



# A new landmark for measuring tibial component rotation after total knee arthroplasty

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## ABSTRACT

**Background:** Existing methods for assessment of total knee arthroplasty (TKA) component rotation on computed tomography (CT) scans are complex, especially in relation to the tibial component. Anecdotal evidence from our practice pointed towards a potential new landmark. The study aims were to check the prevalence of this landmark, define tibial component rotation in relation to it and demonstrate its reliability.

**Methods:** Two hundred and eleven CTs undertaken following TKA were reviewed for presence of the landmark. A protocol to measure tibial component rotation in relation to this landmark was developed and the rotation measured using this method and Berger's protocol. Thirty one of the 211 CT scans were measured twice by two observers. Reliability was calculated using the Intraclass Correlation Coefficient (ICC).

**Results:** The new landmark of a flat area on the lateral cortex of the tibia inferior to the tibial component was identified on all scans. Median tibial component rotation measured using our protocol was  $0.0^\circ \pm 5.4^\circ$  and  $-9.2^\circ \pm 5.5^\circ$  using Berger's protocol. Intra-observer reliability with the new method was excellent (ICCs of 0.899 and 0.871) and inter-observer reliability was good (ICCs of 0.734 and 0.836).

**Conclusions:** The new landmark had a very high prevalence and could be used to define tibial component rotation. This measurement of tibial component rotation had acceptable reliability. This landmark has potential for use in the radiological assessment of tibial component rotation following TKA. Further work is required to determine its relationship to anatomical structures and symptoms of tibial component mal-rotation.

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## 1. Introduction

Assessment of component mal-rotation following total knee arthroplasty (TKA) is usually undertaken using a combination of clinical assessment and computed tomography (CT) scans of the knee joint. Such assessment is necessitated by the small but persistent number of dissatisfied patients following total knee replacement. The Berger protocol is routinely used for assessment of such scans to allow determination of the rotation of both components [1,2]. Measurement of femoral component rotation is relatively simple and the Berger protocol has been accepted as the dominant method for determination of femoral component rotation [3]. The method described for measuring tibial component rotation requires identification of the geometric centre of the proximal tibial plateau, which is then axially transposed to the level of the tibial tubercle – a line connecting these two points identifies the orientation of the tibial tubercle. The second line identified is the tibial component axis, a line perpendicular to the transverse axis of the symmetrical tibial component. The angle subtended by these two lines identifies the rotation of the tibial

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component. The method of assessing tibial rotation is more complex than that described for the femur and relies on the ability of software to identify the geometric centre of an oval, which itself may not accurately represent the true shape of the tibial plateau. Transposing this centre axially also introduces potential for error.

The Berger protocol has demonstrated good reliability with intra- and inter-observer Intra-class Correlation Coefficients (ICCs) of 0.65–0.8 for tibial component rotation [4,5]. In vitro validation of the Berger method has suggested that measurements obtained on a CT differ on average by 2.5° for the femur and 3.2° for the tibia (though the number of measurements used was small) [5]. The difficulties in assessing component rotation are further compounded by anatomical variability in the various landmarks, particularly the tibial tuberosity, used in determining tibial rotation [6]. Hence, these measurements, whilst reproducible, are complex and time consuming.

A number of other methods have been described for measuring tibial rotation. These include a variation of the above protocol for asymmetric tibial components [7]. Measurement of tibial rotation has been modified through the use of a transverse line across the posterior condyles of the tibia instead of identifying the orientation of the tibial tubercle [8]. A further method for measuring tibial rotation uses the angle between the posterior margins of the tibial plateau and that of the tibial tray with the authors finding an intra-observer ICC of 0.93 [9]. Finally, the transverse axis, described by Cobb et al. [10] utilises a line perpendicular to a further line connecting the 'best fit' centres of the medial and lateral tibial condyles respectively. The authors describe an inter-observer ICC of 0.94 in taking these measurements. However, questions have been raised regarding the validity of this method, with one study suggesting that the anatomical tibial axis may lead to an internal rotation error [11].

