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Research Article

Intraoperative Joint Gap in Cruciate-Retaining Total Knee Arthroplasty

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Abstract

Background: The outcome of Total Knee Arthroplasty (TKA) is influenced by various factors, among which the soft tissue balance is extremely important. The intraoperative implant gap is useful for assessing the soft tissue balance after TKA. We hypothesized that a single AP/ML radius design would prevent mid-flexion laxity under Posterior Cruciate Ligament (PCL)-retaining conditions. This study evaluated the joint gap and tilt angle throughout the full range of motion after trial implantation of a single AP axis in mid-flex area cruciate-retaining prosthesis.

Methods: We performed Cruciate-Retaining TKA (CR-TKA) in 101 varus knees and measured joint gap kinematics with a tensor device during surgery. The joint gap and the tilt angle were assessed at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion after trial implantation and patellar reduction.

Results: The mean component gap at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion was 11,8, 12.1, 12.3, 12.3, and 12.2 mm, respectively. The mean tilt angle at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion was 0.7˚, 0.3˚, 0.1˚, 0.2˚, and 0.3˚, respectively. There were no significant differences of the joint gap or the tilt angle at all knee flexion angles. In addition, there was no relationship between the tibial slope and the joint gap.

Conclusion: The present study revealed that a single AP/ML radius design prevented mid-flexion laxity after CR-TKA. Unlike previous reports, the joint gap did not decrease beyond 90˚of knee flexion in our series.

Keywords: Intraoperative Kinematics; Joint Gap Soft; Tissue Balance; Total Knee Arthroplasty

Introduction

The clinical results of Total Knee Arthroplasty (TKA) are influenced by a variety of factors, and achieving the correct soft tissue balance is one of the most important contributors to an excellent outcome [1]. Maintaining stability of the joint gap and the correct medio-lateral soft tissue balance prevents liftoff, mid-flexion instability, and excessive polyethylene wear [2]. Measurement of the intraoperative implant gap is a useful and suitable method for assessing the soft tissue balance when performing TKA [3]. Recently, several authors have reported on methods for measurement of the implant gap using a tensor device. Many factors can influence the joint gap in patients undergoing TKA, including the type of prosthesis (cruciate retaining, posterior stabilized, or mobile insert) and the patellar position (everted or reduced) [4-6]. We hypothesized that the implant design would influence joint gap kinematics, especially mid-flexion laxity or a deep flexion gap.

The Scorpio non-restrictive geometry posterior cruciate ligament-retaining total knee arthroplasty system (NRG CR-TKA system; Stryker, Mahwah, NJ) was designed with a single Medial / Lateral (ML) radius. Its single M/L radius provides full conformity at all flexion angles, while allowing for increased rotation. This prosthesis has low constraint and allows up to 30 degrees of internal or external rotation. In addition, this prosthesis has a single Antero/ Posterior (AP) radius from 0˚ to 95˚ of knee flexion and another single AP radius from 95˚ to 165˚. The single AP radius at the midpoint of knee flexion would provide stability in the sagittal plane during mid knee flexion. We postulated that this design would prevent joint gap increase in mid-flexion and provide a stable joint kinematics under PCL-retaining conditions. In addition, the single ML design would provide high conformity, resistance to lift-off, and good rotational freedom These characteristics could influence soft tissue balance after TKA, especially ML stability. We already revealed *in vivo* kinematics of NRG CR TKA. These data showed medial or central pivot and bicondylar roll back during deep knee bending [7]. The purpose of this study was evaluating the joint gap and tilt angle throughout the full range of motion during surgery with the NRG CR-TKA system.

Patients and Methods

Patients

This prospective clinical study was approved by the institutional review board of Nagano Matsushiro General Hospital and all patients gave written informed consent. From May 2014 to March 2015, 115 consecutive primary TKAs were performed at our hospital with the NRG CR-TKA system (Stryker, Mahwah, NJ). Patients with primary varus osteoarthritis (101 knees) were included in this study, while those with valgus osteoarthritis (4 knees), rheumatoid arthritis (6 knees), or incomplete intraoperative data (4 knees) were excluded. The patients were 8 men and 60 women with a mean age of 75.3±5.9 years (range: 63 to 84 years) at the time of surgery. Their mean height was 151.1±7.2 cm (range: 137 to 163 cm), and their mean body weight was 56.2±7.8 kg (range: 41 to 73 kg). The mean preoperative range of knee motion was 107.5°±22.6° (range: 60 to 140°).

