■ ANNOTATION

Alignment in total knee arthroplasty

WHAT'S IN A NAME?

S. Oussedik,
M. P. Abdel,
J. Victor,
M. W. Pagnano,
F. S. Haddad

From University College London Hospitals NHS Trust

Dissatisfaction following total knee arthroplasty is a well-documented phenomenon. Although many factors have been implicated, including modifiable and nonmodifiable patient factors, emphasis over the past decade has been on implant alignment and stability as both a cause of, and a solution to, this problem. Several alignment targets have evolved with a proliferation of techniques following the introduction of computer and robotic-assisted surgery. Mechanical alignment targets may achieve mechanically-sound alignment while ignoring the soft tissue envelope; kinematic alignment respects the soft tissue envelope while ignoring the mechanical environment. Functional alignment is proposed as a hybrid technique to allow mechanically-sound, soft tissue-friendly alignment targets to be identified and achieved.

Cite this article: *Bone Joint J* 2020;102-B(3):276–279.

Introduction

Dissatisfaction following total knee arthroplasty (TKA) is a well-documented phenomenon.[1] Although many factors have been implicated, including modifiable and nonmodifiable patient factors, emphasis over the past decade has been on implant alignment and stability as both a cause of, and a solution to, this problem.[2] Pioneers of TKA placed much importance on achieving neutral mechanical alignment of the prosthetic joint by implanting both femoral and tibial components perpendicular to the mechanical axis of the limb. This allowed the bone-prosthesis interface to have reduced exposure to sheer and bending forces, thus improving the longevity of the construct.[3] However, this approach ignored the anatomy of the native joint and the relationship between the origin and insertion of the soft tissues that cross the joint. Significant mismatches can occur due to the normal anatomical variation in native joint anatomy. This translates into increased reliance on soft tissue release to achieve a well-balanced joint.

The clash between prosthetic and native joint kinematics has been blamed for persistent pain, stiffness, instability, and dissatisfaction following TKA.[4] Thus, alternative targets for implantation have been sought in order to provide a more soft tissue-friendly TKA. Several such techniques have been described, prompting the need for some standardization in the language used to describe them.

The native knee. The native knee has been shown to possess an oblique joint line in the coronal plane in bipedal stance that is parallel to the floor during walking or running.[5] As the centre of mass shifts laterally during single leg stance, the hip adducts and the joint line becomes more horizontal.[6] This coronal relationship between distal femur and proximal tibia is achieved by having a slight valgus alignment of the distal femur (0° to 4°) and a slight varus alignment of the proximal tibia (1° to 5°).[7,8] The resultant limb alignment is on average in slight varus, although there is considerable variation both within and between population groups.[9]

The effect of sagittal alignment in the native joint on TKA is less well understood and less well characterized. The proximal tibia tends to have a posterior slope (1° to 9°),[10] while distal femoral sagittal alignment usually lies between 0° and 3° of flexion.[11] In addition, the mechanical axis in the sagittal plane is variable as the tibiofemoral contact is influenced by a complex kinematic pattern during flexion. Changes in tibial slope affect anteroposterior stability in the knee, especially in the absence of the cruciate ligaments.

Attempts to identify the best axial targets for TKA have used several methods to locate the flexion axis of the knee. This lies within the distal femur and, when considered in the axial plane alone, is closely approximated to the surgical transepicondylar axis (sTEA), a line connecting the sulcus of the medial epicondyle to the apex of the lateral epicondyle.[8,12]

Tibial axial alignment has been shown to play less of a role in the success of TKA. The optimal rotation is not universally accepted, but lies somewhere close to a line connecting the fossa of the posterior cruciate ligament to the junction of the medial third and lateral two-thirds of the tibial tubercle.[13]

Mechanical alignment. Mechanical alignment can be defined as implanting both tibial and femoral components perpendicular to the limb's mechanical axis, thus achieving a neutral overall

Correspondence should be sent to S. Oussedik; email: sam.oussedik@gmail.com

doi:10.1302/0301-620X.102B3.BJJ-2019-1729 $2.00

Bone Joint J 2020;102-B(3):276–279.

