The Knee 23 (2016) 456–459

Contents lists available at ScienceDirect

The Knee

Femoral insertion site in medial patellofemoral ligament reconstruction

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ARTICLE INFO

Article history:
Received 10 August 2015
Received in revised form 25 October 2015
Accepted 26 November 2015

Keywords:
Patellar instability
Medial patellofemoral ligament
Three-dimensional imaging
Isometry

ABSTRACT

Background: The optimal femoral insertion point in MPFL (medial patellofemoral ligament)-reconstruction still remains ambiguous. Three-dimensional knee simulations based on computerized tomography (CT) images acquired under physiological loading conditions give further insights to predict the optimal femoral insertion site of the MPFL.

The hypothesis of the present study is that the optimal insertion point is not as reliable as thought and is dependent on subject-specific anatomical factors.

Methods: High-resolution 3D images of the knee were acquired in ten weight-bearing knees of healthy subjects in five flexion angles (0 to 120°). The distance between different femoral insertion points and two defined patellar points was computed in each position to quantify length of respective bundles and isometry of the femoral insertion site.

Results: The median length of both bundles was maximal in full extension (proximal bundle: 62.2 mm and distal bundle: 59.9 mm). The shortest ligament length was obtained in the flexion position 90° for bundle I (57.3 mm) and 30° for bundle II (85.3 mm).

The calculated most isometric femoral attachment point showed a non-uniform distribution pattern related to anatomic landmarks. The radiographic landmark showed the worst isometric score value compared to virtually defined spots by surgeons and the computed most isometric point.

Conclusions: This study provides results on the MPFL path length under physiological loading conditions using high-resolution bone geometry.

The most important finding of this study was that the computed, best isometric femoral insertion point showed a variable anatomical distribution. This suggests that the optimal position for femoral MPFL-graft fixation is patient specific.

1. Introduction

The reconstruction of the medial patellofemoral ligament (MPFL) is a reliable option in the treatment of chronic patellar instability with recurrent dislocation of the patella [1–8]. This anatomic structure represents an important passive stabilizer in early flexion degrees in patellofemoral joint kinematics [9–13]; it prohibits the patella from being laterally misrouted near knee extension in the proximal, mostly dysplastic, trochlear portion.

The MPFL reconstruction can be performed in an isolated manner or combined with other surgical interventions such as trochleaplasty or tibial tubercle transfer [3,14], if concomitant risk factors as severe trochlear dysplasia, patella alta and/or high tibial tuberosity-trochlear groove value (TTTG)-value exists. Several surgical techniques have been described for the reconstruction of the MPFL and to imitate its physiological triangular-shaped alignment [15–19].

In addition to an over tightening of the MPFL-graft, which is frequently associated with postoperative pain and stiffness, a suboptimal femoral insertion point also appears to be a major clinical problem [20,21]. It is crucial to find intraoperatively the optimal femoral footprint in order to obtain the most consistent isometric graft length throughout the entire range of motion [22]. Several studies have accurately described the anatomy of the MPFL and its femoral insertion area [23–28]. These anatomical studies specify in detail the topographical relationship of the MPFL footprint with prominent osseous landmarks. This detailed description assists the surgeon in detecting the precise anatomical site for the MPFL insertion. In this situation, the adductor tubercle is easily identifiable, whereby the medial epicondyle is less prominent and more difficult to identify. Some recent studies have designated the optimal femoral insertion of the MPFL to be approximately 10 mm distal of the apex of the adductor tubercle along the axis of the femur [23,26]. Other authors have proposed a radiographic landmark of the femoral attachment, which can be detected intraoperatively in a straight lateral view with an image intensifier [15,29,30].

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http://dx.doi.org/10.1016/j.knee.2015.11.021
0968-0160/

These approaches do not consider the patient-specific anatomy, especially the individual geometric form of the medial condyle and its influence on graft length in different flexion angles.

The hypothesis of this present study is that the optimal insertion point of the MPFL is not as reliable as once thought and is dependent on subject-specific anatomical factors. The proposed approach may be used to find the optimal insertion point with respect to isometry and anatomic factors which may give additional insights into the pre-operative planning in MPFL reconstruction.

2. Material and methods

Ten male subjects without any knee problems participated in this study. The study was approved by the local ethics committee (KEK-ZH Nr. 2013-0374) and informed consent was obtained from each subject.

