Introduction

The geometry of the proximal tibia and distal femur is intimately linked with the biomechanics of the tibiofemoral and patellofemoral joint. In the field of total knee arthroplasty (TKA), positioning of the implants in the axial plane is referred to as 'rotational alignment'. A condylar knee prosthesis functions as a surface replacement in the soft tissue envelope that surrounds the knee. Consequently, positioning and sizing of the components will largely affect the postoperative result. Any misplacement will affect loads on the interface and tension in the ligaments. This will lead to aberrant kinematic behaviour inducing stiffness, instability and early loosening. Several clinical studies have demonstrated this relationship. Skolnick et al. were the first authors to report the relation between clinical outcome and proper alignment in the coronal plane [1]. Lotke and Ecker were able to demonstrate a significant correlation between a good clinical result and a well-positioned prosthesis, using a ‘roentgenographic index’ describing alignment of the tibial and femoral component in the three planes [2]. They concluded that ‘more effort should be expended on the development of better instruments to position the device’s components, so that the operation will become a precise, well engineered procedure and will not depend on gross, subjective perceptions of alignment and mechanical
relationships’. Since that time, multiple papers have confirmed the relation between malalignment in the coronal plane and early failure of TKA [3—14]. Later on, more attention was directed towards the rotational alignment of the components. This issue continues to challenge the surgeons in their efforts of reducing the number of outliers in axial plane alignment. This is reflected in multiple recent studies, specifically dealing with this subject. This paper aims at reviewing the literature on rotational alignment of the distal femur, and disclosing the relationship between the different described axes guiding rotational alignment.

Rationale

Rotational alignment of the femoral component will affect flexion stability, tibiofemoral and patellofemoral kinematics, and alignment in flexion. The relation between rotational alignment and patellofemoral stability was recognized in the early days of knee arthroplasty. Mochizuki and Schurman were the first to emphasize the detrimental effect of inverse rotational alignment on the patella and postoperative function [15]. This was later confirmed in numerous papers [16—22]. Berger was the first to use CT scans to evaluate the rotational alignment of the components [23]. He underlined the clinical relationship between internal rotation of the femoral component and patellofemoral complications. He compared 30 patients with isolated patellofemoral complications after TKA to a group of 20 patients with well functioning TKA. The degree of patellofemoral malfunctioning was directly related to the amount of component internal rotation: mild combined internal rotation (1—4°) caused lateral patellar tracking and patellar tilting, moderated combined internal rotation (5—8°) caused patellar subluxation and severe combined internal rotation (7°—17°) caused patellar dislocation or component failure. He used the anatomic transepicondylar axis and the tibial tuberosity as rotational landmarks for the femoral and tibial component respectively. Similar outcomes were reported by Matsuda et al., using a different prosthesis [19]. They reported a statistically significant correlation of internal rotation of the tibial and femoral component with the patellar tilt angle and clinical symptoms. Akagi compared two consecutive groups, one with TKA implanted in neutral alignment with respect to the posterior condylar line (PCL), and one with an external rotation of 3—5° [18]. The externally rotated group had less need for release of the lateral retinaculum (6% versus 34%) and postoperative patellar tracking was significantly better. Rhoads [20] found in a laboratory study that internal rotation and medial translation of the femoral component caused patellar maltracking, but reported no predictable changes by externally rotating the femoral component. Anouchi et al. performed a cadaver experiment in changing femoral component position from neutral (according to the PCL) to 5° internal and 5° external rotation. Patellar tracking was closest to normal in the group that was externally rotated. Internal rotation caused severe patellar maltracking to the medial side [21].

As appears from these referenced publications, most emphasis was put on the dangers of internally rotating the femoral component. More recently, the detrimental effects of excessive external rotation of the femoral component have been outlined. Olcott and Scott described symptomatic flexion instability resulting from the oversized flexion gap on the medial side of the knee as a consequence of excessive external rotation of the femoral component [24]. Miller et al. were able to demonstrate increased shear forces on the patella as a result of the induced maltracking [25]. Finally, Hanada et al. related the excessive external rotation of the femoral component to varus alignment in flexion, leading to mechanical overload on the medial side of the joint [26].