Table I. Alignment targets in degrees (range) for different strategies in total knee arthroplasty. Coronal values shown as 90° mechanical lateral distal femoral angle for femur; 90° medial proximal tibial angle for tibia. Kinematic alignment: all resections measured from the joint surface compensating for wear and therefore vary between patients; values shown drawn from published achieved ranges.[13]

Alignment	Native[6,8,9]		Mechanical		Kinematic[13]		Functional	
	Femur	**Tibia**	**Femur**	**Tibia**	**Femur**	**Tibia**	**Femur**	**Tibia**
Coronal	+2 (± 2)	-3 (± 2)	0	0	-3 to + 3	-6 to + 9	0 (± 3)	0 (± 3)
Sagittal	2 ± 3	7 (± 3)	0 to 5	0 to 3	2 ± 3	7 (± 3)	0 to 5	0 to 3
Axial	sTEA	PCL - med1/3-lat2/3 PT	PCA - 3	PCL - med1/3-lat2/3 PT	PCA	Perpendicular to a line connecting the centre of each condyle	sTEA ± 3	PCL - med1/3-lat2/3 PT
HKA	-1.3 (± 2.5)	-1.3 (± 2.5)	0	0	N/A	N/A	0 (± 3)	0 (± 3)

sTEA, surgical transepiconylar axis; PCL, posterior cruciate ligament; PCA, posterior condylar axis; HKA, hip-knee angle; N/A, not applicable.

alignment. The coronal targets are achieved by referencing the bone resections to the femoral and tibial anatomical axes and by inference, their mechanical axes. Sagittal targets are dictated by the patient's anatomy and vary with implant design and the level of constraint used. Femoral rotational targets can be defined by reference to the flexion gap (gap-balancing technique) or femoral anatomy (measured resection).

Considering a varus knee, the positioning of a typical component will remove more bone from the lateral tibia than the medial tibia, more bone from the distal medial femoral condyle (MFC) than lateral femoral condyle (LFC), and more bone from the posterior MFC than the posterior LFC. This results in a horizontal joint line; medial collateral ligament (MCL) tightness in flexion and extension usually requiring release in the patient with constitutional varus; and lateral collateral ligament (LCL) tightness in flexion usually accommodated by natural or acquired LCL laxity.

Table I summarizes alignment targets for different strategies.

Anatomical alignment. Hungerford and Krackow[14] first described this method of recreating the oblique joint line seen in native knees by altering the surgical target in the coronal plane. By a process of measured resection, the native femoral anatomy could be recreated. By introducing a fixed 3° of femoral valgus and 3° of tibial varus, the need to externally rotate the femoral component to balance the flexion gap was obviated. Thus, the femoral component was aligned to the posterior condylar axis (PCA). The concept was criticized on the basis of the technical difficulties in performing the varus cut on the tibia in a precise and reproducible way, and for that reason it was largely abandoned. This concept can be viewed as a precursor to kinematic alignment.

Kinematic alignment. First coined by Howell et al,[4] this technique seeks to recreate the anatomy of the native knee. This was first achieved using proprietary cutting blocks, designed on the basis of an MRI of the patient's knee. A software package was used to recreate the predisease tibiofemoral relationships by compensating for cartilage wear, and a cutting block was designed to enable the surgeon to recreate this anatomy when implanting the components.[15] Subsequently, the technique has evolved to allow targets to be identified intraoperatively.[16] The surgeon carries out symmetrical resections of the medial and lateral femoral condyles, and medial and lateral tibial plateaus, having compensated for wear. The tibial slope is matched to the patient's native slope. The axial rotation of the femur is set according to the PCA, having compensated for wear. Axial rotation of the tibia is set perpendicular to a line drawn from the centre of the medial and lateral tibial plateaus. In this manner, minimal soft tissue releases are required. However, the coronal position ignores overall limb alignment, potentially exposing patients with substantial deformities to the risk of alignment-related early failure, although this was not shown in recent studies of component migration and load distribution.[17,18]

Functional alignment. The technique of achieving 'functional alignment' in TKA[19] has evolved using advanced surgical aids. With the use of computer navigation and robotic-assisted TKA, resection thickness, joint gaps, and limb alignment can be assessed during surgery. The additional precision offered by these techniques means that non-neutral limb alignment targets can achieve more reproducibly,[20] reducing the risk of missing the target and producing significant alignment outliers.

This technique has elements of both measured resection and gap-balancing techniques. The limb alignment is assessed intraoperatively once osteophytes have been removed, allowing coronal correction to be carried out through a manually-applied varus or valgus force to correct the deformity. This allows the software to generate the size of the potential gaps, both in extension and in 90° of flexion.

With a traditional gap-balancing technique, the tibia would be cut at 90° to the tibial axis and the femur at 90° to the femoral axis in the coronal plane. Gaps could then be assessed to allow soft tissue release, balancing the knee in extension and flexion. With functional alignment, the gaps can be balanced by changing the implant targets in all three planes. Thus, a smaller medial extension gap can be balanced by placing the tibial component in up to 3° of varus. A tighter lateral flexion gap can be balanced by internally rotating the femoral component. These targets are individualized to the patient's knee and gaps. They can be kept within currently accepted safe limits and allow the overall limb alignment to be kept within the 0° ± 3° safe zone of coronal alignment. These limits may evolve with further study.

