REVIEW ARTICLE

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Current variability in the assessment of component position for the unhappy knee replacement

Andrew M. Suchowersky ,* David Dickison† and L. A. Ashton‡
*Orthopaedics, Middlemore Hospital, Auckland, New Zealand
†Department of Orthopaedics, Mona Vale Hospital, Sydney, New South Wales, Australia and
‡Orthopaedic Surgeons Association, Orange, New South Wales, Australia

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Correspondence
Dr Andrew M. Suchowersky, C/- Middlemore Hospital, 100 Hospital Road, Otahuhu, Auckland 2025, New Zealand. Email: a.suchowersky@gmail.com

A. M. Suchowersky BMedSci (Hons), MBBS; **D. Dickison** MBBS, FRACS (Orth); **L. A. Ashton** BMed, FRACS (Orth).

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Abstract

Introduction: Total knee arthroplasty (TKA) has a success rate of 80–90%, but despite this encouraging figure a painful TKA can be a source of dismay for patients and surgeons. Computed tomography (CT) scan has been developed as a tool to collect data in the analysis of TKA component placement. Protocols used to collect such data exist in orthopaedic and radiology practice with little standardization and significant variation. The aim of this review article was to evaluate such variability by sampling a series of protocols from a range of different radiology practices within NSW, Australia in a case-based manner and to then compare them against any literature standards.
Methods: The literature was surveyed for existing CT scan protocols used in TKA assessment. These were then compared with a series of metropolitan and rural radiology firms across the public and private sectors in NSW, Australia.
Results: Considerable variability exists between current protocols across NSW, Australia, which differ with proposed literature standards.
Conclusion: Variabilities encountered when comparing the different scanning protocols in use for the assessment of TKA constitute a large potential source of error in the analysis of TKA component positioning. The reliance surgeons place on such analyses suggests the need for an established scanning protocol with an incorporated grading system and standardized values to allow reproducible data to help assess and predict TKA function.

Introduction

Total knee arthroplasty (TKA) has established itself as the treatment of choice for advanced arthritis with data from joint registries around the world having returned patient satisfaction rates generally higher than 80%.[1–3] Despite these encouraging results, there are patients who remain unhappy with their knee replacements. These figures can be close to 20% at 2 years following surgery. While the major complications following knee replacement include death, infection and pulmonary embolus;[4] unexplained pain may form the basis for revision in as many as 9% of cases.[5]

The literature has proposed many theories as to the cause for a painful TKA, and while definitive explanations continue to stimulate discussion, component position recurs as a relevant factor relating to pain and instability.[6–8]

Available literature relating to component position for TKA is vast and includes assessment in coronal, sagittal and axial planes with respect to angular, translational and rotational placements. Prostheses may be implanted in flexed, extended, valgus, varus and internal or external rotation. The appropriate combination of these alignment variables is central to reproducing a satisfactory mechanical axis, adequate appropriation of the joint line, a correct soft tissue balance and effective patellar tracking.

Studies linking component malposition with post-operative complications following TKA began to enter the literature in the 1980s, but it was not until computed tomography (CT) scan use became widespread that the placement of knee prostheses began to be studied in detail.

Recently, the literature has demonstrated an increased number of scanning protocols that explore the relationship between component malposition and problematic knee replacements.[9] In the early 2000s, a protocol was developed by Chauhan *et al.* for the purpose of evaluating TKA component position accuracy when comparing computer assisted TKA versus mechanical jig assisted TKA. This protocol became the progenitor of many others that have sought to analyse component position in TKA.

Whilst demonstrating promise as an investigative assessment, the largely unrestrained and unpoliced proliferation of such CT scan protocols has produced variations in methodology that lack reproducibility and make comparison a consistent problem across radiological and orthopaedic practice. Variation in rotational and alignment reference points, a lack of normative values to help assess when malposition in TKA exists, and an absence of any accepted grading system for such thresholds highlights the problems with current protocols. These protocol inconsistencies became clear to the authors during their routine clinical evaluation of problematic TKA cases within regional NSW whereby two different radiology practices would provide reports based on different protocols in use. It was the aim of the authors to evaluate a series protocols from a range of radiology firms and compare them to sourced literature standards to explore inconsistencies across a wider platform. It is the authors' proposal that a standardized protocol with an accepted set of reference values and grading system that could be universally accepted by knee surgeons would provide reproducibly applicable data. With such standardization, this information could also be attached to joint registries that follow the survival of knee replacements to provide prognostic insight and perhaps suggest the holy grail of parameter limits outside of which revision would be more likely.