Despite everyone being convinced of the clinical importance of correct rotational alignment, there is no widely accepted surgical technique leading to superior results. In addition, terminology and semantics are often confusing. There is a distinct difference between the ‘correct’ rotational alignment of the femoral component and the ‘normal’ rotational alignment of the distal femur. This divergence can be explained by the fact that the natural tibial plateau has an average varus orientation of about 3° [27,28]. The perpendicular coronal cut of the tibia will change this angle. Consequently, the femoral component will not be correctly aligned in flexion if it follows the natural anatomy. A rotational compensation to the same degree as the correction of the tibial cut in the coronal plane will generally be advocated. Consequently, as the literature refers to ‘correct’ rotational alignment of the femoral component, the authors always refer to the ‘adapted’ rotational alignment of the femoral component, which is different from the normal situation. One should keep this in mind when comparing normal knee kinematics with the replaced knee kinematics.

Failure to align a component properly with a desired axis can be situated at three different levels [29]. Sometimes, the desired axis is not visible in vivo (e.g. the femoral mechanical axis) and a secondary reference axis (e.g. the centre of the intramedullary canal) is chosen to serve as a guide during surgery. Ideally, this secondary reference axis has a reliable angular relation, in statistical terms small standard deviation, to the desired axis. A first level of error is the individual variability in the angular relation between the desired axis and the surgical reference axis. The second level of error is related to the intraoperative determination of the secondary reference axis, in other words, the ability of the surgeon to locate accurately and reproducibly anatomical landmarks that lead to the secondary reference axis. Previous studies have emphasized the difficulties surgeons face in this area [30—33]. The third level of error is related to the positioning and fixation of the cutting block and the execution of the cut with the saw.

It is yet unclear which is the best rotational reference to which all other parameters can be compared. Several authors have claimed the definition of this ‘ideal’ rotational reference. The rotation of the femoral component can be described, relative to landmarks on the distal femur or relative to its relation with the tibia. Distal femoral references include the PCL [27,34], the anatomical transepicondylar axis (TEA) [35,36], the surgical TEA [23,37,38], the trochlear anteroposterior (AP) [39,40] axis (Fig. 1), and the femoral transverse axis [29] (Fig. 2). References relating to the relative position of the tibia include the flexion gap symmetry [41] and the tibial mechanical axis alignment in flexion [26].

Dorr [41] addressed the issue of rotational alignment and flexion gap symmetry as early as 1986 but it was Insall [42] who popularised the ‘gap technique’ for obtaining a rectan-
Rotational alignment of the distal femur: A literature review

Figure 1 View of the distal femur with the rotational reference axes projected in the axial plane. The Posterior Condylar Line (PCL) is the tangent of the posterior femoral condyles, the Anatomical Trans Epicondylar Axis (TEA) connects the medial to the lateral epicondyle, the Surgical TEA connects the Medial Sulcus to the lateral epicondyle and the Trochlear AP Axis connects the deepest point of the trochlear groove to the top of the femoral notch with the femur viewed along its mechanical axis.

Figure 2 The Femoral Transverse Axis as defined in the description of a Cartesian coordinate system of the femur [29]. The Femoral Transverse Axis connects the centres of the best-fit spheres to the medial and lateral condyles. It lies posterior to the TEA and it is parallel to the Surgical TEA in the axial plane.

Pairwise comparison between reference axes and techniques

Table 1 shows an overview of the published relative relationships between the above described axes and techniques. A discussion of these studies is given below, ordered in pairs studied in their mutual relationship.

Tensioned gap technique versus Posterior Condylar Line

In the tensioned gap technique, the knee is tensed in flexion after ligamentous release in extension [42,43,46]. The tensing of the gaps can be performed manually or force controlled, with laminar spreaders or a tensor device. The idea is to establish equal loads in the medial and lateral compartment and to resect the posterior femoral surfaces parallel to the cut tibial surface. Several authors have compared this technique to different methods of measured resection.

Laskin [34] compared the PCL to the rotational alignment obtained by tensing the flexion gap with laminar spreaders. For neutral and varus knees, he found a very consistent relationship of $3.2 ^\circ \pm 0.3 ^\circ$ of external rotation, relative to the PCL, by tensing the gaps. For knees with a coronal plane anatomical axis of more than $10 ^\circ$ valgus, the values were significantly higher and less consistent: $10.1 ^\circ \pm 4.2 ^\circ$.