The average age, weight and height of the subjects was 35 years (range 25 to 42 years), 83 kg (range 62 to 85 kg) and 180 cm (range 169 to 190 cm), respectively. An open extremity CT scanner (Verity®, Planmed, Norway) was used to acquire high-resolution 3D images of the knee (slice thickness 0.4 mm) at a particularly low dose. The mobile gantry of the device could be rotated around two axes and translated along one axis, to permit the subjects to take a standing, weight-bearing position during computerized tomography (CT) scanning. The left knee of each subject was scanned in five flexion positions, namely 0°, 30°, 60°, 90° and 120°. In full extension, the subject stood with the left foot inside and the right foot outside of the gantry, that was positioned at knee height. When the knee was bent, the left foot was flexed while the right foot was stretched backward. In each position, the flexion angle was determined using a standard goniometer. Subjects held handles on the device in order to hold their position during the CT scan, which took a few seconds for each position. The image data were imported into commercially available image processing software (Mimics, Materialise, Leuven, Belgium). Afterwards, 3D triangular surface models were generated using the marching cubes algorithm [31]. To ensure a closed bone surface, the hole-closing feature of mimics was applied when necessary.

The tridimensional reconstructed knee model of the femur at 0° flexion was used as a reference position for describing the relative patella motion during flexion. For each subject, the femur models were superimposed by applying the iterative closest point (ICP) surface registration algorithm [32]. The motion of the patella relative to the fixed femur was then determined based on the reference position at 0° flexion.

The anticipated isometric femoral insertion point of the MPFL was marked on the 3D reconstructed knee image by two experienced knee surgeons.

Additionally, the radiographic landmark for intraoperative MPFL tunnel placement under image intensifier as proposed by Schöttle [15] was defined. To create a two dimensional view, the plane was adjusted to the posterior femoral cortex in a strict lateral view of the distal femur. Then two planes, perpendicular to the first one, were created. One plane was tangential to the boundary of the posterior condyles. The second one was defined at the deepest proximal point of the notch. The radiographic landmark was chosen on the surface of the medial condyle at the intersection of the different planes, slightly anterior to the first one.

In the next step, two patellar insertion points lying on the medial patellar border (i.e., the most proximal point and a distal point in the proximal third) were identified and marked. Lastly, the relative translocation of the patella was used to automatically compute the positions of the patellar fixation points at 30°, 60°, 90° and 120° of flexion.

The ligament length between the differently selected femoral points and the patellar points 1 and 2 was measured according to the technique described by Graf et al. [33], which respects the epicondylar surface. In addition, the most isometric femoral point was automatically computed by the software, which considered the different patellar positions and related ligament dimensions. Firstly this point was calculated for the entire range of motion of the knee (from 0° to 120°), and secondly the point was estimated only for the patellar positions 30 to 90°.

An isometric score, as described in our previous work [33], was evaluated for each femoral point to quantify its isometry. The value 0 thereby signifies a perfect isometric behaviour of this spot.

3. Results

Fig. 1 shows the distribution of the different femoral insertion points in one of the subjects. Two isometric scores were calculated for each of the femoral points, firstly by incorporating the patellar positions throughout the entire range of motion (0 to 120°) and secondly by only considering the patellar positions 30 to 90°. The former score showed superior values for all of the femoral insertion points in every patient as compared to the isometric score including all patellar positions. This is due to the string length variability in the maximal flexion and extension positions (0°- and 120°-position) compared to other patellar positions in our model.

The isometric score 30 to 90° was applied and calculated for all of the five femoral insertion points in each subject. Fig. 2 shows the distribution of the isometric values applied to the different femoral points. Overall the isometric point calculated for the patellar position 30 to 90° showed the best isometric score value, followed by the isometric point for patellar positions 0 to 120° and the spots defined by the two surgeons. The radiographic landmark had the worst isometric score values.

We assumed that the most isometric point, computed for the range of motion between 30 and 90°, was the ideal femoral insertion point. All remaining calculations were done considering this point. The median shortest distance to this point was 4.0 mm from the isometric point 0 to 120°, 4.5 mm from the spot defined by surgeon 1 and 4.8 mm from the spot of surgeon 2. The distance between the isometric point 30 to 90° and the radiographic landmark was 5.1 mm.

Only one of the 10 subjects had a calculated isometric point 30 to 90°, within the same plane parallel to the posterior cortex of the femur. The other nine subjects had points which were localized more anteriorly to the plane defined by the two surgeons.

The MPFL graft consisting of two strings, namely strings I and II was generated for each of the 10 subjects in all five flexion positions and for the five femoral insertion points respectively, applying the method specified by Graf et al. [33]. The median length of both strings was maximal in full extension (string I: 62.2 mm and string II: 59.9 mm).

