Current concept of kinematic alignment total knee arthroplasty and its derivatives

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The kinematic alignment (KA) approach to total knee arthroplasty (TKA) has recently increased in popularity. Accordingly, a number of derivatives have arisen and have caused confusion. Clarification is therefore needed for a better understanding of KA-TKA. Calipered (or true, pure) KA is performed by cutting the bone parallel to the articular surface, compensating for cartilage wear. In soft-tissue respecting KA, the tibial cutting surface is decided parallel to the femoral cutting surface (or trial component) with in-line traction. These approaches are categorized as unrestricted KA because there is no consideration of leg alignment or component orientation. Restricted KA is an approach where the periartritic joint surface is replicated within a safe range, due to concerns about extreme alignments that have been considered ‘alignment outliers’ in the neutral mechanical alignment approach. More recently, functional alignment and inverse kinematic alignment have been advocated, where bone cuts are made following intraoperative planning, using intraoperative measurements acquired with computer assistance to fulfill good coordination of soft-tissue balance and alignment. The KA-TKA approach aims to restore the patients’ own harmony of three knee elements (morphology, soft-tissue balance, and alignment) and eventually the patients’ own kinematics. The respective approaches start from different points corresponding to one of the elements, yet each aim for the same goal, although the existing implants and techniques have not yet perfectly fulfilled that goal.

Cite this article: Bone Jt Open 2022;3-5:390–397.

Keywords: Knee, Treatment, Arthroplasty, Alignment, Soft-tissue, Mechanical, Kinematic

Introduction

Total knee arthroplasty (TKA) has aimed to achieve neutral leg alignment: hip-knee-ankle angle (HKAA) of 0°, both femur and tibial components being perpendicular to the mechanical axes, and parallel and equal bony gaps in extension and flexion. This combination is known as mechanical alignment (MA) TKA. MA-TKA has acquired satisfactory long-term implant survival, accounting for 95% in national registries.1–3 Nevertheless, 20% of patients after TKA have reported dissatisfaction, 25% of patients do not want to undergo the same operation again, and about 55% of patients have residual symptoms.4–6 Improved materials, such as vitamin D-containing polyethylene bearings, small intervals between component sizes, and sex-specific components, have been introduced with the aim of diminishing dissatisfaction, but there has been little evidence of improvement from the patient’s perspective.7,8

Neutral leg alignment was shown to be rare in a recent study, even in healthy populations, and constitutional varus is prevalent.9,10 Soft-tissue release for patients with constitutional varus alignment is therefore necessary to achieve neutral alignment in such patients (Figure 1).12–14 Moreover, the joint line is not perpendicular to the MA but shows slightly varus obliquity at approximately 3°.11 Eventually, joint line is inevitably altered, so it might be impossible to achieve perfect replication of the joint line and kinematics (Figure 2). Furthermore, MA-TKA aims to achieve equal and parallel gaps, regardless of the patient’s own soft-tissue balancing and alignment. This ‘one-size-fits-all’ concept of MA-TKA has recently been recognized as a systematic approach.15–17 As a variation of the systematic approach, anatomical alignment was introduced by Hungerford et al.,18 where the components are implanted in 3° varus considering the joint line obliquity
maintaining the leg alignment to be neutral. Due to the difficulty in making an accurate slanted bone cut, however, it has been largely disregarded.19

A new approach was reported by Howell et al20 in 2008 as custom-fit positioning TKA, where the component is set along the articular surface. Since then, the approach has developed to become known as kinematic-alignment (KA)-TKA.21 Unlike the MA approach, the KA approach aims to reform the native (or pre-arthritic) joint line along the three kinematic axes. The goal is eventually different between patients, so it is considered to be a personalized, individualized, or patient-specific approach.15,22,23 This approach has received a great deal of attention in recent years, and many surgeons have reported good short-term and medium-term clinical results.24-28

With the spread of KA-TKA, several derivatives with different modifications have been proposed, which has led to some confusion. Therefore, this paper aims to clarify and classify the KA approach and its derivatives for clearer understanding.

