Anatomy of the knee and its kinematics are complex and remain poorly understood. The normal anatomy varies widely, and pathological changes increase its variability further [1–3]. Although total knee arthroplasty (TKA) is considered to be a cost-effective intervention, most patients do not experience natural joints, and it is reported that up to 20% of them are dissatisfied [4,5]. A systematic review of gait analysis after TKA indicates that patients display significant kinematic differences from normal controls [6]. Our understanding of knee anatomy and biomechanics has been enhanced in recent years by studies that may suggest ways of improving TKA outcomes.

In an analysis of healthy individuals, Bellemans et al. [1] noted that 32% of men and 17% of women had constitutional varus knees with hip-knee angle (HKA) of 3° varus or greater. The range of anatomies varies further in patients scheduled for TKA: preop HKA was >3° in 40%, >5° in 19%, and >10° in 3% of them [3]. Creating a neutral mechanical axis in these patients would therefore be a significant anatomical modification and likely cause adjustments in soft tissue balance, differences in joint line orientation, variation of the femoral flexion axis, and alteration of knee kinematics.

Knee kinematics are dictated by the knee flexion-extension axis. Traditionally, the transepicondylar axis is thought to approximate the knee flexion-extension axis. Magnetic resonance imaging studies by Eckhoff et al. [2,7] demonstrated that the flexion-extension axis is actually centered in the posterior femoral condyles, which are circular in shape with a single radius of curvature from 10° to 110°. The transepicondylar axis differs from the cylindrical axis of the condyles by about 5° in 3-dimensional space and is more proximal and anterior [7]. Using traditional orthogonal planes (antero-posterior and lateral) to image the knee had created the false impression of multi-radius curves with variable centers of rotation [7]. This has influenced the development of femoral knee prosthesis components, which are mostly multi-radius designs that have been linked with midrange instability [8,9]. Yoon et al. [10] reported that 36% of TKAs displayed mid-flexion laxity, even when rectangular extension and flexion gaps were achieved at 0° and 90°.

Research by Freeman and Pinskerova et al. [11,12] has influenced our understanding of femoral condyle motion relative to the tibial surface throughout flexion. They demonstrated that the medial condyle barely moves posteriorly, whereas the lateral condyle translates backwards by rolling and sliding about 20 mm, from 0° to 120°, resulting in the femur rotating externally around a medial pivot with flexion. Again, it illustrates a significant difference from classic TKAs, which were designed before this knowledge of femoral kinematics was acquired. Posterior stabilized designs force the translation of both condyles posteriorly, while mobile bearing designs have a central pivot point.

Instrument precision was poor and implantation errors were frequent when TKA commenced in the 1970s [13]. There were many pitfalls to overcome, including infection, implant fixation, joint instability, size limitations, and polyethylene wear. Hence, the focus was on implant survivorship rather than reproducing normal knee anatomy and function. To simplify operations, surgeons selected neutral femoral and tibial cuts to create rectangular extension gaps [13]. For femoral rotation and flexion gap equilibrium, most surgeons considered fixed values according to anatomical landmarks: perpendicular to the anteroposterior axis of the trochlear groove, parallel to the transepicondylar axis, or externally rotated 3° to the posterior condyles.

Gu et al. [14] assessed these alignment landmarks by computer simulation on 50 normal three-dimensional bone models of the lower limbs. They demonstrated that all these techniques frequently result in a wide range of complex collateral ligament imbalances, which are uncorrectable by collateral ligament release. Moreover, surgeons are often unable to accurately and reproducibly identify the transepicondylar axis [15–17] or the anteroposterior axis [18,19]. Using fixed anatomical bony landmarks, there is a wide variability in femoral component rotation, which has been linked to asymmetry of the flexion space, and condylar lift off [20]. Reducing the wide variety of anatomies that exist to single, constant values seems simpler but introduces significant anatomical modifications, which may explain why we do not replicate normal knee function.

The gap-balancing technique is another option to set femoral rotation, aligning the femoral component parallel to tibial resection in 90° of flexion. In most cases, cutting the tibia at 90° introduces significant anatomical change (average 2.9°, range 20.5° to 20.5° valgus), [3] which will be transferred to other bone cuts, modifying the knee flexion axis. Moreover, a recent study assessing ligament tension in 10 native cadaveric knees demonstrated that laxities were two to five times greater at 45° and 90° than at 0° of flexion [21]. It suggests that striving for equal flexion and extension gaps might be over-constraining the knees in flexion.

