Calculating the Position of the Joint Line of the Knee Using Anatomical Landmarks

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abstract

Restoration of the joint line of the knee during primary and revision total knee arthroplasty is a step that directly influences patient outcomes. In revision total knee arthroplasty, necessary bony landmarks may be missing or obscured, so there remains a lack of consensus on how to accurately identify and restore the joint line of the knee. In this study, 50 magnetic resonance images of normal knees were analyzed to determine a quantitative relationship between the joint line of the knee and 6 bony landmarks: medial and lateral femoral epicondyles, medial and lateral femoral metaphyseal flares, tibial tubercle, and proximal tibio-fibular joint. Wide variability was found in the absolute distance from each landmark to the joint line of the knee, including significant differences between the sexes. Normalization of the absolute distances to femoral or tibial diameters revealed reliable spatial relationships to the joint line of the knee. The joint line was found to be equidistant from the lateral femoral epicondyle and the proximal tibio-fibular joint, representing a reproducible point of reference for joint line restoration. The authors propose a simple 3-step algorithm that can be used with magnetic resonance imaging, computed tomography, or radiography to reliably determine the anatomical location of the joint line of the knee relative to the surrounding bony anatomy. [Orthopedics. 2016; 39(6):381-386.]

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f the commonly accepted technical goals of a total knee arthroplasty (TKA), restoration of the joint line of the knee is important. Failure to restore the joint line of the knee to anatomical position can lead to mid-flexion instability, a reduction in range of motion, impingement of the patellar tendon against the tibial tray, and gap imbalance.1-5 Unfortunately, successful restoration of the joint line relies heavily on the presence and integrity of bone and soft tissue landmarks. Unlike in primary TKA, in revision TKA, the necessary landmarks are often missing or obscured, making restoration of the joint line both difficult and unreliable.

Numerous methods, ranging from relative references, including “2 finger breadths from the tibial tubercle,” to absolute distances, including “10 mm from the fibular styloid,” have been described for joint line restoration, yet a lack of consensus remains.1,6,7 Alternatively, the joint line of the knee can be estimated on a preoperative radiograph by measuring the distance from the joint line of the knee to either the medial epicondyle, fibular head, or tibial tubercle.1,8 These methods cannot
be employed if there is no radiograph prior to TKA or if there is previous ipsilateral or contralateral tibial tubercle osteotomy. In another method, the inferior pole of the patella with the knee in 90° of flexion can serve as a guide to joint line position. This method, however, cannot be employed in the setting of patellar baja, tibial tubercle osteotomy, patellectomy, or prior TKA.

Anatomical studies have evaluated the distances from the femoral epicondyles, fibular head, and tibial tubercle to the joint line of the knee, in addition to the ratios of these absolute distances to femoral or tibial widths, compensating for sex and size differences. Although these previous studies yielded valuable anatomical relationships, the absolute distances can be variable. Also, during revision TKA, the identification of the necessary anatomical landmarks can be exceedingly difficult. The purpose of this study was to determine a reproducible, quantitative relationship between the position of the joint line of the knee and identifiable anatomical landmarks about the knee.

**Materials and Methods**

Following institutional review board approval, 50 randomly selected magnetic resonance images (MRIs) of normal adult human knees, originally obtained to rule out meniscal or cruciate ligament pathology after low-energy trauma, were examined by 2 independent observers (M.J.A., K.M.). Joints reported by radiologists to have ligamentous pathology, degenerative articular cartilage, or osteochondral defects were excluded. The experimental group consisted of 50 adults between 24 and 49 years old, including 24 men between 24 and 46 years old and 26 women between 24 and 49 years old. Each anatomical landmark was marked using a digital caliper, included as part of the MRI software.

The following anatomical landmarks were identified on MRI (Figure 1):

1. Joint line of the knee (JL): the line through the most distal points of the medial and lateral femoral condyles in the coronal plane, or the line through the most distal point of the femur perpendicular to the anatomical axis of the tibial shaft in the sagittal plane.

2. Medial epicondyle (ME): the medial-most point on the femur from which the medial collateral ligament originated; coronal section (ME to the joint line of the knee: MEJL).

