The intra-operative joint gap in cruciate-retaining compared with posterior-stabilised total knee replacement

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We have developed a new tensor for total knee replacements which is designed to assist with soft-tissue balancing throughout the full range of movement with a reduced patellofemoral joint. Using this tensor in 40 patients with osteoarthritis we compared the intra-operative joint gap in cruciate-retaining and posterior-stabilised total knee replacements at 0°, 10°, 45°, 90° and 135° of flexion, with the patella both everted and reduced.

While the measurement of the joint gap with a reduced patella in posterior-stabilised knees increased from extension to flexion, it remained constant for cruciate-retaining joints throughout a full range of movement. The joint gaps at deep knee flexion were significantly smaller for both types of prosthetic knee when the patellofemoral joint was reduced ($p < 0.05$).

The aim of a total knee replacement (TKR) is to achieve stable tibiofemoral and patellofemoral joints. This relies on the accurate alignment of the joint components with and balancing of the soft tissues using appropriate surgical techniques and well-designed implants.¹⁻⁴ Using the traditional intra- and extramedullary alignment devices, the proper alignment of each component is dependent on accurate femoral and tibial osteotomies at ideal levels and angles. Improvement in surgical instruments and computer-assisted navigation has enabled more accurate osteotomies to be made with better placement of implants.⁵⁻¹¹ We have previously reported on the accuracy of osteotomies and implantation using a CT-free navigation system and the early clinical outcome.^{12,13} However, evaluation of the soft-tissue balance during operation remains difficult and relies on the subjective feel and experience of the surgeon. Although several methods and devices such as manual distraction,¹⁴ tensor balances,¹⁵⁻¹⁹ and electric instruments²⁰⁻²³ have been described for assessing the soft-tissue balance, they can only be used when the patella is everted. In order to allow soft-tissue balancing under more physiological conditions, we have developed a new tensor which allows its assessment throughout the range of movement with the patellofemoral joint reduced and the tibiofemoral joints aligned.²⁴ We have published our experience using this device for intra-operative measurement with a posterior-stabilised TKR.²⁵⁻²⁷ We noted that the joint gap increased with knee flexion to mid-range but

decreased in deep flexion.²⁵ We also observed that the intra-operative assessment of the joint gap with the patellofemoral joint reduced could predict the post-operative angle of flexion and thus allow evaluation to be made throughout the range of movement.²⁶ We further demonstrated that the correlation between the soft-tissue balance as assessed by the tensor and the navigation system was higher when the patellofemoral joint was reduced rather than that when the patella was everted, suggesting that the soft-tissue balance was assessed better with the patellofemoral joint reduced when using a navigation system.²⁷

In our previous studies²⁴⁻²⁷ only a posterior stabilised TKR was assessed. The long-term results of both cruciate-retaining and posterior stabilised TKRs have been satisfactory but it has not been clear which is superior.^{28,29} In this study we describe our experience with the tensor device for the measurement of the intra-operative gap in both cruciate-retaining and posterior stabilised TKRs, with the patella both reduced and everted. We have evaluated the differences in the joint gap in cruciate-retaining TKR with both patellar orientations, and have compared the joint gap in cruciate-retaining TKR with that in posterior stabilised TKR with the patella reduced, as occurs after the operation.

Patients and Methods

Between September 2003 and August 2005 a series of 40 consecutive women with osteoarthritis who were blinded to the type of implant received, was randomised prospectively

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Fig. 1a

Fig. 1b

The photographs showing the tensor for a) cruciate-retaining and b) posterior-stabilised total knee replacements. It consists of three parts: an upper plate (A), lower platform plate (B) and the extra-articular main body (C). The two plates are connected to the extra-articular main body by the offset connection arm (D) through a medial parapatellar arthrotomy, which allows reduction of the patellofemoral joint while performing measurements.

into 20 who received a cruciate-retaining TKR (NexGen CR Flex; Zimmer Inc, Warsaw, Indiana) and 20 who had a posterior stabilised TKR (NexGen LPS Flex; Zimmer Inc). The cruciate-retaining TKR group had a mean age of 73.7 years (63 to 86) and the posterior stabilised TKR group of 73.8 years (55 to 86). Each patient had a varus deformity, with those receiving a cruciate-retaining TKR having a mean pre-operative coronal plane alignment of 6.2° (2° to 17°) in varus and those with a posterior stabilised TKR 7.5° (2° to 18°) in varus. The surgery was performed by the senior author (HM).

