Knee Surg Sports Traumatol Arthrosc (2010) 18:388–393
DOI 10.1007/s00167-009-0986-7

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A new measurement technique for the tibiofemoral contact point in normal knees and knees with TKR

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Received: 25 May 2009 / Accepted: 29 October 2009 / Published online: 28 November 2009

Abstract Flexion gap instability after cruciate retaining TKR allows paradoxical anterior movement of the femur during flexion. The tibiofemoral contact point (CP) moves anteriorly and produces a decrease in the lever arm of the extensor apparatus. This can provoke patellofemoral, tibiofemoral-joint pain and instability for the patient. In order to quantify the amount of paradoxical motion on a 90° flexion radiograph of the knee, the average normal CP of the natural knee should be known. There are no known CP measurement methods suited for natural knees and knees with TKR that can be applied in daily practice, and only estimations for the CP position have been made. Therefore, a CP measurement technique on lateral radiographs that can be applied to natural knees and knees with a TKR has been developed. The reproducibility of this method was assessed. It was then used to determine the normal range of the CP in natural knees. The medial contact point in the natural knee in 90° of flexion was determined to be at 68% (±6.6%) of the AP diameter of the tibia measured below the tibia-plateau simulating a bone resection with TKR. This reproducible CP measurement method can be used clinically to evaluate the CP after knee prosthesis and also in patients with suspected ligament lesions.

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Keywords Tibiofemoral contact point · Measurement technique · Normal values · Radiographic measurement · Knee

Introduction

The kinematic behaviour of healthy knees differs from that in knees with a total knee replacement (TKR). The kinematic behaviour of the normal knee has been described thoroughly by Pinskerova and co-workers by analysing dynamic MRI studies of the normal knee [10, 25]. From 10 to 120° knee flexion, the medial contact point (CP) is relatively stable with only a few millimetres anterior shift of the femur. In this arc of motion, the medial condyle acts as a circle with a relatively stable contact point which, facilitated by a relatively concave tibia surface, results in a relatively stable CP. The lateral femur condyle shows more rollback due to a more convex tibia and more mobile lateral meniscus, making the lateral contact point more variable. Fluoroscopic studies of the normal knee confirm these patterns [19, 20, 32].

Many fluoroscopic studies conducted after TKR have shown that kinematic behaviour of knee implants can be abnormal compared to the normal knee. A paradoxical anterior movement of the femur in flexion, moving the CP anteriorly, has frequently been described, especially in cruciate retaining (CR) TKR [3, 4, 8, 22, 33]. This produces a decrease of the lever arm of the extensor apparatus [8], patellofemoral pain [8] and instability of the flexion gap with subsequent knee joint pain. The reason for the paradoxical motion is laxity in flexion. Possible causes are an over-resection of the femur condyles and subsequent decrease of femoral offset [1, 3], an insufficient PCL or too much slope in the tibia cut. Banks and colleagues found less flexion in these patients due to posterior impingement of the femur against the tibia [3]. Other fluoroscopic studies also found more anteriorly positioned contact points after TKR when compared to the normal knee [13, 21, 33]. Posterior-stabilised (PS) knees seem to have a more consistent rollback pattern than CR knees [6, 14], but certain types of PS knees may show some paradoxical motion depending upon the point at which the post engages the femur cam [31].

It seems that kinematic abnormalities influence the position of the CP and cause suboptimal function and pain [1, 3, 4, 8, 22, 33]. It is suspected that the position of the CP might have clinical relevance. To study this, a measurement method that could be used to compare the CP of normal knees and after TKR on lateral radiographs was needed. Known literature was searched for useful measurement methods.

