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Posterior cruciate ligament (PCL) reconstruction – an in vitro study of isometry

Part I. Tests using a string linkage model

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Abstract. In six intact cadaver knees, we measured how the distance between six selected points in and around the femoral and tibial attachment area of the posterior cruciate ligament (PCL) changed with knee flexion. After complete removal of the PCL, 2-mm drill holes were made at the selected points. Each femoral point was measured against each tibial point using a heavy string that was passed through the drill holes. The distal end of the string was attached to a measuring unit. The changes in femorotibial distance were noted during flexion from 0° to 110° in 10° steps. The tibial drill hole locations had only a minor effect on the changes in femorotibial distance. The most isometric point was located in the centre of the posterior intercondylar area. The femoral locations of the drill holes were the primary determinant of whether the distance increased, decreased or remained nearly constant. According to our results, the most isometric femoral point is located at the posterosuperior margin of the anatomical PCL attachment. Using the tibial isometric point as a reference, the femoral points positioned anterior or posterior to the isometric point produced considerable changes in the femorotibial distance upon knee flexion. The anterior point led to an increase of about 7–8 mm at 110° of flexion, the posterior point to a decrease of the same extent. Much smaller changes in femorotibial distance resulted from the points located superior or inferior to the femoral isometric point. Our results demonstrate the strong need of correct isometric positioning of the graft or the augmentation device in PCL reconstruction to minimize the risk of graft stretching or disruption. A reproducible method to define the correct isometric area is described.

Key words: Posterior cruciate ligament – Isometry – Method for correct placement

Introduction

The motion of the knee is tightly controlled by the cruciate ligaments [1, 3, 6–9]. The typical course of the roll-sliding knee motion occurs as a result of the insertion points and lengths of the cruciate ligaments. This fact needs to be considered in all reparative reconstructions of these ligaments. There is an extensive literature regarding isometry in ACL surgery. However, up to the present time there has been little research on isometry in posterior cruciate ligament (PCL) reconstruction [1, 2, 5, 10]. While it is recognised that there is a significantly higher rate of ACL operations as opposed to PCL operations, it is necessary to apply the same high standards in both reconstructive procedures.

In PCL substitution with or without synthetic augmentation, correct isometry constitutes an essential biomechanical precondition for the renewed attainment of a stable and physiological motion of the knee. For quantitative analysis of the isometric relationship between the femoral and tibial insertion of the PCL, tibiofemoral measurements were carried out by using a string linkage model. Various points of measurement were explored over a range of motion from 0° of extension to 110° of flexion.

Materials and methods

For these investigations, 3 left knee joints and 3 right knee joints were removed from 6 cadavers (4 female and 2 male, with an age range from 52 to 69 years) by osteotomising the femur in the distal and the tibia in the proximal shaft area. The specimens were freed of soft tissue, with special attention being paid to the capsular-ligamentous apparatus. None of the knee joints showed relevant previous injuries. They were placed in plastic bags for deep freezing at –20° C and then thawed at room temperature at the time of the experiments. The PCL were completely removed from the tibial and femoral insertion areas.

In and around the femoral and tibial PCL insertion areas, six measuring points were established. In Fig. 1 the localisation of the femoral measuring points, designated Y1 to Y6, is evident. Points Y1, Y2 and Y3 were arranged on the borderline between the inner wall of the medial femoral condyle and the roof of the intercondylar notch. The distance from the anterior to the posterior cartilage-bone border of this line was measured and divided by three. The beginning point on the anterior cartilage-bone border corresponded to measuring point Y1. After a further one-third of the section, points Y2 and Y3 followed, respectively. Measuring point Y4 was placed about 5 mm from point Y2, and measuring point Y5 about the same distance away from Y3 towards the medial condylar wall. Measuring point Y6 was positioned about 5 mm distant from Y2 towards the intercondylar notch.

