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Soft Tissue Balance Changes Depending on Joint Distraction Force in Total Knee Arthroplasty

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ABSTRACT

The influence of joint distraction force on intraoperative soft tissue balance was evaluated using Offset Repo-Tensor® for 78 knees that underwent primary posterior-stabilized total knee arthroplasty. The joint center gap and varus ligament balance were measured between osteotomized surfaces using 20, 40 and 60 lbs of joint distraction force. These values were significantly increased at extension and flexion as the distraction force increased. Furthermore, lateral compartment stiffness was significantly lower than medial compartment stiffness. Thus, larger joint distraction forces led to larger varus ligament balance and joint center gap, because of the difference in soft tissue stiffness between lateral and medial compartments. These findings indicate the importance of the strength of joint distraction force in the assessment of soft tissue balance, especially when using gap-balancing technique.

The acquisition of appropriate soft tissue balancing and accurate alignment is an essential procedure in total knee arthroplasty (TKA) [1–3]. To assess the intraoperative soft tissue balance that reflects postoperative condition after TKA, an offset-type tensor was developed. This tensor enables surgeons to assess soft tissue balance after reduction of the patellofemoral joint (PF) and with the femoral component in place. Initial intraoperative measurements obtained using the tensor [4] demonstrated the importance of PF joint reduction and femoral component placement in measuring soft tissue balance [5,6]. The different patterns between cruciate-retaining (CR) and posterior-stabilized (PS) TKA [6,7] and postoperative soft tissue balance, which reflects intraoperative values [8], have also been reported. However, in the previous study series, the tensor was used with 40 lbs of joint distraction force to assess soft tissue balance in TKA, using the measured resection technique. This distraction force was determined based on a preliminary study that adjusted the thickness of the polyethylene insert. However, in the gap-balancing technique, the tensor is used as a surgical tool for determining the rotational alignment of the femur; therefore, the amount of distraction force is quite important.

Intraoperative soft tissue balancing, originally described by Freeman et al [9] and Insall et al [2], is an established method for preparing equal rectangular flexion and extension gaps by releasing various soft tissue structures around the knee. However, the lateral tibiofemoral articulation is physiologically lax; as a result, the flexion gap may not be rectangular [10–12]. In this context, Tokuhara et al [13] reported that the tibiofemoral flexion gap in a normal knee was not rectangular and that the lateral joint gap was significantly lax, as assessed by magnetic resonance imaging (MRI). By using the stiffness measurements, Asano et al [14] showed that the soft tissue complex around the knee was elastic and consequently extensible and that the joint gap in TKA depended on the strength of the joint distraction force applied.

Based on the above evidence, we hypothesized that a larger joint distraction force leads to a larger varus ligament balance and joint gap, due to the difference in soft tissue stiffness between the lateral and medial compartments. Therefore, the purpose of the present study was to investigate the influence of the joint distraction force on intraoperative soft tissue balance and to evaluate the stiffness of the soft tissue complex of the knee in PS TKA using the measured resection technique.

Materials and Methods

The subjects were 78 consecutive patients (78 osteoarthritic knees) who underwent primary PS TKA between 2009 and 2012. All knees had varus deformity, and those with valgus deformity and severe bony defects were excluded. The patient population comprised 70 women and 8 men with a mean age of 74.8 ± 5.7 years (± standard deviation; SD). The average preoperative coronal plane alignment in varus was 11.2° ± 4.9° (± SD). Each surgery was performed by the same senior author (H.M.) using cemented PS TKA

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(NexGen LPS Flex, Zimmer, Inc, Warsaw, IN) with a standardized surgical technique.

Surgical Procedure

Using a tourniquet, we performed a medial parapatellar arthrotomy. Each surgery was carried out using a measured resection technique with a conventional resection block. The anterior cruciate ligament (ACL) and posterior cruciate ligament (PCL) were both resected. Distal femoral resection was performed perpendicular to the mechanical axis of the femur according to preoperative long-leg radiographs. Femoral posterior condylar resection was performed using the anterior reference technique. The surgical epicondylar axis was preoperatively measured using computed tomography (CT). As Berger et al [15] reported, the surgical epicondylar axis is a line connecting the sulcus of the medical epicondyle and the lateral epicondylar prominence, and the angle between the surgical epicondylar axis and posterior condylar line is defined as the posterior condylar angle. Femoral external rotation was preset at 0°, 3°, 5°, and 7° relative to the posterior condylar axis, which was determined on the basis of preoperative CT, intraoperative Whiteside line, and the trans-epicondylar axis. The mean femoral external rotation was 4.0° ± 1.1° relative to the posterior condylar axis. Proximal tibial resection was then performed 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 resection, 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 resection and soft tissue release were performed using a spacer block.