Materials and methods

To establish an appropriate series of parameters, the authors sought out Chauhan's original Perth Protocol and drew from it three relevant measurements to compare amongst a sample of protocols sourced. This representative sample drew from public, private, metropolitan and rural centres. Interestingly, sourcing guidelines from radiology practices proved difficult as many firms, particularly in the private sector, reacted with suspicion as to the reasoning for requesting this information. The three parameters chosen as comparators were those of femoral rotation, tibial rotation and femoro-tibial mismatch. These were chosen first, because they were routinely assessed measurements in sourced protocols. Second, a link between these parameters and complications post knee replacement had already been proposed in the literature[9] and thirdly, these measurements seemed critical discriminators in Chauhan's original protocol, which the authors' sample was being compared with in this review article.

For the purposes of comparison with existing knowledge, the MEDLINE database was consulted from 1946 to present and search string terms of; X-ray – computed tomography, rotation, alignment and knee arthroplasty were entered and then overlapped. This returned 132 articles which were summarily assessed. The study which continued to recur with the greatest relevance appeared to be that of Berger *et al.* which not only described in detail a scanning methodology for component position but proposed a link between it and knee replacements which suffered post-operative complications. As a result of these endeavours both Chauhan and Berger's source papers formed the basis of our comparison with the literature.

Inclusion criteria that admitted protocols for assessment included those which addressed component rotation and those which presented diagrammatic representations of their protocols (so as to facilitate ease of comparison with Berger's method and Chauhan's protocol). Exclusion criteria were a complete lack of consideration of component rotation and the absence of CT scanning as a means to assess position. Metropolitan and rural protocols were sourced from a mixture of radiology firms and hospital departments across the public and private sectors in order to draw a representative sample. These protocols were then analysed by an orthopaedic consultant (LAA) and registrar of more than 5 years of experience (AMS) through scrutiny of representative diagrams of parameter calculations and descriptions of how relevant measures were made. Similarities and differences were then cross-examined with the literature standards of parameters used to evaluate TKA component placement.

Results

A total of seven firms and departments responded to requests to provide their respective protocols. Of these, one was local, one was in a neighbouring town within the region, and five were based within a major metropolitan area of New South Wales. Of these respondents, four were private radiology firms and three were radiology departments within a public hospital.

Of the protocols received, two were from regional centres and five from a metropolitan facility. Because city hospitals commonly incorporate public and private counterparts within the same campus, some overlap of protocol methodology was noted.

There was considerable variability in the information that was provided with regard to the protocols.

The qualitative nature of protocol descriptions, which ranged from more thorough detailed explanations to informal discussions amongst staff, were compared with regard to calculation of femoral rotation, tibial rotation and femoro-tibial mismatch; all of which are of crucial importance when evaluating TKA component position.[7] These methodologies were then compared with the protocol provided by Chauhan *et al.*, this being the original 'Perth Protocol', and finally with Berger's protocol as the authors' choice of a literature standard. The compared results are tabulated below, and diagrammatic representations may also be seen in the appendix (Table 1).

All protocols assessed seemed to agree on utilization of the surgical epicondylar axis and posterior condylar axis as a means to judge rotation of the femoral component. This also appeared to coincide with methods used by Berger and Chauhan. Tibial rotational measurements, however, seemed far more variable and utilized the posterior cruciate ligament (PCL), tibial tuberosity (TT) and posterior tibial condyles (PTCs) as reference landmarks in significantly different ways.

Comparing the protocol case series with our chosen standards, Firm 1 (Orange, NSW) and Firms 3 and 4 (Sydney, NSW), make use of the TT differently as a landmark when compared with Berger's method; namely from its most prominent point (Berger) to the medial 1/3. Differences were also noted regarding use of the TT's posterior counterpart, with Berger's paper and Firm 1 using the geometric centre of the tibia as the posterior reference point, whereas Firms 3 and 4 used the PCL (as does Chauhan's method), demonstrating its inconsistency with Berger. There was an unclear representation of the tibial rotation calculation by Firm 2 (Bathurst, NSW).

