

# Influence of intra-operative joint gaps on post-operative flexion angle in posterior cruciate-retaining total knee arthroplasty

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Received: 21 February 2011 / Accepted: 21 June 2011 / Published online: 1 July 2011  
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## Abstract

**Purpose** The purpose of this study is to examine the joint component gap and its relationship with post-operative flexion angles in posterior cruciate-retaining (CR) total knee arthroplasty (TKA). In posterior-stabilized (PS) TKA, an inverse correlation between the joint component gap and the post-operative flexion angle was reported. However, the kinematics of the joint component gap has a different pattern in PS and CR TKA. It was hypothesised that CR TKA has a different correlation between the joint component gap and the post-operative flexion angle compared to PS TKA.

**Methods** The joint component gap was measured with an offset-type tensor. The joint component gaps were measured at 0°, 10°, 30°, 60°, 90° and 120° knee flexion angle and various values of the change in the joint component gap were calculated; 10°–0°, 30°–0°, 60°–0°, 90°–0° and 120°–0°. Multivariate regression analysis was used to determine the influencing of these parameters to post-operative knee flexion angle.

**Results** The post-operative flexion angle was positively correlated with a joint component gap of 90° and 120° and

the values of the change in the joint component gap of 90°–0° and 120°–0°. Multivariate regression analysis demonstrated pre-operative knee flexion angle, and the values of the change in the joint component gap of 90°–0° had a significant independent factor of post-operative knee flexion angle.

**Conclusions** Post-operative flexion angle is multi-factorial. However, it is important to avoid flexion component gap tightness as well as excessive flexion component gap looseness for acquisition of better flexion angle in CR TKA.

**Level of evidence** IV.

**Keywords** Total knee arthroplasty · Soft tissue balance · Offset-type tensor · Navigation system · Cruciate-retaining · Flexion angle

## Introduction

One of the most important goals of total knee arthroplasty (TKA) is to improve the functional range of flexion without making instability especially in the mid-flexion angle. Factors influencing range of flexion after TKA can mainly be classified as intra-capsular and extra-capsular factors. Among extra-capsular factors, the importance of pre-operative range of motion for post-operative results has been previously recognised [1, 10, 16, 31, 33]. Similarly, the pre-operative tightness of extensor mechanisms is an important factor influencing the post-operative knee flexion angle [24]. In contrast, intra-capsular factors, including implant design, varus/valgus ligament balance, flexion–extension gap balance, height of joint line, posterior condylar offset, the tibial slope and patella resurfacing, have been also discussed by many authors [5, 9, 10, 12, 14, 18,

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25, 34, 35]. Among such factors, although soft tissue balancing has been recognised as an essential surgical intervention for improving the outcome of TKA [8, 26, 30, 36, 37], little has been clarified about the direct relationship between intra-operative soft tissue balance and post-operative outcomes.

The accuracy of measurement and the clinical relevance of an offset-type tensor for TKAs has been reported [20, 22, 23]. In the series of analysis in PS TKA, the joint component gap and the post-operative knee flexion angle had an inverse correlation [20]. However, the joint component gap kinematics has a different pattern in PS and CR TKA [19, 21]. It was hypothesised that CR TKA has a different correlation between the joint component gap and the post-operative flexion angle compared to PS TKA.

## Materials and methods

The subjects were 38 patients (38 osteoarthritic knees) who underwent primary CR TKA between 2006 and 2009. To make a fair assessment and minimise the influences of clinical variables, patients with valgus deformity, severe varus deformity (varus alignment  $>20^\circ$ ), severe bony, pre-operative severe flexion ( $<90^\circ$ ) and extension ( $>15^\circ$ ) restriction, were excluded. The patient population comprised 35 women and 3 men with a mean age of  $74.0 \pm 6.4$  years. The average coronal plane alignment was  $9.7 \pm 2.7^\circ$  in varus pre-operatively. Surgeries were performed by the same senior author using CR TKA (e-motion. B. Braun Aesculap, Germany). The CT-free navigation system (Orthopilot 4.2. B. Braun Aesculap, Germany) was used to ensure accuracy of implantations and to measure the accurate flexion angle of the knee during the joint component gap measurement with an offset tensor. The amount of bony cut and varus/valgus/flexion/extension alignment on the screen of the navigation system was determined based on the soft tissue balance measured using the tensor.