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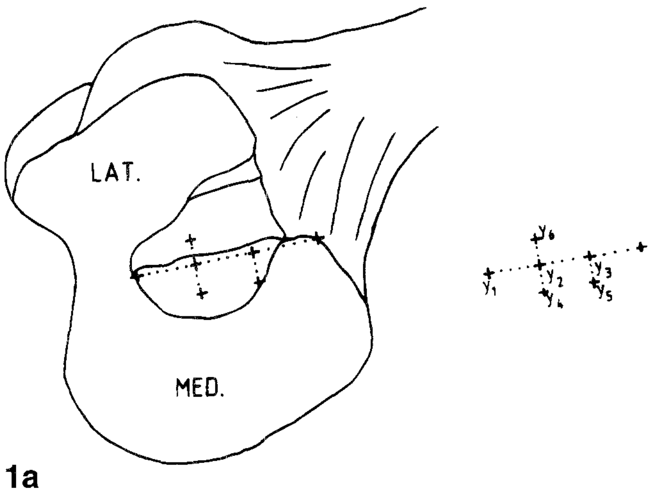

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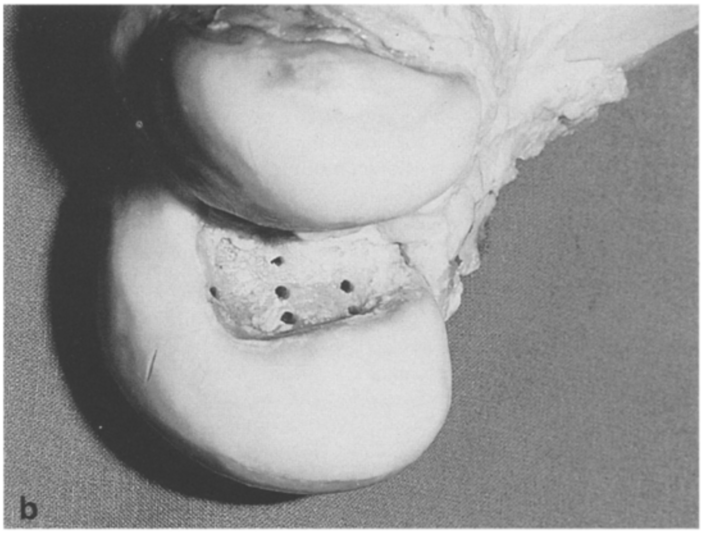

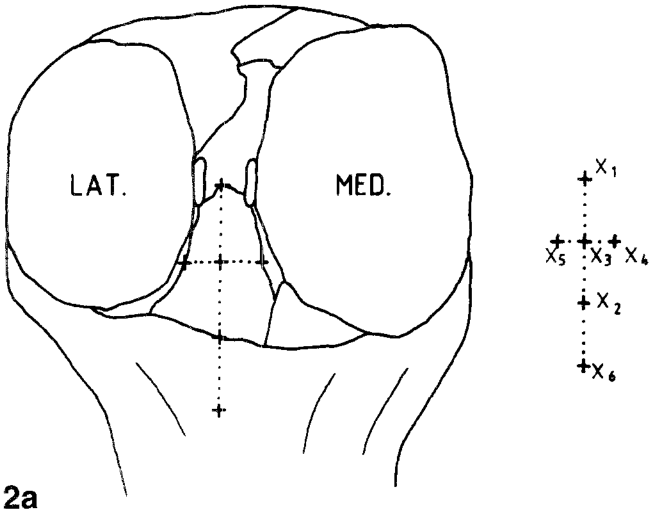

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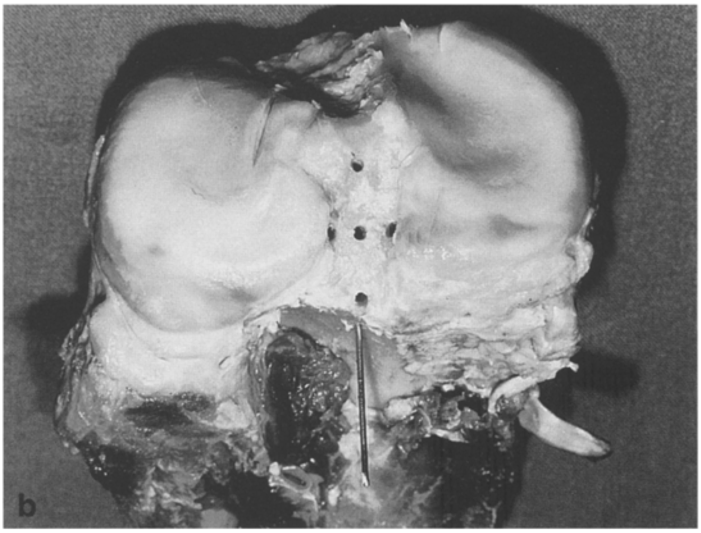