The fact that the literature demonstrates a variety of methods for measuring this single variable would suggest that there is a need for an easily identifiable, interpretable, valid and reliable marker of tibial component rotation following TKA. The senior author, a high volume arthroplasty surgeon, noted a clear anatomical landmark evident on a number of CT scans taken following TKA. This study was undertaken to check the prevalence of this landmark, define tibial component rotation in relation to it and to demonstrate the reliability of the measurement of tibial component rotation using this landmark. We also explored whether there was a correlation between measured tibial component rotation and preoperative lower limb coronal plane alignment.

## 2. Methods

This was a retrospective cohort study examining CT scans from patients who had undergone primary TKA at a high volume arthroplasty unit. This study was carried out under the clinical and data governance procedures of the hospital as required for a retrospective study.

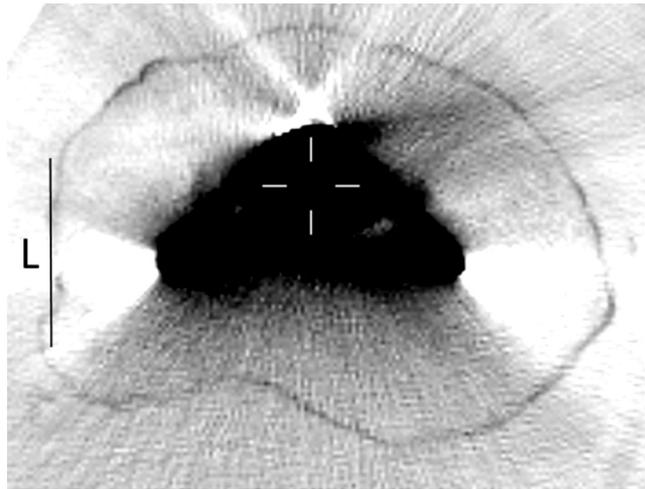
Two hundred and eleven postoperative CT scans of the operated limb from a previous, unrelated ethically approved study [12] were used. For the initial study patients were recruited prior to TKA so the cohort of CT scans represented a normal TKA population with the following exclusions: Body Mass Index (BMI) >40; knees requiring patellar resurfacing or complex knees potentially requiring more constrained implants. All patients had navigated TKA with the B-Braun Columbus Total Knee System implants. Surgery was performed by one of three surgeons at the same institution. All but a single procedure were performed through a medial parapatellar approach; the remaining procedure was performed using a lateral parapatellar approach. Tibial cuts were made at 90° to the mechanical axis under guidance of the navigation system. Cutting jigs were used to resect 10 mm of bone from the least worn side of the tibial plateau. Tibial rotation was set using the tibial tuberosity and the transverse axis [10] as landmarks. All surgeons ensured the patella was tracking appropriately prior to closure; no patients required a lateral release for patellar mal-tracking. The CT scans were taken six weeks post-operatively using the "low dose" Imperial knee protocol [13] which gives a voxel size of 0.03 mm for the region from 10 cm above to 10 cm below the joint line. The raw CT scans were stored and viewed in Carestream Client Picture Archiving and Communications System (PACS) (Carestream Health Inc., Rochester, NY, USA). Before any measurements were taken the raw scans were re-processed to define an appropriate coordinate system. The multi-planar reconstruction function was utilised to allow the scan to be viewed in three orthogonal planes. This allowed the orientation of scans in the transverse axis to be aligned to the tibial anatomical axis just inferior to the tibial implant making the coordinate system orthogonal to the tibial axis (Figure 1). Using appropriate magnification and inverse windowing settings, the transverse slice directly inferior to the tibia implant was identified. The image was then fine-tuned using windowing properties that enabled the reduction of metal artefact and optimisation of image contrast, allowing identification of the new landmark.

The new landmark that had been noted was that the lateral cortex of the tibia inferior to the tibial component was flat at a depth of approximately 10 mm from the joint line (Figure 1). The lateral aspect of the tibia just underneath the tibial implant demonstrated the flattest part of the area (straightest line on a CT slice image). However, in some cases osteophytes did disrupt the obvious straight line of this area. In these cases the line representing the new landmark was drawn through the straightest part of the lateral tibial cortex, ignoring any osteophytes. All 211 CT scans were reviewed by one observer for the presence of this landmark. Figure 2 illustrates the depth of the landmark on a sawbone knee model.

A protocol to measure tibial rotation in relation to this landmark was developed.

