Reliability evaluation of inter-eminence line, Akagi and Dalury lines for intraoperative tibial rotation: An osteology-based study

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# Abstract

**Background:** This large osteology study examined the reliability, reproducibility and correlation between previously described tibial tray rotation alignment lines (including Akagi and Dalury lines). In addition, it described a novel inter-eminence line utilising the tibial plateau inter-condylar eminences as a landmark.

**Methods:** A total of214 post-medieval (18-19th century) skeletal tibia were examined. The inter/intra-observer variation and correlation between reference lines was measured.

**Results:** Inter-observer reproducibility was excellent and no different between Akagi (ICC = 0.90; 95% CI 0.83–0.94), Dalury (ICC = 0.94; 0.90–0.97), and inter-eminence lines (ICC = 0.88; 0.80–0.93). Similarly, intra-observer reliability was excellent for Akagi (ICC = 0.77; 0.62–0.86), Dalury (ICC = 0.91; 0.85–0.95), and inter-eminence lines (ICC = 0.90; 0.82–0.94). Qualitative review of tibial inter-condylar eminences suggested that these could be easily identifiable. When taking the medial angle from a medial-lateral reference line, the Akagi line showed a mean of 96.90º (± 10.27), inter-eminence line 94.52º (± 12.84), and Dalury line 88.06º (± 11.75). The angle produced by the Dalury line was significantly different from both the Akagi and inter-eminence lines (*P*≤0.001). The Akagi line and inter-eminence line showed a strong correlation *r* = 0.74. The Dalury line showed a weaker correlation with both the Akagi line *r* = 0.69 and inter-eminence line *r* = 0.40.

**Conclusion:** This study suggested that tibia rotation lines showed excellent intra/inter-observer reliability and reproducibility. The novel and easily drawn inter-eminence line showed strong correlation with the Akagi line and could be used for tibial tray rotational alignment in total knee arthroplasty.

***Keywords*:**

Alignment

Rotation

Tibia

Total knee replacement

# Introduction

Total knee arthroplasty is considered to be one of the most cost-effective interventions in orthopaedic surgery due to its ability to restore function and quality of life. However, in a small percentage of patients this can cause persistent pain and failure, which can lead to revision arthroplasty surgery, with significant personal and socio-economic implications. The recorded causes of aseptic failure include instability, fracture, tibia and femur component loosening, and polyethylene wear.1,2 Technical factors, including proper component alignment, can affect the patient-reported outcome and survival following total knee arthroplasty.3 Component malalignment leads to alteration of joint kinematics, patella mal-tracking, premature polyethylene wear, and knee instability.4

Several bony anatomical landmarks have been described to aid adequate component alignment. On the femoral side, gold standards include the transepicondylar axis and the anteroposterior axis (Whiteside’s line), which are assumed to be closely associated with the flexion-extension axis of the knee.5,6 Similarly, on the tibial side, several bony and soft tissue anatomical landmarks have been described to achieve proper rotational and transverse plane component alignment.7 These include the medial third of the tibial tubercle, the medial border of the tibial tubercle, the transverse axis of the tibia, and the projected femoral transepicondylar axis.8 In addition, a combination of the above has been described as alignment lines, including Dalury and Akagi lines.9,10 However, in comparison to the femoral alignment guides, none of the latter has achieved gold standard status due to paucity of research in the area.

This large osteology study aimed to examine the reliability, reproducibility and correlation between the most commonly utilised tibial tray rotation alignment lines (including Akagi and Dalury). In addition, it described a novel inter-eminence line utilizing the tibial plateau inter-condylar eminences as a landmark.

# Materials and Methods

This was an osteological survey analysing selected individuals from the St Bride’s Church crypt in Fleet Street, London, United Kingdom. The Centre for Human Bioarchaeology (CHB), Museum of London, assists the church with the curation of the individuals and provides access to the skeletal remains for research purposes. The 227 skeletal individuals available for research were post-medieval in date, with the osteological analysis recorded for each individual onto the Oracle platform Wellcome Osteological Research Database (WORD). The skeletal remains of those curated were of individuals interred in lead coffins in the crypt of the church from the late 1670s until the crypt was closed in 1853. The association of coffin plates with the skeletal remains provides invaluable biographical information and enables other documentary sources to be researched, so that more can be learned about them and the time in which they lived. The individuals in St Bride’s crypt are a significant and large biographical skeletal collection, and contemporary with the biographical skeletal collection at Christ Church, Spitalfields. The skeletal remains from St Bride’s crypt provide an important insight into a post-medieval population of London. Their well-documented background – including age and date of death, socioeconomic status, demographics, cause of death and occupation – makes this population ideal for comparative social studies between osteological assemblages. Permission was granted, by the church and Centre for Human Bioarchaeology, for photography and handling of the skeletal remains for research purposes.