Fehring [22] compared the tensioned gap technique to measured resection. In 100 posterior stabilised TKAs he used gap tensing with laminar spreaders and performed a rectangular gap resection. Based upon the size of the resected posterior femoral bone, a virtual assessment of the resection relative to the PCL + $3 ^\circ$ was made. The mean external rotation relative to the PCL was $2.6 ^\circ$ with a large variation (range $-7 ^\circ$ to $+8 ^\circ$). He concluded that 45% of the patients would have had a rotational error of at least $3 ^\circ$ if the PCL + $3 ^\circ$ would have been used as a reference. This is in contradiction with the results published by Laskin. These results have to be considered in the light of the assumptions made by the author. First, he assumed that every single knee was correctly balanced and that the tensioned gap technique yielded the correct rotational alignment. As no postoperative assessment of the rotational alignment was made, all conclusions depend on this assumption. Second, no compensation was made for existing bone deficiencies, despite the fact that many surgeons who use measured resection would do this. Third, the series comprised both varus and valgus knees.

Transepicondylar axis (TEA) versus Posterior Condylar Line

Mantas was the first to measure the relationship between the PCL and the anatomic TEA. He used 19 paired cadaveric femoral and found a mean angle of $4.9 ^\circ$, being consistent
<table>
<thead>
<tr>
<th>Author</th>
<th>Subjects</th>
<th>n</th>
<th>Method</th>
<th>Reference</th>
<th>Comparison</th>
<th>Mean</th>
<th>S.D. (°)</th>
<th>Range</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yoshioka (1987)</td>
<td>Cadavers</td>
<td>32</td>
<td>Instr</td>
<td>Anat TEA</td>
<td>PCL</td>
<td>5°</td>
<td>1.8</td>
<td></td>
<td>Male</td>
</tr>
<tr>
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<td>Cadavers</td>
<td>19</td>
<td>Instr</td>
<td>Anat TEA</td>
<td>PCL</td>
<td>6°</td>
<td>2.4</td>
<td></td>
<td>Female</td>
</tr>
<tr>
<td>Berger (1993)</td>
<td>Cadavers</td>
<td>75</td>
<td>Instr</td>
<td>Surg TEA</td>
<td>PCL</td>
<td>3.5°</td>
<td>1.2</td>
<td></td>
<td>Left</td>
</tr>
<tr>
<td>Laskin (1995)</td>
<td>MED OA PTS</td>
<td>80</td>
<td>Instr</td>
<td>Gap Tens</td>
<td>PCL</td>
<td>3.1°</td>
<td>0.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arima (1995)</td>
<td>Cadavers</td>
<td>30</td>
<td>Instr</td>
<td>⊥ Troch AP</td>
<td>PCL</td>
<td>3.8°</td>
<td>2</td>
<td>−1°/10°</td>
<td></td>
</tr>
<tr>
<td>Poilvache (1996)</td>
<td>MED OA PTS</td>
<td>89</td>
<td>Instr</td>
<td>⊥ Troch AP</td>
<td>Anat TEA</td>
<td>0.53°</td>
<td>2.36</td>
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<td>Instr</td>
<td>Surg TEA</td>
<td>PCL</td>
<td>3.7°</td>
<td>2.2</td>
<td>0°/10°</td>
<td>Male = Female</td>
</tr>
<tr>
<td>Nagamine (1998)</td>
<td>All</td>
<td>84</td>
<td>CAT</td>
<td>Anat TEA</td>
<td>PCL</td>
<td>6°</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td>40</td>
<td>CAT</td>
<td>⊥ Troch AP</td>
<td>Anat TEA</td>
<td>1.4°</td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volunteers</td>
<td></td>
<td>40</td>
<td>CAT</td>
<td>⊥ Troch AP</td>
<td>Anat TEA</td>
<td>5.8°</td>
<td>2.7</td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
<td>27</td>
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<td>⊥ Troch AP</td>
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<td>6.2°</td>
<td>1.9</td>
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</tr>
<tr>
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<td>⊥ Troch AP</td>
<td>Anat TEA</td>
<td>0.1°</td>
<td>3.3</td>
<td></td>
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<tr>
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<td>17</td>
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<td>Anat TEA</td>
<td>PCL</td>
<td>6.4°</td>
<td>2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matsuda (1998)</td>
<td>Volunteers</td>
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<td>MRI</td>
<td>Anat TEA</td>
<td>PCL</td>
<td>6.03°</td>
<td>3.6</td>
<td></td>
<td>No relation with deformity</td>
</tr>
<tr>
<td>Akagi (1999)</td>
<td>OA PTS</td>
<td>26</td>
<td>CAT</td>
<td>Anat TEA</td>
<td>PCL</td>
<td>6.8°</td>
<td>1.8</td>
<td>4°/12°</td>
<td></td>
</tr>
<tr>
<td>Griffin (2000)</td>
<td>OA PTS</td>
<td>10</td>
<td>Instr</td>
<td>Surg TEA</td>
<td>Gap Tens</td>
<td>8/4° ≤ 1 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Griffin (2000)</td>
<td>Non OA PTS</td>
<td>10</td>
<td>MRI</td>
<td>Surg TEA</td>
<td>PCL</td>
<td>3.11°</td>
<td>1.75</td>
<td>0°/8.2°</td>
<td>Male = Female</td>
</tr>
<tr>
<td>Non OA PTS</td>
<td></td>
<td>10</td>
<td>MRI</td>
<td>Surg TEA</td>
<td>PCL</td>
<td>2.71°</td>
<td>1.56</td>
<td>&lt; 41Y</td>
<td></td>
</tr>
<tr>
<td>Non OA PTS</td>
<td></td>
<td>10</td>
<td>MRI</td>
<td>Surg TEA</td>
<td>PCL</td>
<td>3.50°</td>
<td>1.86</td>
<td>&gt; 41Y</td>
<td></td>
</tr>
<tr>
<td>Fehring (2000)</td>
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<td>Instr</td>
<td>Gap Tens</td>
<td>PCL</td>
<td>2.7°</td>
<td></td>
<td>−7°/8°</td>
<td></td>
</tr>
<tr>
<td>Yoshino (2001)</td>
<td>OA PTS</td>
<td>33</td>
<td>CAT</td>
<td>Surg TEA</td>
<td>PCL</td>
<td>3°</td>
<td>1.6</td>
<td></td>
<td>No relation with degree of arthritis</td>
</tr>
<tr>
<td>Asano (2005)</td>
<td>Volunteers</td>
<td>9</td>
<td>CAT</td>
<td>Anat TEA</td>
<td>PCL</td>
<td>6.7°</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hanada (2007)</td>
<td>Cadavers</td>
<td>6</td>
<td>Instr</td>
<td>⊥ Troch AP</td>
<td>Gap Tens</td>
<td>8.5°</td>
<td>3.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Instr: instrumented; anat TEA: anatomic transepicondylar axis; surg TEA: surgical transepicondylar axis; ⊥ Troch AP: perpendicular to trochlear anteroposterior axis; PCL: posterior condylar line; Gap Tens: tensioned gaps; OA: osteoarthritic; pts: patients; med: medial; lat: lateral.
left and right [47]. Griffin performed a clinical measurement during surgery on 107 arthritic patients. He found a mean external rotation of the surgical TEA compared to the PCL of 3.7° [37]. This angle was smaller in patients with varus malalignment (3.3°) than in patients with valgus malalignment (5.4°). As the standard deviation was greater than 2° in all groups, the authors concluded that the posterior condyles are potentially unreliable references for femoral component rotation.

