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Accuracy and reliability of determining the isometric point of the knee for multiligament knee reconstruction

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Abstract
Purpose To compare the accuracy and reliability of the anatomic and radiographic techniques for identifying the isometric point of the knee.
Methods Only four specimens were used; however, eight experienced multiligament knee injury surgeons were recruited to address this limitation. Surgeons estimated the isometric point (EIP) on the medial and lateral sides using an anatomic and radiographic method. The x and y coordinates of the EIP were compared to the true isometric point (TIP). T-tests and interclass correlation coefficients (ICC) were performed to determine the accuracy and reliability between the methods.
Results There was no difference in placement of the EIP on the medial side of the knee in the anterior/posterior (x; p = n.s.) and superior/inferior direction (y; p = n.s). The EIP was anterior ($p = 0.001$) to the TIP with the radiographic method on the lateral side and approached significance ($p = 0.05$) in the superior/inferior direction. The ICC (95 % CI) for identifying the EIP on the medial side in the anterior/posterior direction using the anatomic method was 0.64 (0.28–0.96) and 0.11 (−0.06 to 0.77) in the superior/inferior direction. Using the radiographic method, the ICC in the anterior/posterior and superior/inferior direction was 0.49 (0.14–0.94) and 0.15 (−0.47 to 0.81), respectively. On the lateral side, the ICC for the anatomic method was 0.84 (0.56–0.99) in the anterior/posterior direction and 0.36 (0.05–0.90) in the superior/inferior direction. Using the radiographic method, the ICC in the anterior/posterior and superior/inferior direction was 0.61 (0.26–0.96) and 0.89 (0.67–0.99), respectively.
Conclusions There was no difference in accuracy on the medial side of the knee. On the lateral side, the anatomic method was more accurate in the anterior/posterior direction. Reliability was greater in the anterior/posterior direction on both sides of the knee. Surgeons were most likely to place the isometric point anterior and superior to the TIP on both the medial and lateral sides of the knee with either method which has the potential to cause graft lengthening. This should be taken into consideration during reconstruction/repair of the MCL/PMC and LCL/PLC.

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Introduction

Accurate identification of the isometric point of the knee joint is critical for the successful reconstruction of the medial collateral ligament (or tibial collateral ligament)/posteromedial corner (MCL/PMC) and the lateral collateral ligament (or fibular collateral ligament)/posterolateral corner (LCL/PLC) of the knee. Two common methods for identifying the isometric point of the knee include the use of anatomic landmarks and intra-operative fluoroscopy. Although the exact method of identifying the isometric point with either method may vary slightly between surgeons, it has not been established whether one method is more accurate or reliable than the other.

Reconstruction/repair of the PMC and PLC of the knee is often warranted following a multiligament knee injury [19]. Injuries to the structures of the posterior corners of this synovial hinge-type joint result in significant instability and pain. Reconstruction/repair of the PMC and PLC of the knee joint is extremely difficult given the intricate complexity of these structures [2, 23, 31, 33, 34] and the low incidence of multiligament knee injuries (<0.02 % of all orthopaedic injuries) [10, 12, 13, 21]. Several reconstruction/repair techniques have been proposed for the PMC [1, 6, 20], and PLC [3–5, 9, 11, 14, 16, 18, 22, 24, 25, 28, 29, 35] with a lack of consensus on the most efficacious technique. However, regardless of the surgical technique proposed, establishment of the isometric point of the knee joint on the femoral condyle is paramount to restoring the biomechanics of the knee joint following this traumatic, high-velocity injury [7–9, 15, 25–27].

Accuracy and precision are not interchangeable and the two terms are often used incorrectly. Accuracy refers to the proximity of a measurement or diagnosis to the gold standard, whereas precision is defined by reliability of the measurements or diagnosis [32]. With respect to multiple raters, precision refers to the inter-rater reliability. Therefore, when comparing methods used to identify the isometric point of the knee joint, it is imperative to assess both the accuracy and reliability of the proposed methods to ensure the estimated isometric point is close to the true isometric point (TIP) (accuracy) and can be repeated between investigators (precision).

