUSSION

In this study the conventional navigation in combination with the extension gap first tech- nique could demonstrate proper bone cuts in the frontal, sagittal and axial planes in 95% of the patients, which is comparable to the published literature for computer navigation [6],[10],[16],[28]. It has been shown in several studies, that without proper planning or using computer navigation the overall frontal alignment will be out of the "biomechanical window" of ± 3° from the neutral mechanical axis in 20-30% of the cases [6],[10],[28]. Proper planning and cut verification with conventional navigation [16] or computer navigation [16],[28] can solve the problem of frontal malalignment. The efficacy and practicability of the combined concept of conventional navigation and extension gap first technique could be proven with this current study, even when using MIS surgical techniques.

Although the main goal of this report was to describe the technique, tips, tricks and pitfalls of the combined conventional navigation with extension first technique this study has some limitations. There was no control group with "conventional technique" or computer navigation. Nevertheless the historical comparison with the published literature shows comparable results with computer navigation [6],[10],[28]and significant better results compared to the "conventional technique" [1],[26],[28]. Furthermore there was no control of rotational alignment of the components postoperative with CT scans [10]. This additional CT scan after surgery in well functioning TKA is an ethical problem. Therefore in this study the rotational control was based on intraoperative standardized stress tests using conventional spacers, control of proper patella tracking and postoperative clinical controls of the stability in the flexion gap.

Planning is a crucial part of a successful TKA and should include history, clinical examinations, radiographic analysis and planning on a weight bearing full leg length radiograph [22]. The standardized weight bearing full leg radiograph represent the key for deformity analyzes and planning of the long axis in the frontal plane (Figures 1 and 2). On short x-rays the tibiofemoral angle can be measured only, which does not allow analysis of the deformity and the mechanical axis of the whole leg. The overall mechanical axis, deformity analysis and IM-correction angle are necessary for proper frontal alignment correction [16],[22].

With deformity analysis according to Paley [21] about half of the varus knees (48%) the bony deformity was located at the femur and the tibia was normal in this study (Figure 1). This means, that the lateral and not the medial condyle was the most distal part for the cutting block positioning at the femur. Additional in valgus knees 35% showed the deformity at the tibia only and in 47% it was located at tibia and femur. As we operate in almost all cases knees with deformities, the frontal distal femur and proximal tibia cuts are individual, depending on the location of deformity only and should be planned by deformity analyzes using LDFA and MPTA (see Table 2).

LDFA	**Femur**	**Correction cut**	**Medial condyle**	**Lateral condyle**
90°	Neutral	Neutral	Equal	Equal
> 90°	Varus	Valgus	Less	More
< 90°	Valgus	Varus	More	Less
MPTA	**Tibia**	**Correction cut**	**Medial plateau**	**Lateral plateau**
90°	Neutral	Neutral	Equal	Equal
> 90°	Varus	Valgus	Less	More
< 90°	Valgus	Varus	More	Less

Table 2: Planning of bone resections according to LDFA and MPTA measurements.

In this study the IM-correction angle showed an average of 6.2° with a wide range of individual variations (2-11) (Figure 10). In some population this angle might increase up to 15°. Still a lot of surgeons routinely use 4-6° of valgus correction at the femur without any further planning which might cause a clinical significant malalignment at the femur (more 3° deviation from the neutral mechanical axis) in a significant number of patients. This could be confirmed in this study where 26% of the femur alignment would have been off more than 3° when using a valgus correction of 5° in all the cases. Even with preoperative planning the conventional intramedullary instruments at the femur are not very accurate because the location of the intramedullary entry point and the distance of the isthmus at the femur may influence the planned correction angle. Furthermore when hammering the distal plate on the femur the instrument has always the tendency to be flush on both condyles. In this study the LDFA was used as “golden standard” and the planned IM-correction angle had to be adjusted according to the LDFA in 8% of the cases. This concept of using the LDFA as “golden standard” has been used for an extramedullary alignment system without using an intramedullary rod in a recent study [4].

Extramedullary control of the alignment by using rods or a wire cable only is not very accurate. At the femur the proximal reference (centre of the femoral head) is not visible and the spina iliaca anterior represents a relative landmark only. Furthermore neutral rotation and alignment of the leg along the body axis is important. Deviation of the rod for 1 cm to medial/lateral to the proximal reference point will cause ~ 1° valgus / varus malalignment at the joint level. At the tibia the extramedullary control seems to be more accurate because the landmarks can be identified more easily. Nevertheless the control should be done in extension to better reference to the proximal and distal landmarks. Deviation of the rod for 1 cm medial/lateral to the centre of the ankle will cause ~ 1.5° varus / valgus malalignment at the joint level.