With respect to 'femoro-tibial mismatch', differences were also noted. Berger did not use this calculation at all but rather referred to 'combined rotation' (being the addition rather than subtraction of

Table 1 Qualitative assessment of parameter calculations from various protocols as compared with Berger's original paper and that of Chauhan *et al*. who developed the Perth CT scan protocol

	Femoral rotation	Tibial rotation ('Berger's angle')	Femoro-tibial mismatch
Firm 1 – Regional private	Angle between: • SEA • Posterior condylar line.	Angle: • AP axis of the tibial component • Line centre-centre from base plate to the TT	Angle between: • Posterior condylar line of the femoral component • Posterior condylar line of the tibial baseplate.
Firm 2 – Regional private	Angle between: • SEA • 'Most posterior aspect of the femoral component'	Not addressed within protocol	Angle between: • 'The most posterior aspect of the femoral component' • Line medial-lateral through the centre or posterior aspect of the tibial stem.
Firm 3 – Metropolitan private Firm 4 – Metropolitan public	Angle between: • SEA • Posterior condylar line.	Angle between: • Bisecting line of the flange angle of the base plate stem • Line from the medial third of the TT to the tibial insertion of the PCL.	Angle between: • Posterior condylar line of the femoral component • Posterior condylar line of the tibial baseplate.
Firm 5 – Metropolitan public	Angle between: • SEA • Posterior condylar line.	Angle between: • AP axis of the tibial component • Line centre-centre from the base plate to the TT	Angle between: • Posterior condylar line of the femoral component • Posterior condylar line of the tibial baseplate.
Firm 6 – Metropolitan public Firm 7 – Metropolitan private	Angle between: • SEA • Posterior condylar line.	Not addressed within protocol	Angle between: • Line along the base of the femoral component • Line medial-lateral along the posterior aspect of the tibial stem.
Berger *et al*.	Angle between: • SEA • Posterior condylar line.	Angle between: • Orthogonal of the posterior condylar line through the GS • Line centre-centre from the GS to the most prominent aspect of the TT.	Did not use a mismatch measurement
Chauhan *et al*. (original Perth Protocol)	Angle between: • SEA • Posterior condylar line.	Angle between: • AP axis of the tibial base plate • Line from the TT centre to the tibial insertion of the PCL.	Angle between: • Line along the base of the femoral component • Line medial-lateral through the centre of the stem of the tibial base plate.

AP, antero-posterior; GS, geometric centre; PCL, posterior cruciate ligament; SEA, surgical epicondylar axis; TT, tibial tuberosity.

individual component rotational values). Within the series, the measurement of the femoral component rotation remains relatively standard with a line drawn along the posterior aspect of the prosthetic femoral condyles. The tibial reference lines, however, vary from proceeding along the stem flanges (Firm 2 (Bathurst, NSW)) and Firms 3 and 4 (Sydney, NSW)); along the PTCs and through the geometric centre (Firm 1 (Orange, NSW)) as compared with Chauhan's paper that refers to a line drawn through the centre of the tibial component, which Firms 3 and 4 also appear to recommend (Figs S1–S3).

Discussion

The literature has suggested that an improper rotational profile of the femoral and tibial components may contribute to complications following knee replacements.[5,6,8–11] A number of papers including the landmark study by Berger *et al*. in 1998 attempted to establish a system by which this profile can be assessed (Fig. 1).

Berger's assessment, based on CT, was the antecedent of other systems including one established by Chauhan *et al*. that was formalized as 'The Perth Protocol'.[12] Based on Chauhan's methodology, radiology firms across Australia now routinely assess component positioning in TKAs to help investigate problematic knee replacements.

This review article attempted to clarify the extent to which protocols within NSW, often loosely based on Chauhan's protocol, aligned themselves to Berger's original method from the literature. In addition, the protocols within our case series were analysed as to whether sufficient similarities existed within their methodologies to generate standardized data. The authors, however, discovered a lack of clarity around any accepted uniform algorithm for assessment of TKA component position, and no useful grading system that could correlate with symptomatic consequences.