3. Lateral epicondyle (LE): the most prominent bony point of the femur from which the lateral collateral ligament originated; coronal section (LE to the joint line of the knee: LEJL).

4. Medial flare (MF): the point at which the medial femoral metaphyseal flare met the medial condylar cortex and also where the epiphyseal scar met the medial cortex; coronal section (MF to the joint line of the knee: MFJL).

5. Lateral flare (LF): the point at which the lateral femoral metaphyseal flare met the lateral condylar cortex and also where the epiphyseal scar met the lateral cortex; coronal section (LF to the joint line of the knee: LFJL).

6. Tibial tubercle (TT): the proximal-most corner of the junction between the tiberosity and the anterior cortex of the tibia; sagittal section. If this corner was not identifiable, the most proximal point of the patellar tendon insertion was chosen (TT to the joint line of the knee: TTJL).

7. Proximal tibio-fibular joint (PTFJ): the center of the horizontal portion of the proximal tibio-fibular joint; coronal section (PTFJ to the joint line of the knee: PTFJL) (Figure 2).

The absolute perpendicular distance between the joint line and each anatomical landmark was measured and reported. The following diameters were measured (Figure 1):

A. Interepicondylar diameter of the femur (IED): the distance between the ME and the LE in the coronal plane, also known as the surgical transepicondylar axis; coronal section.

B. Intermetaphyseal diameter of the femur (IMD): the distance between the MF and the LF in the coronal plane.

Figure 1: Coronal (A) and sagittal (B) diagrams of anatomical landmarks. Arrows: LE, lateral epicondyle; LF, lateral flare; ME, medial epicondyle; MF, medial flare; PTFJ, proximal tibio-fibular joint; TT, tibial tubercle. Red line: CTD, coronal tibial diameter; IED, interepicondylar diameter; IMD, intermetaphyseal diameter; STD, sagittal tibial diameter. The blue line represents the joint line of the knee in the coronal and sagittal planes.
C. Coronal tibial diameter (CTD): the diameter of the tibia at the level of the PTFJ in the coronal plane, perpendicular to the tibial shaft.

D. Sagittal tibial diameter (STD): the diameter of the tibia at the level of the TT in the sagittal plane, perpendicular to the tibial shaft.

To control for variation due to differences between the sexes, the absolute distances were normalized to their respective bony diameters by dividing the appropriate diameter by the corresponding absolute distance (eg, IED:MEJL). These were termed either “femoral ratios” or “tibial ratios.” To quantify the overall spatial relationship of the femoral and tibial landmarks about the joint line of the knee, the ratios between absolute femoral and tibial distances were reported. These were termed “femoro-tibial ratios.”

All measurements were repeated twice by each of the 2 observers. The mean of the 4 measurements was reported and the error was reported as SD. Statistically relevant results were determined via a 2-tailed Student’s t test and the significance level was chosen to be $P<.005$ after Bonferroni correction.

RESULTS

The absolute distances between each of the anatomical landmarks and the joint line of the knee are presented in Table 1. With the exception of the TTJL, all of the measured absolute distances were statistically different between the sexes ($P<.005$; Table 1). The absolute femoral and tibial diameters are listed in Table 2. All of the absolute diameters were also statistically different between the sexes ($P<.005$; Table 2).

To negate the effect of the difference between the sexes, the absolute distances between the anatomical landmarks and the joint line of the knee were normalized to their respective femoral or tibial diameters. The LEJL was found to be one-third of the IED (IED:LEJL=3.2±0.2). The femoral and tibial ratios for all of the landmarks are provided in Table 3. After normalization, no statistically significant differences in the femoral and tibial measurements remained between the sexes ($P>.05$; Table 3). The CTD:TTJL and the STD:PTFJL ratios were not calculated because it is not possible to measure these absolute distances in the same plane of an MRI.

