Principles, Alignment, Balancing, and Results of Kinematic Alignment: An Option for Total Knee Arthroplasty

by Stephen M Howell, MD

Professor of Mechanical Engineering, Member of Biomedical Engineering Graduate Group, University of California at Davis
8120 Timberlake Way Ste 112 Sacramento CA 95823
EMAIL sebhowell@mac.com
OFFICE (916) 689-7370
FAX (916) 688-5610

Kinematically aligned TKA was first performed in 2006 and has gained interest among surgeons that would like to improve the pain, satisfaction, and function of a TKA to that of a total hip arthroplasty. In a recently published level I randomized trial and a multicentre study, patients treated with a kinematically aligned TKA reported significantly better pain relief, function, flexion, and a more normal feeling knee than patients treated with a mechanically aligned TKA.

Firstly, kinematically aligned TKA strives to set the anterior-posterior, proximal-distal, and medial-lateral, flexion-extension, varus-valgus, and internal-external rotational position (6 degrees-of-freedom) of the femoral and tibial components on the tibial-femoral articular surface of the native knee. Setting the femoral and tibial components on the native tibial-femoral articular surfaces co-aligns the axes of the components closely to the three kinematic axes of the normal knee (Figure A). The kinematic axes are either parallel or perpendicular to the native tibial-femoral articular surfaces of the knee. Setting the articular surface of a component in a position that is different from the native tibial-femoral articular surfaces would malalign the rotational axes of the components with the three kinematic axes, which shortens or lengthens the native resting length of the collateral, retinacular, and posterior cruciate ligaments. Shortening or lengthening the ligaments causes unnatural knee motions and laxities that patients may perceive as pain, binding, stiffness, instability, and implant loosening and wear.

Secondly, kinematically aligned TKA strives to restore the native or ‘constitutional’ alignment of the knee and limb (Figure B). Restoring mechanical alignment in patients with constitutional varus and valgus alignment is unnatural, and causes strain deviations in the medial and lateral collateral ligaments that are greater than that of the native knee. There are benefits to restoring the native alignment, as patients with pre-operative varus had better clinical and functional outcome scores and the same implant survivorship at 7 years when the limb alignment was left in mild varus, as compared with patients in which the limb alignment was corrected to neutral.

Thirdly, kinematically aligned TKA strives to restore the native laxities of the knee, which are markedly different at 0 and 90 degrees of flexion (Figure C). At 0 degrees of flexion the native tibia-femoral joint essentially behaves as a rigid body because the average
varus (0.70), valgus (0.50), internal (4.60), and external (4.40) rotations of the tibia on the femur are nearly negligible \(^7,23\). At 90\(^\circ\) of flexion, the mean laxity was reported to be fivefold greater in varus (3.10) rotation, fourfold greater in distraction, threefold greater in valgus (1.40), internal (14.60), and external (14.70) rotations, and twofold greater in anterior translation than at 0\(^\circ\) of flexion. Hence, kinematically aligned TKA does not strive to gap-balance the laxities equally at 0\(^\circ\) and 90\(^\circ\) of flexion. Over-tightening the soft tissues of the TKA relative to normal laxities at 90\(^\circ\) of flexion may lead to pain, stiffness, and limited flexion \(^23\).

The following techniques were developed to kinematically align the femoral and tibial components and restore the tibial-femoral articular surface, alignments, and laxities of the native knee \(^13,15\).

The femoral component is kinematically aligned with use of a distal and a posterior femoral referencing guide placed sequentially at 0 degrees and 90 degrees of flexion, respectively. When treating an osteoarthritic varus knee, a distal referencing guide is selected that compensates for 2 mm of wear on the distal medial femoral condyle and no wear on the distal lateral femoral condyle. When treating an osteoarthritic valgus, a distal referencing guide is selected that compensates for 2 mm of wear on the distal lateral femoral condyle and no wear on the distal medial femoral condyle. A comprehensive analysis of magnetic resonance scans of end-stage osteoarthritic knees treated with kinematically aligned TKA have shown that wear is rare at 90 degrees of flexion in the varus and valgus osteoarthritic knee, a posterior referencing guide is selected without use of a compensation adjustment and set at 0 degrees of rotation \(^15,19\). A caliper is used to measure the thickness of the distal and posterior femoral resections, and when the thicknesses equals the thickness of the condyles of the femoral component after compensating for wear and kerf the femoral component is kinematically aligned. Consequently, kinematic alignment of the femoral component does not reference the femoral mechanical axis, intramedullary canal, transepicondylar axis, or anterior-posterior axis of the trochlea (Whiteside's Line) \(^5,6,8\).