The conventional navigation with using conventional instruments without a computer has been developed as a cost effective alternative to computer navigation and was performed in more than 2,500 cases successfully within the last 8 years in our institution [13]. Especially in MIS this technique is helpful and even with smaller incisions proper alignment is not an issue when using this technique [16],[23].

The sequences of the distal femur & proximal tibia cut are not important. Especially in MIS the femur is the more saver cut to start with [23]. Once the distal femur cut is done, a better over- view and more space for cutting the tibia will be present. The distal femur cut corrects the varus- or valgus deformity and should end up with a neutral mechanical axis in all knees [17]. Furthermore in TKA the distal femur cut determines the distal joint line, which should not be changed. Therefore the distal femur cut should be determined by the thickness of the distal femoral component only (measured resection). The uncontrolled change of the distal and posterior joint lines is one of the disadvantages of the classical "balanced gap" technique (see Table 1).

Measured resection	Balanced Gap
• Preferred by 80% of surgeons • Bone cuts independent from ligaments • 3 different landmarks possible • Difficult to find landmarks • Minimum 3° ER for all • Soft tissue control after all cuts only releases • May lead to recutting femur for: wrong size or rotation possible	• Preferred by 20° only • Cuts independent from bony landmark • Ligaments must be intact • Extension gap must be released perfect • Risk for internal malrotation does not work after extensive • Femur deformity has to be addressed • Uncontrolled change of joint line

Table 1: Comparison measured resection versus balanced gap technique.

The sagittal bone cuts are more demanding and determine the flexion and extension positioning of the component at the femur and the slope at the tibia. Both represent important biomechanical factors in the sagittal plane. The flexion/extension positioning of the distal femur should be in slight flexion (3-5°) to the sagittal axis to be more anatomical and prevent undercutting. In this series this slight flexion was achieved by using the most posterior entry point in the sagittal plane at the distal femur. An alternative would be to use a more central entry point and a distal cutting jig with fix 3° of flexion. The recommended slope at the tibia depends on the type of implant, constrain and fix or mobile bearings. In the NexGen LPS Flex Fixed® a slope of 7° in all cases is recommended. The relatively less slope in this series might be caused by the use of an intramedullary alignment system with a too far anterior entry point (first to middle third of the ap tibia dimension). According to the Perth CT protocol [10] we now use a more posterior entry point (centre of the tibia) when using this intramedullary system.

The bone cuts in the axial plane are a challenge for the surgeon and remain the most difficult work at the bones to properly balance the gaps. In a recent CT-based kinematic cadaver study the several problems of proper rotational alignment at the femur and tibia were summarized [29]. At the femur the anterior and posterior cuts determine the sizing, anterior and rotational positioning and posterior offset of the femoral component. The decision for in between sizes depends on the deformity, design of prosthesis, types of constrain and the surgical technique used (measured resection with anterior versus posterior referencing or balanced gap technique). In this study the closer size or for clear in between sizes the larger size was used. With bringing the implant position 1-2 mm more anterior or posterior this mismatch can be partly compensated (modified posterior referencing). More posterior positioning is allowed only when the femur component will be in slightly flexion, otherwise undercutting will occur. More anterior positioning should be performed with caution otherwise overstuffing might occur. In clear in between sizes situations the larger femur is the more saver solution, because downsizing is possible always. Furthermore downsizing of the femur causes less posterior offset and might limit flexion due to impingement [7]. In 8% of the cases the primary chosen size was the wrong decision, but with the extension gap first technique this mismatch could be detected before the bone cuts were performed.