The purpose of this study was to compare the accuracy of the anatomic and radiographic techniques for identifying the isometric point of the knee on the medial and lateral condyles of the femur. A second purpose was to determine the inter-rater reliability of each method for locating the isometric point of the knee for PMC and PLC reconstruction/repair. The hypothesis was that there would be no difference in accuracy for identifying the isometric point of the medial and lateral knee joint using the anatomic method compared to the radiographic technique. It was also hypothesised that the reliability of each method would not be different between techniques.

Materials and methods

Prior to commencement of study activities, approval was obtained from the institutional review board. Four unpaired (three right, one left) fresh frozen lower limb cadaveric specimens, disarticulated at the femoroacetabular joint, of unknown age, sex and race were used for the study. The femur was mounted and secured in a Bench Mount Repair Stand (Park Tool Co., St. Paul, MN, USA) with the knee in 90° of flexion. A vertical incision was made through the skin and subcutaneous tissue on the anterior aspect of the knee approximately 10 cm above the superior border of the patella to 15 cm distal to the inferior aspect of the patella. Circumferential incisions were made at the proximal and distal ends of the vertical incision to allow the skin, subcutaneous tissue and deep fascia to be reflected down to the muscular layer. We did not carry the dissection any deeper in order to prevent direct visualisation of the ligaments or their respective bony attachments. Once the dissection was complete, the medial and lateral aspects of the knee were prepared for data collection.

For the medial aspect of the knee, a Kirschner (K-, Synthes, Zeist, The Netherlands) wire was inserted into the tibia, just proximal to the insertion point of the semitendinosus muscle. The purpose of the tibial K-wire was twofold since it represented the common orientation point for all images and the distal attachment for the isometer. Following insertion of the K-wire, a Sony HDR-XR100 Handycam (Sony of Canada Ltd, Toronto, ON, Canada) was mounted on a tripod at a predetermined distance from the specimen to allow for manipulation of the Siremobil 2000 fluoroscopic imaging unit (Siemens, Erlangen, Germany). The lens of the camera was oriented in the sagittal plane of the specimen to allow for accurate identification of the x and y coordinates of the estimated isometric point and the TIP.

On the lateral side, a K-wire was inserted into the head of the fibula. The fibular K-wire was the orientation point for all images of the lateral knee and the distal attachment for the isometer. A video camera was oriented in the sagittal plane of the specimen at a predetermined distance to allow for movement of the fluoroscopy machine.

Following set-up of the cameras and specimen, eight expert multiligament knee injury surgeons from the Knee Dislocation Study Group [19] were randomly assigned to

identify the isometric centre of the medial and lateral aspects of the knee joint using the anatomic and radiographic method. For each specimen, a random number generator was used to determine which side of the knee was used first. Following randomization of knee side (i.e. medial or lateral), the order of surgeons was determined from a random number generator, in addition to, the method (i.e. anatomic or radiographic) the surgeon used first. Researchers ensured that all surgeons were blinded and were not able to see where the estimated isometric point of the previous participant was located. For the anatomic method, on the medial side of the knee, the centre of the origin of the superficial MCL is the most isometric point and is located approximately 3.2 and 4.8 mm proximal and posterior, respectively, to the medial epicondyle of the femur [7]. On the lateral side, surgeons used the origin of the LCL at the junction of the posterior margin of the femur and the anterior to posterior centre of the lateral femoral condyle as the isometric point. The centre of the LCL is proximal (1.4 mm) and posterior (3.1 mm) to the lateral epicondyle of the femur [17]. To determine the isometric point of the knee with the radiographic method, surgeons used the intersection of an imaginary line drawn from the posterior femoral cortex to Blumensaat's line [27, 30]. This method was incorporated for both the medial and lateral aspects of the knee. For specimen #1, the surgeon randomly selected as rater #1 used the radiographic method to identify the estimated isometric point on the medial aspect the femoral condyle. A straight pin was inserted into the soft tissue such that the sphere of the straight pin marked the estimated isometric point. A metric ruler was placed against the soft tissue and in the sagittal plane, just below the straight pin, to serve as a calibration factor. An image was obtained, and the straight pin was removed.