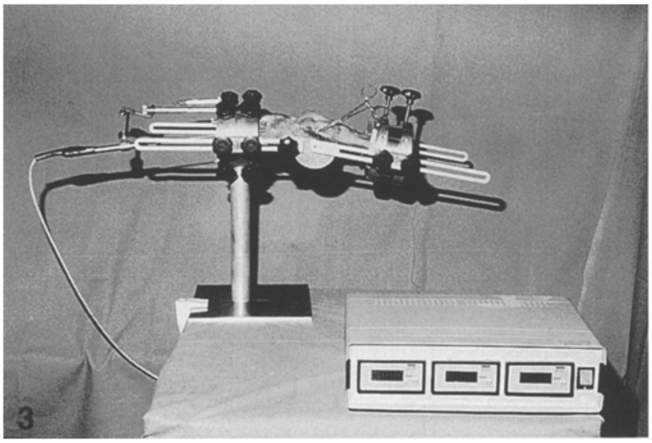

Fig. 1. Localisation of the femoral measuring points in and around the anatomical PCL insertion area shown schematically *(a)* and in a specimen *(b)* (from: Unfallchirurg 1992, 95:349–354; 354–357)

Fig. 2. Localisation of the tibial measuring points in and around the anatomical PCL insertion area shown schematically *(a)* and in a specimen *(b)*. The "over the back" measuring point X6 is cleared by a K-wire

Fig. 3. The experimental apparatus: special holding device for the specimen with tensiometer, inductive measuring apparatus and digital indicator. The string excursions were registrated in 10° increments with a range of motion from 0° extension to 110° of flexion

The tibial measuring points, designated as X1 to X6, were established in such a way that a line could be drawn in a sagittal direction through the middle of the posterior intercondylar area and from the dorsal limit of the intercondylar eminence to the dorsal edge of the fovea tibialis (Fig. 2). The beginning point of the section corresponded to measuring point X1. The final point denoted measuring point X2. Point X3 was located exactly in the middle of a line between X1 and X2. Points X4 and X5 were placed at the level of measuring point X3 on the inner borderline of the medial and lateral tibia plateaus, respectively. Measuring point X6 was located on the posterior aspect of the tibia outside, but on the X1–X2 line, at a distance halfway between X1 and X2.

Proceeding from each measuring point, transosseous bone tunnels were made with a 2 mm Kirschner wire. To anchor while ensuring free motion of the joint during measuring, a special holding device was constructed. The proximal tibia was solidly fixed, while the femur was connected to a flexible hinged framework (Fig. 3).

In order to record the femorotibial changes in distance between the individual measuring points in relation to the flexion position of the knee, every tibial point was connected sequentialy with every femoral point by means of a tensile and expansion-resistant string, which was passed through the previously prepared bone tunnels. The string was fastened on the femoral side, whereas on the tibial side it was connected to a tensiometer brought to a preload of 10 N.

The excursions of the tensiometer were recorded with an inductive measuring apparatus and demonstrated by a digital indicator. Before each individual measurement, the measuring apparatus was adjusted to zero in 10° knee flexion following repeated movements over the complete range of motion. Then the knees were put in the neutral position and finally flexed to 110°. In 10° increments the string excursions were documented. A total of 36 single measurements were carried out on every specimen, whereby each single measurement was repeated three times and the resulting mean value calculated. The femoral and tibial isometric points were determined.

Results

The femoral isometric point was proven to be identical to Y2, and the tibial isometric point corresponded to X3. In Fig. 4 the mean values of the femorotibial changes in distance are graphically represented in reference to the isometric X3. Over the entire range of motion, the changes in distance were the smallest for Y2. With 110° of flexion, the average maximum increase of distance amounted to 0.42 mm, so that within the scope of exact measurement, this point could be defined as the femoral isometric point. Also, Y4 and Y6 produced only short distance alterations, which did not exceed 2 mm. For Y1 located on the anterior cartilage-bone border, we noted a considerable increase of the tibiofemoral distance in the course of knee flexion. With 110° of flexion, the average maximum distance was 7.25 mm. On the opposite side, the posterior Y3 showed a nearly identical decrease of the femorotibial distance. Therefore, for Y5 we also measured a significant decrease in distance during flexion.