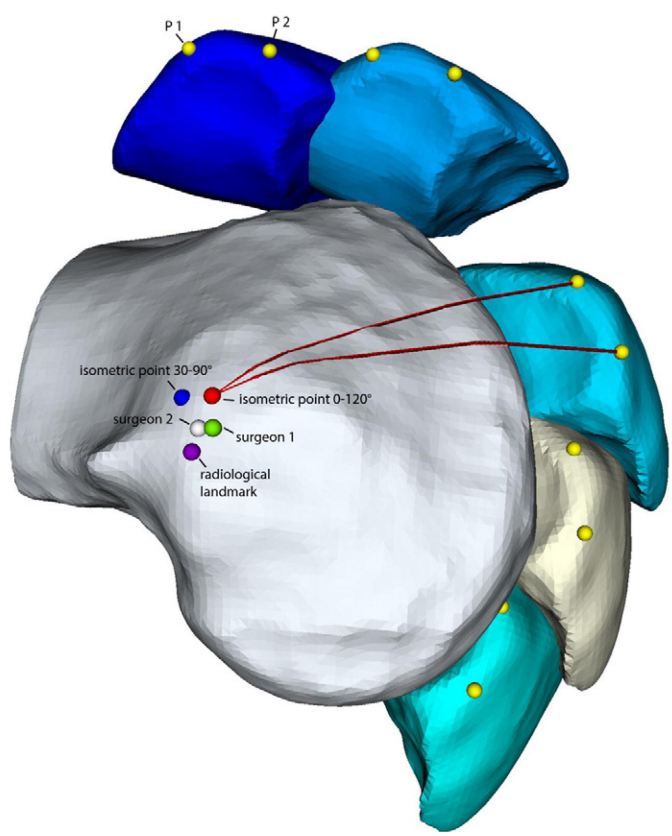

Fig. 1. 3D image of a knee with distribution of the different femoral insertion points and the two defined patellar points P1 and P2. The two red lines (strings I and II) show exemplary the distance between P1 and P2 in the 60° patellar position and the computed isometric point 0 to 120°.

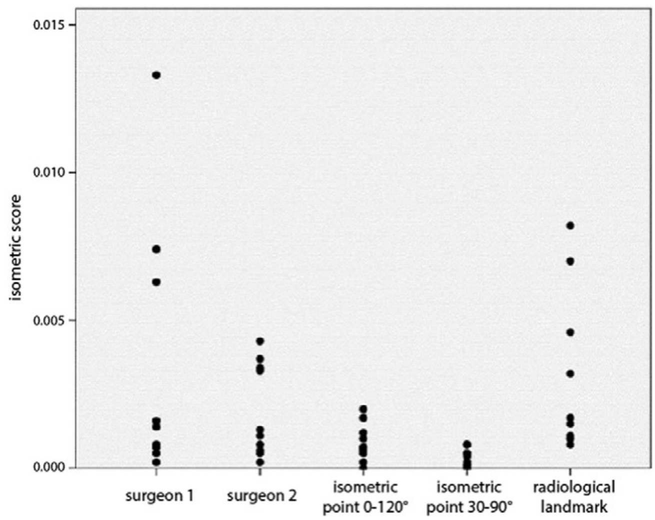

Fig. 2. Distribution of the isometric values of each subject applied to the different femoral points. The isometric sore 0 signifies an ideal isometric behaviour of this femoral anchorage point.

The shortest ligament length was obtained in the flexion position 90° for string I (57.3 mm) and in 30° for string II (85.3 mm). The maximal length difference during full range of motion was 9.8 mm for string I and 7.2 mm for string II. Fig. 3 shows the relative difference in length in percent of each string for the isometric femoral point 30 to 90°.

4. Discussion

The most important finding of this study was that the computed, best isometric femoral insertion point showed a variable anatomical distribution, suggesting that the optimal position for femoral MPFL-graft fixation is patient specific.