The total knee replacement tensor. The tensor consists of three parts: an upper seesaw plate, a lower platform plate with a spike and an extra-articular main body.²⁵⁻²⁷ Both plates are placed at the centre of the knee and we applied one of two tensioning devices which were designed to fit either a cruciate-retaining (Fig. 1a) or a posterior stabilised (Fig. 1b) TKR. The posterior stabilised TKR tensor consists of a plate with a proximal post, which fits into the intercondylar space with a cam for the femoral trial prosthesis. This post-and-cam mechanism controls the tibiofemoral position in both the coronal and sagittal planes. The cruciate-retaining TKR tensor has a plate with a proximal convex-shaped centraliser which fits into the intercondylar space and controls coronal alignment of the joint. These mechanisms allow reproduction of joint constraint and alignment after implantation of the components.

The device was designed to allow surgeons to measure the ligament balance and the gap between the centre of the joint

and the component while applying a constant distraction force. Distraction forces ranging between 13.6 kg and 36.3 kg can be exerted between the plates through a specially made torque driver which can change the applied torque value. After sterilisation, the driver is placed on a rack which contains a 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 distracted, the angle between the plates and the distance (mm) between the midpoints of the upper surface of the proximal plate and the proximal tibial cut were measured under a constant joint distraction force. We were thus able to determine the ligament balance and the gaps between the centre of the joint and the components.

Intra-operative measurement. After analysing the accuracy and reproducibility of the tensor, we proceeded with intra-operative measurements to determine the feasibility of our system and to assess the effect of both patellar reduction and eversion on soft-tissue balance.

All the TKRs were carried out using a measured resection technique with a conventional resection block. Under a tourniquet we performed a medial parapatellar arthrotomy. In the 20 patients randomised to receive a cruciate-retaining TKR, the anterior cruciate ligament (ACL) was resected and the posterior cruciate ligament (PCL) preserved along with its bony island. In the 20 patients randomised to receive a posterior stabilised TKR, the ACL and

Table I. The mean (SEM) joint component gap in mm with patellar eversion and patellofemoral joint reduction

Flexion (°)	Cruciate-retaining		Posterior-stabilised	
	Eversion	Reduction	Eversion	Reduction
0	12.7 (0.4)	12.7 (0.4)	11.2 (0.4)	11.3 (0.5)
10	15.6 (0.5)*	15.8 (0.4)*	14.5 (0.5)*	14.7 (0.5)*
45	14.8 (0.5)	15.3 (0.5)	16.6 (0.7) [†]	17.1 (0.7) ^{†‡}
90	15.1 (0.7)	14.1 (0.5)	17.7 (0.6) [§]	17.6 (0.9) [§]
135	15.3 (0.9)	12.9 (0.5) [¶]	19.6 (0.7) [†]	14.8 (0.7) ^{***}

Statistical difference between each angle: *, $p < 0.01$ vs the less angle; †, $p < 0.05$

Statistical difference between patellar eversion and patellofemoral joint reduction: ‡, $p < 0.05$; §, $p < 0.01$ vs cruciate retaining

Statistical difference between cruciate-retaining and posterior-stabilised: ¶, $p < 0.05$; ***, $p < 0.01$ vs patellar eversion

PCL were both resected. A distal femoral osteotomy was performed perpendicular to the mechanical axis of the femur according to pre-operative long-leg radiographs. Femoral external rotation was preset at 3° relative to the posterior condylar axis in all patients. A proximal tibial osteotomy was then undertaken with each cut made perpendicular to the mechanical axis in the coronal plane and with 7° of posterior inclination along the sagittal plane. No bony defects were observed along the eroded medial tibial plateau. After each osteotomy, we removed the osteophytes, released the posterior capsule along the femur and corrected any ligament imbalances in the coronal plane by appropriately releasing the medial soft tissues. The osteotomy and soft-tissue releases were carried out with a spacer block.

After bony resection and soft-tissue release, we fixed the tensor to the proximal tibia and fitted the trial femoral component. The joint distraction force was set at 40 lb (18 kg) in all patients. We selected this distraction force because it creates a gap in the joint in full extension with the trial femoral component in place which corresponds to the thickness of the insert derived from our preliminary clinical studies. We loaded the joint distraction force several times until the gap between components remained constant in order to reduce the error which can result from creep elongation of the surrounding soft tissues. At this point, we measured the joint component gap (mm) with the knee at 0° (full extension), 10° (flexion), 45° (mid-range flexion), 90° (flexion) and 135° (deep flexion), each with the patella everted and then reduced. For measurement with a reduced patellofemoral joint we inserted a trial patellar component and temporarily repaired the medial parapatellar arthrotomy by applying stitches both proximally and distally to the connection arm of the tensor. During each measurement, the thigh and knee were aligned in the sagittal plane in order to eliminate the external load on the knee at each angle of flexion.