The same surgeon identified the estimated isometric point of the medial aspect of the knee joint using the anatomic method and inserted a straight pin to mark that point. The metric ruler was oriented as described previously and an image was captured. The straight pin was removed and the remaining seven surgeons followed the same protocol. Once all surgeons had identified the estimated isometric point on the medial aspect of the knee joint using both the anatomic and radiographic methods, the TIP of the medial side of the knee was determined with an isometer. Using the radiographic method, a K-wire was placed into the isometric point of the femur. The isometer was placed on the wire representing the TIP on the medial femoral condyle and the tibial K-wire that was inserted previously. The knee was then cycled from 90° of flexion to full extension. Excursion of < 2 mm was considered isometric. If the change in length of the isometer was > 2 mm, the femoral K-wire was relocated until isometry was achieved. Once the TIP had been determined, the K-wire was removed and a straight pin was inserted into the drill hole. An image was captured and each estimated isometric point was compared to the TIP for analysis.

Following completion of the medial side of the knee, the same procedures were followed for the lateral side of the specimen. Isometricity was determined on the lateral side of the knee by placing the isometer on the K-wire representing the isometric point on the lateral femoral condyle (using the radiographic method) and the fibular K-wire. Excursion of less than 2 mm was considered isometric. Once the TIP had been determined, the K-wire was removed and a straight pin was inserted into the drill hole. An image was captured and the estimated isometric point was compared to the TIP for analysis. Specimen #1 was removed and specimen #2 was mounted on the device with the knee in 90° of flexion and prepared accordingly.

Following the acquisition of all images, NIH ImageJ software was used to identify the x and y coordinates of the estimated isometric points identified by all eight surgeons using both the anatomic and radiographic methods on the medial and lateral aspects of the knee. A calibration factor was determined for each image using the metric ruler (captured in the image) to ensure that the scaling factor was consistent between images. Once the image was calibrated, the x (i.e. anterior/posterior direction) and y (i.e. superior/inferior direction) coordinates (in mm) of the reference point (tibial and fibular K-wire for the medial and lateral side, respectively) and the estimated isometric point were determined. The x and y coordinates of the estimated isometric point were adjusted relative to the reference point to ensure the coordinate system between all images was identical. Then, the x and y coordinates of the TIP were identified and a Cartesian coordinate system was applied using the TIP as the origin of the x axis and y axis (Fig. 1). The x and y coordinates of the estimated isometric points were expressed relative to this origin. Anterior and superior to the TIP (point of origin) had positive x and y coordinates. Contrarily, posterior and inferior to the TIP had negative x and y coordinates. For example, if an isometric point had the coordinates $(2, -1)$, the point was located 2 mm anterior to the TIP and 1 mm inferior. The Cartesian coordinate system was incorporated into the analyses so investigators could not only determine the magnitude of the difference between estimated isometric points and the TIP, but also the direction. All measurements were recorded to the 100th of a millimetre, but since measurement to this precision is challenging in a clinical setting, values were rounded to the 10th of a millimetre.