**Kinematic alignment approaches.** In KA-TKA, components are set respecting three kinematic axes: the cylindrical axis (CA), or condylar axis, is the axis between the centres of the estimated circle of medial and lateral condyles.22 The femur rotates around the CA. The patellar axis is parallel to the CA and located anterior and
superior to it. Then, the patella rotates around the patellar axis. The tibial rotation axis locates medial to the centre of the knee, and the tibia locates axially around this axis, producing so-called medial pivot motion. As a result of the restoration of the three kinematic axes, the native articular surface, good soft-tissue balance, and similarity to native kinematics are expected to be restored. The term ‘kinematic’ was intended to express or highlight the implantation following the kinematics of these three axes, but currently many surgeons do not take these axes into account and instead aim to replicate the native joint surface.

Finding the native femoral articular surface. The first step of the KA approach is to restore the native articular surface of the femur by the use of components. The procedure is straightforward; the femoral condyle (distal and posterior) is cut at the same thickness as the component. On the affected condyle, bone resection is made 2 mm thinner than the component thickness, compensating for cartilage wear. Bone resections are made using mechanical instruments,29,30 or computer-aided instruments.25,31,32 However, the bone defects have not been considered in this approach and the thickness can vary between patients, the sides, and the site of the condyle.13,16,33-36 More recently, the inversed KA technique has been advocated, in which the femoral cutting plane is decided based on the tibial cutting plane.17

Tibial cutting concepts. On the tibial side, various methods have been reported to replicate the native joint surface (Figure 3), and this has led to the development of various derivatives.

Calipered technique. The calipered technique (Figure 3a) is an anatomical approach in which the bone cut is made parallel to the articular surface to compensate for the cartilage wear, similar to the femoral side. As a result of the restoration of the three kinematic axes, the native articular surface, good soft-tissue balance, and similarity to native kinematics are expected to be restored. The term ‘kinematic’ was intended to express or highlight the implantation following the kinematics of these three axes, but currently many surgeons do not take these axes into account and instead aim to replicate the native joint surface.

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The variation of deciding the tibial cutting surface in the kinematic alignment total knee arthroplasties (KA-TKAs). a) Calipered (or pure, true) KA technique. The tibia is cut parallel to the tibial articular surface, compensating for the cartilage wear, similar to the femoral side. b) Soft-tissue respecting technique. The tibia is cut parallel to the femoral cutting surface under proper traction, parallel to the distal cutting surface of the femur in extension with respect to the trial component, and parallel to the posterior cutting surface of the femur in flexion. The calipered and soft-tissue respecting approaches are categorized as unrestricted KA. c) Restricted KA technique. A similar bone cut is done within the safe range (e.g. <5° varus); otherwise, the resection is performed at a defined angle. Intraoperative adjustment with computer assistance: d1) Functional alignment. The tibial cutting surface along with the femoral cutting surface is decided based on the intraoperative information, including alignment and gap under computer assistance. d2) Inverse kinematic alignment or tibia-based KA. In this technique, the alignment of tibial component is decided first, followed by that of femoral component. Note that the femoral cutting line can be altered in these techniques. HKA, hip-knee-ankle angle; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.
**Soft-tissue respecting technique.** In the soft-tissue respecting technique (Figure 3b), the tibia is cut parallel to the femoral cutting plane or to the femoral component trial under appropriate in-line traction with the knee in full extension or a slight flexion.46,47 Similarly, the Zimmer Biomet (USA) operation manual describes the tibial cutting technique in reference to the posterior cutting surface with the knee in 90° flexion.48 These techniques are based on the assumption that if the components are implanted in the same alignment as the native articual surface, the soft-tissue balance becomes similar to the native pre-disease condition. There is concern, however, that the alignment is decided passively following the soft-tissue envelope, which can result in an extreme alignment. Moreover, soft-tissue abnormality, such as elongated lateral and/or contracted medial structure in medial OA knees, can be observed,49,50 but the components can be implanted in an altered alignment in such cases. The soft-tissue respecting technique is also categorized as unrestricted KA-TKA because neither whole-leg alignment nor joint line obliquity is considered in deciding the bone cutting surface. Until now, there have been no reports regarding the long-term survival or clinical outcomes of this approach.