The existing data relating to component positioning is considerable, as are the theories on which measurements are thought to relate more closely to clinical problems. Component rotation has been deemed to be particularly relevant with respect to patellar

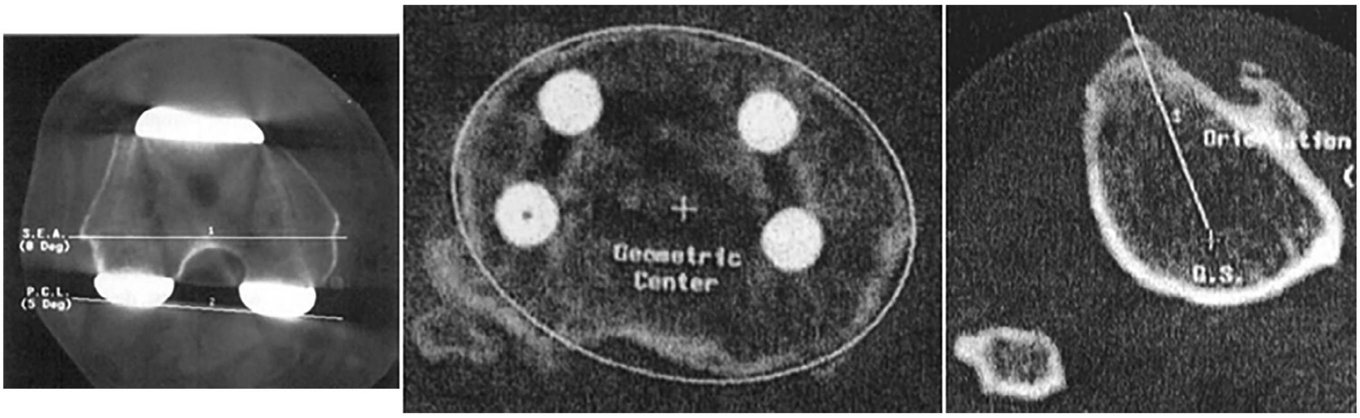

Fig. 1. The rotational calculations of the femur and tibia of Berger as depicted in his paper.

tracking.[6,7,9] Berger found that excessive combined internal rotation of femoral and tibial components was associated with increasing patello-femoral complications ranging from lateral mal-tracking to dislocation.

Our review found that despite protocols' detailed rotational analyses of TKA components, there were no standardized reference values or any useful grading systems offered.

This appeared to overlook a grading system already proposed in the literature by Berger's study many years earlier. Berger's paper proposed a rotational hierarchy which correlated with 'mild, moderate and severe' patello-femoral problems post TKA. Suggested 'normal' values for rotation were stated as 0.3° external for females and 3.5° external for males with respect to femoral rotation, and correct tibial rotation was stated as 18° internal in males and females.[9] These measurements were based on the SEA and PCA for femoral rotation, and for tibial rotation the 'geometric centre' and most prominent point of the tibial tuberosity were used (Figs 1, 2).

In his analysis of 30 patients with patello-femoral complications post TKA, he reported that five patients with lateral patellar tracking and tilting possessed a combined excessive internal rotation of 1–4°; eight patients with patellar subluxation possessed a combined internal rotation of 3–8°, and those with dislocation or prosthesis failure had 7–16° of internal rotation.

Berger's approach has been cited and modified by some protocols within our series, indicating some consideration of his method and its potential as a standard. Indeed, elements of his approach appear in the protocol developed by Chauhan *et al*., albeit with discrepancies.

The authors' assessment discovered that much of the inconsistency surrounds tibial rotation. It is our theory that the complexity of bony reference points available for tibial component orientation may be responsible. With respect to femoral rotation the SEA and PCA mostly characterize demonstrably reproducible landmarks with native and prosthetic distal femurs (although Berger and Chauhan both state that the medial sulcus may on occasion be absent and in that case, to use the most prominent aspect of the medial epicondyle). The variability of native tibiae, however, can make component positioning in this context difficult.[16] Degenerative changes disturb the perimeters of the tibial plateau and can