As is clear in Fig. 5, all tibial measuring points in reference to the femoral isometric point X2 produced considerably smaller femorotibial changes in distance, regardless of their localisation. In none of the points did the value exceed 2 mm. With an average maximum of 0.47 mm at 110° of flexion, X3, located in the centre of the intercondylar area, showed the smallest tibiofemoral changes in distance. This point could be defined as the tibial isometric point. The greatest changes of distance, representing a reduction of distance with increasing flexion, were found with X6 distal to the fovea tibialis on the posterior tibial surface.

From the acquired data, in Fig. 6 isometric zones have been drawn in and around the femoral isometric point. With the tibial isometric point as a point of reference, the borderlines of the individual zones show the femorotibial changes of distance to be expected with 110° flexion. With increasing deviation from the femoral isometric point and with increasing knee flexion, the femorotibial changes of distance become greater. For points anterior to the isometric point, an increase in distance was measured; for points posterior to the isometric point, there was a decrease in distance. The hatched surface around the isometric point shows an isometric zone in which the femorotibial changes of distance have a maximum of ± 2mm.

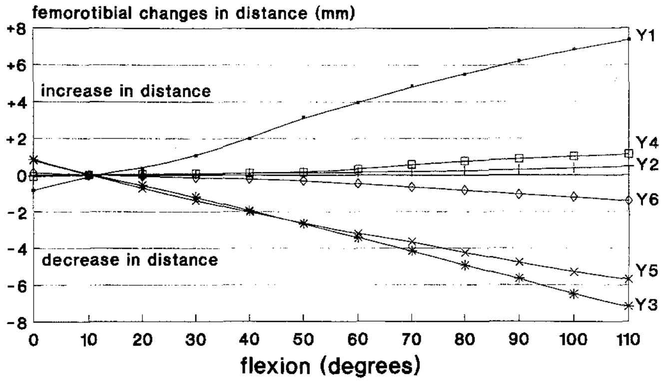

Fig. 4. The curves show the average values of femorotibial changes in distance for the femoral points in reference to X3, in relation to knee flexion. —●— Y1 —+— Y2 —✳— Y3 —□— Y4 —×— Y5 —◇— Y6

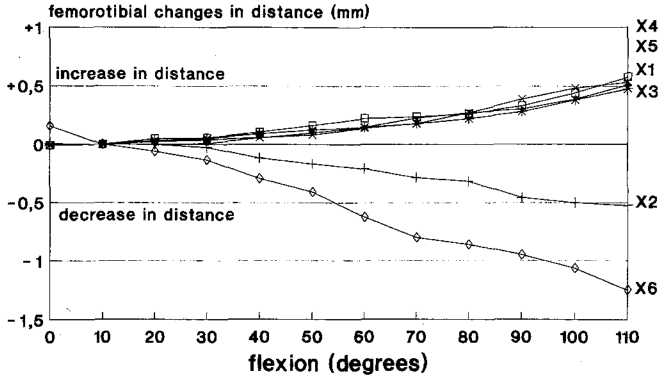

Fig. 5. The curves show the average values of femorotibial changes in distance for the tibial points in reference Y2, in relation to knee flexion. —●— X1 —+— X2 —✳— X3 —□— X4 —×— X5 —◇— X6

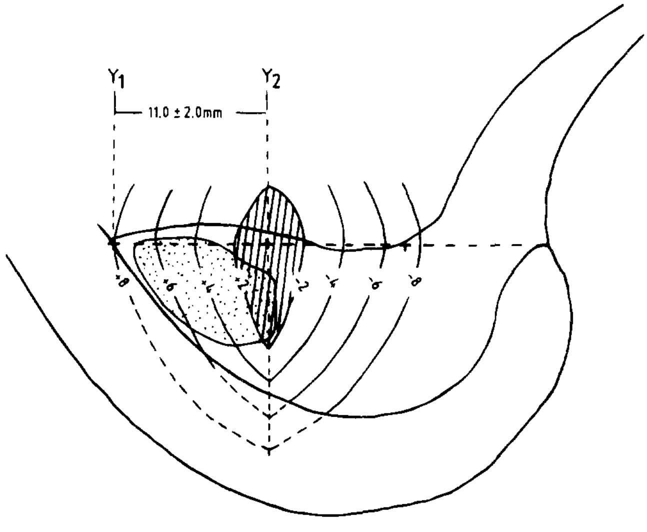

Fig. 6. Isometric zones around the femoral isometric point. The borderlines of the individual zones show the femorotibial changes in distance expected with 110° of flexion. Anterior to the isometric point, an increase in distance can be expected while flexing the knee, and posterior to the isometric point, a decrease in distance if knee flexion occurs. The *hatched surface* shows the important 2-mm isometric zone. The *dotted surface* marks the anatomical PCL insertion