Valgus correction can be applied to the distal femoral resection and varus correction to the tibial resection. In such a manner, the obliquity of the joint line is restored. By avoiding over-resection of the distal femur, the height of the joint line is maintained, avoiding the potentially difficult problem of mid-flexion instability associated with raising the joint line.[21] By the same token, avoidance of under-resection of the distal femur avoids attempts to compensate for a tight extension gap by using a thinner polyethylene insert, thereby inducing flexion instability.

This description emphasizes the coronal plane, but the goal of functional alignment is to position the components in the position that least compromises the soft tissue envelope of the knee, and hence to restore the plane and obliquity of the joint to that which the soft tissues dictate. If there are fixed deformities, ligament release may be required to balance the gaps, although the extent and frequency of such releases is smaller when compared with the standard mechanical alignment technique.

Other alignment targets. With the proliferation of technological aids, the number of techniques by which a well-balanced TKA can be achieved have multiplied. It is now possible to balance the knee more precisely and accurately by maintaining the tibial cut at 90° and modifying the position of femoral component alone. Such 'reverse kinematic' is espoused by some surgeons but poorly described in the literature, although changes in alignment of the tibial component have been associated with more detrimental effects compared with changes in alignment of the femoral component.[22]

Modified mechanical alignment has been suggested as a safer way to achieve non-neutral mechanical alignment. The coronal targets are occasionally modified to under-correct the deformity, preserving some varus in the tibial cut for varus knees or performing a valgus femoral cut in valgus knees. This also allows fewer and less extensive soft tissue releases to be performed, reducing postoperative morbidity.[23]

Discussion

When considering the optimal targets for implanting a modern, condylar TKA, two competing paradigms can be distinguished. The first, epitomized by neutral mechanical alignment, considers the relationship between the prosthesis and the mechanical axis of the limb to be of paramount importance. The second, perhaps best illustrated by kinematic alignment, emphasizes the relationship between the prosthesis and the soft tissue envelope.

What is clear is that paying attention to the mechanical alignment without performing the correct sequence of soft tissue releases to allow the soft tissue envelope to adapt to the kinematics of the TKA will not provide a well-balanced knee. Instability remains a major source of dissatisfaction after TKA and should not be taken lightly. As stabilizing structures, such as the menisci and anterior cruciate ligament are removed during TKA, stability will rely on the conformity of the components and the tension of the ligaments. Within this framework, the physiological tension of the MCL is paramount as tension which is too tight or too lose inevitably leads to problems.

Similarly, over-reliance on the diseased joint surfaces to guide bone resections can result in prosthetic and limb alignment that fall outside the purported safe range, and this may prejudice longevity.

These limitations suggest that a hybrid model, providing a balanced knee that remains within safe limits of limb alignment, may be a promising compromise, allowing patients to achieve improved satisfaction without prejudicing longevity. Functional alignment may represent this safe compromise target for implantation, but longer-term studies are required to confirm this and allow its widespread adoption. Reliance on expensive technological aids may also hinder its spread. In the absence of such methods of providing dynamic, real-time assessment of resection and limb alignment, it may be advisable to restrict alignment targets to those suggested by the mechanical alignment technique, emphasizing the importance of correct and adequate soft tissue release and balance.

Take home message

- The postoperative alignment of total knee arthroplasty has been implicated as both a reason for, and a solution to, postoperative dissatisfaction.
- Respecting the soft tissue envelope while achieving mechanically-sound prosthetic alignment is a promising way of improving outcomes following total knee arthroplasty.
- Functional alignment is proposed as a new method for determining alignment targets intra-operatively.