Besides sizing the rotational positioning of the femoral component represents the key for a balanced flexion gap [14],[25],[29]. Varus knees showed on average 2° and valgus 4° of external rotation correction according to the posterior condylar line (posterior condylar angle) in a recent CT study [1]. But in several studies the external correction angle demonstrated a wide range of individual variety (0-10° external rotation) depending on the deformity of the knee [11],[14],[25],[26],[29]. In this study the average external rotation was 3° (0-7) in varus and 5° (3-9) in valgus knees. This slightly higher average external rotation compared to the CT study of Aglietti [1]occurred, because even when the intraoperative measurement was less than 3° of external rotation, 0° was used in varus knees in cases with clear 0° only and never in valgus knees. Slightly more external rotation is always saver compared to internal malrotation [14],[25],. When using always 3° of external rotation a clinical relevant internal malrotation (> 3°) might occur in about 10% of the varus knees and 35% of the valgus knees [14],[26],[29]. This could be confirmed in this study also. Based on our findings we recommend 3° external rotation in varus and 5° in valgus knees. Nevertheless the "outliers", who do not fit to this concept, have to be indentified during surgery.

In principal there are two philosophies described and used for more than 25 years for performing the rotational bone cuts at the femur. The "measured resection" refers to bony landmarks [2],[17],[29]and "balanced gap" technique to soft tissues [11],[27],[31] only. Both have shown advantages and disadvantages (Table 1) and most of the surgeons are using either the landmark or soft tissue oriented technique only. The difficulty to identify the surgical epicondylar line remains the main disadvantage of the measured resection technique [14],[29]. Several studies have already shown that palpation of the surgical epicondylar line as well as the AP-line is not very reliable [26],[29]. But preparing of the medial and lateral condyles with removing the soft tissues and identification of the ligaments insertion makes the identification much more accurate (Figure 8). Furthermore recutting the femur for flexion-extension mismatch or malrotation of the component represents a further disadvantage of the measured resection technique. On the other hand the balanced gap technique represents an easy but not save technique and shows some important pitfalls (Table 1). Especially the potential risk for internal malrotation of the femoral component is relevant [14]. These patients will still have a rectangular flexion gap, but the knee will not rotate along the surgical epicondylar axis. This might produce clinical relevant midflexion problems and end up in a painful flexion instability or stiff knee [11],[14],[25].

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Table 1: Comparison measured resection versus balanced gap technique.

The extension gap first technique described in this paper has been developed independently by several authors using special instruments, computer navigation or conventional instruments with spacers or spreaders to perform more accurate bone cuts in the axial plane at the femur [10],[16],[20],[24],[31]. Using this concept the two worlds of bony landmarks and soft tissues are coming together. In this study it could be shown that this "double checking" was very helpful, outliers could be identified easily and the proper rotational positioning worked within a variation of ± 2°. Especially in MIS the extension gap first technique has been very helpful to prevent outliers and to make proper bone cuts in all three planes.

At the tibia the rotational positioning of the cut is important for a neutral varus/valgus alignment and a symmetric flexion gap [2],[14],[17],[28]. Only when using a zero slope knee design this can be ignored. Finally the rotational positioning of the tibia component is the most important factor for patella tracking in knees with fix bearings [8],[14]. Mobile bearing knees might compensate for a rotational malpositioning of the tibia component up to 10° [14]. Several landmarks have been proposed for rotational positioning at the tibia [17]. We prefer the functional alignment (mid to medial third of the tibia tubercle to the centre of the posterior cruciate insertion). This determines the Q-angle, which represents the most important factor for proper patella tracking [14]. This functional landmark is slightly different to the rotational positioning proposed by Akagi [2]. In his CT study the measurements were done in full extension only. Therefore the slightly more internal rotated landmark in his study included the several degrees of external rotation with the "screw home" mechanism in full extension. As the patella comes in contact with the trochlea in 30° of flexion only, less internal rotation as proposed by Akagi seems to be more functional. It is important to identify the knees with proximal tibia torsional deformities, where the tibia tubercle is not lying on the anterior tibia crest. Especially patients with isolated or dominating arthritis at the patellofemoral joint showed a lateral malpositioning of the tibia tubercle (increased Q-angle or TT-TG distance) in this study. This torsional deformity has to be compensated by a compromise positioning of the tibia cut and baseblate positioning. The second anatomical landmark using the "curve on curve" concept [5] was very helpful to control the functional landmark in this study.