It appeared that the CP and rollback have been studied with lateral view radiographs of the normal knee both with and without stress [11, 17, 26, 28, 30]. Most of these studies focused on PCL insufficiency and used the AP distance of the tibia as the reference to measure the contact point position. MRI studies as well as fluoroscopic studies demonstrated that the medial contact point lies approximately 5 mm posterior from the middle of the AP joint surface distance [10, 19, 25]. Lateral view radiographs have also been used to measure CP and rollback after TKR [2, 9, 13, 18]. Some of these authors used either the tibia AP dimension or the tibial base plate, whereas others measured the AP dimension of the tibia bone at the level of the tibial base plate to describe the CP [12]. This can make a difference since the tibial base plate does not always cover the whole tibia which influences the contact point. No measurement method has been found in the literature that could be applied to lateral radiographs of both normal and TKR knees.

Therefore, a tibiofemoral contact point measurement technique for plain lateral radiographs for natural knees and knees with TKR has been developed. The goal of this study was to determine the intra- and interobserver reproducibility of this new technique and to define normal values for the position of the contact point in natural knees. It was hypothesised that the normal contact point lies at the posterior 1/3 of the tibia plateau.

Patients and methods

Contact point measurement technique

Because of its suitability for daily practice we chose conventional lateral radiographs as the medium with which to study the CP. The radiographs were taken without muscle contraction. The measurement technique we developed is constructed upon the posterior tibial cortex because this is one of the most reliably constant radiographic elements in knees [28, 29]. To be able to reproduce and compare the CP after TKR, we have introduced an artificial proximal tibial "cut" of 7 mm on (pre-operative) radiographs. This adjustment makes it possible to compare pre- and post-operative radiographs since the remaining bony landmarks do not change; the method can be used on radiographs of healthy knees or knees with ligament insufficiency suspected. The stepwise CP measurement method is described below and in Fig. 1.

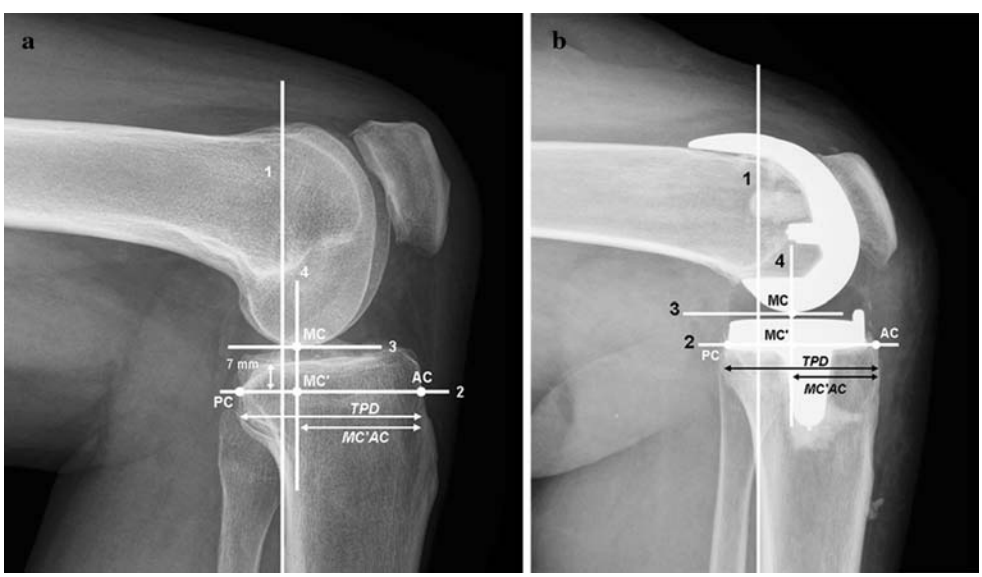

Fig. 1 **a** Measurement technique on a natural knee. The CP lies at 68% of the AP distance. **b** Measurement technique on a knee with a TKR. The CP lies at 58% of the AP distance

Measurement technique on plain lateral radiographs in 90° flexion.

It is important that the medial and lateral femoral condyles are overlapping. Ignore any osteophytes present. Names of the lines and the points between brackets refer to the names used in Fig. 1a and 1b.