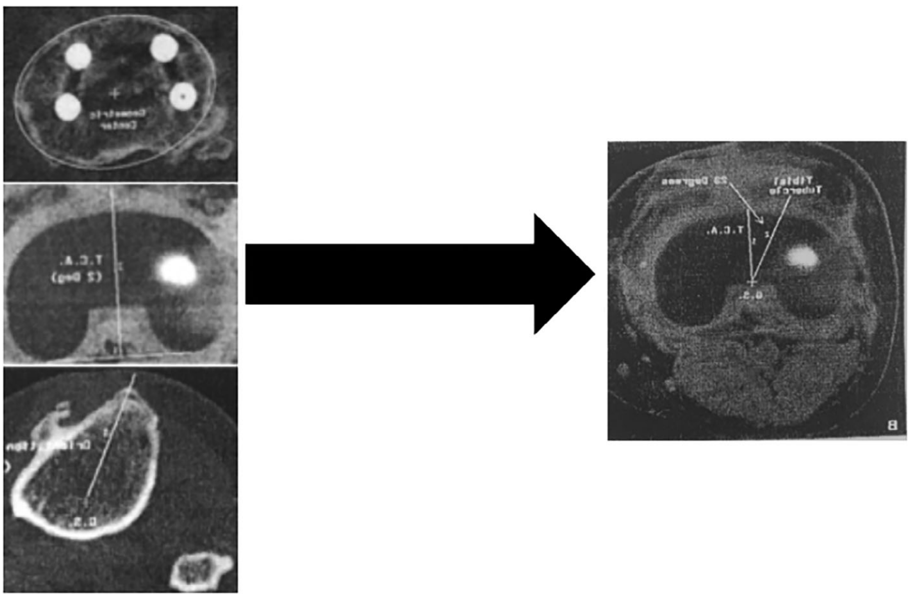

Fig. 2. Calculation of axes and then superimposition to determine tibial component rotation as proposed by Berger.

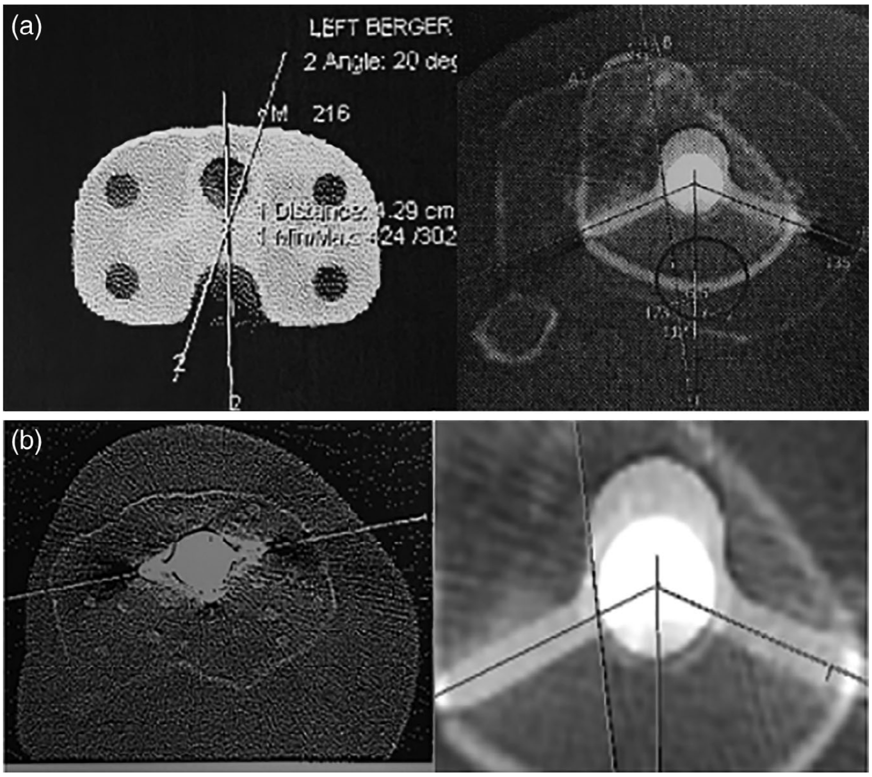

Fig. 3. (a) Diagrammatic representation highlighting the variation in rotational calculation of a tibial base plate with different designs. On the left is Berger's method from his study, utilizing the antero-posterior (AP) axis of the component, through the geometric centre (GS) and a line drawn through the GS to the most prominent aspect of the tibial tuberosity (TT). On the right is the Perth Protocol from another centre which utilizes the origin of the posterior cruciate ligament (PCL) and the medial 1/3 of the TT. The angles calculated would be different given the points subtending them are not the same. Moreover, this comparison highlights a difference in tibial base plate design. (b) Lines drawn completely differently as part of tibial component orientation calculations.

make calculation of the tibial 'geometric centre' difficult (Fig. 2) Furthermore, greater variability in tibial tray design with asymmetrical shapes now populate the market. Our review found that none of these tibial tray design variabilities appeared to be adequately addressed in the literature (Fig. 3)

The ambiguity surrounding tibial rotation appears established with some radiology firms stating that tibial rotation measurement is intrinsically unreliable citing excessive variability in its measurement. Castlereagh Imaging, a reputable radiology firm in Sydney NSW for example, purports that true tibial rotation is not able to be accurately calculated and is somewhat irrelevant insofar as it should be considered in conjunction with rotation of the femoral component. They place greater emphasis on the femoro-tibial mismatch angle. Firm 3 also presents femoro-tibial mismatch as important and state that the mismatch angle should ideally be '$90 \pm 3°$'.