The distance from Y1 to the isometric point was measured in all specimens and had a mean of 11 mm with a standard deviation of ± 2 mm. In Fig. 6 the anatomical area of insertion of the PCL is outlined. It should be observed that the femoral isometric point is not located in the centre of the insertion position of the ligament, but is located on the posterosuperior margin.

Discussion

In the past, PCL reconstruction has not consistently produced the desired knee stability. One primary factor leading to unsatisfactory results was the poor understanding of isometry. According to our research data, the femoral isometric point lies on the border between the inner wall of the medial femoral condyle and the sulcus roof, i.e. on about one-third of the line described in Fig. 1. In all specimens examined, this distance from the anterior cartilage-bone border to the femoral isometric point was calculated and found to have an average of 11 mm (11 mm ± 2 mm). Grood et al. [5] also placed the isometric point on this line and measured nearly identical distances. The location of our isometric point is nearly the same as that described by Friederich and O'Brien [1]. These authors as well as Ogata and McCarthy [10] and Funahashi et al. [2] place the isometric point at the posterosuperior margin of the anatomical PCL insertion.

With the femoral isometric point as a reference point, we established the average maximum femorotibial changes in distance for the tibial measuring points to be between 0.47 and 1.25 mm. For the "over the back" position, distal to the fovea tibialis, the greatest changes in distance were measured. As is evident in Fig. 5, on the whole, no significant differences in the changes of distance could be established. From a clinical perspective, there is sufficient evidence that the entire posterior intercondylar area of the tibia serves as a favourable isometric zone.

In PCL reconstruction, the femoral procedure receives the most critical judgement. Like Ogata and McCarthy [10] we could demonstrate, with increasing deviation from the femoral isometric point, that the femorotibial changes of distance increase during flexion of the knee. As can be observed in Fig. 4, we found an average increase of the femorotibial distance of 7.2 mm for Y1 with the tibial isometric point as a reference. Y3 showed an average decrease in the femorotibial distance of 7.2 mm. For the measuring points located superior to the isometric point in the sulcus roof and inferior to the isometric point in the condylar wall, we noticed significantly smaller femorotibial changes in distance, which did not exceed 1.5 mm.

Therefore, in operative practice it is necessary to localise the femoral point precisely in the anteroposterior direction, whereas in the craniocaudal direction deviations are more tolerable. The stated descriptions of direction refer to a knee flexed 90°.

Like Grood et al. [5] and Friederich and O'Brien [1], we have established isometric zones around the femoral isometric point. The limits of the individual isometric zones specify the maximum femorotibial changes of distance which can usually be expected during knee flexion to 110°. In zones anterior to the isometric point, we encounter an increase in distance, whereas in zones posterior to it, we note a decrease in distance. For the points within the hatched isometric zone, femorotibial changes in distance amount to no more than 2 mm. This isometric zone is not identical to the anatomical insertion area of the PCL. The greater part of the zone lies posterosuperior to the anatomical insertion area and encloses only a small marginal area of the ligament's anatomical insertion.

In PCL reconstruction it can be expected that the graft or the augmentation device maintains nearly the same length and tension over the entire range of motion when the bone tunnels are placed in the 2-mm isometric zone.

As the main results of our investigation, we can describe an easily reproducible method to define the exact femoral isometric area during PCL reconstruction. The surgeon has to measure the length of the borderline between the roof of the intercondylar notch and the medial femoral condyle (Fig. 1). The distance from the anterior to the posterior cartilage-bone border has to be divided by three. The exact femoral isometric area is localised one-third of this distance away from the anterior cartilage-bone border in the posterior direction at the inner wall of the medial femoral condyle.

This method was checked in investigations with 20 cadaver knees and in operative practice. In all cases we were able to precisely localise the most important femoral isometric PCL area. We believe that this method guarantees satisfying isometric relationships without intraoperative isometry measurements.

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