Surgical Technique and Intraoperative Measurements

We performed all operations with the measured resection technique. Under general anesthesia, an air tourniquet was inflated to 280 mmHg in all patients. A midline skin incision about 13 cm long was made from the suprapatellar area to the medial side of the tibial tubercle. The trivector approach was always used. In all patients, PCL-retaining TKA was performed because the PCL showed normal tension, volume, and function. We removed osteophytes from both the femoral and tibial condyles, e.g., peripheral osteophytes interfering with the deep layer of the Medial Collateral Ligament (MCL). The superficial layer of the MCL, posterior capsule, semimembranosus, pes anserinus, and lateral structures were not released to ensure an adequate soft tissue balance. Using a dedicated instrument, rotation of the femoral component was determined parallel to the surgical epicondylar axis and the femoral cut was made. After preparation of the femoral side, the proximal tibia was cut perpendicular to the tibial shaft in the coronal plane, and an adequate posterior slope was created for each patient in the sagittal plane. The tibial insertion of the PCL was preserved as a bone island. Following tibial osteotomy and removal of excess bone from the posterior femoral condyle, if required, soft tissue release was mainly performed at the medial side of the proximal tibia [8].

After the femoral and patellar trial components were placed, we measured the intraoperative joint gap and tilt angle by using a JDK mini (Styrker, Mahwah, NJ) with the same shape as the femoral component [9]. The tensor had three parts: an upper seesaw plate, a lower plate, and an extra-articular main body. The tensor indicated the center gap (mm) and the tilt angle (degrees) between the upper seesaw plate and the cut surface of the proximal tibia. The lower plate had 2 pin holes, which were used to fix the plate to the proximal tibia with 2 small pins (Figure 1).

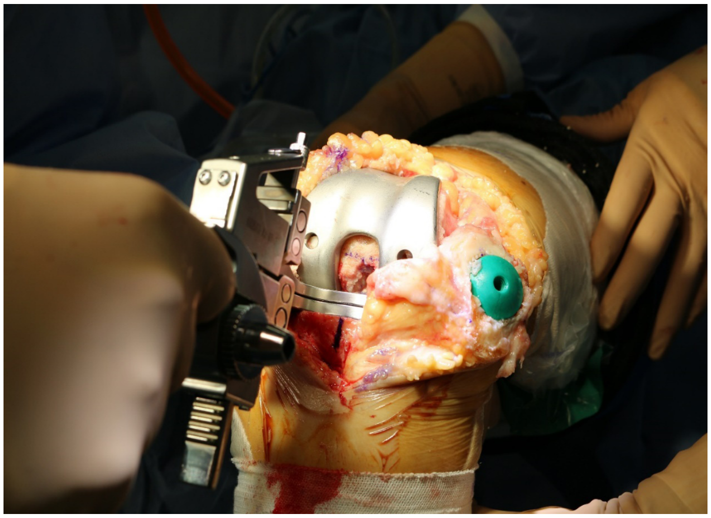

Figure 1: The offset tensor device has been set in the knee with the trial femoral and patella components. The lower plate has 2 small pin holes for attaching the tensor device to the proximal tibia with 2 pins.

The direction of the lower plate was matched to the axis of the posterior slope for the proximal tibial cut. The arms between the plate and the body of the device allowed space for reduction of the patella, and the mechanism was expected to be able to predict the postoperative kinematics and soft tissue balance. After the trial femoral component, trial patella, and tensor device were positioned, the patello-femoral joint was reduced. Then the quadriceps were sutured with two stiches (Figure 2).

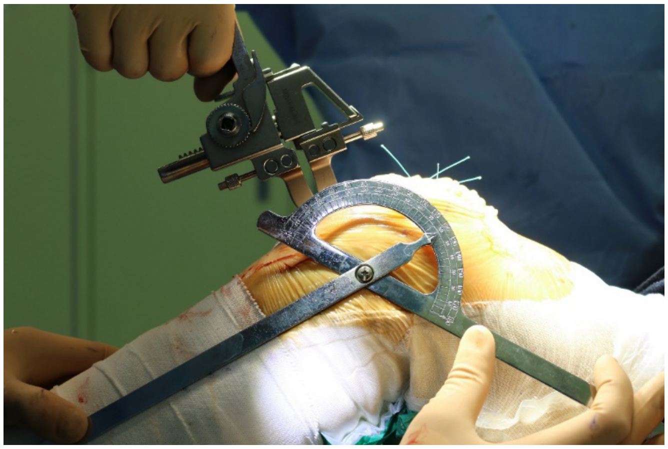

Figure 2: The patella was reduced, and the quadriceps tendon was sutured with 2 stiches. Then the joint gap and the tilt angle were evaluated throughout the fill range of motion with a distraction force of 30 lb. Each flexion angle of the knee was checked with a goniometer.