**Restricted KA technique.** The unrestricted technique can cause an extreme alignment that has been considered an outlier of MA-TKA. Although an increasing number of reports show that implant failure does not occur regardless of the alignment,45 adopting the KA technique within a safe alignment range is attractive (Figure 3c).51,52 Satisfactory clinical outcomes have been widely reported,41,52,54 but the safe range for restriction has not been defined based on scientific evidence. Importantly, the restriction requires computer-assisted technology because it is essential to have precise control of bone cut alignment. Matsumoto et al.53 reported the modified kinematic alignment technique, where the tibial bone cut is made in 3° varus in every case. This approach is also considered to be a kind of restricted KA, but has been labelled as ‘pseudo KA’.56 It seems reasonable for Asian patients, however, because constitutional varus alignment is common in Asians, and approximately 80% of Japanese knees eventually require restriction using restricted KA protocol.57

**Intraoperative adjustment with computer assistance techniques.** Recent computer-assisted technologies, such as navigation and robotics, enable dynamic intraoperative planning based on intraoperative measurements, including alignment, soft-tissue laxity, and joint gaps acquired with computer-assistance (Figure 3d).25,53,58,59 Further manipulation is possible if the gap balancing is unsatisfactory. Consequently, the component can be set in a well-balanced soft-tissue within the safe alignment.19,32,59

The functional alignment (FA) technique introduced by Chang et al.59 is a typical computer-assisted surgery. In the FA technique, the intraoperative manipulation of the femoral and tibial components positions starting from the neutral MA is facilitated based on the intraoperative measurements.

More recently, the inverse kinematic alignment (iKA) technique has been introduced, whereby the tibial cut is made first to restore the periarthritic joint line, and the femoral cutting planes are then decided using intraoperative measurement; this has shown good short-term results.57 A similar concept of technique is reported as tibia-based functional alignment with favourable results.50 They are different from most KA approaches, where the femoral periarthritic articular surface is firstly restored prior to the tibial cut.

**Is an extreme alignment safe?** Given that the native articular surface is provided and is an extreme alignment in terms of MA-TKA, there should be discussion on whether or not extreme alignment can be accepted. Several reports have shown that the malalignment of the femur,61–63 tibia,61,62,64,65 and HKAA61–64 are associated with the increased failure rate, whereas other reports show no such association.63,65–69 These results were based on MA-TKA, and so cannot be directly applied to KA-TKA. Regarding unrestricted KA, Howell et al reported six-year62 and ten-year63 survival rates of 97.5% (for all causes of revision) and 98.4% (for aseptic loosening) in a single-arm study. More recently, a comparison study of registry data from Australia and New Zealand revealed a cumulative revision rate of 3.1% with unrestricted KA and the rate of 3.0% for all other alignment methods.44 Furthermore, a radio stereometric study revealed that there was no longitudinal migration between unrestricted KA and MA-TKA.70 Furthermore, the forces in the medial and lateral compartments were similar in a cadaveric study between outlier and in-range alignment knees in unrestricted KA-TKA.71 Similar results of intraoperative measurements were reported by Shelton et al,38 who also reported similarity in the medial and lateral compartmental forces between outlier and in-range alignments.72

However, most of these studies have been conducted in Western countries and constitutional varus has been reported to be more common in Asian countries.73,74 Adapting the results to Asian patients should therefore be done with caution, and long-term results of unrestricted KA in Asian patients have not yet been reported. Similarly, patients with excessive alignment or obvious intra- or extra-articular deformities might be out of the range of the unrestricted KA.72 The restricted KA might therefore be a safe and a promising procedure and there have been reports of satisfactory short-to-midterm clinical results.72,75 Soft-tissue release is sometimes necessary, however, and it can induce a deterioration of the soft-tissue envelope and a dissimilar restoration of the kinematics.76 Moreover, up to 3° to 5° for the femoral and tibial component orientations, and up to 3° for the whole leg angle, are used.
for the safe range.\textsuperscript{51,52} There is no evidence, however, that these ranges are appropriate. Evidence-based definitions of the safe range along with long-term results require evaluation.

