During total knee replacement (TKR) the surgeon aims to achieve good alignment of the femoral, tibial and patellar components. This can reduce both the mechanical stress placed on the bearing surfaces and the shear stress on the bone/prosthesis or bone/cement/prosthesis interfaces. Good alignment also helps to balance the forces transmitted to the soft-tissue envelope, which is crucial for proper function of the joint.

Under normal circumstances, in the standing position, a vertical line drawn downwards from the symphysis pubis is known as the vertical axis. Meanwhile, the mechanical axis of the lower limb is a line drawn from the centre of the femoral head to the centre of the ankle joint, and passes through the knee just medial to the tibial spine. The mechanical axis does not correspond to the vertical axis (a common cause of confusion), but generally makes an angle of 3˚ with the vertical axis (Fig. 1); however, this can vary subtly depending on the height of an individual and the width of the pelvis.

The anatomical axis refers to a line drawn along the length of the intramedullary canal of either the femur or the tibia. In general, looking from the front, the anatomical axis of the tibia corresponds to the mechanical axis of the lower limb, while the anatomical axis of the femur makes an angle of 5˚ to 7˚ with the mechanical axis. The anatomical axis of the tibia thus subtends an angle of 3˚ with the vertical axis, while for the anatomical axis of the femur this subtended angle is from 8˚ to 10˚.

In contemporary knee replacement systems, the intramedullary rod, which may be surprisingly flexible, determines the anatomical axis of the femur. It is passed retrograde through a drilled entry point in the distal femur; a distal femoral cutting block is then applied over it. When performing this simple step, it is possible to select an entry point that may lead to errors in alignment. In the coronal plane, a more valgus distal femoral cut can be made if the intramedullary entry hole is too lateral, while a more varus distal femoral cut can occur if the hole is too medial. This has implications for soft-tissue balancing and subsequent polyethylene wear. In the sagittal plane, a posterior entry point may cause the distal femoral cut to be relatively flexed, while for an anterior entry point the end result may be a distal femoral cut that is relatively extended. This has implications for component size. When the block is applied for anterior and posterior femoral cuts, the femur can be relatively oversized or can be notched anteriorly. This latter problem can be a risk factor for peri-prosthetic fracture.

The anatomical axis of the tibia can be determined by intramedullary or extramedullary alignment jigs. With intramedullary methods care is needed in the presence of a very bowed tibia and, as with the femur, the selected entry point is critical. Alternatively, extramedullary alignment methods rely on an estimation of the anatomical axis and hence, mechanical axis of the tibia, by aiming to be parallel to the coronal and sagittal axes of the bone. The extramedullary technique can be technically more demanding: defining the tibia is more difficult with large or obese patients, where it may be hard to identify the subcutaneous border of the bone and the centre of the ankle joint. A varus tibial cut may cause tightness on the lateral aspect of the knee in both extension and flexion. If the tibia is cut with an excessive posterior slope there may be instability in flexion. If the cut fails to recreate the normal posterior slope, or is too extended, this may result in a knee that is too tight in flexion and the range of movement is compromised.
Accurate alignment of the patellofemoral joint is also crucial to the performance of a TKR. A key determining factor is rotation of the implanted femoral and tibial component. For the tibia, rotation is referenced to the anteroposterior axis, which is a line that runs perpendicular to the plane, passing medial to lateral through the widest point of the tibia. In practice, the tibial component is aligned to the medial third of the insertion of the patellar tendon. In a normal knee the tibial tuberosity is offset laterally from the trochlear groove by approximately 1 cm; the same must be recreated during a TKR in order to ensure similar forces are passed through the patellar tendon. Excessive internal rotation of the tibial component will result in relative external rotation of the tibial tuberosity, increasing the chance of subluxation or dislocation of the patella. Excessive external rotation of the tibial component may lead to posterolateral overhang of the prosthesis with soft-tissue impingement and relative internal rotation of the tibial tuberosity. This can lead to pain and poor function.

For accurate rotation of the femoral component, the key reference is the transepicondylar axis, which lies in the coronal plane with the knee extended and flexed; it is perpendicular to the mechanical axis. The transepicondylar axis is determined by drawing an imaginary line between the lateral epicondyle and the origin of the medial collateral ligament, which is found at the bottom of a sulcus in the medial epicondyle. The axis is perpendicular to ‘Whiteside’s line’, a line drawn along the deepest part of the trochlear groove.

The transepicondylar axis can be difficult to reliably define in up to 50% of cases, whereas Whiteside’s line is more reliably found. The exception can be in cases where there has been significant patellofemoral wear, which can alter the normal anatomy of the trochlear groove. Identifying these landmarks is key to determining rotation of the femoral component, which is controlled by the anterior and posterior cuts made to the distal femur after application of the femoral cutting block (Fig. 2). In most knee systems a sizing jig is first applied to the distal femur, which can be referenced from the anterior or posterior aspects of the femoral condyle. There are advantages and disadvantages of both methods, but in each case pins are used to define the rotation of the femoral cutting block. A line connecting the pinholes should be perpendicular to Whiteside’s line and parallel to the transepicondylar axis (Fig. 3).

If a posterior condylar referencing system is used for a valgus knee with a relatively hypoplastic lateral femoral condyle, it may be necessary to keep the paddle of the sizing jig away from the posterior aspect of lateral condyle. This permits less lateral bone resection, compared with the more common situation seen with a varus knee. It is more important to ensure correct alignment of the anatomical landmarks for rotation, rather than attempting to equalise bone resection from both posterior condyles. The latter would result in an internally rotated femoral component, which has clear implications for patellar tracking. In addition, there will be relative laxity in flexion on the lateral side, but with tightness on the medial side. This can be difficult to balance by soft-tissue release. In contrast, excessive external rotation may make the lateral side tight in flexion and the medial side relatively lax, which can cause a medial lift-off as the knee is flexed. In both situations, because of ligament tightness, there will be restriction in the range of flexion. The force through the extensor mechanism

Fig. 2. Diagram showing anterior and posterior cuts based on the Transepicondylar Axis (TEA).

Fig. 3. Diagram showing anterior and posterior femoral cuts based on the posterior condylar axis.
in both situations will be altered, causing abnormal loading of any patellar component and contributing to early wear and loosening.

The technology of computer navigation has developed further in recent years. There is evidence that the accuracy of placing components in the coronal plane within 3° of ideal alignment may improve. However, there is little evidence to confirm a long-term effect on function or survivorship and no evidence to confirm increased accuracy of patellofemoral tracking and soft-tissue balance. Computer navigation relies on accurate data input in order to calculate the mechanical axis from the centre of hip rotation, through the centre of the knee, to the centre of the ankle. It will not take into account variations in anatomy, such as a very bowed tibia or a pronounced femoral bow in the sagittal plane. In the latter situation it is possible to cause femoral notching. A direct evolution from computer navigation has been the use of bespoke jigs, manufactured by taking measurements from pre-operative MRI or CT scans. To perform this, the mechanical axis has to be determined and numerous points registered on three-dimensional reconstructions. The benefits of this technique include more accurate component placement in coronal, sagittal and transverse planes and better rotational alignment of the components (Fig. 4).

Performing a TKR requires the accurate execution of key bone cuts in the correct orientation to the appropriate axes. There is huge potential for cumulative errors to occur, which may have significant and dramatic effects on function and longevity.

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