The offset tensor consists of three parts: an upper seesaw plate, a lower platform plate with a spike and an extra-articular main body, as previously described [19–23, 27, 28]. Following bony resections and soft tissue releases, the femoral component was fitted, and this tensor was placed with the lower platform fixed to the proximal tibia. The upper seesaw plate fitted to the femoral prosthesis and has a proximal convex shaped centralizer fitted to the intercondylar space and controls coronal joint alignment. After the PF joint was reduced, the medial parapatellar arthrotomy was temporarily repaired by applying stitches both proximally and distally to the connection arm of the tensor. These mechanisms make it possible to intra-operatively reproduce the post-operative alignments of the PF and

tibio-femoral joints [28]. The accuracy of measurement and the clinical relevance of this tensor have previously been reported [20, 22, 23]. This device is ultimately designed to measure the joint component gap both before and after femoral trial prosthesis placement, 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 that can change the applied torque value. After sterilization, this torque driver is placed on a rack that 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, an error for joint distraction was obtained within  $\pm 3\%$ . The joint distraction force was set at 40 lb (18.1 kg) in all measurements. This distraction force was selected because it re-created a joint component gap at knee full extension that corresponds to the insert thickness. This joint distraction force was loaded several times until the joint component gap remained constant; this was done to reduce the error that can result from creep elongation of the surrounding soft tissues. During each measurement, the thigh and knee were aligned in the sagittal plane to eliminate the external load on the knee at each flexion angle. Once appropriately distracted, attention is focused on a scale that corresponds to the tensor: the distance (in millimetres to the first decimal place; joint component gap) between the centre midpoints of the upper surface of the seesaw plate and the proximal tibial cut (Fig. 1).

All the operations were performed using the navigation system according to the manufacturer's instruction. After inflating the air tourniquet with 280 mmHg and registration of the navigation system, a medial parapatellar arthrotomy was performed. After removing all osteophytes, the tibial osteotomy was first performed perpendicular to the tibial axis in the coronal and sagittal plane. The insertion of the PCL was preserved by a bony island. After the tibial osteotomy, the necessary releases of the medial structures were made in extension. Following the measurement of the extension and flexion gaps with the tensor, distal and posterior femoral osteotomies were performed to create an acceptable rectangular extension and flexion gap with the navigation system. The posterior femoral osteotomy was performed posterior referencing and paid attention to maintain the posterior condylar offset. In this step, a residual lateral laxity of less than 3 degrees was allowed. Following bony resections and soft tissue releases, the joint component gap (mm) was measured with the knee at  $0^\circ$ ,  $10^\circ$ ,  $30^\circ$ ,  $60^\circ$ ,  $90^\circ$  and  $120^\circ$  knee flexion angle guided by navigation system. Various values of the change in the joint component gap were calculated;  $10^\circ-0^\circ$ ,  $30^\circ-0^\circ$ ,  $60^\circ-0^\circ$ ,  $90^\circ-0^\circ$ , and  $120^\circ-0^\circ$ . Following measurement, a cemented e-motion prosthesis (Aesculap) was implanted



**Fig. 1** Offset-type TKA tensor. The tensor consists of three parts: upper seesaw plate, lower platform plate and 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. The tensioning device is adjusted to appropriately fit CR TKA. Joint component gap measurements can be performed by the torque driver with the PF joint reduced and the femoral component in place

with cement. The e-motion is a mobile-bearing cruciate-retaining prosthesis that achieves a large contact area, and its femoro-tibial articulation has a somewhat conforming design. The tibial base plate has a posterior slope of 3°, and the polyethylene insert is slightly dished in the sagittal plane with a slightly elevated anterior tip. The thickness of the posterior and distal femoral component condyles were same size.

### Statistical analysis

All values were expressed as mean  $\pm$  standard error of the mean (SE). The results were analysed statistically using SPSS 18 software (IBM, Chicago, Ill). Correlations among post-operative flexion angles and joint component gaps and joint component change values were analysed using linear regression. Multivariate regression analysis was performed to identify independent factors for post-operative flexion angle. Variables eligible for inclusion in the multivariate analyses included those with  $P$ -values of  $<0.20$  in the univariate analyses. After identification of the main effects in the multivariate regression models, Pearson product-moment correlation coefficient was used to test the correlations between independent factors. The final

model(s) were checked for goodness of fit with Akaike Information Criterion (AIC), Durbin-Watson ratio (DW) and outlier, to ensure they were well specified and fit the data [11]. Data analyses were performed with PASW Statistics 18 (SPSS, Chicago, IL).  $P$ -values below 0.050 were considered statistically significant.