Balancing of the knee depends on the bone cuts and the soft tissue situation of the deformity. Once the bone cuts for correction of the malalignment are done correctly, in almost all patients some type of soft tissue work has to be performed to balance the knee [17],[30]. In principal the soft tissue balancing techniques might be separated in three types due to the underlying pathology (varus, valgus and sagittal deformities). To balance the knee several different techniques and sequences of soft tissue work had been published [9],[12],[18],[19],[30]. There is no difference between the standard open approaches and standard MIS approaches (Mini-midvastus, Mini-subvastus and Quadriceps sparing) concerning the different steps of soft tissue balancing [15]. A classical step-by-step approach (Table 3) was used for all patients in this study. In very severe deformities where grade 2 releases in step 2 (balancing extension gap) were not enough to balance the knee in extension, further releases (grade 3 and 4) were not performed. After grade 3 and 4 releases in the extension gap the contract side will significantly open in flexion and therefore the ligament information for the flexion gap control will be lost. In these cases the remaining trapezoidal extension gap was noted in mm opening. When controlling the flexion gap after positioning the 4in1 cutting block (see above), the same trapezoidal flexion gap as in the extension gap has to be present (symmetric asymmetry). This indicates proper rotational positioning of the cutting block. After final preparation of the femur this soft tissue imbalance can now be solved by further grade 3 or 4 release to end up in symmetrical flexion / extension gaps.

VARUS DEFORMITY	
Step 1	Deep medial MCL, posterior medial capsule and PCL
Step 2	Semimembranousus insertion
Step 3	Superficial MCL
Step 4	Medial condylar osteotomy (pes anserinus)
VALGUS DEFORMITY	
Step 1	Iliotibial band, posterior lateral capsule and PCL
Step 2	Lateral collateral ligament
Step 3	Popliteus tendon
Step 4	Long head biceps tendon

Table 3: Step by step soft tissue releases.

Surgeons relying more on the ligaments prefer the balanced gap technique [11],[14],[27],[31]. This technique is especially recommended for mobile bearing knees, where a tight and absolute symmetric flexion gap is necessary [14],[27],[31]. Nevertheless the extension gap first concept can be also used for the balanced gap technique in a slightly modified way. The extension gap is prepared and balanced in the same way as described above. To position the 4in1 cutting block at the femur, the flexion spacer block with the same thickness as in the extension gap is used to find the rotational positioning according to the ligaments only. Before performing the anterior and posterior femur cuts the landmarks on the distal femur (surgical epicondylar axis and AP-line) are used to “double check” the proper rotational positioning of the cutting block. At this stage malrotation of the cutting block according to landmarks may be caused by wrong identification of the rotational landmarks, improper frontal alignment at the tibia, insufficient soft tissue releases, over release or insufficient soft tissues in the extension gap, or malrotation of the flexion spacer block to other reasons (see Table 1). The cause of this rotational malalignment has to be analysed and corrected before the anterior and posterior femur cuts are performed. Internal malrotation with a negative posterior condylar angle should never be accepted, because these knees do not exist. The proper sizing of the femur is then performed by posterior or anterior referencing with measuring the distance of the anterior cut slot to the anterior cortex of the femur to prevent undercutting. In severe deformities where grade 3 and 4 releases in the extension gap would be required, it is not allowed to use a trapezoidal extension gap for the flexion gap control (see above). A trapezoidal flexion gap will cause a wrong rotational alignment in the axial plane by using the balanced gap technique (external malrotation in medial and internal malrotation in lateral contract gaps). On the other hand after grade 3 and 4 releases in the extension gap the contract side will significantly open in flexion (see above). In these cases the balanced gap technique does not work anymore and landmarks can perform orientation of the rotational positioning only. Therefore surgeons using the tensioned gap technique don’t perform extensive releases in the extension gap [11],[27],[31]. To compensate for this under releasing of the contract side, they prefer cheating at the distal femur cut and therefore allow under correction of the frontal deformity.

Measured resection	Balanced Gap
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Table 1: Comparison measured resection versus balanced gap technique.

CONCLUSION

In this report the described concepts of "conventional navigation" and "extension gap first" technique have shown to be efficient and practicable. Proper frontal, sagittal and axial bone cuts to correct the individual bony deformities are possible in almost all of the knees with this technique. This concept is a step-by-step approach and independent of the underlying deformity. Conventional navigation has shown to be a cost-effective alternative to computer navigation. The axial bone cuts at the femur, which are the most important factor for balancing the flexion gap, are still a challenge for most of the surgeons. The extension gap first concept allows including bony landmarks and soft tissues for decision-making. Therefore the extension gap first concept offers a reproducible surgical technique for performing proper bone cuts in the axial plane at the femur also.

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