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ORIGINAL PAPER

Soft tissue balance using the tibia first gap technique with navigation system in cruciate-retaining total knee arthroplasty

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Abstract
Purpose The procedures of bone cut and soft tissue balancing in total knee arthroplasty (TKA) are usually performed using the measured resection technique or the gap technique; however, the superiority of these techniques is controversial. An increase of extension gap after resection of the femoral posterior condyle and a difference between gaps before and after femoral component placement have been reported. We therefore postulated that the use of the tibia first gap technique might have an advantage in avoiding the mismatch before and after resection of the femoral posterior condyle and femoral component placement.
Methods We performed cruciate-retaining TKAs for 60 varus type osteoarthritic patients with tibia first gap technique using a CT-free navigation system. A TKA tensor designed to facilitate soft tissue balance measurements throughout the range of motion with a reduced and repaired patello-femoral joint was used to assess soft tissue balance (joint gap and varus ligament balance) at extension and flexion between the basic value after tibial cut and the final value following femoral cut and with the femoral component in place.
Results Whereas varus ligament balance at flexion showed significant decrease in the final value at flexion due to the amount of femoral rotation, the basic value of the joint gap before femoral osteotomy reflected the final value following femoral cut and with the femoral component in place.
Conclusion The tibia first gap technique may have the advantage that surgeons can predict final soft tissue balance before femoral osteotomies.

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Introduction

Total knee arthroplasty (TKA) should be performed to achieve stable and well-aligned tibiofemoral and patello-femoral (PF) joints, aiming at long-term clinical patient satisfaction [1–3]. Recently, the use of computer-assisted navigation systems has been reported to improve the achievement of accurate bone cuts and implantations [4–7]. We previously reported on a CT-free navigation system (Vector Vision R, Depuy–Brain LAB, Heimstetten, Germany) which significantly improved the accuracy of implantations in relation to the mechanical axis, and achieved an early and mid-term clinical outcome equivalent to that of a manual group [8–10].

Despite the success of manual TKA, a common difficulty in the manual procedure is obtaining accurate intra-operative soft tissue balancing, which surgeons traditionally address through "subjective feel" and experience with the PF joint everted. Knee instability after primary TKA due to inadequate correction of soft tissue imbalances is considered an important factor for early TKA failure [11, 12]. We therefore developed a new tensor for TKA that enables us to assess soft tissue balancing throughout the range of motion in the knee with a reduced PF joint and femoral component in place. This tensor permits us to intra-operatively reproduce post-operative alignment of the PF and tibio-femoral joints [13]. We previously described the design of this tensor, our initial intra-operative soft tissue balance measurement, and its clinical relevance in TKA [14–21].

In our previous study, soft tissue balance measurements were only performed in posterior-stabilised (PS) or cruciate-retaining (CR) TKAs using the measured resection technique. However, the best method of obtaining rotational alignment of the femoral component in flexion remains controversial. Some investigators favour a measured resection technique in which bony landmarks (femoral epicondyles, posterior femoral condyles, or the anteroposterior axis) are the primary determinants of femoral component rotation [22–27]. Others recommend a gap-balancing methodology in which the femoral component is positioned parallel to the resected proximal tibia with each collateral ligament equally tensioned [28–30]. In our study, using an offset type tensor, we performed soft tissue balance assessment during TKA using the tibia first gap technique with a navigation system. Based on evidence pointing to an increase of extension gap after resection of the femoral posterior condyle [31] and a difference between gaps before and after femoral component placement [21], we postulated that the use of the tibia first gap technique might have an advantage in avoiding the mismatch before and after resection of the femoral posterior condyle and femoral component placement. In the study to investigate this hypothesis, basic and final soft tissue balance including joint gap and varus ligament imbalance were compared with the PF joint reduced using the offset type tensor.

Materials and methods

The subjects were 60 patients (60 osteoarthritic knees) who underwent primary CR TKA (e-motion, B. Braun Aesculap, Germany) between 2007 and 2010. Those with valgus deformity and severe bony defects were excluded. The patient population comprised 54 women and 6 men with a mean age of 74.2±6.6 years. The average coronal plane alignment was 9.1±2.2° in varus pre-operatively. Operations were performed by the two senior authors who each have more than ten years experience with TKA. In all cases, the CT-free navigation system (Orthopilot 4.2, B. Braun Aesculap, Germany) was used to obtain accuracy of implantations and to accurately measure the flexion angle of the knee during intra-operative soft tissue balance measurement with the offset type TKA tensor. As mentioned below, the amount of bony cut and vaus/valgus/flexion/extension alignment on the screen of the navigation system were determined based on soft tissue balance measured using the tensor.