Next, the central joint gap and tilt angle were measured through the full range of motion (0°, 30°, 60°, 90°, and 120° of flexion) under 30 lb of distraction force (Figure 2). Flexion of the knee was checked with a goniometer to set each flexion angle and a distraction force of 30 lb was employed for all intraoperative evaluations [9] because this value is within the range used in similar studies

[5,9,10]. In addition, we used the NRG CR-TKA system before this study and found that a distraction force of 30 lb is suitable for the indicated insert thickness of this prosthesis. In this series, all of the femoral and tibial components were cement-less HA-coated components of the NRG CR TKA system, while the patella was always resurfaced with a cemented polyethylene component. On closing, the retinaculum and fat pad were sutured in their original positions to prevent postoperative adhesions. We evaluated the postoperative posterior slope of the tibial component on plain radiographs according to the Knee Society classification [11].

Statistical Analysis

Analysis of Variance (ANOVA) was performed to compare the joint gap and the tilt angle at different knee flexion angles. Correlations between the tibial slope and the joint gap were assessed by regression analysis. Analyses were done with Stat View 5.0 software (Abacus Concepts Inc., Berkeley, CA).

Results

The mean component gap at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion was found to be 11.8±1.4 mm, 12.1±1.7 mm, 12.3±1.8 mm, 12.3±1.7 mm, and 12.2±1.8 mm, respectively (Figure 3).

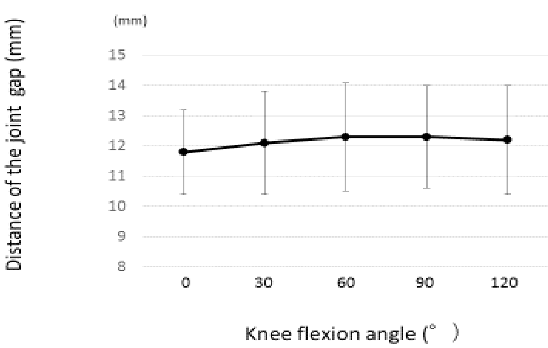

Figure 3: Kinematics of the joint gap. There was no significant difference of the joint gap from 0 to 120˚of knee flexion.

There was no significant difference of the gap at any flexion angle. The polyethylene insert that was actually implanted had a thickness of 10 mm in 34 knees, 12 mm in 56 knees, and 15 mm in 11 knees. The mean tilt angle measured at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion was 0.7±1.1˚, 0.3±0.6˚, 0.1±0.5˚, 0.2±0.6˚, and 0.3±0.7˚, respectively (Figure 4).

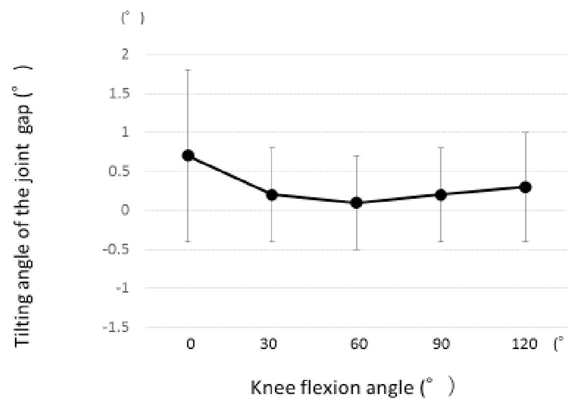

Figure 4: Kinematics of the tilt angle. The tilt angle was varus from 0˚to 120˚, and there was no significant difference of the tilt angle during knee flexion. Note: varus is positive and valgus is negative.

The mean tibial slope was 8.4±2.4˚ in this series. There was no relationship between the tibial slope and the joint gap at 0˚, 30˚, 60˚, 90˚, or 120˚ of knee flexion.