The tibial component is kinematically aligned when the position of the component matches the native internal-external, flexion-extension, and varus-valgus positions of the proximal tibial articular surface \(^15,21\). The internal-external rotation of the tibial component is set by drawing the major axis of the elliptical-shaped boundary of the articular surface of the lateral tibial condyle. A guide is used to drill two pins parallel to the major axis through the articular surface of the tibia. A conventional extra-medullary tibial resection guide is applied to the ankle. The varus-valgus position of the tibial component is set by laterally translating the slider at the ankle of the guide until the saw slot is parallel to the proximal tibial articular surface after compensating for cartilage and bone wear. The proximal-distal position of the tibial component is set by adjusting the thickness of the tibial resection to accommodate a 10-11 mm thick tibial component \(^15\). The flexion-extension position is set by adjusting the slope of an angel wing placed in the saw slot of the guide until parallel to the slope of the proximal medial tibia. The internal-external position of the anterior-posterior axis of the tibial component is set parallel to the two pin holes drilled in the medial tibia. The native laxities and alignment of the knee and limb are restored at 0 degrees of flexion by removing all
osteophytes and adjusting the varus-valgus angle and the thickness of the tibial component until the varus-valgus laxity is negligible without ligament release. The native laxities are restored at 90 degrees of flexion by adjusting the anterior-posterior slope and thickness of the tibial component until the normal anterior offset of the anterior tibia from the distal medial femoral condyle matches the knee at the time of exposure and the internal and external rotation of the tibia approximates 14 degrees (Figure D) 15,21. Consequently, kinematic alignment of the tibial component does not need to reference the tibial mechanical axis, intramedullary canal, or posterior condylar axis 8,10,15,21.

There has been a misconception that kinematic alignment places the limb, knee, and tibial component in a degree of varus that might lead to early catastrophic implant failure 17. A multicenter study reported that TKAs performed to restore the mechanical axis with patient-specific or conventional instrumentation actually aligned the limbs and knees in significantly more varus angulation than TKAs performed to restore the kinematic axes 22. A ten-year follow-up study of mechanically aligned TKAs with a one degree greater average varus angulation of the tibial component of 3 ± 3 degrees reported an acceptable implant survivorship of 96 per cent 4,18. This acceptable ten-year implant survivorship is consistent with three- and six-year follow-up studies of kinematically aligned TKA that showed a 0% and 0.5% incidence of catastrophic failure and restoration of high function as measured by Oxford Knee and WOMAC scores regardless of the alignment category. Interestingly, this excellent scores were achieved even though 75% and 80% of tibial components, 33% and 31% of knees, and 6% and 7% of limbs were categorized as varus outliers, respectively 12,14. Collectively these studies suggest that the concern that kinematic alignment compromises function and places the components at a high risk for early catastrophic failure is unfounded and should be of interest to those surgeons that desire better function for their patients and are committed to cutting the tibia perpendicular to the mechanical axis of the tibia 12.

References


The composite shows a right femur and a kinematically aligned TKA and the three kinematic axes. The green line represents the flexion axis of the tibia, the magenta line represents the flexion axis of the patella, and the yellow line represents the longitudinal rotational axis of the tibia. All three axes are either parallel or perpendicular to the joint lines of the native knee and the TKA. Compensating for wear and kerf and resecting bone from the distal and posterior femur condyles equal in thickness to the condyles of the femoral component kinematically-aligns the femoral component.

The composite shows an anterior-posterior computer tomographic scanogram of a kinematically aligned right TKA (A) and a mechanically aligned right TKA (B). The kinematically aligned TKA restored the native tibial-femoral joint surface (blue line) and limb (white line) and co-aligned the flexion axes of the tibia and patella of the femoral component with the femurs. The mechanically aligned TKA changed the native tibial-femoral joint surface (red line) and the native limb and knee alignment and mal-aligned the flexion axes of the tibia and patella of the femoral component with the femurs.
The composite shows column graphs of the varus (+), valgus (-), internal (+), and external (-) rotational laxities of the native knee at 0° and 90° of flexion (A and B) and the native gaps of the knee at 0 and 90 degrees of flexion after making resections parallel to the native joint line with use of the kinematic alignment technique (C). The native gap at 0 degrees has a symmetric shape, whereas the native gap at 90 degrees has an asymmetric shape (C). The gap at 90 degrees has greater laxity laterally than medially, and the gap at 90 degrees greater laxity lateral and medial than at 0 degrees of flexion. Those paired columns connected by a p-value less than 0.05 indicate the laxity at 90 degrees is greater than at 0 degrees of flexion. Error bars show ±1 standard deviation.

Flowchart shows the algorithm or decision tree for balancing the knee with a kinematically aligned femoral component. The predicate step is kinematic alignment of the femoral component, which is confirmed when the thicknesses of the distal and posterior bone resections equal the thicknesses of the condyles of the femoral component. Any balancing is performed by adjustment of the proximal-distal, varus-valgus, and anterior-posterior slope of the tibial component by fine-tuning the resection of the tibia.