Restricted Kinematic Alignment: The Ideal Compromise?

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Key Points

- The normal knee anatomy varies widely, and the more extreme ones may be inherently biomechanically inferior which may have deleterious effects on the TKA biomechanics and wear patterns.
- The restricted kinematic alignment protocol (rKA) has been developed as an alternative solution to the “true” KA technique in situations of patients with atypical knee anatomy.
- The rKA protocol limits the femoral and tibial prosthesis coronal alignment to within $\pm 5^\circ$ of neutral, with the overall combined lower limb coronal orientation within $\pm 3^\circ$ of neutral.
- 50% of patients fit within the rKA safe range allowing a pure KA technique. Minimal cor-

rections are needed for one third, and more important anatomy changes are needed for the rest (1/6).

- rKA protocol offers a satisfactory compromise, avoiding the important anatomy modifications and ligamentous releases required with MA but preventing the extremes of implant positioning that true KA technique may produce.

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17.1 Mechanical Alignment: The End of an Era

Most patients following conventional total knee arthroplasty (TKA) do not experience a natural joint [1]. One fifth of patients are dissatisfied [2], over half may have residual symptoms [3], and up to a quarter would, in retrospect, not undergo the same surgery again [4]. Gait analysis studies have demonstrated that patients following TKA walked with less total range of knee motion and significant kinematic discrepancies [5].

When TKA was first introduced, instrument precision was poor, and implantation errors were frequent. There were many pitfalls to overcome; hence the focus was on implant survivorship, rather than reproducing normal knee function [6]. To achieve this, surgeons introduced the mechanical alignment (MA) technique. By selecting a neutral femoral and tibial cut with femoral rotation adapted and ligamentous releases to create equal femoral and extension gaps, a simpler

method for alignment was created. This “one size fits all” approach, whilst reproducible, does not respect the wide range of normal anatomy of the knee [7]. Although the mean hip-knee-ankle angle (HKA) of patients scheduled for TKA is near neutral, a study of 4884 patients found only 0.1% of patients had both medial proximal tibial angle (MPTA) and lateral distal femoral angle (LDFA) at neutral, which is what MA aims to generate. Furthermore, a study on 1000 knee CT scans found that a systematic use of MA for TKA leads to many cases with gap asymmetries [8, 9]. Mediolateral imbalances >3 mm were created in 25% of varus and 54% of valgus knees. Using the trans-epicondylar axis for femoral rotation, only 49% of varus and 18% of valgus knees had <3 mm of imbalance in both mediolateral and flexion-extension gaps. Some imbalances may not be correctable surgically and may explain residual TKA instability and poor results.

With a better understanding of normal knee joint anatomy and function, kinematic alignment (KA) technique has been introduced to improve clinical results following TKA. The KA technique for TKA aims to restore the pre-arthritis patient’s constitutional lower limb alignment and joint surface orientations. It is a joint resurfacing procedure with only exceptional soft tissue release [10, 11]. We believe it is the end of the MA Era [12].

17.2 Are All Anatomies Physiologic?

The normal knee anatomy varies widely, and pathological changes increase its variability further [7, 13, 14]. In 4884 knees scheduled for TKA, HKA was >3° in 40%, >5° in 19%, and >10° in 3% of them [7]. The MPTA range was from 20.5° varus to 20.5° valgus, with a mean of 2.9° varus. The LDFA range was from 11° varus to 15.5° valgus with a mean of 2.7° valgus. The wide ranges demonstrate the huge variability in patient’s anatomy (Fig. 17.1).

The more extreme anatomies may be inherently biomechanically inferior and may have been altered by factors that might predispose to degenerative disease such as trauma, tumours,

Fig. 17.1 Anatomic modification linked to mechanical alignment technique on the distal femur and proximal tibia

childhood deformity, or previous surgery (Fig. 17.2). A strong argument for the existence of patho-anatomies is the unilateral occurrence in some patients. We believe that surgeons should not blindly reproduce the same anatomy in these outlier patients as it may have deleterious effects on the TKA biomechanics and wear patterns. On the other hand, creating a neutral mechanical axis in these patients would be a significant anatomic 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.