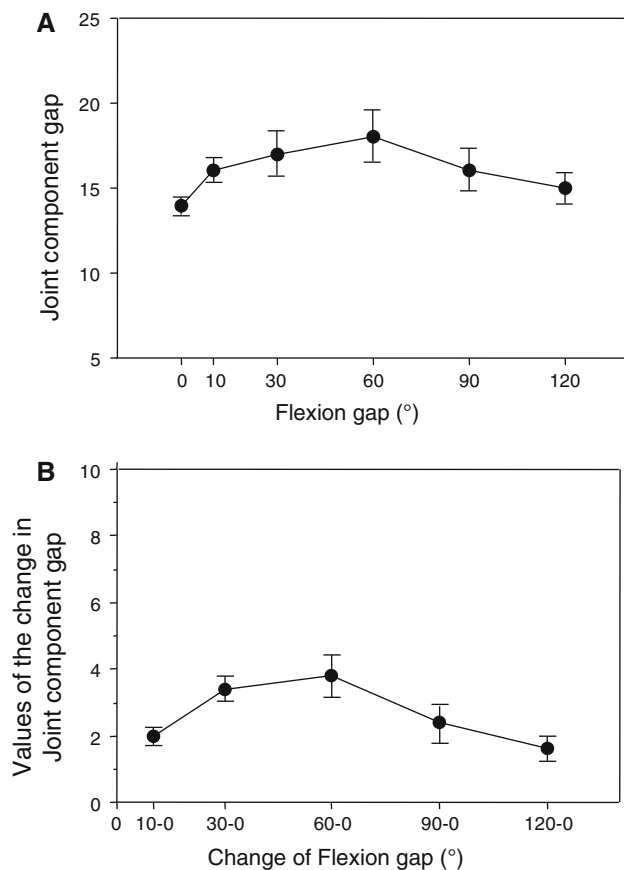
### Results

The follow-up duration was  $24.3 \pm 0.5$  months, and no patient was lost during follow-up evaluations. The pre- and post-operative knee flexion angle averaged  $120.5 \pm 15.4^\circ$  and  $121.2 \pm 8.3^\circ$ , respectively. There is no significant difference between the flexion prior and after surgery. However, the pre-operative flexion angle was positively correlated with the post-operative flexion angle ( $R = 0.408$ ,  $P = 0.025$ ), consistent with previous reports [1, 10, 16, 31, 33].

Average joint component gaps were 13.7, 15.7, 17.1, 17.5, and 16.0 and 15.3 mm at 0, 10, 30, 60, 90 and 120° of flexion, respectively (Fig. 2a). Following a significant increase during the initial 30° of knee flexion, the joint component gap showed a gradual decrease toward 120° of flexion. Average values of the change in the joint component gap were 3.1, 3.4, 3.8, 2.4 and 1.6 mm at each range of motion with 10–0°, 30–0°, 60–0°, 90–0° and 120–0° knee flexion, respectively (Fig. 2b).

Univariate analysis showed that joint component gaps with 90° ( $R = 0.48$ ,  $P = 0.007$ ) and 120° ( $R = 0.41$ ,  $P = 0.02$ ) flexion angles showed positive correlations with the post-operative flexion angle (Fig. 3). To further examine this phenomenon, correlations between post-operative flexion angle and the values of the change in the joint component gap were analysed. The values of the change in the joint component gap of 90°–0° ( $R = 0.48$ ,  $P = 0.007$ ) and 120°–0° flexion angles ( $R = 0.40$ ,  $P = 0.03$ ) also showed positive correlation with post-operative flexion angles (Fig. 4). No other parameters showed correlation with post-operative flexion angles.

Multivariate regression analysis, which included pre-operative knee flexion angle, joint component gaps with 90° and 120° and the values of the change in the joint component gap of 90°–0° and 120°–0°, was demonstrated. Joint component gaps with 90° and 120° and the values of the change in the joint component gap of 90°–0° and 120°–0° had a high correlation coefficient ( $|r| > 0.8$ ) with each other by Pearson product-moment correlation coefficient, the joint component gaps with 90° and 120° and the values of the change in the joint component gap of 120°–0° were exacted. Multivariate regression analysis demonstrated pre-operative knee flexion angle (95% confidence interval [95% CI] = 0.056–0.368,  $P = 0.009$ ) and the