First, the CT scan slice immediately distal to the tibial implant was identified. A line was drawn through the straightest lateral cortex surface of the tibia; a line perpendicular to this defined the reference axis (A) (Figure 3). The posterior tibial component axis was then drawn (B) (Figure 4). The angle between A and B was measured to allow rotation to be determined (Figure 4). Internal rotation was recorded as being negative and external rotation positive.

The tibial component rotation on all scans was measured by a first observer using the above protocol and the Berger protocol [1,2]. The Berger protocol was chosen as the comparison as it is used extensively in the literature to assess tibial rotation. In addition to the 211 scans, 31 scans were selected randomly and were measured again for tibial component rotation using



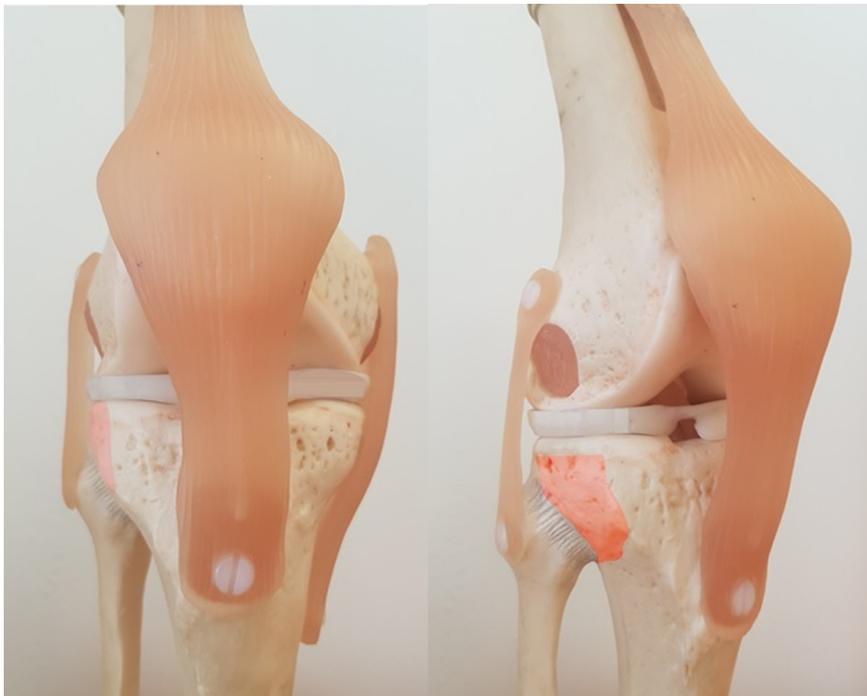
**Figure 1.** Transverse CT image showing the new landmark of the flat area of lateral cortex (L) of the tibia inferior to the tibial component.

the new protocol by the first observer at least one week after the first reading and on two occasions by a second observer, again with at least one week between readings.

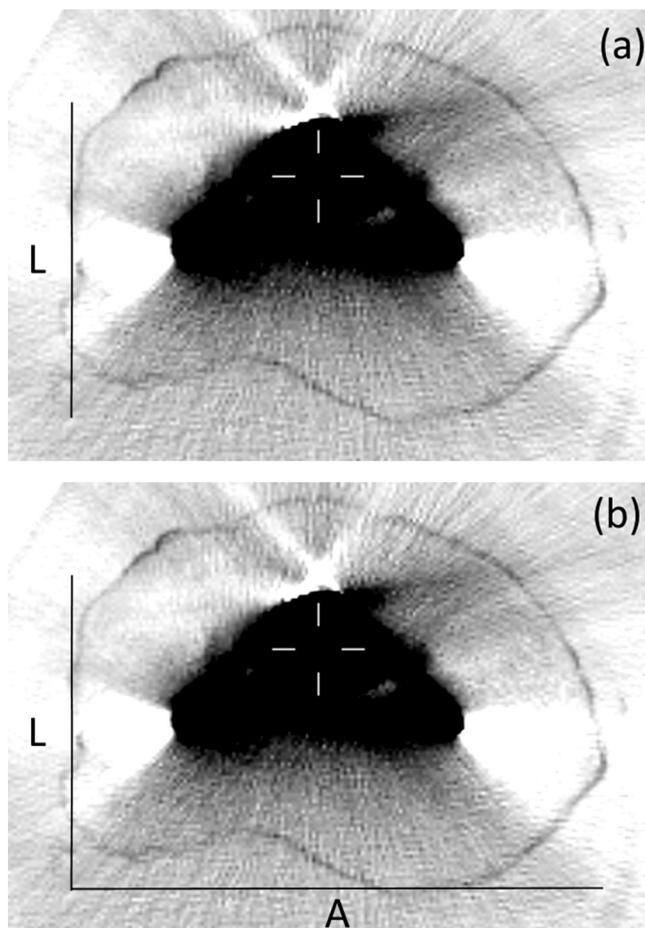
Coronal lower limb alignment was measured by a single observer using full length lower limb x-rays. Measurements were recorded using the angle measurement tool available in the PACS system. Valgus alignment was recorded as positive and varus alignment as negative.