Statistical analysis. After expressing each measurement as the mean $\pm$ SEM, we used the statistical software package

Statview 5.0 (Abacus Concepts Inc, Berkeley, California) to analyse the data. We performed repeated measure of analysis of variance (ANOVA) to compare the joint gap for different angles of flexion and carried out a *post hoc* analysis by using Fisher's protected least significance difference test. We also used the paired Student *t*-test to compare the joint gaps between the cruciate-retaining and posterior stabilised TKRs, with the patella both everted and reduced. A *p*-value ≤ 0.05 was considered to be statistically significant.

Results

The mean joint gaps in the cruciate-retaining TKR with the knee at 0°, 10°, 45°, 90° and 135° of flexion were 12.7 mm, 15.6 mm, 14.8 mm, 15.1 mm and 15.3 mm with the patella everted, and 12.7 mm, 15.8 mm, 15.3 mm, 14.1 mm and 12.9 mm with the patella reduced. The mean gaps in the posterior stabilised TKR at these same degrees of flexion, respectively, were 11.2 mm, 14.5 mm, 16.6 mm, 17.7 mm and 19.6 mm with the patella everted, and 11.3 mm, 14.7 mm, 17.1 mm, 17.6 mm and 14.8 mm with the patella reduced (Table I).

With the cruciate-retaining TKR, there were significant increases in the joint gap during the first 10° of flexion with the patella both everted ($p = 0.0006$) and reduced ($p < 0.0001$). After the first 10° of flexion, the knees maintained a constant joint gap when the patella was everted, whereas this gap slowly decreased when the patella was reduced. By 135° of flexion, the joint gap was significantly decreased in the reduced compared with the everted patellofemoral joint ($p = 0.024$) (Fig. 2).

With the posterior stabilised TKR, there were significant increases in the joint gap during the first 45° of flexion with the patella both everted (0° to 10°, $p = 0.0002$; 10° to 45°, $p = 0.0151$) and reduced (0° to 10°, $p = 0.0004$; 10° to 45°, $p = 0.0152$). Beyond 90° of flexion the size of the gap significantly increased with the patella everted ($p = 0.0316$) and significantly decreased with it reduced ($p = 0.0037$). The joint gap was significantly smaller at 135° of flexion with a reduced, compared with an everted patellofemoral joint ($p < 0.0001$) (Fig. 3).

When comparing both types of TKR, there was a significantly decreased joint gap in the cruciate-retaining TKR at 45°, 90° and 135° of flexion ($p < 0.05$) with the patella both everted and reduced (Fig. 4).

Discussion

We realise the importance of reproducing physiological conditions in the joint after TKR. Hence when assessing the joint with the patella reduced we inserted a trial patellar component and repaired the medial parapatellar arthrotomy by applying stitches both proximally and distally to the connection arm of the tensor. We have previously reported studies using this TKR tensor, in which we discuss the importance of maintaining a reduced and anatomically orientated patellofemoral joint in order to obtain accurate and more physiologically-relevant soft-tissue balancing.²⁵⁻²⁷

Fig. 2

Graph showing the joint component gap according to the flexion angle in cruciate-retaining total knee replacement. With a reduced patella, the mean joint gap predominantly remained constant from extension to flexion, with a tendency to decrease during deep knee flexion. With an everted patella, however, the joint gap remained constant during the entire arc of movement (* $p < 0.01$ vs the less angle; † $p < 0.05$ vs patellar eversion).

Fig. 3

Graph showing the joint component gap according to the flexion angle in posterior-stabilised total knee replacement. With a reduced patellofemoral joint, the mean joint gap increased from full extension to flexion, but decreased during the extremes of knee flexion. With an everted patella, the joint gap increased continuously well into deep knee flexion. (* $p < 0.05$; † $p < 0.01$ vs less angle; ‡ $p < 0.01$ vs patellar eversion).