The majority of CT scan protocols in use, however, attempt to measure some form of tibial rotation (usually referring to 'Berger's angle' or a variation on his measurement technique). Acknowledgement of the variability and difficulty in the measure of tibial rotation along with its continued use confirms not only an ongoing lack of consensus on true tibial rotation, but also a lack of established reference points from which such calculations can be made.

Errors may also be made when different CT images are superimposed over others when calculating 'Berger's angle'. For tibial rotation measurements, slices at three different levels are required to allow correct measures to be taken to compare tibial tuberosity bony landmarks (which also vary) and prosthetic tibial tray axes. Furthermore, the use of different bony landmarks within our protocol series suggests ambiguity. Bony references of the posterior tibia include the geometric centre, centre of the tibial baseplate, PCL centre and centre of the posterior tibial condyles. Anterior landmarks have included the most prominent aspect of the tibial tuberosity along with its junction at the medial and middle thirds (Figs 1, 2, S1, S3).

All protocols assessed in this review article present their own methodological rationales, however Berger's original method for tibial rotation (or variances thereof) appear to permeate much of current practice. His study was amongst the first to propose a grading system that compared ranges of component malrotation with severity of complications. Though his grading system was limited (only assessing patello-femoral complications), the evolution of his original premise has led to advances as proposed by Roper *et al.*,[11] who presented a method of three-dimensional CT scan analysis to eliminate anatomical landmark selection error when using multiple two-dimensional CT scan slices.

Akagi *et al.* suggested a tibial rotational measurement which compares a line from the medial third TT to the centre of the PCL with the orthogonal of the femoral SEA. This was an attempt to avoid the variability and difficulty when using tibial landmarks for measurement and rather rely on the more reproducible SEA of the femur.

Saffi *et al.*[17] have also addressed this variability in tibial rotation calculations by suggesting a Centre of Tibial Tray to Tibial Tubercle measurement, this being a millimetre distance rather than degree measurement. In his method, a tangential line to the most prominent TT tip is drawn perpendicular to the AP axis of the tibial tray. Whilst he purports the three-dimensional method by Roper should be adopted as the most accurate new 'gold standard', the CTTT demonstrates a correlation with it and is less time consuming.

Next to rotation measurements, an appraisal of alignments necessitates consideration. Such measurements also exhibited inconsistency within our sample of firms (though perhaps less so than for rotational measures). The protocol from Firm 3 appeared to provide the best considered option from our series. Alignment was defined as the measurement of the axis from the centre of the femoral head to the centre of the talus (mechanical axis).[13] Other coronal plane parameters relate to femoral and tibial component varus/valgus orientation and mechanical axis deviation. Sagittal plane measurements include femoral and tibial component flexion and extension; these being calculated through lines from the centres of the femoral head and distal tibia; and then being compared with lines along the posterior condylar flanges of the femoral component and along the slope of the tibial baseplate (Fig. S4). Worthy of note, this protocol aims to define 'normal values' and suggests overall mechanical limb alignment being acceptable to within 0–3° at the knee joint, component varus/valgus to within 3° from the femoral and tibial mechanical axes, and mechanical alignment offset to within 2 mm of the limb axis. 'Normal' sagittal plane measurements are presented as 0–5° for component flexion and extension, however all assessed protocols fail to account for differing brand specific recommended tibial flexion angles which range from 3 to 7°.

A further limitation of current protocols is their inability to address the 'kinematic' approach to TKA where traditional anatomic landmarks, upon which many protocols are based, give way to focus on component orientation based on soft tissue envelope, balance and 'natural' pre-existing alignment that is individualized.[14] This revelation may not just further confound the methodology of current Perth Protocols but invalidate them entirely. The kinematic basis for TKA, however, requires further research.