### 2.1. Statistical analysis

The number of scans needed for reliability analysis was calculated using the method described by Bonett [14]. Assuming an anticipated value of the ICC of 0.85 and acceptable width of the 95% confidence interval of 0.2 (puts lower bound at 0.75), the optimal number of measurement pairs was 30.



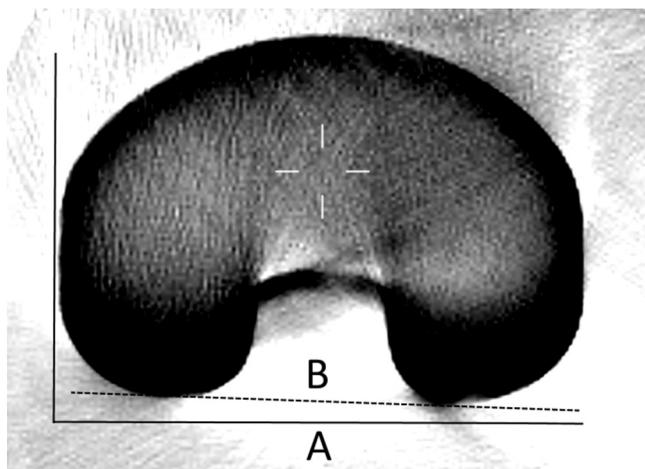
**Figure 2.** Illustration of landmark on a sawbone.



**Figure 3.** (a) Measurement of tibial component rotation using the new landmark. The initial line (L) is aligned with the landmark of the straight lateral cortex of the tibia. (b) A second line (A) drawn perpendicular to L defines the reference (anatomical) axis.

Thus 31 pairs of measurements were used to calculate ICCs for intra- and inter-observer variation. ICCs were calculated using IBM SPSS Statistics v23 with a two-way random model with absolute agreement and taking the average measures result.

The Pearson correlation coefficient was used to explore whether a relationship existed between measured tibial component rotation and preoperative lower limb coronal plane alignment.



**Figure 4.** A line (B – dashed) is drawn through the posterior of tibial component and defines the tibial component axis. The angle between A and B gives the tibial component rotation with internal rotation of the component (B with respect to A) being negative.

### 3. Results

The new landmark of the flat lateral cortex was identified on all scans reviewed.

The median tibial component rotation measured using the new landmark protocol was 0.0° with an IQR of 4.8° (range –18.6° to 14.0°). The median rotation measured as per the Berger protocol was –9.2° with an IQR of 7.7° (range –29.0° to 5.2°). The frequency plots showed the different distributions of rotations between the two methods with the new landmark being more tightly centred (Figure 5).

For the new protocol for tibial component rotation the intra-observer ICCs were 0.899 (observer 1) and 0.871 (observer 2), indicating excellent reliability. Inter-observer ICCs were 0.734 (reading 1) and 0.836 (reading 2) indicating good reliability.

The Pearson correlation coefficient was –0.142, suggesting a weak relationship between the recorded tibial component rotation and coronal plane lower limb alignment. A scatterplot comparing these variables with the associated regression line is presented in Figure 6.