A computer simulation study looking at the effects of MA or KA in TKA on a single knee model found that KA TKA produced near-normal knee kinematics (with greater femoral rollback and more external rotation of the femoral component) [15]. However, there were also increased contact stresses, raising concerns about long-term outcomes. A retrieval study of 178 MA TKA revisions found that knees with greater varus alignment had increased total damage on the retrieved polyethylene inserts [16]. They also found that these MA TKAs tended to drift back towards the preoperative varus deformity before revision surgery, away from a neutral mechanical alignment. Other clinical [17] and simulator [18, 19] studies have similarly found an association between polyethylene wear and varus alignment. Greater tibial varus has also demonstrated a weak correlation ($r^2 = 0.45$) with tibial baseplate migration at 10-year follow-up, in an RSA study [20]. Interestingly, overall limb alignment, from an HKA of 1.3° valgus to over 10° varus, did not affect baseplate migration. There was

Fig. 17.2 Lower limb full-length radiographs show bilateral valgus lower limbs with severe right knee OA with LDFA of 11° and MPTA of 6° . Reproducing her right lower limb alignment with systematic KA would leave her lower limb HKA in 5° of valgus. We consider her right lower limb anatomy to be pathologic. One argument in favour of this assumption is the difference between the two lower limbs, with the left side being less extreme. Applying our protocol, we would reduce the LDFA to 5° valgus and the MPTA to 2° varus, resulting in a combined HKA of 3° valgus

no difference between those within $\pm 3^\circ$ of neutral and those $> 3^\circ$. These studies would suggest that systematically reproducing patients' patho-

anatomy might not be suitable for implant survivorship using current TKA materials and fixation methods.

17.3 Restricted Kinematic Alignment Protocol (rKA)

The restricted kinematic alignment protocol (rKA) has been developed as an alternative solution to the “true” KA technique [11] in situations of patients with atypical knee anatomy. The concept of rKA is to reproduce the patient's constitutional knee anatomy within a safe range, avoiding the extreme pathological anatomies that have been demonstrated to exist [7]. The rKA protocol limits the femoral and tibial prosthesis coronal alignment to within $\pm 5^\circ$ of neutral, with the overall combined lower limb coronal orientation within $\pm 3^\circ$ of neutral (e.g. placing a femur in 4° of valgus with a tibia in 5° of varus would result in an overall combined coronal orientation of 1° varus). To resurface the posterior condyles, a posterior referencing guide is set to neutral rotation, thus resecting only the implant thickness of the posterior condyles and matching each patient's native femoral orientation. Tibial baseplate rotation is set relative to the trial femoral component with the knee in extension.

The surgeon aims to reproduce the patient's normal anatomy as in the KA technique. This can be achieved using measured resection techniques with a calliper, intraoperative computer navigation or preoperative planning with patient-specific instrumentation. Resections are only modified from the patient's anatomy if the measured angles fall outside the predefined safe range. A study assessed the preoperative CT scans of 4884 knees undergoing TKA surgery to analyse the effect of the rKA technique [7]. This demonstrated that 51% of patients fell within the safe range allowing a pure KA technique. Allowing for minimal corrections (mean of 0.5° for the tibia and 0.3° for the femur), this was increased to 83% of all patients.

The protocol for performing these minimal corrections is as follows (Fig. 17.3). First, the surgeon

HKA: hip knee ankle mechanical angle
MPTA: medial proximal tibial angle
LDFA: lateral distal femoral angle

Fig. 17.3 rKA decision-making flow diagram

corrects the tibial and/or femoral bone cuts to fall within the 5° limit. This will then correct the overall HKA to within $\pm 3^\circ$ of neutral in a significant proportion (51%). In 8% of the cases, the patient maintained an HKA of $> 3^\circ$ of varus (e.g. femur 1° valgus and tibia 5° varus = HKA 4° varus). In these cases, the tibial varus was further reduced until the HKA was 3° varus. In 7% of cases, the patient maintained an HKA of $> 3^\circ$ of valgus (e.g. femur 5° valgus and tibia 1° varus = HKA 4° valgus). In these cases, the tibial varus was increased until the HKA was 3° valgus. When anatomic correction is needed, we prefer to modify the tibia to preserve as much as possible the femoral anatomy and its

flexion axis. Ligamentous releases are usually not needed in cases with anatomic modifications of $< 3^\circ$. In larger corrections, minimal releases can be added (usually, to a much lesser degree compared to MA).