1. Draw a line parallel to the posterior tibial cortex (PTC), preferably in line with midshaft level (Line 1 in Fig. 1a and b).
2. a. (knees without TKR) Identify the medial tibial plateau and, 7 mm below the medial tibial plateau, draw a line perpendicular to line 1 (line 2 in Fig. 1a). b. (knees with TKR) Draw a line perpendicular to line 1 at the level of the most distal and posterior edge of the tibial tray (line 2 in Fig. 1b).
3. Parallel to line 2, and perpendicular to line 1, draw a tangent to the most posterior point of the medial condyle (line 3, point MC in Fig. 1a and b).
4. Perpendicular to line 3 (and thus parallel to line 1) draw a line through point MC and line 2 (line 4 in Fig. 1a and b). Point MC′ is the crossing between line 2 and line 4 (also: point MC transferred to line 2).
5. Identify the most anterior cortex of the tibia on line 2 (point AC in Fig. 1a and b).
6. Identify the most posterior cortex of the tibia on line 2 (point PC in Fig. 1a and b).
7. Measure the distance between point AC and point PC (total tibial plateau distance; TPD in Fig. 1a and b).
8. Measure the distance between point MC′ and point AC (distance MC′AC).
9. Calculate the tibiofemoral contact point: (MC′AC/TPD) × 100%.

We chose to express the CP as a percentage of the tibial plateau distance in order to eliminate any problems associated with the magnification factor of the radiograph. In addition, when expressed as a percentage the CP between patients can be compared.

Patients

To determine the intra- and interobserver reproducibility, we used the measurement technique on lateral radiographs of natural knees (10 radiographs) and knees of patients with a TKR (10 radiographs). The natural knee radiographs were randomly obtained from a pool of patients who visited our outpatient clinic and were scheduled for a lateral radiograph of a knee. The pool consisted of patients who had had no previous surgery, no clinical antero-posterior instability, no severe osteoarthritis or other malformations that could disturb the normal anatomy of the knee. We also included radiographs of healthy volunteers. For the radiographs of knees after TKR, we randomly chose plain lateral radiographs from our database. Only true lateral radiographs of the knees in 90° flexion were used for the study.

For the second research question (determine normal contact point), 30 radiographs were measured in 25 subjects (13 male, 12 female subjects, mean age was 36 (SD 19.3) years).

Analyses and statistics

Each radiograph (whether taken from a normal knee or a knee with TKR) was measured using the above described technique by three independent observers. To test the intraobserver reproducibility, observer 1 (RJ) carried out the measurements twice on separate occasions. The second time, the radiographs were measured in a different sequence (randomised). To test the interobserver reproducibility, the three observers measured the same series of images independently, thus they did not know the findings of the others. The measurements were carried out by hand, using a geometry triangle. The distances were measured with 1 mm precision.

For all series, the intra-class correlation coefficient (ICC) was determined. This is a qualitative method to determine the reliability of a measurement. When the ICC is acceptable, the (quantitative) reproducibility is determined. Reproducibility was assessed according to Bland and Altman's statistical method [15]. To assess the variability between measurements of observer 1, the difference between these two measurements was plotted against their mean. The mean difference is expected to be zero since the same method was used. With the help of the mean difference and the standard deviation of the differences, the limits of agreement, also known as the 95% prediction limits, were calculated [15].

The same protocol was followed to assess the interobserver reproducibility. For this, the first series of measurement results by observer 1 was compared with those by observers 2 and 3.

The normal contact point position was presented with descriptive statistics (mean (SD) and 95% CI).

Results

CP measurement technique reproducibility

The ICC ranged from 0.78 to 0.99 which was consistent with the small differences observed between measurements. The intraobserver outcomes of the 95% prediction limit for the calculated CP(%) were smaller than the interobserver outcomes (Table 1). CP measurement on radiographs of natural knees had a slightly lower 95% prediction limit compared to measurements on TKR radiographs.

Table 1 95% Prediction limit of the relative contact point (CP)

Medial CP	Intraobserver	Interobserver
Normal knee	1.9	4.8
TKR	2.9	4.9

CP normal values of the natural knee

The mean CP was 68% (SD 3.3, 95% CI 61.7–74.9%), measured from the anterior tibial plateau. The distribution of the CP was normal (Fig. 2).