Berger et al. [23] examined 75 embalmed anatomic specimens with a caliper. They described the medial sulcus as a ‘clearly discernible, reproducible landmark’ and measured the angle between the surgical TEA and the PCL. They found a mean value of 3.5° for the male specimens and 0.3° for the female specimens. In comparing the anatomical TEA, the angles were respectively 4.7° and 5.2°. It should be noted that the study involved 35 femurs of known gender and 40 of unknown gender, assumed to have the same sex distribution. Yoshioka et al. examined 32 cadaveric femora and reported a small gender-based difference: a condylar twist angle of 5° in males and 6° in females [36]. No gender difference was reported in other studies.

Arima and Whiteside were not convinced that the epicondylar axis was a reliable reference [39]. In a cadaver study on 30 specimens they reported the mean angle between the anatomical TEA and the PCL to be 4.4° but the range was excessive: −4.5° to 15.5° giving a standard deviation of 2.9°. These results improved a little when the landmarks were identified on radiology instead of clinically but they were still not reliable.

Akagi used a CT scan to compare the pre- and postoperative relationship between the anatomical TEA and the PCL. He found a mean value of 6.8° on the preoperative scans of 26 patients undergoing TKA [18]. This angle was reduced after TKA (comparing with the prosthetic PCL) to 3.2° ± 1.7° in the group that underwent TKA by referencing off the PCL and adding 3°–5° of external rotation to the instrument.