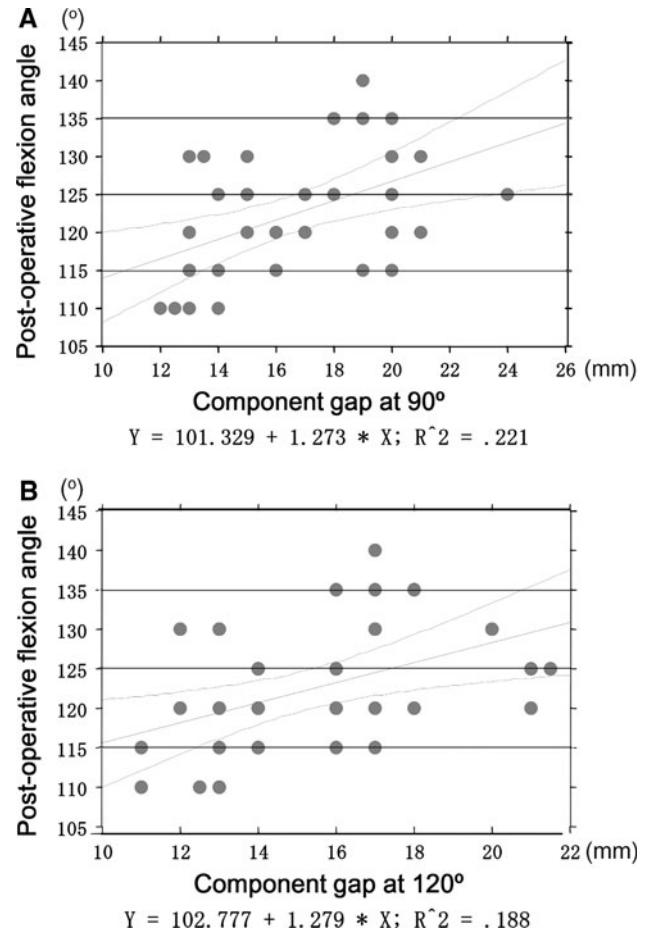


**Fig. 2** Average joint component gaps and values of the change in the joint component gap. Average joint component gaps were 13.7, 15.7, 17.1, 17.5, 16.0 and 15.3 mm at 0, 10, 30, 60, 90 and 120° of flexion, respectively (a) and Average values of the change in the joint component gap were 3.1, 3.4, 3.8, 2.4 and 1.6 mm at each range of motion with 10–0°, 30–0°, 60–0°, 90–0° and 120–0° knee flexion, respectively (b)

values of the change in the joint component gap of 90°–0° (95% CI = 0.411–2.164,  $P = 0.005$ ) had a significant independent factor of post-operative knee flexion angle. The final model(s) were checked for goodness of fit with Akaike Information Criterion (AIC), Durbin-Watson ratio (DW) and outlier, to ensure they were well specified and fit the data.

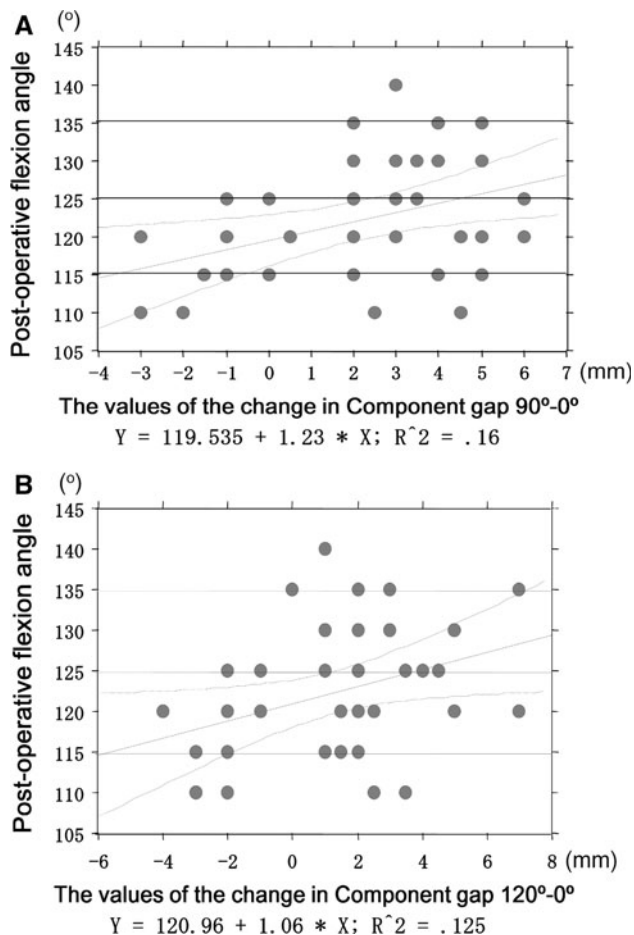
## Discussion

The most important finding of the present study was the values of the change in the joint component gap of 90°–0° ( $R = 0.401$ ,  $P = 0.013$ ) showed positive correlation with post-operative flexion angles in CR TKA. It showed the smaller flexion gaps than extension gaps led to the poorer post-operative flexion angles in this CR TKA series. In previous PS TKA series, the values of the change in the joint component gap of 90°–0° showed inverse correlation with a post-operative knee flexion angle ( $R = -0.484$ ,