Reformatting, which pertains to the manipulation of raw CT scan images into an orientation that allows accurate measurement of alignment and rotation, may also generate error. It is entirely dependent on each individual radiographer being adept at selecting true coronal, sagittal and axial images, marking appropriate bony landmarks and generating accurate lines which must then be further interpreted by the radiologist. A lack of familiarity with the protocol and poor attention to detail may lead to inaccuracies, particularly in the absence of a clear, standardized protocol. This error may be compounded by variable reporting methods in current use. Current 'standard' methods report deviation from a 90° axis or a positive/negative value from 0°. Frequently it is unclear which measurement pertains to varus/valgus, flexion/extension and internal/external rotation. Current reporting nomenclature is at best confusing and frequently incomplete or inaccurate. Appropriate standardization would compel degree measurements for varus/valgus, flexion/extension and internal/external rotation in conjunction with acceptable margins of error (to the best of current knowledge) as suggested by Gemescu *et al.*[15]

Revisiting Saffi *et al.*'s proposed CTTT method, this may also offer more reproducibility through ease of instruction to radiographers in a clinic setting.[17]

The controversial yet necessary consideration of financial reward for the generation of such detailed reports also warrants address. Relevant to Medicare in Australia, item numbers for this particular CT study recompenses the same as that for a simple tibial fracture series. In addition, if the CT scan machine is more than 10 years old, then remuneration constitutes barely half of that provided if the scanner is younger than 10 years old. This recompense model potentially acts as a disincentive for the provision of the appropriate time requirement to generate an accurate, detailed and quality report.

Whilst confirming the authors suspicions that protocol variability exists, this case series does have some limitations. It was difficult to present objective data because protocols were often subjective descriptions rather than quantifiable measurements. Furthermore, radiology practice type may be a relevant consideration. It is conceivable that a large academic centre with many radiologists on site would enable more time devoted to achieving an accurate, detailed report. Finally, such academic centres may be better placed to enable regular consultation with the literature to update their protocols.

The advent of CT to assess prosthetic position in TKA has suggested a relationship between component mal-orientation and complications.[6] However, without a clearly standardized protocol or reproducible set of values, the practice may lend itself to conjecture and ambiguity. Many current protocols have deficiencies with respect to how specific measurements are taken, what values may be accepted as 'within normal limits', and reporting formats that are often confusing and not accurately adhered to. With respect to complications surrounding TKA, there are many factors outside the surgeons' control, however implant positioning is not one of them. Current 'correct' positioning recommendations, however, have never been more controversial. Whilst the link between CT protocol results and clinical significance demands further study, there is little doubt that poorly placed implants cause clinical problems, and without a formalized, reproducible and accepted CT protocol to measure TKA component positioning, this field of study remains limited. In an environment where poorly functioning TKAs cost billions of dollars, there should be no disinterest in thoroughly and accurately evaluating them. The doubt surrounding the evaluation of TKA should serve as a wake-up call to radiologists, surgeons and governments alike. In order to clear this doubt, the authors propose that an accepted 'gold standard' be adopted that is applicable, reproducible and reliable.

Conclusion

A snapshot of protocol variability in CT scan analysis of TKA across NSW Australia, suggests that there is an opportunity to add significant value to this area of study through the establishment of a new endorsed protocol from an appropriate governing body in orthopaedic practice. This could be from the Australian and/or New Zealand Orthopaedic Associations or from subspecialty interest groups such as the Australian Knee Society. Such a protocol would need to address patient positioning, accurate reformatting of images, usable bony landmarks, angular measurement methodology and an appropriately simplified reporting standard. A consensus for 'best available' normative references could also be agreed upon. This would not only provide a far more clinically applicable assessment when evaluating the 'unhappy' TKA, but could also supplement Joint Registries around the world, thereby continuing to evolve our understanding of what parameters are required for success.

Conflicts of interest

None declared

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Figure S1. Diagrammatic representation of Perth Protocol methodology utilized by Firm 1, Orange, NSW.
Figure S2. Diagrammatic representation of Perth Protocol methodology utilized by Firm 2, Bathurst, NSW.
Figure S3. Diagrammatic representation of Perth Protocol methodology utilized by Firms 3 and 4, Sydney, NSW.
Figure S4. Diagrammatic representation of the mechanical axes calculation in the coronal and sagittal planes and component flexion and extension as done by the protocol from Firm 3, Sydney, NSW.