All 227 available skeletal remains were analysed; 13 were excluded due to post-mortem damage to the proximal aspect of the tibia or extensive wear to the tibial plateau. The final sample consisted of 214 tibiae: 200 paired (100 left and 100 right, same individual) and 14 unpaired. There were a total of 108 left and 106 right tibiae. The tibiae were placed on an osteometric board and digital images were taken using a standardised system (Fig. 1). The images where then analysed with ImageJ software (version 1.50, National Institute of Health, USA). Measurements included the following: 1) Akagi line: a line was drawn connecting the mid-point of the posterior cruciate ligament (PCL) attachment to the point one-third from the medial border of the tibial tuberosity.9 2) Dalury line: a line was drawn from the point 1 mm medial to the medial border of the tibial tuberosity and passing to the deepest groove between the tibial spines.10,11 3) Inter-eminence line: the four inter-condylar eminences were marked, and lines were drawn connecting the posterior (medial and lateral) tibial eminences; similarly, parallel lines were drawn connecting the anterior tibial eminences. A perpendicular line was drawn to the parallel lines between the inter-condylar eminences to the anterior plateau, this formed the inter-eminence line (Fig. 2). The angle formed between these lines and the transverse axis (medial-lateral reference line) connecting the widest part of the plateau was measured. Qualitative assessment of the tibial eminences was undertaken and scored from poor (1) to excellent (4) as follows: 1, unable to identify inter-condylar eminences; 2, able to identify at least (2/3)/4 inter-condylar eminences with (1/2)/4 being damaged or harder to identify; 3, at least three inter-condylar eminences very prominent and easily identifiable, with one being harder but present to a good quality; 4, all inter-condylar eminences very prominent and easily identified. Measurements on a sample of 50 images were then performed separately by two authors, to quantify the inter-observer variation and, on two separate occasions, to quantify the intra-observer variation.

**Statistical analysis**

The Minitab software package (version 17.0, Minitab Ltd., Coventry, United Kingdom) was used for all statistical analyses except intraclass correlation coefficient (ICC) and Cohen Kappa (*K*) (version 12.5, MedCalc Software, Ostend, Belgium). An ICC value >0.75 was considered excellent, 0.4-0.75 good/fair, and <0.4 was considered poor.12 The *K-*value for strength of agreement was interpreted as follows: 1.00-0.8 very good, 0.8-0.61 good, 0.6-0.41 moderate, 0.4-0.21 fair, and <0.20 poor.13 Continuous data were tested for normality using the Anderson-Darling test. Statistical differences and relationships between groups were examined using the unpaired Student’s *t*-test or one-way ANOVA. Post hoc determinations were made using the Tukey’s test. Correlations were tested using Pearson correlation coefficient (*r*). All values were expressed as mean ± standard deviation of the mean. A *P-*value of <0.05 was considered significant.

# Results

**Measurement reproducibility and reliability**

The inter-observer reproducibility was excellent and not different between Akagi (ICC = 0.90; 95% CI, 0.83–0.94), Dalury (ICC = 0.94; 95% CI, 0.90–0.97), or inter-eminence lines (ICC = 0.88; 95% CI, 0.80–0.93). Similarly, the intra-observer reliability was excellent for all the lines including the Akagi (ICC = 0.77; 95% CI, 0.62–0.86) and Dalury (ICC = 0.91; 95% CI, 0.85–0.95) lines, with the highest being for the inter-eminence line (ICC = 0.90; 95% CI, 0.82–0.94).

Qualitative review of tibial inter-condylar eminences suggested that they could be easily identifiable in most specimens. The median score was 3: three easily identifiable eminences (124 tibiae, 57.4%). Two eminences were easily identifiable in 97.7% of cases. Five tibiae (2.34%) had a score of 1, indicating difficulty in identifying the inter-condylar eminences. Inter-observer reproducibility showed a good (*K-*value 0.62) strength of agreement for this assessment.

**Correlation between alignment lines**

When taking the medial angle from a transverse axis (medial-lateral reference line) it was found that the Akagi line showed a mean angle of 96.90º (± 10.27) and the inter-eminence line was 94.52º (± 12.84); therefore, both lines were externally rotated to the tibia plateau midline. These measurements were not significantly different from each other on post hoc determination. The Dalury line was rotated to a mean of 88.06º (± 11.75). The angle produced by the Dalury line was significantly different from both the Akagi and inter-eminence lines (*P*≤0.001) (Fig. 3). The Akagi and the inter-eminence lines showed a strong correlation *r* = 0.74 (*P*≤0.001). The Dalury line showed a weaker correlation with both the Akagi *r* = 0.62 (*P*≤0.001) and inter-eminence lines *r* = 0.24 (*P*≤0.001).