**Fig. 3** Correlation between post-operative flexion angle and joint component gap. Joint component gaps of 90° (a) and 120° (b) showed positive correlation with post-operative flexion angle

$P = 0.019$ ) [20]. One of the reasons for this discrepancy may be the different patterns of soft tissue balance between PS and CR TKA [13, 21]. In this report, CR TKA showed significantly smaller gaps when the arc of movement ranges from mid- to deep-flexion, compared to PS TKA [19]. The posterior cruciate ligament in osteoarthritic knee is considered relative rigid and shortened despite relative macroscopically intact [21]. Regarding flexion gap tightness, Ritter et al. reported that 30% of CR TKA required ligament balancing to obtain a smooth flexion arc [32]. If the PCL was too tight, excessive femoral rollback resulted in anterior lift-off of the tibial trial in flexion, leading to a limitation of flexion [15]. To make a better post-operative flexion angle, balancing the flexion gap can result in a satisfactory range of motion [2, 17]. In the present study, it was identified that 16% of flexion gap tightness (smaller flexion gap than extension gap) resulting in a smaller flexion angle. Therefore, in these cases, surgeons are advised to avoid flexion gap tightness by soft tissue release such as posterior cruciate ligament (PCL) [2, 32, 39].



**Fig. 4** Correlation between post-operative flexion angle and values of the change in the joint component gap. The values of the change in the joint component gap of 90°-0° (a) and 120°-0° (b) also showed positive correlation with post-operative flexion angle

On the other hand, in PS TKA series, there are 25% of the patients who had the value of the change in the joint component gap of 90°-0° is more than 9 mm, resulting in a reduced post-operative flexion angle [20]. In CR TKA series, the maximum value of the change in the component gap 90°-0° was 6 mm. CR TKA with the appreciate tension of PCL did not make a excessive lager flexion gap looseness. However, if the PCL is not adequately balanced, paradoxical roll-forward can occur in CR TKA [6, 7, 29]. The paradoxical femoral roll-forward has been reported to limit the post-operative knee flexion angles, because it is likely to lead to an earlier posterior tibio-femoral impingement [3, 6, 38]. Restoration of posterior condylar offset is important for sufficient PCL tension in CR TKA. Previous studies have reported the effect of posterior condylar offset (PCO) on post-operative flexion angle [4, 9, 18, 25]. Bellemans et al. have demonstrated the role of the PCO in delaying the tibio-femoral impingement [4]. In these cases, posterior referencing instrumentation was

used and attention was paid to maintaining the posterior condylar offset. For better post-operative flexion angle, it is important to create a relatively larger flexion gap compared to extension, with appropriate tension of PCL and maintain the posterior condyle offset.

Lombardi et al. [17] reported that the ultimate range of motion was enhanced by the posterior cruciate ligament release when the slope was <3°. Balancing the flexion gap by either increasing the posterior tibial slope or by releasing the posterior cruciate ligament, or by both when necessary can result in a satisfactory range of motion. In this study, the tibial osteotomy was performed perpendicular to the tibial axis in the sagittal plane and tibial, and the tibial base plate had a posterior slope of 3°. For better post-operative knee flexion angle in the implant design of this study, increasing the posterior tibial slope is one of the surgical option as well as releasing the PCL ligament.

This study has several limitations. First, the patient number of the study is not enough to make a final decision. This study should be continued for making a conclusive decision that the post-operative flexion angle was significantly correlated with the intra-operative component gap 90° and the values of the change in the joint component gap 90°-0°. Second, post-operative flexion angle is multifactorial. Different prosthetic designs may afford varying results in post-operative range of motion. Third, there is no radiographic assessment in this study. It is also influenced by other technical factors such as the radiographic tibial slope and the presence of retained post osteophytes.

## Conclusion

An intra-operative assessment of joint component gap kinematics using an offset-type tensor in CR TKA with a navigation system was performed. In CR TKA, flexion gap tightness led to poorer flexion angles. For acquisition of a better flexion angle, it is important to avoid flexion component gap tightness as well as excessive flexion component gap looseness.

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