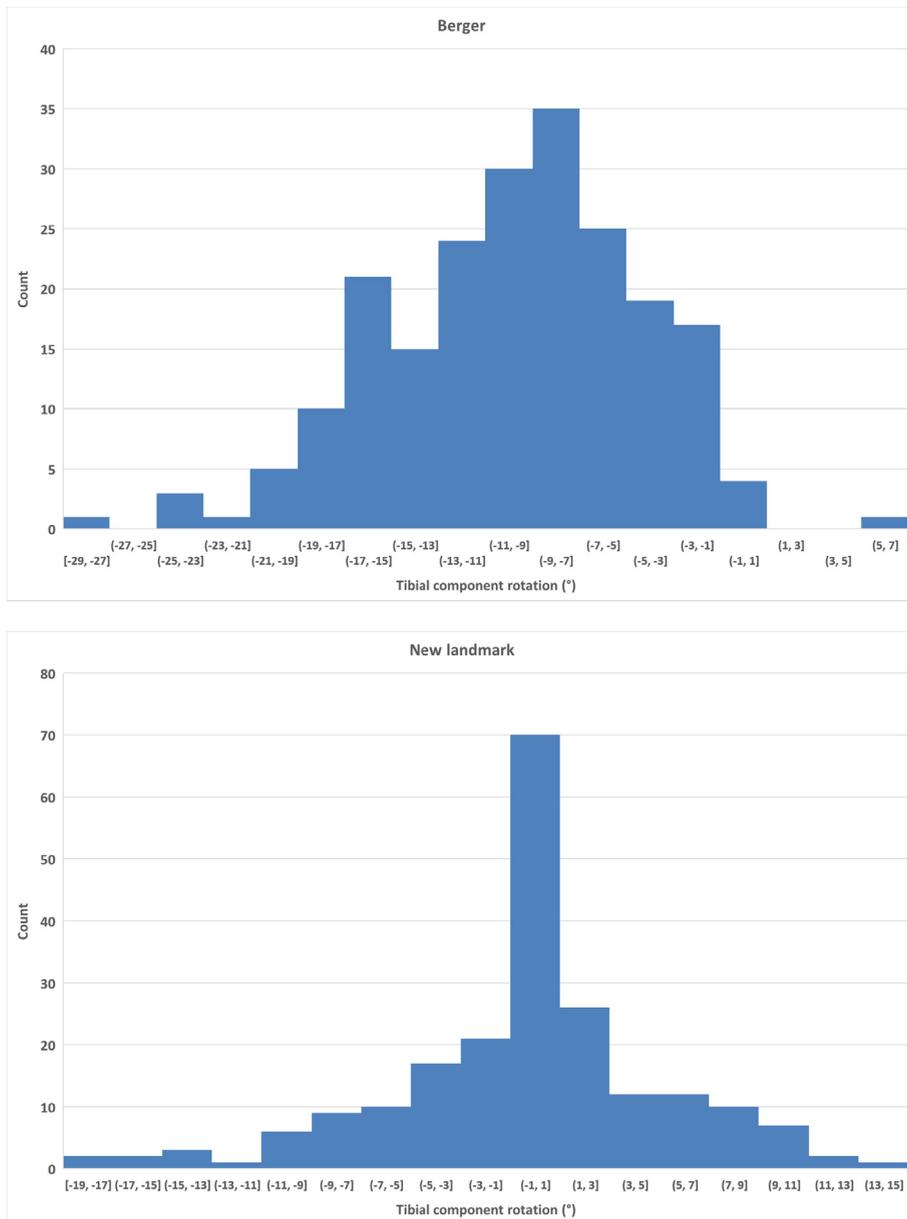
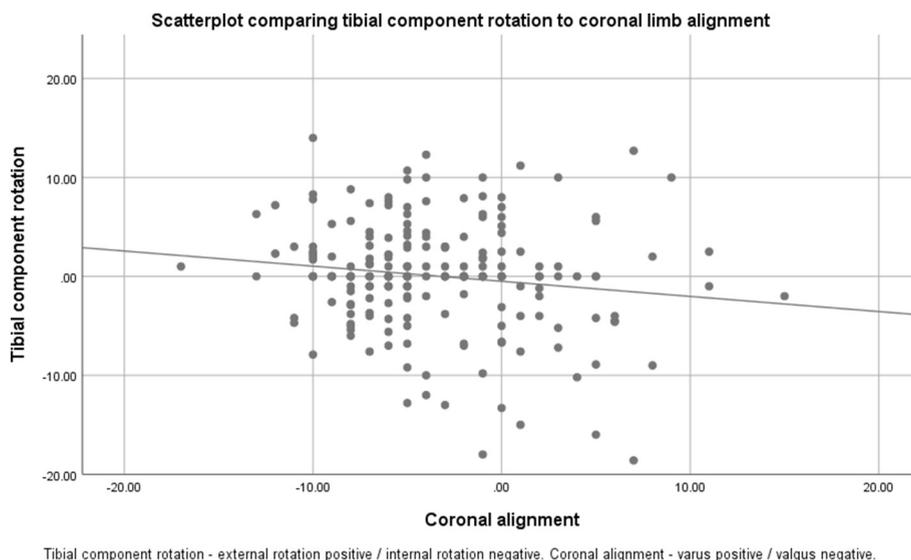