Griffin et al. used MRI taken in patients with minor soft tissue pathology to examine the relationship between the TEA and the PCL [48]. They described the medial epicondyle as a bony ridge surrounding a central sulcus, present in all knees that were imaged. As the authors used MRI, they drew the PCL according to the posterior cartilage, not to the bony border of the condyles. The mean value of the posterior condylar angle was 3.11° ± 1.75°. Interestingly, younger patients seemed to have a smaller angle than older patients. It was hypothesized that this might be due to postero-lateral cartilage wear, increasing with age. This finding could not be confirmed however, based on the data published in the study. No significant differences between males and females were found. Matsuda examined the relation between the PCL angle and varus deformity. As the angle between PCL and anatomical TEA was consistent in normal and in varus knees (6.03° and 6° respectively), he concluded that varus constitution is not associated with posterior medial condyle dysplasia [49].

### Trochlear Antero-Posterior axis versus PCL

Arima and Whiteside stated the trochlear AP axis, defined as the line connecting the deepest point of the trochlea to the centre of the notch, was a reliable rotational landmark [39]. The mean angle with the PCL was 3.8° of external rotation. Still the range was high: −1° to 10°, SD 2°. Radiographic examination improved this to 3.1° with a range of 0.5° to 7°. In a clinical paper on the valgus knee, Whiteside reported less patellar complications if the trochlear AP axis was used than when the PCL was used as a reference [35].

Nagamine investigated the reliability of the anatomical TEA and the trochlear AP axis versus the PCL in patients with different types of arthritis and in volunteers with normal knees [50]. The mean values were as follows: the PCL was 6.0° ± 2.4° internally rotated, relative to the anatomical TEA. The values for normal knees, medial tibiofemoral arthritis and patellofemoral arthritis were 5.8° ± 2.7°, 6.2° ± 1.9° and 6.4° ± 2.4° respectively, being not significantly different. In contrast, the angle between the line perpendicular to the trochlear AP axis and the anatomical TEA showed a mean internal rotation of 1.4° ± 3.3°. The distinct groups of normal knees, medial tibiofemoral arthritis and patellofemoral arthritis displayed angles of 2.3° ± 3.1°, 0.1° ± 3.3° and 1.3° ± 3.3° respectively, showing a significant difference between the normal knees and the knees with medial patellofemoral arthritis. The authors concluded that the PCL is more reliable than the trochlear AP axis in knees with medial tibiofemoral arthritis.

### Trochlear AP axis versus tensioned gap technique

Hanada et al. used 12 cadaveric knees to compare both techniques. In the first six specimens, a TKA was inserted using the perpendicular to the trochlear AP axis as a reference [26]. In the second group of six specimens, the tensioned gap technique was used, creating an equal load of 35 N mediolaterally. Alignment was measured as the angle between the trochlear AP axis and the projected extension of the tibial mechanical axis. This angle was 0.6° ± 4° in the normal knees. In group 1, where the AP axis was used for rotational reference, the postoperative angle was −0.5° ± 0.2°. In group 2 with the tensioned gap technique, the angle was 8.5° ± 3.3°. The tibia shifted in varus as the knee went into flexion. As a consequence, peak pressures on the medial side of the knee were greater than on the lateral side upon axial loading. Also, the patellar groove shifted laterally.

### Anatomic versus Surgical TEA

Yoshino et al. studied the relationship between the anatomic and the surgical TEA [51]. In 48 patients with osteoarthritis, a CAT scan was performed prior to TKA. The medial sulcus could only be determined in 30% of the knees. As the arthritis was more severe, the sulcus was more difficult to locate. In those knees with a discernable sulcus, the angle between anatomical and surgical TEA was 3.2° ± 1°. The angle between the anatomical TEA and PCL was 6.4° ± 1.6°, between the surgical TEA and PCL it was 3° ± 1.6°. No relation between the progression of disease severity and the condylar twist angle could be demonstrated.
Kinematic considerations

Kinematics of the tibiofemoral joint are difficult to describe in an intuitive way that could serve surgical applications. The mathematical correct helical axis model is often used in engineering applications but is too complex to apply in the clinical setting. Churchill tried to bridge the gap by proposing a model of kinematic description based upon two axes: one longitudinal axis located in the tibia and one ‘optimal flexion axis’ located in the distal femur. He concluded that knee kinematics could be described as rotations around these two axes, if one allows for a rotation error of 2.9° and a translation error of 3.4 mm within an applicable motion range of 5–90° flexion [52]. He found the ‘optimal flexion’ axis to coincide with the transepicondylar axis. This model was countered by Eckhoff, who took a different approach and looked at the line that was equidistant from the articular surface of each femoral condyle on a three dimensional reconstruction [53]. This line was called ‘the cylindrical axis’. It was found not to coincide with the anatomic transepicondylar axis, in contrast to earlier work by Churchill. This was later confirmed by Lustig et al. who tried to fit circles to CT slices in a plane perpendicular to the epicondylar axis [54].