Offset type TKA tensor

As previously described [14, 16, 18], our TKA tensor consists of three parts: an upper seesaw plate, a lower platform plate with a spike and an extra-articular main body (Fig. 1). Following bony resections and soft tissue releases, we can place this tensor with the lower platform fixed to the proximal tibia. Even if the femoral condyle is not resected, the upper seesaw plate with shaped insert can be fitted to the femoral condyle (Fig. 2a) or femoral prosthesis (Fig. 2b). After the PF joint is reduced, the medial parapatellar arthrotomy is temporarily repaired by applying stitches both proximally and distally to the connection arm of the tensor. These mechanisms permit us to reproduce joint constraint. This device is ultimately designed to permit surgeons to measure the joint centre gap and varus angle, while applying a constant joint distraction force. Joint distraction forces ranging from 30 lb (13.6 kg) to 80 lb (36.3 kg) can be exerted between the seesaw and platform plates through a specially made torque driver (Fig. 1), which can change the applied torque value. After sterilisation, this torque driver is placed on a rack that contains a

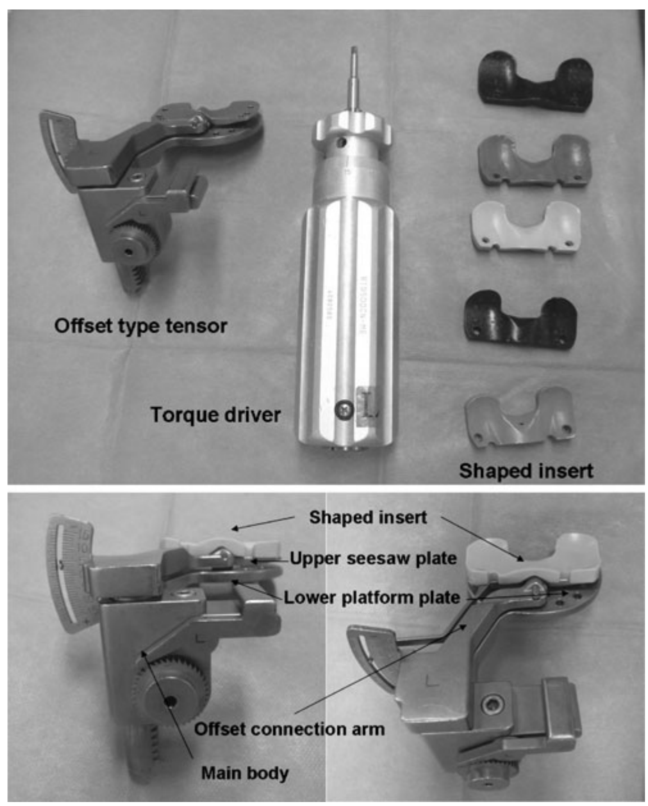

Fig. 1 Offset type tensor. The tensor consists of three parts: the upper seesaw plate to which a shaped insert can be attached, a lower platform plate, and an extra-articular main body. Two plates are connected to the extra-articular main body by the offset connection arm through a medial parapatellar arthrotomy, which permits reduction of the PF joint while performing measurements

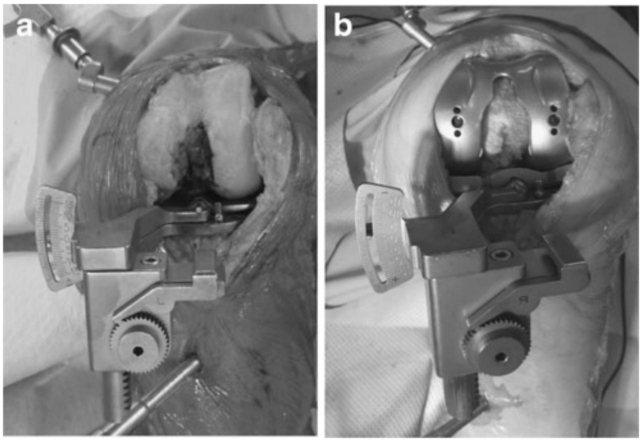

Fig. 2 Measurement of soft tissue balance using the tensor. Whether the femoral condyle was resected or not, the upper seesaw plate can be fitted to the femoral condyle (**a**) or femoral prosthesis (**b**)

pinion mechanism along the extra-articular main body, and the appropriate torque is applied to generate the designated distraction force; in preliminary *in-vitro* experiments, we obtained an error for joint distraction within ± 3%. Once appropriately distracted, attention is focused on a scale that corresponds to the tensor: the angle (positive value in varus ligament balance; varus angle) between the seesaw and platform plates, and the distance (mm) (joint centre gap) between the centre midpoints of the upper surface of the seesaw plate and the proximal tibial cut. By measuring these angular deviations and distances under a constant joint distraction force, we are able to measure ligament balance and joint centre gaps, respectively.