**Three key elements.** As described in the four-bar linkage model,\textsuperscript{77} soft-tissue balancing decides the morphology of the epiphysis, and the morphology determines the alignment. Eventually, three key elements of the knee – morphology, soft-tissue balance, and alignment – form a unique harmony (Figure 4). Each element determines the others and is determined by the others, resulting in individualized kinematics.\textsuperscript{78} If one of the three elements is altered from the native configuration, a complete or even satisfactory harmony will not be achieved. The harmony might differ between patients, so individualized goal setting instead of a systematic ‘one-size-fits-all goal’ would be necessary. Each derivative of KA-TKA starts from each element (the calipered KA from the morphology, the soft-tissue respecting KA from the soft-tissue balance, and restricted KA from the alignment and an inoperative adjustment, stems from each of the three elements at the same time) and aims for the same goal: unique harmony and individual kinematics, with consideration of the other elements. The modern computer-assisted, intraoperative adjustable techniques aim to find the best harmony. However, complete replication of the joint surface and kinematics has not been achieved using current components.\textsuperscript{79} An improved component that works well with the KA-TKA technique might be helpful.\textsuperscript{22}

What is ‘alignment’ in KA? ‘Kinematic alignment’ originally referred to the approach that aimed to follow three kinematic axes. More recently, it has evolved to mean recreation of the native articular surface by components, and it is used to refer to a contrast to the MA approach. Furthermore, the alignment seems to be considered as component alignment rather than in reference to the kinematic axes.\textsuperscript{15,16} The means of finding the native joint line and whether the joint line can be accepted (unrestricted) or not (restricted or adjusted) remain matters of controversy. Future studies will gain evidence regarding these matters.

KA approaches aim to restore the patients’ best harmony of morphology, soft-tissue balance, alignment, and kinematics similar to that in pre-arthritic knees. All KA approaches aim for the same goal, but the starting point differs between approaches. The calipered approach starts from ‘morphology’, focusing on replicating the original articular surface, the soft-tissue
respecting approach starts from the soft tissue balance, and the restricted approach starts with controlling the alignment. All other issues are expected to be eventually overcome and the patients’ original native kinematics might be restored, although the goal has not yet been achieved. ‘Kinematic’ might be used to indicate the goal of the approaches and ‘alignment’ might be considered a means of fulfilling the goal by component alignment. KA has gained in popularity, but there has been confusion about its exact meaning and implications.

KA-TKA aims to restore the patients’ individual harmony of three knee elements (morphology, soft-tissue balance, and alignment) and eventually replicate patients’ own kinematics. The respective approaches start from different points corresponding to one of the three elements, yet aiming for the same goal, although the existing implants and techniques have not yet perfectly fulfilled the goal.

Take home message
- Kinematically aligned total knee arthroplasty aims to restore the patients’ individual harmony of three knee elements (morphology, soft-tissue balance, and alignment) and eventually replicate the patient’s own kinematics.
- The respective approaches start from different points corresponding to one of the three elements, yet aim for the same goal, although existing implants and techniques have not yet perfectly fulfilled the goal.

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Funding statement:
The authors received no financial or material support for the research, authorship, and/or publication of this article.

Acknowledgements:
The authors thank Benjamin Phillis at the Clinical Study Support Center, Wakayama Medical University, for proofreading and editing.

Open access funding
The open access fee for this study was self-funded.

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