We worked on a kinematic basis, comparing the femoral transverse axis (connecting the centres of the two best-fit spheres to the femoral condyles, Fig. 2) to the tibial transverse axis, as previously described by Cobb et al. [55]. We found the projection of the femoral transverse axis in the axial plane to coincide with the tibial transverse axis in the extended knee [29]. With the knee at 90° of flexion, the tibial mechanical axis was at 90° with the femoral transverse axis. The femoral transverse axis did not coincide with the epicondylar axis as it was located posterior to it. In the axial plane it was parallel to the surgical TEA.

Conclusion

Rotational alignment of the femoral component TKA remains an important challenge. The number of outliers in postoperative axial alignment has long been overlooked, as measurement of axial alignment after TKA is not easy. It requires CT scan, scatter reduction software and correct understanding of the reference axes (Fig. 3). Nevertheless, as outlined in the introduction, the clinical consequences of rotational malalignment are significant and often lead to important functional impairment or revision surgery.

Some conclusions can be drawn from a review of available publications in the literature. The reported ranges and standard deviations are generally high, indicating an important interindividual variability. It is probably not wise to rely systematically on a single reference axis or technique for every patient. Pitfalls and caveats related to specific situations have been discovered and are summarized in Table 2.

Based on the papers discussed, the following mean angular relationships between the rotation axes of the distal femur in the axial plane can be calculated: the PCL is on average 3° internally rotated relative to the surgical TEA, 5° relative to the anatomical TEA and 4° relative to the trochlear AP Axis. The greatest interindividual variability is described for the trochlear AP axis [29,50]. The worst track record regarding inter- and intraobserver variability is for the TEA [30–33], despite a growing consensus that optimal rotational alignment of the femoral component in TKA should be parallel to the TEA. Given the importance of correct rotational alignment and the variability induced by interindividual differences, and inter/intraobserver variability, some authors started using CT scans as a preoperative planning tool for rotational alignment [56,57]. We have recently demonstrated small inter- and intraobserver variability in the marking of the transepicondylar axis on a CT scan [58]. As such, the relation between a hard and reliable intraoperative reference line (the PCL) and a reliable CT derived optimal axis (the surgical TEA) can be determined preoperatively (Fig. 4). Michaut et al. proposed this methodology and were able to align 77% of cases within 2° of optimal axial alignment [56]. Given the pitfalls, outliers and difficulties described with different techniques, we support this line of thought and recommend the use of a preoperative CT scan, prior to performing TKA.

Table 2 Caveats, distilled from the papers discussed, according to the technique or reference lines used.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pitfall</th>
<th>Result</th>
</tr>
</thead>
<tbody>
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<td>Tensioned gaps</td>
<td>Natural lateral laxity</td>
<td>External rotation</td>
</tr>
<tr>
<td></td>
<td>Tight patellar tendon</td>
<td>Internal rotation</td>
</tr>
<tr>
<td></td>
<td>Ligament imbalance</td>
<td>Inconsistent</td>
</tr>
<tr>
<td></td>
<td>Wrong tibial cut</td>
<td>Inconsistent</td>
</tr>
<tr>
<td></td>
<td>Lateral dysplasia</td>
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<td></td>
<td>Large variability</td>
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</tr>
<tr>
<td>PCL</td>
<td>Inconsistent location</td>
<td>Inconsistent</td>
</tr>
<tr>
<td>Trochl AP axis</td>
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<td>Inconsistent</td>
</tr>
<tr>
<td>TEA</td>
<td>Inconsistent location</td>
<td>Inconsistent</td>
</tr>
</tbody>
</table>

Figure 3 Evaluation of axial alignment after TKA requires a CT scan with scatter reduction software to allow visualisation of the medial and lateral epicondyly. The femoral component shown is at 6° of internal rotation, relative to the surgical epicondylar axis.
Figure 4 Example of preoperative planning in a 62-year-old man with varus arthritis of his right knee. The angle between the surgical TEA and the posterior condylar line, including osteophytes is calculated on the CT scan and implemented during surgery. In this particular case, the PCL was at 2° internal rotation, relative to the surgical TEA.

References