Statistical analysis

Data were input into SPSS 17.0 (SPSS Inc., Chicago, IL, USA) for analysis. T-tests were performed to determine

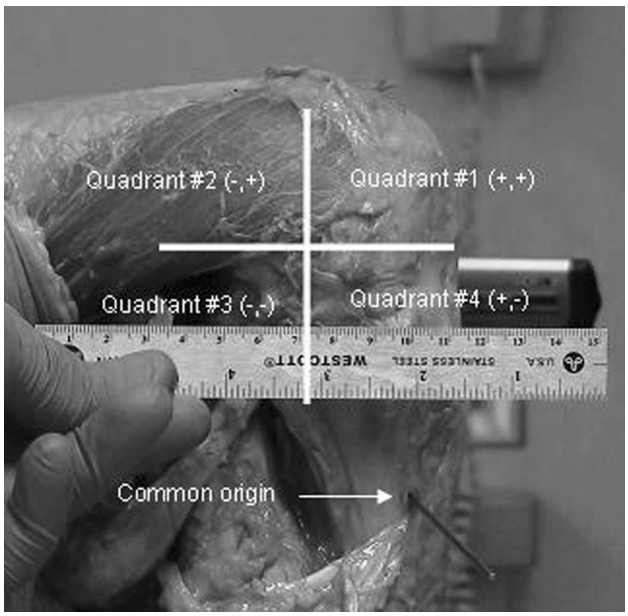

Fig. 1 A Cartesian coordinate system was applied to the medial (shown here) and lateral aspects of the knee with the TIP located at the intersection of the *x* axis and *y* axis. The *x* axis represents anterior (+) or posterior (−) to the TIP, whereas the *y* coordinate indicates superior (+) or inferior (−) to the TIP

whether there was difference between the mean *x* and *y* coordinates of the anatomic group compared to the radiographic group on both the medial and lateral aspects of the knee joint. Intra-class correlation coefficients [ICC (3, 1)] and 95 % confidence intervals (CIs) were calculated to determine inter-rater reliability for the identification of the isometric point (*x* and *y* coordinates) of the knee using an anatomic and radiographic method. Model 3 for the ICC was chosen since the raters (i.e. surgeons) were a select group and not randomly chosen. Since each surgeon only made a single measure for each side and method, a single measures form was used for the ICC. A significance level of $p < 0.05$ was used for the study.

Results

With respect to the medial aspect of the knee, there was no difference in placement of the estimated isometric point in the anterior/posterior (*x*) direction between the anatomic and radiographic method (n.s.). Similarly, no difference was noted in superior/inferior direction (n.s.) between the anatomic and radiographic method. Results indicate that mean placement of the estimated isometric point using the anatomic radiographic method was in Quadrant #1, anterior and superior to the TIP (Fig. 2).

Estimated isometric points identified with the radiographic method on the lateral side of the knee were more

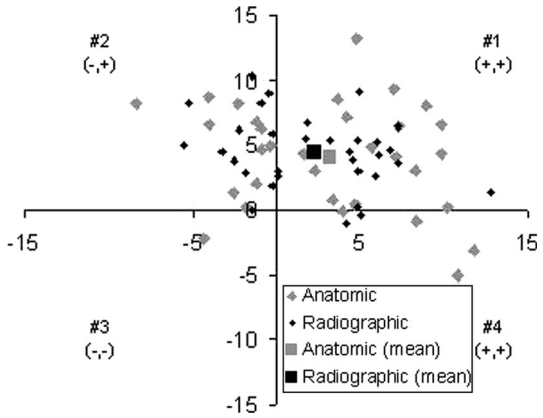

Fig. 2 Scatter plot indicating the *x* and *y* coordinates of the estimated isometric point relative to the TIP (intersection of *x* axis and *y* axis) on the medial side of the knee using the *anatomic* and *radiographic* methods

anterior ($p = 0.001$) to the TIP than those identified using the anatomic method. The comparison of accuracy between the two methods regarding the superior/inferior direction between the anatomic and radiographic method at the lateral side of the knee shows a trend towards significance ($p = 0.05$). Regardless of the method used, the mean of the estimated isometric point was located in Quadrant #1, and anterior and superior to the TIP (Fig. 3).