Discussion

Joint kinematics are influenced by several factors, including patient characteristics, surgical technique, component alignment, tibial insert design, and component design. This single-center study of 101 knees receiving CR-TKA revealed that the joint gap and tilt angle were stable from 0˚to 120˚ of knee flexion. In the present study, the mean component gap at 0˚, 30˚, 60˚, 90˚, and 120˚ of knee flexion was found to be 11.8±1.4 mm, 12.1±1.7 mm, 12.3±1.8 mm, 12.3±1.7 mm, and 12.2±1.8 mm, respectively. Several previous studied showed similar intra-operative component gap length with distraction force of 30-40 lb [4,6,8,12]. We recognized that our intra-operative joint gaps are reasonable.

There have been several previous reports that the joint gap increases from 30˚to deep flexion compared with that at full extension, suggesting that mid-flexion laxity exists after surgery [4,9,12,13], However, the present study did not reveal mid-flexion laxity after CR-TKA using a prosthesis with a single AP/ML radius. Recently, Fitzpatrick reported that mid-flexion stability was improved by a femoral component with a gradually decreasing radius compared to a dual radius implant [14]. In addition, their findings indicated that implant design factors have a larger influence on deep knee bending. Based on our data, the single AP/ML radius design provided stable joint kinematics from full knee extension to deep knee bending. Accordingly, an implant with a single AP/ML radius can prevent mid-flexion laxity and allow successful deep knee flexion after CR-TKA. Recently, a tensor device has been developed to evaluate the intraoperative joint gap, both the bone gap and component gap, during TKA [5,9,11,12,15] In particular, assessing the component gap with a tensor device which has the same articular face can measure joint gap kinematics throughout the full range of knee motion, which is useful for ensuring adequate intraoperative soft tissue balance and predicting the soft tissue balance after TKA [3].

Matsumoto et al. used a tensor device to compare the intraoperative soft tissue balance between CR-TKA and PS-TKA at 0˚, 10˚, 45˚, 90˚, and 135˚ of knee flexion with a reduced patella. They only enrolled varus osteoarthritis patients, as was done in the present study [16]. In CR-TKA patients, the central gap decreased after showing a significant increase during early knee flexion, whereas the central gap decreased significantly after a significant increase at 90˚ of knee flexion in PS-TKA patients. They considered these patterns to be reflective of true kinematics after TKA. Minoda et al. evaluated the joint gap and tilt angle over a full range of motion with a tensor device after implantation of a mobile-bearing PS-TKA prosthesis, and they detected mid flexion laxity, especially at 30˚ [6]. There was a significant increase of the mean joint gap between 0˚ and 30˚ of knee flexion. Subsequently, the mean joint gap decreased gradually from 30˚ to 90˚, but there was no significant change. However, after 90˚ of knee flexion, the mean joint gap decreased significantly up to 145˚. They considered that the most likely reason for this result was tension on the extensor mechanism in deep flexion.

In the present study, there was no significant difference of the tilt angle from 0˚ to 120˚ of knee flexion. Because all of our patients had varus osteoarthritis of the knee, the joint gap was slightly in varus at all knee flexion angles. However, the mean tilt angle only showed 0.7˚ varus at 0˚ of flexion and was ≤ 0.3º varus after that. There have been several previous reports of similar soft tissue balance data in varus knees [6]. It seems that slight varus bias is acceptable in patients with varus osteoarthritis of the knee and the small bias in our patients (0.7˚ varus at 0˚ of flexion and < 0.3˚ varus subsequently) did not lead to postoperative clinical problems. In the present series, we only released the deep layer of the MCL to remove peripheral osteophytes [8]. Of course, medial laxity is never acceptable, and our goal is to achieve stable knee kinematics, especially medial stability.

Several reports on kinematics of the normal knee have revealed that lateral joint space laxity in deep knee flexion is related to the medial joint gap [17-19]. In order to obtain a better range of motion after CR-TKA, it might be necessary to aim for more normal joint kinematics. However, the surgical technique for achieving normal knee kinematics has not been established, so providing stable joint kinematics over the full range of motion is our current objective for CR-TKA. In PS-TKA patients, joint kinematics and patellar tendon strain were investigated with a trial femoral component and an everted or reduced patella. Patellar tendon strain increased with deep knee flexion. When the patella was reduced, the joint gap was significantly decreased at 90˚ and 135˚ compared to the gap with an everted patella. In addition, the joint gap with a reduced patella was smaller at 60˚, 90˚, and 135˚ of knee flexion compared with 45˚ [4].