In our simulation study [7], 17% of knees had unusual anatomy, with both the femur and tibia articular orientations being in varus or valgus. As both bones contribute the same direction to the overall HKA deviation, the surgeon needs to decide which bone to correct to fall into the safe range. As stated earlier, we believe that the femoral flexion axis plays the more significant role in knee kinematics, our practice is to pre-

serve femoral anatomy as closely as possible and perform greater modifications on the tibial side. For example, in a valgus knee with a femur in 9° valgus and a tibia with 1° valgus (overall HKA of 10° valgus), the femoral cut is modified to our maximum of 5° valgus and the tibial cut corrected to 2° varus, giving an overall HKA of 3° valgus. Similarly, in a severe varus knee with 2° varus femur and 6° varus tibia (overall HKA of 8° varus), the femoral orientation is maintained (2° varus), and the tibial varus is reduced to 1° , giving an overall HKA of 3° varus. One must consider that most of these cases have associated extra-articular deformities explaining these extremes HKAs. The severe valgus often has a tibia valga deformity in the diaphysis, and the severe varus may have a femoral bowing contributing to the lower limb alignment [21]. In these cases, resurfacing the knee joint (KA) will favour ligament laxities preservation but will not address the lower limb deviation linked to the extra-articular deformity. On the other hand, performing the rKA protocol will correct the extra-articular deformity with intra-articular cuts and may require ligament release/adjustment to avoid secondary instability.

The rKA protocol brings back the extreme anatomies towards acceptable values, modifying their deformities to allow an implant orientation compatible with current materials and fixation methods. On the other hand, simulating an MA technique in this same cohort of patients, significantly larger corrections were necessary [7]. The mean MPTA correction was 3.3° for MA versus 0.5° for rKA ($p < 0.001$). Similarly, the mean LDFA correction was 3.2° for MA versus 0.3° for rKA ($p < 0.001$). This highlights that across a large population, performing MA requires significant changes to normal anatomy. These greater anatomic modifications then necessitate larger soft tissue releases to balance the knee, which may have detrimental effects on normal biomechanics.

required minor ligamentous release. A study of gait analysis comparing patients operated on with rKA compared to MA technique demonstrated that the rKA patients had knee kinematics that were significantly closer to healthy controls than MA patients [22]. The MA group displayed several significant knee kinematic differences to the healthy group: less sagittal plane range of motion (49° vs. 54° , $p = 0.020$), decreased maximum flexion (52° vs. 58° , $p = 0.002$), and increased adduction angle ($2.0\text{--}7.5^\circ$ vs. $-2.8\text{--}3.0^\circ$, $p < 0.05$). These kinematic differences translated in significantly higher postoperative KOOS score in the KA group compared to the MA group (74 vs. 61 , $p = 0.034$).

In a study of 1000 preoperative CT scans of patients undergoing TKA, bone cuts, we compared the mediolateral and flexion-extension gap asymmetry between measured resection MA and rKA protocol bone cut simulations. Two MA techniques were simulated for rotation: using the surgical transepicondylar axis (TEA) and 3° to the posterior condyles (PC). Extension space mediolateral (ML) imbalances (>2 mm) occurred in 33% of TKA with MA technique versus 8% of the knees with rKA; imbalances (>4 mm) were present in up to 11% of MA knees versus 1% rKA ($p < 0.001$). Using the MA technique, for the flexion space, higher ML imbalance rates were created by the TEA technique ($p < 0.001$). rKA again performed better than both MA techniques using TEA or 3° PC techniques ($p < 0.001$). Using MA with TEA or PC, there were only 49% and 63% of the knees respectively with < 3 mm of imbalance throughout the extension and flexion spaces and medial and lateral compartments versus 92% using rKA ($p < 0.001$). Other studies have similarly reported that the MA technique frequently results in significant anatomical modifications with a wide range of complex collateral ligament imbalances, which are not correctable by collateral ligament release [7, 23].