Fig. 4a

Graphs showing a comparison of the joint gap kinematics between cruciate-retaining (CR) and posterior-stabilised (PS) total knee replacements in a) patellar eversion and b) patellar reduction. The joint gap measurement was significantly lower for the cruciate-retaining compared with the posterior-stabilised total knee replacement at 45°, 90° and 135° of flexion, both with the patella everted and reduced (* $p < 0.05$; † $p < 0.01$ vs cruciate-retaining).

Fig. 4b

We further reported that when performing intra-operative measurements with the tensor and the navigation system, reduction of the patellofemoral joint significantly affected the knee in a posterior stabilised TKR. In this study, compared with a PFC Σ RP-F (Depuy) posterior stabilised TKR,²⁵ we showed a similar pattern of joint gap and the importance of a reduced patella for the NexGen posterior stabilised TKR.

Our previous studies using a posterior stabilised TKR²⁵⁻²⁷ showed a smaller gap especially in deep flexion with a reduced patella when compared with the findings of the

present study (11.1 mm (SD 0.5) vs 14.8 mm (SD 0.7)). The tibial cut had a posterior inclination of 3° in the previous studies, compared with 7° in the present investigation. This may partly provide an explanation for the difference in the deep flexion gap with a reduced patella. Also, the measurements were all made with the tensor at a distraction force of 40 lb. Performing further measurements with various joint distraction forces may explain the change in the joint gap.

Our results suggest that the conventional methods of balancing the gap with an everted patella overestimate the gap in deep knee flexion, and that undertaking these with a

Diagrams of the relationship between a) the conventional extension gap, and the component extension gap b) 10° and c) 0°.

reduced patella reproduces the post-operative physiological conditions more closely, and yields more accurate measurements intra-operatively. The superiority of either the cruciate-retaining or posterior-stabilised TKR remains a source of controversy. Proponents of the cruciate-retaining TKR advocate maintaining the PCL in order to increase stability to promote femoral roll-back and thereby to enhance the patient's ability to climb stairs,³⁰⁻³⁴ while those who favour the posterior-stabilised TKR highlight studies in which patients with a resected PCL have a greater post-operative range of movement.³⁴⁻³⁶ However, no difference in the clinical outcome of these two TKRs has been shown.^{28,32,33} We have previously shown that in patients undergoing bilateral TKR performed by the same surgeon, with a cruciate-retaining and posterior-stabilised TKR in alternate knees, there was no difference in the post-operative knee score, yet the range of movement was significantly better after resecting the PCL.²⁹ Our study has shown that the TKR has stable joint kinematics from extension into deep flexion, while those for the posterior-stabilised TKR are more dynamic, supporting previous studies which indicated that the cruciate-retaining TKR afforded greater stability. We have also shown that compared with a cruciate-retaining TKR, a posterior-stabilised TKR with a reduced patella has significantly larger gaps when the arc of movement ranges from mid- to deep-flexion, which may explain why the latter implant has a better post-operative range of movement. However, some of these differences in the flexion gap could relate to the differences in the design of the femoral component, since the two components were of different designs.

In our study, we measured the 'joint component gap' which is determined with the femoral component in place, whereas the conventional gap measurement is made between the cutting surfaces of the femur and tibia. By keeping the femoral component in place, the knee is afforded a greater degree of extension because of its curving arc. The posterior condyle of the component then tightens the posterior capsule, resulting in a smaller joint gap at full extension (Fig. 5). Because of the posterior slope of the tibia and a slight femoral anterior bowing, we consider that the 'conventional extension gap' corresponds to our component gap at about 10° of flexion (Fig. 5). Taking this into consideration, our results are consistent with those of previous reports,^{37,38} which showed a larger flexion gap in the posterior-stabilised TKR compared with the cruciate-retaining TKR, although these studies were carried out with an everted patella.

There has been debate as to whether rotational alignment of the femoral component is best undertaken by positioning the femoral component in flexion using a measured resection technique or the tensioned gap technique.³⁹⁻⁴⁵ We have performed TKRs using the measured resection technique, but the tensor can also be used with the tensioned gap technique.⁴⁵ After the first tibial cut, we can determine the rotational alignment of the femoral component in flexion using the tensor, after which the posterior cut of the femur can be carried out. We propose to compare these techniques to acquire the real aligned soft-tissue balance post-operatively.

We believe that by maintaining a reduced patella for each intra-operative measurement, the surgeon will be able to adjust the soft-tissue balance more accurately and thereby achieve a better outcome.

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