Intraoperative Measurement with the Offset Repo-Tensor® (OFR Tensor; Zimmer)

The OFR 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 [7–13] (Fig. 1). The offset connection arms from the main body, which connect the two independent plates at the anteromedial corner of the tibia, are passed through the medial parapatellar arthrotomy. The seesaw plate is attached to the offset connection arm of the main body via a single shaft, providing a central pivot in the coronal plane. In addition, the seesaw plate can move in a

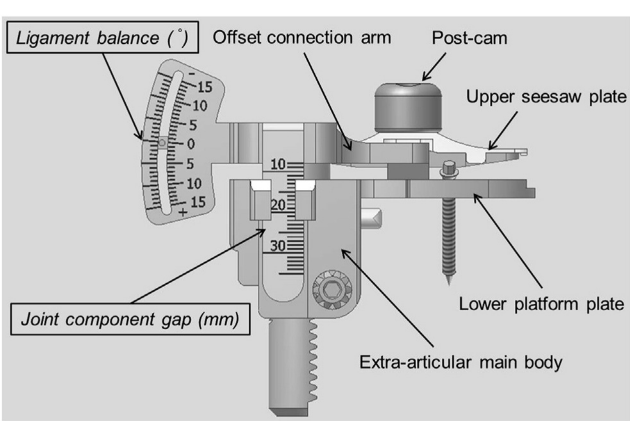

Fig. 1. The Offset Repo-Tensor® (anteroposterior view). The tensor consists of three parts: an upper seesaw plate, a lower platform plate with a spike and an extra-articular main body. The offset connection arms from the main body connecting two independent plates at the anteromedial corner of the tibia are passed through the medial parapatellar arthrotomy, which permits reduction of the patellofemoral joint, while performing measurements.

proximal–distal direction by means of a rack-and-opinion mechanism within the main body.

After both tibial and femoral osteotomies, two flat plates are placed at the center of the knee, and the OFR tensor can be firmly fixed to the osteotomized tibia using the spikes and additional pins on the platform plate. The seesaw plate has a post at the proximal center to fit the intercondylar space and the cam of the femoral trial prosthesis used in the PS TKA. This post-and-cam mechanism controls the tibiofemoral position in both the coronal and sagittal planes, reproducing the joint constraint and alignment after the prostheses are implanted.

This device is ultimately designed to permit surgeons to measure the joint center gap and ligament balance, both before and after placement of the femoral trial prosthesis, while applying a constant joint distraction force. Joint distraction forces ranging from 20 lbs (9.1 kg) to 60 lbs (27.2 kg) can be exerted between the seesaw and platform plates using a specially made torque driver, which can change the maximum torque value. After sterilization, this torque driver is placed on a rack that contains a rack-and-pinion mechanism along the extra-articular main body. Subsequently, the appropriate torque is applied to generate the required distraction force. In preliminary in vitro experiments we obtained an error for joint distraction within ±3%. Once appropriate distraction is achieved, attention is focused on two scales that correspond to the OFR tensor: the angle (°, positive value in varus balance) between the seesaw and platform plates and the distance (mm, joint center gap) between the center 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 the joint center gap and ligament balance.

Intraoperative Measurement

A conventional gap measurement was performed between the osteotomized surfaces in a parallel orientation at extension and flexion of the knee. We loaded 20, 40, and 60 lbs of distraction force and measured each joint center gap and varus ligament balance. All measurements were obtained with the PF joint reduced. We loaded this distraction force 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. After evaluating soft tissue balance between the osteotomized surfaces, the femoral trial component was placed with the OFR tensor on the surface of the tibial bone cut, and the PF joint was temporarily reduced by applying stitches proximally and distally to the connection arm of the OFR tensor. Joint component gap assessments were carried out at eight knee flexion angles of 0°, 10°, 30°, 45°, 60°, 90°, 120°, and 135° with 20, 40, and 60 lbs of joint distraction force at each angle. During each measurement, the thigh was held and the knee was aligned in the sagittal plane to eliminate the external load on the knee at each angle of knee flexion. After measurements were obtained, a NexGen prosthesis was implanted using cement.

Examined Parameters

The joint center gap (mm) and varus ligament balance (°) between the osteotomized surfaces of the knee were measured at extension and flexion and after the femoral component trial was placed. The joint component gap (mm) and varus angle (°) between the component surfaces were also measured at each flexion angle. Subsequently, the medial and lateral compartment gaps (mm) were calculated at each flexion angle using the joint component gap, varus angle, and the width between the medial and lateral apexes of the femoral component; these apexes represent the contact points of the polyethylene insert, and the width was consistent for each size of implant (Fig. 2). The lateral compartment gap = [component