# Discussion

This large osteology study reported adequate reliability and reproducibility between previously described tibial tray rotation alignment lines (including Akagi and Dalury lines). In addition, a novel inter-eminence line utilising the tibial plateau inter-condylar eminences as a landmark showed excellent inter-observer and intra-observer variability. This line also showed good correlation with the Akagi line, which is believed to be the most reliable tibial rotation guide to date. It is felt that the inter-eminence line constitutes somewhat of an improvement on the Dalury concept to achieve appropriate tibial tray rotation when performing total knee arthroplasty. The current results suggest that the inter-eminence line leads to a significantly more external rotated position than when using the Dalury line. This is not unexpected since in its original description, comparison with a “self-seeking” or free range of motion tibial tray technique showed a 3 mm more lateral tibial tray position than the marked Dalury line.10 Similarly, the inter-eminence line does not utilise the tibial tuberosity as a landmark and this should decrease variability.

In 2011, Bonnin et al. showed significant variability in tibial tuberosity position when compared to the transepicondylar axis.14 In 2016, Hatayama et al. reported that both the tibial tubercle and Akagi line were significantly more laterally rotated in valgus knees compared to varus knees.15 In addition, the current authors feel that the inter-eminence line might be more easily drawn when compared to the Akagi line, since it does not utilise a soft tissue landmark such as the PCL landmark. In the current study, the bony landmarks of the tibial condylar eminence were surprisingly easy to identify despite using post-medieval tibiae, with a good intra-observer agreement for the assessment. The identification of an adequate tibial rotation line is important, as technical factors, including proper component alignment, can affect the patient-reported outcome and survival following total knee arthroplasty.3 The presence of a validated and easily identifiable alignment line, such as the inter-eminence line, should allow proper positioning of the tibial base plate and, thus, avoid component malalignment. The latter would lead to alteration of joint kinematics, patella mal-tracking, premature polyethylene wear, and knee instability.

There were several limitations to the current study. As this was an osteological study of individuals predominantly from the 1800s, the population was fairly homogenous and it was not possible to include diverse ethnic backgrounds. Similarly, the individuals were not differentiated by sex. It has been shown that natural femoral rotational alignment varies by both ethnic background and sex.16 Therefore, it is within reason to assume that such variations due to ethnicity/sex also exist in the rotational alignment in the tibia and should be accounted for in future studies. Similarly, a wide variation was present in the results with large standard deviations (± 12.84º for inter-eminence line) in the measured medial angle from the transverse axis. This is likely secondary to natural anthropometric variation in a human population, rather than measurement inaccuracy, since the same degree of variation was present also in the Agaki and Dalury lines.

In addition, existing pathologies were not taken into consideration. This was partly because medical records of the time were unreliable and most individuals had cause of death recorded as “died of natural causes/died of age”. Some individuals showed visible signs of osteological co-morbidities such as syphilis and cancer, which could have affected the identification of the condylar eminences and measurements. In addition, bone preservation could have been affected by extrinsic taphonomic factors such as burial depth and soil acidity.17 Although the individuals used in the current study were largely protected from these extrinsic factors due to crypt burial, minor bone deterioration secondary to excavation, cleaning and curation could have influenced bone quality and, therefore, results.18,19

Finally, this was an osteological study conducted to establish an intraoperative anatomic landmark that will be helpful in improving the tibial tray rotation for knee arthroplasty in arthritis. As such, the current authors suggest further intra-operative investigation to assess the robustness of this method. In particular, they were unable to evaluate the effect of arthritic changes, including osteoarthritis or inflammatory arthritis, on the identification of anatomical features. The current study was able to identify the tibial eminences in most samples; however, it was unable to confirm how many of the samples suffered from arthritis. As such, osteoarthritis might make identification of the eminences easier. This is since “spiking", "sharpening" or "peaking" of the tubercles of the intercondylar eminence of the tibial plateau have been described as early signs of osteoarthritis of the knee joint.20,21 Therefore, further intra-operative studies in patients undergoing knee arthroplasty are required. This would allow for taking into consideration variations such as age, sex, ethnicity and presence of intra-articular disease.

In summary, the tibia rotation lines that were studied showed excellent intra/inter-observer reliability and reproducibility. The novel and easily drawn inter-eminence line showed strong correlation with the Akagi line and could be used for tibial tray rotational alignment in total knee arthroplasty.

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