Discussion

The position of the CP at 68% of the AP diameter of the tibia is the most important finding of the present study. Together with the introduced measurement method this provides a tool to compare the pre- and post-operative CP in TKR. This measurement method that can be used for CP measurements on plain lateral radiographs of normal knees and in knees after TKR, and the assessment of its intra- and interobserver reproducibility was the first goal of this study. Determining the normal values of the CP in normal knees was the second goal.

The intra- and interobserver reproducibility values were good for both measurements on radiographs of natural knees and knees with TKR. The 95% prediction limits were 1.9 and 2.9 for intraobserver measurements on natural and TKR knees, respectively, indicating that the introduced measurement technique is reproducible. Intraobserver variability was smaller than the interobserver variability,

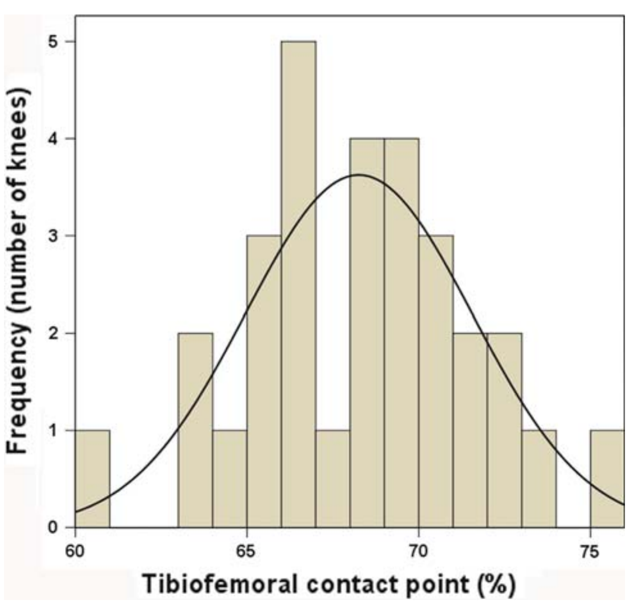

Fig. 2 Histogram of CP distribution

which was expected. However, the interobserver reproducibility was acceptable, with a 95% prediction limits of 4.8 and 4.9 for normal knees and after TKR, respectively. Apparently, the observer's ability to identify specific points on a radiograph can vary.

The idea underlying the measurement technique introduced in the present study is comparable to the techniques that other authors used: it focuses mainly on the tibia AP dimension as the reference line [2, 9, 12, 13, 18, 22]. However, the reference for the longitudinal tibia axis varied; some authors used the implant itself as a reference which has the disadvantage that pre- and post-operative radiographs within an individual patient cannot be compared. In the introduced measurement method, the posterior cortex, as defined by Staubli was used as the tibia axis reference [28, 29]. A stable posterior cortex reference for the longitudinal tibia axis and the tibia AP line perpendicular to it has a definite advantage over a variable reference, such as the tibial slope in an individual patient. It was also preferred to measure the tibial AP dimension on the bone and not only the tray distance since sometimes the tray does not cover the whole proximal tibia, and this might influence the contact point.

The mean contact point in patients with normal stable knees without joint space narrowing and with intact ligaments was determined to be 68% (SD 3.3%) of the tibia AP distance, measured 7 mm below the medial joint line at a right angle to the posterior cortex line. Consequently, a CP that lies outside the 95% confidence interval (61.7–74.9%) could be considered as abnormal. The results of the present study were consistent with suggestions in the literature [7, 25, 34].

The medial CP has been focussed on since the lateral CP was found to be too variable for comparisons between or within individuals. This variability can mainly be attributed to the anatomy of the lateral compartment and the strong dependence on the foot position [25]. The mean medial CP showed limited variation as indicated by the low standard deviation. Apparently, the natural variation of the medial contact point is quite small. The sample size of 30 knees was, therefore, large enough to determine a reliable estimate of the average contact point in a normal knee. Before a knee was included in the normal study population, no clinical evidence was found indicating ligament lesions that could affect the CP. Cartilage loss (if found on a radiograph) was also a reason for exclusion. Thus, only biomechanical stable joints were included. Therefore, we are quite confident that our estimation of the normal contact point reflects the normal knee.