Also, Minoda et al. reported that the joint gap gradually decreased during knee flexion from 30˚ to 120˚ in PS-TKA patients [13]. However, in our CR-TKA series using a single AP/ML implant, there was no significant difference of the joint gap during knee motion, even beyond 90˚ of flexion. We considered that the constant joint gap during deep knee flexion was due to both implant design and creating an adequate posterior slope of the proximal tibia. Sagittal implant design affects the joint gap and the soft tissue balance, especially mid-flexion laxity and during deep knee bending. The NRG femoral component is designed with a distal thickness of 8.5 mm and posterior thickness of 7.5 mm, which means the posterior condyle is thinner than that of the distal femur. Our data indicated that the joint gap does not decrease beyond 90˚ of knee flexion with this prosthesis, suggesting some advantages for deep knee bending after TKA.

When CR-TKA is performed, the tibial slope has an important influence on postoperative knee flexion angle and joint kinematics [20,21]. There have been several reports about the relationship between the flexion gap and tibial slope in CR-TKA [20, 22-25]. Deceasing the tibial slope increases the risk of flexion gap tightness [25], while increasing the tibial slope improves the soft tissue balance in knee flexion [22,23]. In addition, increasing the tibial slope improves deep knee bending by avoidance of posterior impingement and achievement of adequate PCL tension [20,24]. According to Oka et al., the tibial slope did not influence the joint gap and soft tissue balance after CR TKA [26]. However, they mentioned that their data did not suggest increasing the tibial slope was unnecessary. In our series, the mean tibial slope was 8.4˚ and this is within the range reported previously for CR-TKA [21,25,26]. As Oka reported, the tibial slope was not correlated with the component gap or the soft issue balance in the present study [26]. It seems likely that implant design influences these results and that an adequate tibial slope was achieved for each patient in our series.

Hayashi et al. studied the intraoperative component gap in 103 knees of patients undergoing NRG PS-TKA [9]. They evaluated component gap at 0˚, 45˚, 90˚, and 120˚ of knee flexion with a JDL mini balancer and found that the component gap at 45˚, 90˚, and 120˚ was significantly larger than at 0˚. While they did not evaluate AP laxity, these data indicate that mid-flexion laxity was involved. However, in the present study, the component gap showed no significant change from 0˚ to 120˚ of knee flexion in patients undergoing CR-TKA. The PCL may act as a passive stabilizer after TKA, especially with regard to maintaining the flexion gap and stability during flexion [4]. An AP single radius prosthesis may be more effective at preventing mid-flexion instability under PCL retaining conditions, but further studies would be necessary to test this hypothesis.Hunt et al. compared laxity after CR and PS Triathlon single AP radius TKA in a cadaver study [27]. They reported that anterior translation increased with flexion for both CR and PS prostheses. Their measurements showed no significant difference of laxity between CR and PS prostheses through a defined arc of flexion (0° to 110°). Comparison of anterior translation at each flexion angle showed no significant differences between the two types of TKA. However, both types of prosthesis exhibited slightly increased anterior translation and decreased varus-valgus and internal-external rotation laxity compared with the native knee. On the other hand, the NRG CR-TKA system that we used is designed with a single AP/ML radius. Although the difference between CR and PS was not evaluated in present study, at least we showed that CR-TKA with this system prevents mid-flexion laxity. However, further investigation is necessary to determine whether the difference between a single AP radius and a single AP/ML radius affects joint kinematics, especially mid-flexion laxity, after CR-TKA.

The present study had several limitations. First, we only investigated one type of CR-TKA implant with a single AP /ML radius design and did not evaluate the intraoperative kinematics of other implants. Accordingly, comparison of the joint gap between this system and other prostheses implanted by the same surgical technique needs to be done in the future. Second, the tensor we used did not assess knee rotation and anterior-posterior translation, so we could not determine the rotational alignment or femoral rollback. Third, we only enrolled patients with varus osteoarthritis, so joint gap kinematics in valgus knees remain unclear and need to be investigated. Fourth, we evaluated the intra-operative component gap and tilting angle in CR TKA. Our data indicated that a single AP in mid-flexion radius and a single ML radius design would provide stable kinematics and prevent mid-flexion laxity. However, post-operative AP laxity is not unclear. We recognize the further study is necessary.

Conclusions

A CR-TKA system with a single AP radius from 0°to 95°and a smaller deep flexion angle from 95°to 165° /a single ML radius provided stable joint gap and tilt angle kinematics. Unlike previous reports, we found that the joint gap did not decrease beyond 90° of knee flexion. In addition, the posterior slope of the proximal tibia was not correlated with the joint gap during knee flexion.

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