17.4 rKA Clinical Results

A clinical series of the first 100 patients operated on using the rKA protocol demonstrated satisfactory functional outcomes at early follow-up (mean 2.4 years, range 1–3.7). Only 5% of the knees

17.5 rKA Versus True KA: A Compromise?

Many surgeons worry about leaving too much varus or valgus with the KA technique. Howell

et al. [24] observed 97.5% implant survivorship in a cohort of 208 KA TKAs at 6-year follow-up, with no increased failure in those with greater varus. In another study, radiostereometric analysis of TKAs randomised to MA or KA did not discern significant differences in implant migration between groups [25]. There are no long-term follow-up studies on KA TKAs, whereas MA TKAs have a long history of good survivorship [26–28]. Achieving a mechanical axis within 3° of neutral has been associated with better functional outcomes than malaligned TKAs in some studies [29–31]. Other studies have demonstrated increased aseptic loosening and rates of failure with malaligned components [32–34]. In contrast, more recent studies have failed to demonstrate greater survivorship or functional outcomes in well-aligned prostheses (within $\pm 3^\circ$ of neutral) compared to malaligned TKAs [35–38]. The results of these studies should be generalised to KA with caution. It must be understood that accurate KA, aiming for an HKA other than neutral, is very different from a malaligned TKA when aiming for neutral. There are no doubt other factors than coronal prosthesis alignment that affect how the knee will be loaded dynamically. Studies, both in asymptomatic patients [39] and in kinematic TKA patients [40], have demonstrated that despite a range in alignment, the joint line remains parallel to the ground when standing. The resultant functional joint line orientation may well be favourable for the overall load profile of the prosthetic joint.

In the absence of further evidence from long-term studies of KA TKAs, however, some authors have cautioned against widespread adoption of KA technique [41]. We believe the rKA protocol offers a satisfactory compromise, allowing recreation of normal patient anatomy for the majority of cases, avoiding the excessive corrections and ligamentous releases required with MA, but preventing the extremes of implant positioning that an unrestricted KA technique may produce.

17.6 Case Example

17.6.1 Case Example 1

A 65-year-old male, with severe varus right knee OA. Preoperative long leg radiographs (see Fig. 17.4) demonstrate right femoral varus (LDFA of 93°) with a valgus tibia (MPTA of 88°). The patient elected to undergo right TKA using our rKA protocol. In this case, as is the case with ~50% of cases, no modifications were required from his preoperative constitutional alignment allowing a pure KA approach. Although his resultant HKA is near neutral (1° varus), his joint surface orientations were maintained. With MA technique, both the femoral and tibial anatomies would have been significantly modified to neutral. This joint line orientation and flexion axis changes would affect knee kinematics. It is interesting to note that in such a case, using intramedullary rod alignment for the tibia would lead to an important error in valgus.

17.6.2 Case Example 2

An active 58-year-old female, with painful right knee OA and previous left knee MA TKA. Preoperative planning long radiographs demonstrate right femoral valgus (LDFA of 83°) with a neutral tibia (MPTA of 90°) (see Fig. 17.5). The patient elected to undergo right TKA using our rKA protocol. In this case, to stay within our rKA safe range, we increased her LDFA to 85° (reducing valgus from 7° to 5°) and reduced her MPTA to 88° (from neutral to 2° varus). Resultant HKA was valgus 3° . With such corrections, we tried to minimise femoral axis and femoral anatomy modifications. No ligament release was needed. The patient underwent an uneventful postoperative recovery. At 4 months post-surgery, she feels she has a right forgotten knee without restrictions. On the left MA TKA, even with a LDFA and MPTA at 90° , the resulting HKA is 3° varus. The patient prefers her right TKA.

Fig. 17.4 Standing long radiographs of case example 1

Fig. 17.5 Standing long radiographs of case example number 2

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