The CP measurement method introduced in the present study is relatively simple and is, therefore, suitable for use in every clinical (orthopaedic) practice. Since it is a relative position of the CP, there is no need for calibrated radiographs or other specialised radiological imaging. However, the quality of the lateral radiograph is important since joint rotation and, to a lesser extent, joint obliquity will influence the CP measurement. We accepted rotation (i.e. over projection of the femoral condyles) up to 2–3 mm and thought that this amount of rotation did not severely affect the contact point. Clear communication with the radiology department to explain the importance of a correct position of the knee on the lateral view is needed: in our experience, it is certainly achievable and technically not difficult when in experienced hands and if a short learning curve of two to three radiographs is taken into consideration. Besides these extra radiographs during the learning curve there were only a few cases where an image intensifier was used, because conventional methods did not yield the desired images. Although the measurement technique is not difficult, the position of the CP, given in percentages, is highly sensitive to small changes in measured distances. Therefore, it is important that the instructions are followed, and the technique is trained before one applies it to clinical situations.

After TKR implantation, the reference plane on the lateral radiograph of the joint surface of the natural knee is lowered by the usual 9–10 mm bone resection from the lateral tibia plateau in order to replace bone with the same amount of implant thickness. This will lower the medial joint line approximately 7 mm since the natural joint line is 3 degrees varus and less bone is resected on the medial tibia plateau. To facilitate the transfer of the CP measurements for the natural (normal) knee to a patient with a TKR, the AP tibia distance 7 mm below the medial joint surface was used as a reference, mimicking a tibial tray implantation. We aimed at 90° flexion position since this is the position in which the flexion gap is created by the surgeon and in which the PCL is balanced. Although from a biomechanical point of view, any comparison between the contact point of the natural knee and after a TKR is not anatomically possible, in our opinion the described measurement technique presented here allows a "technical" comparison between natural knees and knees with TKR.

Determination of the medial contact point on a lateral radiograph can help to diagnose flexion instability in CR TKR. When a large paradoxical anterior shift of the femur occurs in flexion, patients may experience instability, pain and patellofemoral problems due to a smaller lever arm of the extensor mechanism. This phenomenon is often underrecognised [5, 23, 24, 27], but CP measurement on a simple lateral radiograph view in 90 degrees of flexion with or without stress will easily identify the problem. Even a flexion gap that is too tight may also be evaluated with a CP measurement since in these patients the contact point will be too posterior, often resulting from a too tight PCL. The lateral X-ray with CP determination in 90° of flexion can also be helpful to analyse the clinical results of various knee insert designs which are flatter or more dished or fixed or mobile. All these design characteristics may influence the contact point. In many studies that compare PCL-retaining and -substituting knees, a clear analysis of the contact point is lacking, and this technique can be helpful [16]. It is believed that restoration of the natural contact point at least in flexion, will restore knee kinematics and patellofemoral tracking, but further research is needed to document this.

The clinical relevance of CP-measurement can be found in identifying paradoxical anterior femoral rollback and other kinematic abnormalities in symptomatic TKR. Also the measurement method can be used as a tool to objectively diagnose an anterior or posterior cruciate ligament lesions. Further research, for example using stress radiographs, is necessary.

Conclusion

In conclusion, the contact point measurement technique introduced and described in the present study is reproducible on lateral radiographs of knees with or without a TKR. The contact point for a normal knee was determined to be 68% (SD 3.3%) of the AP tibia distance at 90 degrees of flexion, measured 7 mm below the medial joint line. The CP measurement method can be used clinically to evaluate the CP after TKR as well as in patients with suspected cruciate ligament lesions.

Acknowledgments The authors wish to acknowledge John Berns and his team of the Radiology Department of the Sint Maartenskliniek for taking the lateral radiographs. The authors also thank P.G. Anderson for her editorial support.

Conflict of interest statement The authors declare that they have no conflict of interest.

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