The interclass correlation coefficient (3, 1) (and 95 % CI) for identifying the estimated isometric point on the medial side of the knee in the anterior/posterior direction using the anatomic method was 0.64 (0.28–0.96). The ICC (3, 1) for identifying the isometric point in the superior/inferior direction was 0.11 (−0.06 to 0.77) for the anatomic method. Using the radiographic method, the ICC (3, 1) for the estimated isometric point in the anterior/posterior and superior/inferior direction was 0.49 (0.14–0.94) and 0.15 (−0.47 to 0.81), respectively.

With respect to the lateral aspect of the knee, the ICC (3, 1) for the estimated isometric point using the anatomic method in the anterior/posterior direction was 0.84 (0.56–0.99), whereas the ICC (3, 1) in the superior/inferior direction was 0.36 (0.05–0.90). When the radiographic method was incorporated, the ICC (3, 1) in the anterior/posterior and superior/inferior direction was 0.61 (0.26–0.96) and 0.89 (0.67–0.99), respectively.

Discussion

The most important finding of the present study was that there is no difference in accuracy between the anatomic and radiographic methods for identifying the isometric point on the medial femoral condyle in the anterior/posterior direction. Using both methods, surgeons identified

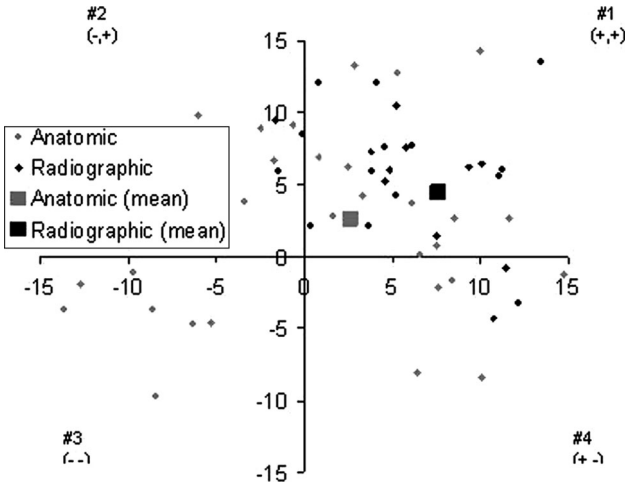

Fig. 3 Scatter plot indicating the *x* and *y* coordinates of the estimated isometric point relative to the TIP (intersection of *x* axis and *y* axis) on the lateral side of the knee using the *anatomic* and *radiographic* method

the estimated isometric point to be anterior to the TIP. However, the estimated isometric point was within 3.14 and 2.18 mm of the TIP for the anatomic and radiographic methods, respectively. Feeley et al. [8] demonstrated that placing a graft 4 mm anterior to the centre of the superficial MCL footprint resulted in a change in graft length of up to 5.7 mm when the knee was cycled from 0° to 90° of flexion. However, it should be noted that when the knee was cycled with the graft positioned in the centre of the superficial MCL, change in length of the graft was 2.7 mm [8], which was greater than the permitted length change for isometry in the present study (2 mm). Stannard et al. also reported that anterior placement of the isometric point resulted in graft elongation during flexion [27]. There was no difference in accuracy of identifying the isometric point in the superior/inferior direction between the anatomic and radiographic method. Surgeons estimated the isometric point to be approximately 4 mm superior to the TIP with both methods. Research suggests that placing a graft 4 mm superior to the TIP can lead to a change in graft length of 8.5 mm [8]. Therefore, inaccurate placement of the isometric point in the superior/inferior direction in this study may have more negative functional implications than displacement of the isometric point in the anterior direction. Anterior placement of the isometric point on the medial side of the knee in the current study may have resulted in graft elongation, but since mean estimated isometric points were placed within 3.5 mm of the TIP with both methods; change in graft length during knee flexion would have been less than reported in previous studies.