Intraoperative measurement

We performed all TKAs using the navigation system according to the manufacturer's instruction. After inflating the tourniquet to 280 mmHg and registering the anatomical landmarks for the navigation system, we performed a medial parapatellar arthrotomy. The tibial osteotomy was performed first perpendicular to the tibial axis in the coronal and sagittal plane. The insertion of the PCL was preserved by a bony island. After tibial osteotomy, the necessary osteophyte removal and medial ligament release were made in extension. At this point, step-by-step appropriate release of medial side soft tissue (posteromedial capsule, medial collateral ligament (MCL), semimenbranosus, and pes anserine tendons) was performed, in which residual lateral laxity was allowed. Following these procedures, the offset type tensor was placed with the lower platform fixed to the proximal tibia. The upper seesaw plate with shaped insert was fitted to the femoral condyle to avoid anterior translation of the tibia. The first measurement of soft tissue balance, joint centre gap (mm) and varus angle (°) were measured at 0° and 90° flexion angle guided by the navigation system with the PF joint reduced as "the basic value". During each measurement, the thigh and knee were aligned in the sagittal plane so as to eliminate the external load on the knee at each flexion angle. The joint distraction force was set at 40 lb. in all patients. We selected this distraction force because it re-creates a joint gap in full extension with femoral trial, which corresponds to the insert thickness of our preliminary clinical studies. We loaded this joint distraction force several times until the joint centre gap remained constant; this was done to reduce the error that can result from creep elongation of the surrounding soft tissues. Following the first measurements, the amount of distal femoral osteotomy was determined perpendicular to the femoral mechanical axis on the screen of the navigation system. And then, based on the basic values with the tensor, the amount of the posterior femoral osteotomy and varus/valgus balance were determined on the screen of the navigation system to create an acceptable rectangular extension and flexion gap. Next, bony resections were performed following the navigation system. If osteophytes on the posterior aspect of the femur existed, they were removed at this time. Following each bony resection, we fixed the tensor and the femoral trial prosthesis and the PF joint was reduced by temporarily suturing the medial parapatellar arthrotomy. At this point, we measured the joint centre gap (mm) and varus ligament balance (°) with the knee at extension and flexion guided by the navigation system as "the final value".

All values were expressed as mean ± standard error of the mean (SE). The results were analysed statistically using a statistical software package (Statview 5.0, Abacus Concepts Inc, Berkeley, CA, USA). We used the paired Student's *t*-test to compare the parameters between the basic and final values. $P<0.05$ was considered statistically significant.

Results

Basic and final joint centre gap

The mean values of joint centre gap with the knee at extension and flexion were 12.5 and 15.0 mm in the basic value, and 12.6 and 14.1 mm in the final value (Table 1). In the assessment of joint centre gap, there were no significant differences between the basic and final value both at extension and flexion (Fig. 3).

Basic and final varus angle

The mean external rotation of femoral component placed was 3.8±0.2°, which was shown by the navigation system. The mean varus angles with the knee at extension and flexion were 1.0° and 3.1° in the basic value, and 1.5° and −0.8° in the final value (Table 1). In the assessment of varus angle, while there was no significant difference

Table 1 Basic and final value of soft tissue balance

Flexion	Joint component gap (mm)	Varus ligament imbalance (°)
0°	12.5±0.3 / 12.6±0.4	1.0±0.4 / 1.5±0.5
90°	15.0±0.3 / 14.1±0.6	3.1±0.5 / −0.8±0.5*

Basic/final values given as mean±SE. Statistical difference between each angle (*P<0.05 vs. basic value)

between the basic and final values at extension, the final value at flexion significantly decreased to valgus value compared to the basic value (Fig. 4).

Discussion

We previously reported studies using the offset type TKA tensor, in which we discussed the importance of maintaining a reduced and anatomically oriented PF joint in order to obtain accurate and more physiologically-relevant soft tissue balancing [14–16, 18, 19]. To assess accurate soft tissue balancing during TKAs, we emphasise the importance of reproducing the physiological joint condition after TKAs. However, in our previous study, TKA procedures with the tensor were performed after bone resection, in which soft tissue balance was assessed after the bone cuts. The superiority of techniques for positioning the femoral component in flexion using the measured resection technique or tensioned gap technique remains controversial with regard to rotational alignment. In our study, the tensor that can be used for the gap technique as well as measure the resection technique [32] was used for TKA using the tibia first gap technique. Following tibia cut first, we determined the rotational alignment of the femoral component using the navigation system based on the basic soft tissue balance assessed by the tensor in advance. After that, we performed the posterior cut of the femur.