Figure 5. Frequency plots of measurement of tibial component rotation for (a) Berger protocol and (b) new tibial landmark.



**Figure 6.** Scatterplot comparing tibial component rotation to coronal plane lower limb alignment.

#### 4. Discussion

Despite the ubiquitous use of TKA to treat arthritis of the knee joint and improvements in outcomes over the past decade approximately one third of young patients report residual symptoms and functional limitations [15]. The reasons for this are multifactorial. One of the factors clearly identified is component mal-rotation. Mal-rotation is understood to lead to multiple issues following TKA, including mal-tracking of the patella [16], anterior knee pain [17], accelerated polyethylene wear [18], limited range of motion [19] and stiffness [7]. Improved patient reported outcomes scores have been reported following revision for mal-rotated components [20,21], though not to levels seen following a successful primary TKA [19,22]. Tibial mal-rotation in particular has been independently verified as a significant cause of postoperative knee pain [23], with Bell et al. [24] reporting that internal rotation of both components individually or in combination results in pain following TKA. Finite element analysis work suggests that absolute internal tibial rotation of 15° is associated with a 60% increase in stress across the posterior elements of the knee joint in deep flexion [25]. Computer simulations also suggest that tibial mal-rotation is associated with anteroposterior instability [26]. Component mal-rotation has been identified as one of the leading causes for revision TKA [3]. External rotation of both tibial and femoral components of between two degrees and five degrees is thought to maximise the longevity of the implant [9].

Therefore there is a need for an easily identifiable and reproducible tibial landmark which will allow radiological determination of tibial component rotation following TKA. Although there is much discourse regarding intraoperative landmarks for determining such rotation [27–29], including the suggestion of novel landmarks [30], there has been little dialogue concerning potential radiological landmarks. The results of this study indicate that the new landmark identified fulfils the criteria above. The measurement method does not require reliance on software calculation or estimation of the centre of the tibial plateau. It is easy to explain to trainees and students. In addition it is centred around a value of zero which makes the rotation easy to understand and the frequency plots of the measured tibial component rotation demonstrate a narrower distribution than that for the Berger protocol which may aid precise measurement of tibial component rotation.

It should be noted that there is extensive debate over the optimal method to determine tibial component rotation intraoperatively. Over the years, several landmarks have been described to optimally orient the tibial tray during TKA. Two main concepts are mainly debated. The first relies on anatomical landmarks and the second is the so-called “self-adjusting technique”. Since the introduction of TKA and following its refinement techniques, numerous anatomical landmarks have been described. Amongst these landmarks are the tibial tuberosity [27], medial third of the tibia [31], posterior tibial condyle [18], second metatarsal axis [32], the middle of the bimalleolar axis, the Dalury axis [33], tibial transverse axis [10] and others. As well as these landmarks, the self-adjusting technique described by Ishii relies on knee manipulation during TKA trialling, allowing the tibial trial tray to adjust to the position of the femur trial component, such that there is no micro-motion of the tibial trial tray [34]. This final concept is recommended by some authors [35] with successful outcomes, but unfortunately this technique cannot be applied to asymmetrical design (though such designs should help avoid tibial mal-rotation in the first instance). Overall, the multitude of surgical techniques to rotationally orient the tibial tray demonstrates that this is a controversial issue in TKA. We believe our anatomical landmark may help not only the radiological assessment of mal-rotation, but also the identification by surgeons of a reliable anatomical landmark for avoiding component misplacement. This will however, require further study.

Our work suggests a weak association between the measured tibial component rotation and coronal limb alignment – this is likely of limited clinical significance.