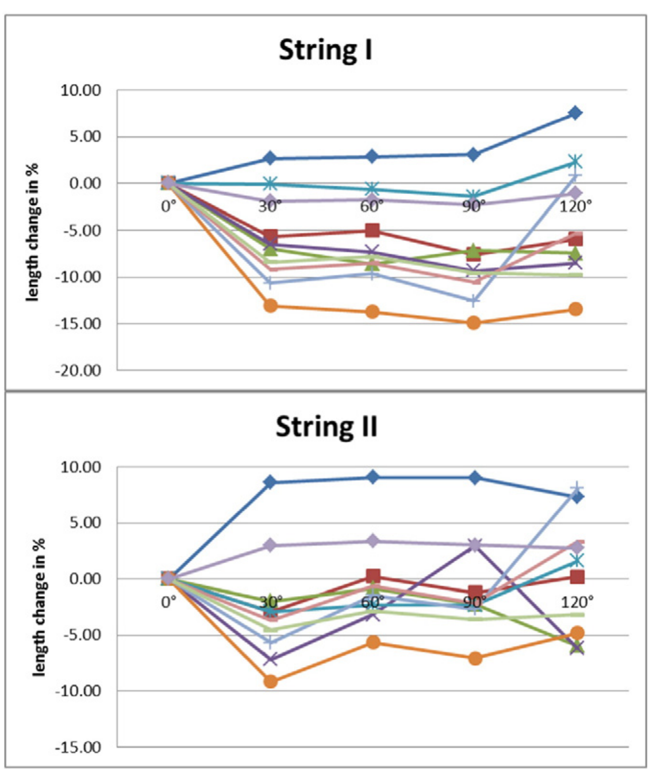

Fig. 3. Percentaged length changes between the femoral attachment point (isometric femoral point 30 to 90°) and the patellar point I (string I) and patellar point II (string II) in each of the 10 subjects related to the different knee flexion angles 0 to 120°. Positive values signify a longer distance, negative values a shorter distance between the femoral and patellar attachment sites. The patellar position 0° thereby acts as reference.

Femoral malposition can lead to a potentially insufficient graft with persistent patellar instability, a flexion constriction or can provoke a conflict between the graft and the medial condyle, which could potentially induce pain [20,21,34]. Furthermore an excessive anterior or proximal graft positioning induces an increased patellofemoral pressure during flexion. To avoid these problems an accurate localization of the femoral MPFL attachment is crucial. The goal of this study was to find the optimal femoral insertion point in MPFL-reconstruction with respect to isometry and subject-specific anatomy.

Three dimensional models and our previously specified technique for automatic string generation [33] were used in order to analyse and simulate MPFL-reconstruction in vivo throughout the entire range of motion of the knee.

We investigated length changes of the graft and defined arithmetically the most isometric femoral insertion point and correlated this point with the recommended radiological landmark and the attachment point favoured by two experienced knee surgeons.

Our findings confirm that the MPFL is not a fully isometric structure [9,13]. We measured a considerable length change with a maximal string length difference throughout full range of motion of 9.8 mm for string I and 7.2 mm for string II. Minimal length change was 1.4 mm for string I and 1.9 mm for string II.

In most of the 10 cases, the calculated strings showed the maximal length in the 0° knee flexion position. Contrary to our expectations, the shortest distance between the femoral and the patellar insertions points, was measured in 30° knee flexion, where we anticipated a tight ligament situation and therefore a longer distance between the three fixed points in our model. The fact that with CT scans, soft-tissues as periost, joint capsule and particularly cartilage at the medial condyle are subtracted, may explain an alteration of the ligament length in knee flexion positions and therefore may have falsified the real values.

The computed most isometric point for patellar position 30 to 90° showed a non-uniform distribution in regard to landmarks as the readily identifiable adductor tubercule and the less definite medial epicondyle. This fact suggests that the optimal femoral insertion point is patient-specific and can vary dependent on anatomic factors as the anatomic shape of the medial condyle.

In nine out of 10 cases, the optimal femoral insertion point was located slightly anterior to the entry points defined by the two surgeons. The latter showed a quite uniform pattern regarding the surrounding anatomical landmarks, but a moderate isometric score. The radiographic landmark applied to the three-dimensional model showed the worst isometric score and a non-uniform distribution pattern.

Anatomic landmarks and radiographic orientation can assist the surgeon in finding the appropriate femoral fixation point [23,26], but is not sufficient alone in defining the subject specific MPFL point [35]. An additional dynamic testing of the ligament tension over the full range of motion during surgery is mandatory with an adjusting of the site of anchorage if needed. Attachment points too far anterior or proximal should be avoided to prevent an over-tightening of the graft in flexion-positions.

This study has several limitations. Firstly, a small sample size of only 10 subjects was analysed. Secondly, data was acquired by CT scan reproducing only bony structures and therefore subtracting all soft tissues such as cartilage, joint capsule and synovial tissue. In particular, the missing cartilage covering the medial condyle can modify string length in vivo. Furthermore the MPFL graft was simplified to two non-penetrating string between small insertion points, ignoring biomechanical and material properties (e.g. fibre direction and stiffness). The two patellar fix points were defined experientially by a knee surgeon.

However, this study provides preliminary results on the MPFL path length under physiological loading and may give additional insights for pre-operative planning of this well-established surgical procedure.

5. Conclusion

This study provides results on the MPFL path length under physiological loading conditions using high-resolution bone geometry. The aim was to find the optimal femoral insertion point with respect to isometry of the length of the two MPFL bundles.

The calculated most isometric point showed a non-uniform distribution pattern related to anatomic landmarks, arguing that the optimal attachment point is dependent on subject-specific anatomy. Therefore a meticulous intraoperative examination of isometry of the MPFL graft is mandatory in every subject and adjustment of the insertion point could be necessary in some cases.

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