In a paper included in this edition, Riviere et al. undertook computer simulation to assess TKA implantation with a mechanical alignment (MA) technique [22]. Modification of native distal femoral joint line obliquity (reducing its valgus) with MA resulted in frequent trochlear facet and lateral femoral condyle overstuffing as well as uncorrectable knee imbalance. Aligning femoral implants with the femoral flexion-extension axis (cylindrical axis) is of primary importance in obtaining collateral ligament

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balance and reproducing knee kinematics. In a second paper, Riviere et al. assessed the accuracy of specific manual instrumented design to implant femoral components aligned with the cylindrical axis of the knees [23]. Although they only studied a small number (13 cases) of patients, they demonstrated minimal differences between planned and actual positioning of femoral implants on post-operative imaging, suggesting that it is a reproducible technique for femoral alignment, which should be further assessed in a larger cohort of patients.

Kinetically-aligned (KA) TKA has grown in popularity in recent years. KA TKA aims to reproduce the pre-arthritis knee anatomy and kinematics of patients. In theory, it represents a resurfacing of articular surfaces, removing equivalent amounts of bone and cartilage to match implant thickness. As this method has completely upended the last 40 years of TKA development, many uncertainties exist regarding functional benefits and related implant survivorship, a scientific review of the current literature may be beneficial. In the current edition, Riviere et al. systematically reviewed four randomized-control trials (RCTs) comparing KA and MA TKAs [24]. At up to 2 years follow-up, two of the RCTs reported better functional outcomes with KA TKAs, [25,26] while the other two showed no difference [27,28]. Howell et al. [29] observed 97.5% implant survivorship in a cohort of 208 KA TKAs at 6-year follow-up. In another study, radiostereometric analysis of TKAs randomized to MA or KA did not discern significant differences in implant migration between groups [30]. Some authors remain concerned about restoring severe patho-anatomies, which may not be comparable with current TKA prostheses and fixation methods [31,32]. Almaawi et al. [3] analyzed pre-operative CT scans of 4884 patients undergoing TKA and demonstrated that 19% of HKAs were >5° and 3% were >10°. It led us to develop a restricted KA protocol, which aims for anatomical alignment, but restricts tibial and femoral cuts to a maximum ±5° deviation from the coronal mechanical axis and with resulting HKA within ±3° of neutral [33]. This technique has demonstrated good early functional outcomes at a mean of 2.4 years in a series of 100 patients [33].

It is noteworthy that MA TKAs have a long history of good survivorship [34–36]. Achieving a mechanical axis within 3° of neutral has been associated with better outcomes than “malaligned” TKAs [37–39]. Many surgeons worry about leaving some varus or valgus with the KA technique. It must be understood that accurate KA, aiming for HKA other than neutral, is very different from malaligned TKA when aiming for neutral. KA does not mean keeping the lower limb in slight varus in the frontal plane, it is a knee resurfacing, aiming to reproduce the 3D anatomy of the knee. Joint load is assumed to be balanced between both medial and lateral compartments during gait. Ji et al. [40] calculated the plane orientation of native knees by measuring radiographs in 50 young, healthy individuals. Mean joint line orientation angle was parallel to the floor (0.2 ± 1.1°). This angle was best reproduced by KA TKAs (with 50.8% of knees within 1 standard deviation of mean native knee angle) compared to conventional MA (6.9%) and navigated MA (16.9%). Another study of KA knees obtained similar results, showing that joint line obliquity tended to be parallel to the floor when standing [41].

Due to the significant knowledge and technology deficiencies in past years, we are far from replicating normal knee kinematics with MA TKA. Limitations of TKA function and patient satisfaction should stimulate us to restart the entire TKA development process. Riviere et al., authors of three KA studies included in this edition [22–24], should be applauded for their contribution to what is a controversial area in knee arthroplasty. Going forward, long-term studies are required to assess the survivorship and functional outcomes of KA TKAs. Implant design needs to be advanced to reproduce the anatomy and kinematics of native knees. More precise surgical techniques with navigation, patient-matched instrumentation and robotics need to be further refined. The aim is to produce more natural knee joints, with resultant patient satisfaction and ultimately a forgotten joint.

**Disclosure of interest**

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**References**


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