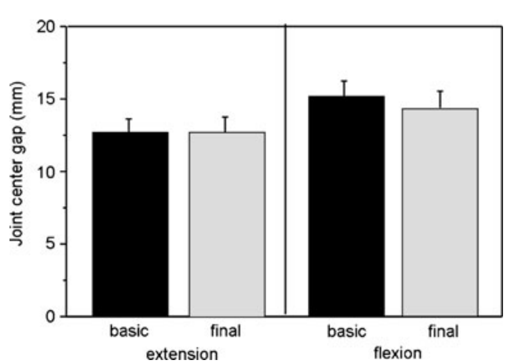

Fig. 3 Joint centre gap. In the assessment of the joint centre gap, there were no significant differences between the basic and final values both at extension and flexion

Preparing equal and rectangular extension and flexion joint gaps is recognised as an essential concept in TKA. In the procedure using the gap technique, the extension gap has been reported to be wider after resection of the posterior femoral condyle and removal of the osteophytes on the posterior aspect of the femur, a procedure performed to re-establish the posterior capsular recess in CR TKA [33] as well as PS TKA [31]. Therefore, if the flexion gap is matched to the previously prepared extension gap, the extension gap will increase, and the flexion gap will become smaller than the extension gap. In contrast, we reported that the extension gap decreased and varus ligament balance is reduced after femoral component placement. This is caused by the tensed posterior structures of the knee with the posterior condyle of the externally rotated aligned femoral trial [21]. Based on this background, we postulated that the use of the tibia first gap technique might have an advantage of avoiding the mismatch before and after resection of the femoral posterior condyle and femoral component placement. As expected, the study demonstrated that there is no significant difference between the basic value of the joint gap before femoral osteotomy and the final value following femoral cut and with the femoral component in place. Accordingly, with the tibia first gap technique, surgeons are able to predict the final value of the joint gap from the basic value before femoral osteotomies.

However, in our study, varus ligament balance showed significant differences between the basic and final values at flexion. The results showed varus ligament balance before femoral osteotomies at flexion changed to a valgus ligament balance of 3.9° following femoral osteotomies and the placement of the femoral component. The basic value of varus ligament balance at flexion is based on the femoral posterior condylar axis, while the final value of varus ligament value at flexion is based on a 3.8° external rotated axis related to the posterior condylar axis. The

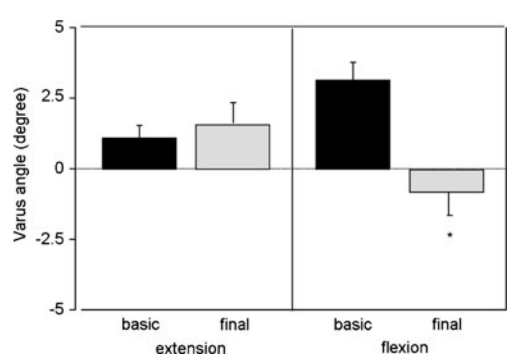

Fig. 4 Varus ligament imbalance. In the assessment of varus ligament imbalance, while there was no significant difference between the basic and final values at extension, the final value at flexion significantly decreased to the valgus value compared to the basic value (*P<0.05 vs. the basic value)

tendency toward varus to valgus imbalance was mainly based on the rotational alignment determined. Similarly, Heesterbeek et al. reported that the gap technique resulted in a balanced flexion gap but that the femoral component was placed with −4° to 13° of external rotation in relation to the posterior condylar axis owing to patient variability and variation in ligament releases [34]. In addition, with the gap technique, focusing on an adjustment of varus/valgus ligament balance sometimes results in excessive release of medial structures and the use of a thicker polyethylene insert [35, 36]. Taken together, with these procedures, while the final value of varus/valgus imbalance may be predictable before femoral osteotomies, surgeons should take care not to implant the femoral component in the over-external rotated position.

Our study has some limitations. We did not specifically investigate the effects of osteophytes removal and soft tissue release on the posterior aspect of the femur. These procedures were difficult to perform before femoral osteotomies. Minoda et al. assessed the three different extension gaps before and after femoral osteotomy of the posterior condyle, and after removal of femoral posterior osteophytes [33]. In the future, we need to further investigate the effect of these procedures at flexion as well as at extension. In addition, the tensor was used with only 40 lbs. distraction force. The different load may influence the balance and rotation of femoral component determined. In the future, different loads should be examined to clarify the influence on soft tissue balance and femoral component rotation determined. Furthermore, the study with the tibia first gap technique was not directly compared to the measured resection technique and this comparison should be performed in the future.

In our study, we assessed basic soft tissue balance and final soft tissue balance with the patellar reduced using an offset type tensor in CR TKA with the tibia first gap technique. The basic value of the joint gap and ligament imbalance before femoral osteotomies using the tibia first gap technique reflected a final value following femoral cut and placement of the femoral component. Accordingly, the tibia first gap technique may have the advantage that surgeons can predict the final soft tissue balance prior to femoral osteotomies.

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Conflict of interest The authors declare that they have no conflict of interest.

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