Finally, the overall spatial relationship of the femoral and tibial landmarks about the joint line of the knee was determined by calculating the ratios between absolute femoral distances and absolute tibial distances. The LEJL was found to be equal to the PPTJL (LEJL:PTFJL=1.0±0.1), suggesting these landmarks are equidistant from the joint line. The femoro-tibial ratios for all of the landmarks are presented.
None of the femoro-tibial ratios showed statistically significant differences between the sexes ($P > .05$; Table 4). Although the ratios using the TTJL require measurements in 2 different planes of an MRI, the authors included the TTJL in their femoro-tibial ratios because it is a potentially visible intraoperative landmark.

### Discussion

This study has defined the position of the joint line with respect to the anatomical landmarks about the knee and has introduced the concept that the joint line is at a constant ratio from both the femoral and the tibial anatomical landmarks.

The authors confirmed the following absolute distances: MEJL (27.6±3.2 mm), LEJL (23.6±2.3 mm), PTFJJL (22.2±3.2 mm), and TTJL (20.9±4.4 mm). These data are comparable to those of previously published anatomical studies as reported in Table 1 and Table 3.10–12

Previous anatomical and radiographic studies have attempted to establish a reproducible relationship between the fibular head and the tibial plateau, but a consensus point of reference on the fibular head from which to make observations is lacking.13,14 In addition, the fibular styloid is variable in morphology.11 Further, the fibular styloid can be excised intraoperatively, during the proximal tibial cut, and is not always available as a reference during revision TKA. The fibular head is highly variable and unreliable as an anatomical landmark.11,13,14

Compared with the fibular head, the PTFJ used in this study is a superior anatomical landmark. Unlike the fibular head, the PTFJ is a clearly defined anatomical landmark that can be seen on a plain radiograph, making it a widely usable point of reference regardless of preoperative imaging modality. If it is not visible because of fibular rotation, the PTFJ can be found at the intersection of the lateral prominence of the fibular head and the fibular styloid.

The authors observed that the LEJL has the lowest SD (2.3 mm) compared with the other landmarks (ie, MEJL, MFJL, LFJL, PTFJJL, and TTJL). This observation confirms previous reports that, despite statistically significant inter- and intraobserver variability, the mean LEJL intraobserver deviation was the most precise at 1.7 mm.15–17 This precision

<table>
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<tr>
<th>Table 3</th>
<th>Femoral and Tibial Ratios</th>
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<td>Ratio</td>
<td>Current Study</td>
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<tr>
<td>IED:MEJL</td>
<td>2.8±0.3</td>
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<tr>
<td>IED:LEJL</td>
<td>3.2±0.2</td>
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<tr>
<td>IMD:MFJL</td>
<td>1.7±0.2</td>
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<tr>
<td>IMD:LFJL</td>
<td>2.1±0.2</td>
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<tr>
<td>CTD:PTFJJL</td>
<td>3.3±0.5</td>
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<td>STD:TTJL</td>
<td>1.9±0.6</td>
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**Abbreviations:** CTD, coronal tibial diameter; IED, interepicondylar diameter; IMD, intermetaphyseal diameter; LEJL, lateral epicondyle to joint line of the knee; LFJL, lateral flare to joint line of the knee; MEJL, medial epicondyle to joint line of the knee; MFJL, medial flare to joint line of the knee; PTFJJL, proximal tibio-fibular joint to joint line of the knee; STD, sagittal tibial diameter; TTJL, tibial tubercle to joint line of the knee.

<table>
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<th>Table 4</th>
<th>Femoro-Tibial Ratios</th>
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<tr>
<td>Ratio</td>
<td>Overall</td>
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<tr>
<td>MEJL:TTJL</td>
<td>1.4±0.3</td>
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<tr>
<td>LEJL:TTJL</td>
<td>1.2±0.2</td>
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<td>MFJL:TTJL</td>
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<td>LFJL:TTJL</td>
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<tr>
<td>MEJL:PTFJJL</td>
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<td>LEJL:PTFJJL</td>
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<td>1.6±0.3</td>
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**Abbreviations:** LEJL, lateral epicondyle to joint line of the knee; LFJL, lateral flare to joint line of the knee; MEJL, medial epicondyle to joint line of the knee; MFJL, medial flare to joint line of the knee; PTFJJL, proximal tibio-fibular joint to joint line of the knee; TTJL, tibial tubercle to joint line of the knee.
is likely a direct result of the anatomy of this structure. The LE is readily identified as the most prominent point on the lateral distal femur, whereas, in contrast, the ME, for example, is actually a sulcus between 2 prominences on the medial distal femur. As such, the LEJL is the most reliable of the authors’ measured distances for accurate joint line reconstruction.