The hypothesis that there would be no difference in accuracy when identifying the isometric point on the lateral side of the knee between the anatomic and radiographic methods was rejected in the anterior/posterior direction, but not in the superior/inferior direction. Using both methods, surgeons identified the isometric point to be anterior to the TIP, but the anatomic method (2.60 mm) was more accurate than the radiographic method (7.63 mm). These results are in contrast with the findings of Stannard et al. [27, 30] in which the radiographic method was significantly more accurate than the anatomic method. It is possible that our study demonstrated conflicting results since we investigated inter-rater accuracy and reliability as opposed to intra-rater accuracy and reliability. Since the use of fluoroscopy varied within our study group, it is likely that the accuracy and reliability of either method are dependent on the standard practice of each individual surgeon. Anterior placement of the isometric point compared to the TIP has been associated with graft lengthening [27]; therefore, it can be hypothesised that use of the radiographic method would have resulted in greater graft lengthening than the anatomic method. There was no difference between the anatomic and radiographic methods for identifying the isometric point in the superior direction although results did approach significance ($p = 0.05$). Once again, in this direction, the anatomic method (2.63 mm) was closer to the TIP than the radiographic technique (4.46 mm). It can be hypothesised that placing the isometric point superior to the TIP would result in graft elongation during knee extension. However, the consequence of superior graft placement on the lateral femoral condyle warrants further investigation.

As with any reliability study, it was imperative not only to investigate the accuracy of each method, but also to determine the reliability of the anatomic and radiographic techniques between experienced multiligament knee injury surgeons. With respect to the medial aspect of the knee, reliability of the anatomic method ranged from substantial agreement to moderate agreement in the anterior/posterior direction. Only slight agreement was evident in the superior/inferior direction with either method. On the lateral side, substantial agreement was achieved in both directions with the radiographic method, whereas substantial agreement was only evident in the anterior/posterior direction for the anatomic method. To our knowledge, this is the first study to investigate the reliability of identifying the isometric point of the knee on the medial and lateral sides using anatomic and radiographic techniques.

A limitation of this study was that only four cadavers were used. However, it is important to note that this small sample size was addressed by recruiting eight knee surgeons from the Knee Dislocation Study Group [19] to be raters for the techniques used. Since the purpose of the study was to address the accuracy and reliability of the two techniques, and not to address the variability of the location of the isometric point on the medial and lateral aspects of the knee between cadaveric specimens, the sample size was adequate. A total of 128 images of the medial and lateral

aspects of the knee were obtained and analysed to determine the accuracy and reliability of the anatomic and radiographic methods for identifying the isometric point on the femur. Another limitation of this research was that the specimens were not dissected to the femur after the study to identify the anatomic landmarks of the isometric point on the femoral condyle. However, an isometer was used to identify the functional isometric point on both sides of the knee which is pivotal to restoring the biomechanics of the knee joint and predicting function following surgical intervention. In addition, an isometer may be more accurate for identification of the isometric point of the knee since the isometric point is not centrally located on the medial [8] and lateral [17] femoral epicondyles. Although surgeons were blinded to the preceding participant and efforts were made to ensure the previous pin placement was not visible, it is possible marks may have remained in the soft tissue that indicated previous straight pin placement. Whenever possible, efforts were made to ensure the previous pin placement was not visible.

Conclusion

Using a novel technique, not only have we demonstrated the accuracy and reliability of identifying the isometric point of the knee joint on the medial and lateral sides of the knee, we have also identified the magnitude and direction of the estimated isometric point compared to the TIP. Knowing the magnitude and direction of the difference between the estimated isometric point and the TIP has the potential to guide technical modifications that may increase the effectiveness of this basic, but difficult skill, inherent to successful reconstruction/repair of the MCL/PMC and LCL/PLC of the knee joint. Surgeons were most likely to place the isometric point anterior and superior to the TIP on both the medial and lateral sides of the knee with either method which has the potential to cause graft lengthening. This should be taken into consideration during reconstruction/repair of the MCL/PMC and LCL/PLC.

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