Notably, a number of authors [36,37] have described the use of three dimensional CT scanning to determine component rotation following TKA. Landmarks used here are similar to those described above, though Roper et al. [37] use the centre of the tibial component along with a line between the medial and middle thirds of the tibial tubercle to measure rotation. Higher intra-observer and inter-observer reliability has been reported [3] for three dimensional CT scanning as compared to conventional two dimensional techniques. However, the availability of this technique is limited and most practicing orthopaedic surgeons are not familiar with the interpretation of such scans.

#### 4.1. Strengths and limitations

This work has a number of strengths. A large number (>200) CT images from a normal TKA population were reviewed. The tibial component rotation as calculated by the Berger protocol, the current predominant method for calculating tibial component rotation, shows that this is a representative series of TKAs as although Berger gives a mean internal rotation of  $18^\circ \pm 2.6^\circ$  (standard deviation) other studies have showed that most well-functioning tibial components are placed between two and five degrees of external rotation and  $9.5^\circ$  of internal rotation [3,9,16,24]. Our series falls just within this range – if one were to assume that the ‘optimal’ rotation was at the mid-point of this range, i.e. approximately four to five degrees of internal rotation as measured by the Berger protocol, this would suggest that the optimal tibial component rotation measured using our method is a few degrees internally rotated compared to the current cohort. Hence, in Figure 3b, Line A should lie at  $85\text{--}86^\circ$  to line L. However, we did not correlate clinical outcome with tibial component rotation in this work.

A further strength lies in the fact that two independent reviewers measured rotation, allowing calculation of intra- and inter-observer correlation coefficients.

There are also some weaknesses of the study. As there is no ‘true’ measure of tibial rotation in the literature our findings had to be compared with existing methods and from the wide range available only the Berger protocol was used to assess tibial component rotation. This was chosen as it is the most widely used and accepted measurement so is the most appropriate to make a first assessment of a new method. The variability of pre-existing anatomical landmarks has been confirmed in previous studies [6] hence there is a need for the landmark identified here to be validated to determine its reproducibility across populations and its relationship to known anatomical structures. We have conducted this study on CTs where navigation was used to control the coronal and sagittal alignments of the cuts and it is possible that a grossly mal-aligned cut may render this landmark invisible. It would be beneficial to quantify the dimensions of the landmark and as such we are currently in the process of gaining access to a CT scan database to ascertain the dimensions of this landmark as well as its relationship to known bony landmarks such as the tibial tuberosity and other tibial rotation landmarks in an effort to address these issues. This will also allow us to explore whether the position of this landmark varies with sex, bony length or ethnicity, as well as to determine if it is present in scans of non-arthritis patients. Furthermore, at six weeks 96% of the cohort were satisfied with their TKA. Although this is a very early time point for assessment this low rate of problems did not allow reliable analysis of clinical symptoms with this new measurement of tibial component rotation to investigate its utility as a diagnostic test for tibial mal-rotation. However, we reviewed the casenotes of all patients not satisfied with their procedure at a minimum of four years post-procedure – none of these patients had been found to have symptoms related to the patellofemoral joint, with no further surgical intervention to their joint for such problems recorded. As the aim of this study was to establish the prevalence of the reported landmark in a generic TKA cohort, we assessed both satisfied and unsatisfied patients throughout a range of tibial component rotation to ensure that the landmark was useful for measurement in all patients. Ideally, correlation of tibial component rotation as assessed by this landmark with functional outcomes would provide insight into its potential prognostic utility and we hope to explore this in future work.

#### 4.2. Conclusions

The new landmark had a very high prevalence and could easily be used to define tibial component rotation. The landmark had acceptable reliability. Therefore, this new landmark has potential for use in the radiological assessment of tibial component rotation following TKA. Further work is required to determine the relationship to other anatomical structures and clinical symptoms of tibial component mal-rotation.

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#### Conflicts of interest

None.

## Ethics statement

The study was granted approval as a Retrospective Data Analysis by the Data Governance Manager at our institution. As this study used anonymised data collected in the course of the patients' treatment, according to the requirements of the Governance Arrangements for Research Ethics Committees (GAFREC) 2011, published by the NHS Health Research Authority, Research Ethics Committee review is not required.

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