Individual variation related to sex renders absolute measurements of anatomical landmarks irrelevant.10,11 With the exception of the TTJL (P>.05), the authors found that all of the absolute distances and diameters were significantly different between the sexes (P<0.005). Normalization to diameter negates statistically significant differences between the sexes, offering a more reliable metric for localizing the joint line. In addition, normalization eliminates susceptibility to magnification or positional distortion, which is present in all imaging formats. Normalization allows the authors’ MRI-based technique to be employed more broadly with either plain radiographs or computed tomography scans, as all of the landmarks used in this study are visible with these modalities as well.

The current authors’ data corroborate published computed tomography and MRI data (Table 3)10–12 that the LEJL was one-third of the IED (IED:LEJL=3.2±0.2) (Figure 3). This anatomical relationship is thus a valid and useful ratio for joint line determination. Further, the authors independently verified previous reports (Table 3)11 that the TTJL was one-half the STD (STD:TTJL=1.9±0.6) (Figure 3).

Among the authors’ most functionally useful findings was the establishment of a novel femoro-tibial ratio of 1.0 between the LEJL and the PTFJL (LEJL:PTFJL=1.0±0.1). This suggests that the joint line of the knee is halfway between the LE and the PTFJ, 2 readily identifiable landmarks (Figure 3). This is the first description of an equidistant spatial relationship of anatomical landmarks around the joint line of the knee.

Servien et al11 first introduced the idea that normalization of absolute distances to femoral or tibial diameters can control for the high individual variability observed in absolute measurements about the joint line. They described the use of an epicondylar to femoral width ratio to determine the relative location of the joint line of the knee.11 On the basis of their own results, the current authors propose the following modification to the Servien et al11 algorithm for establishing the location of the joint line of the knee (Figure 4).

First, if the epicondyles are visible, determine the IED of the femur. The femoral articular line is approximately one-third this distance from the LE. If the epicondyles are difficult to identify, determine the IMD of the femur. The femoral articular line is one-half this distance from the LF. Second, if the TT is visible, determine the STD. The tibial articular line is one-half this distance from the TT. If the TT is not visible, determine the CTD. The tibial articular line is approximately one-third this distance from the PTFJ. Finally, the location of the joint line of the knee can be reliably verified using the authors’ novel reported LEJL to PTFJL femoro-tibial ratio, as the joint line should be equidistant from the LE and the PTFJ.

Incorporation of this algorithm into computer-assisted orthopedic surgery, especially when a preoperative MRI has been obtained (eg, patient-specific instrumentation), may prove more useful than gross estimation. Further, the same spatial relationships used to calculate the position of the joint line of the knee relative to anatomical landmarks can be used in reverse to calculate the position of anatomical landmarks relative to the joint line of the knee. This reversal may be useful in estimating ligament insertion points during reconstruction, especially when the identification of an anatomical landmark (eg, ME and LE) is subject to high interobserver and intraobserver variability.15–17

**CONCLUSION**

The purpose of this study was to determine a quantitative relationship between anatomical landmarks about the knee and the joint line of the knee. The authors have presented a modified algorithm for successful restoration of the joint line of the knee during TKA using the novel LEJL to PTFJL femoro-tibial ratio. In TKA, successful restoration of the joint line can be verified by
ensuring the joint line lies equidistant from the LE and the PTFJ. The relationships defined in this article can be applied broadly to a variety of perioperative imaging modalities, including MRI, computed tomography scans, and radiographs. Further studies validating the authors’ observations in retrospective radiographic review of primary and revision TKA will help to translate these observations into clinical practice.

REFERENCES