References

1. **Nam D**, **Nunley RM**, **Barrack RL**. Patient dissatisfaction following total knee replacement: a growing concern? *Bone Joint J.* 2014;96-B(11 Suppl A):96–100.
2. **Allen MM**, **Pagnano MW**. Neutral mechanical alignment: is it necessary? *Bone Joint J.* 2016;98-B(1 Suppl A):81–83.
3. **Insall J**, **Scott WN**, **Ranawat CS**. The total condylar knee prosthesis. A report of two hundred and twenty cases. *J Bone Joint Surg Am.* 1979;61(2):173–180.
4. **Howell SM**, **Howell SJ**, **Kuznik KT**, **Cohen J**, **Hull ML**. Does a kinematically aligned total knee arthroplasty restore function without failure regardless of alignment category? *Clin Orthop Relat Res.* 2013;471(3):1000–1007.
5. **Victor JMK**, **Bassens D**, **Bellemans J**, **et al**. Constitutional varus does not affect joint line orientation in the coronal plane. *Clin Orthop Relat Res.* 2014;472(1):98–104.
6. **Niki Y**, **Nagura T**, **Nagai K**, **Kobayashi S**, **Harato K**. Kinematically aligned total knee arthroplasty reduces knee adduction moment more than mechanically aligned total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(6):1629–1635.
7. **Bellemans J**, **Colyn W**, **Vandenneucker H**, **Victor J**. The Chitranjan Ranawat Award: is neutral mechanical alignment normal for all patients? the concept of constitutional varus. *Clin Orthop Relat Res.* 2012;470(1):45–53.
8. **Victor J**, **Van Doninck D**, **Labey L**, **et al**. A common reference frame for describing rotation of the distal femur: a CT-based kinematic study using cadavers. *J Bone Joint Surg Br.* 2009;91-B(5):683–690.
9. **Harvey WF**, **Niu J**, **Zhang Y**, **et al**. Knee alignment differences between Chinese and Caucasian subjects without osteoarthritis. *Ann Rheum Dis.* 2008;67(11):1524–1528.
10. **Nunley RM**, **Nam D**, **Johnson SR**, **Barnes CL**. Extreme variability in posterior slope of the proximal tibia: measurements on 2395 CT scans of patients undergoing UKA? *J Arthroplasty.* 2014;29(8):1677–1680.
11. **Hood B**, **Blum L**, **Holcombe SA**, **et al**. Variation in optimal sagittal alignment of the femoral component in total knee arthroplasty. *Orthopedics.* 2017;40(2):102–106.
12. **Oussedik S**, **Scholes C**, **Ferguson D**, **Roe J**, **Parker D**. Is femoral component rotation in a TKA reliably guided by the functional flexion axis? *Clin Orthop Relat Res.* 2012;470(11):3227–3232.
13. **Saffarini M**, **Nover L**, **Tandogan R**, **et al**. The original Akagi line is the most reliable: a systematic review of landmarks for rotational alignment of the tibial component in TKA. *Knee Surg Sports Traumatol Arthrosc.* 2019;27(4):1018–1027.
14. **Hungerford DS**, **Krackow KA**. Total joint arthroplasty of the knee. *Clin Orthop Relat Res.* 1985;192:23–33.
15. **Klatt BA**, **Goyal N**, **Austin MS**, **Hozack WJ**. Custom-fit total knee arthroplasty (OtisKnee) results in malalignment. *J Arthroplasty.* 2008;23(1):26–29.
16. **Howell SM**, **Papadopoulos S**, **Kuznik KT**, **Hull ML**. Accurate alignment and high function after kinematically aligned TKA performed with generic instruments. *Knee Surg Sports Traumatol Arthrosc.* 2013;21(10):2271–2280.
17. **Laende EK**, **Richardson CG**, **Dunbar MJ**. A randomized controlled trial of tibial component migration with kinematic alignment using patient-specific instrumentation versus mechanical alignment using computer-assisted surgery in total knee arthroplasty. *Bone Joint J.* 2019;101-B(8):929–940.
18. **Shelton TJ**, **Nedopil AJ**, **Howell SM**, **Hull ML**. Do varus or valgus outliers have higher forces in the medial or lateral compartments than those which are in-range after a kinematically aligned total knee arthroplasty? limb and joint line

alignment after kinematically aligned total knee arthroplasty. *Bone Joint J*. 2017;99-B(10):1319–1328.

19. **Kayani B**, **Konan S**, **Tahmassebi J**, **et al**. A prospective double-blinded randomised control trial comparing robotic-arm assisted functionally aligned total knee arthroplasty versus robotic-arm assisted mechanically-aligned total knee arthroplasty. *Trials*. 2020:In press.
20. **Kayani B**, **Konan S**, **Pietrzak JRT**, **et al**. The learning curve associated with robotic-arm assisted unicompartmental knee arthroplasty: a prospective cohort study. *Bone Joint J*. 2018;100-B(8):1033–1042.
21. **Luyckx T**, **Vandenneucker H**, **Ing LS**, **et al**. Raising the joint line in TKA is associated with Mid-flexion laxity: a study in cadaver knees. *Clin Orthop Relat Res*. 2018;476(3):601–611.
22. **Innocenti B**, **Bellemans J**, **Catani F**. Deviations from optimal alignment in TKA: is there a biomechanical difference between femoral or tibial component alignment? *J Arthroplasty*. 2016;31(1):295–301.
23. **Vanlommel L**, **Vanlommel J**, **Claes S**, **Bellemans J**. Slight undercorrection following total knee arthroplasty results in superior clinical outcomes in varus knees. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(10):2325–2330.

Author information:
S. Oussedik, BSc, MBBS, FRCS(Tr&Orth), Consultant Orthopaedic Surgeon and Clinical Director, University College London Hospitals NHS Foundation Trust, London, UK.

M. P. Abdel, MD, PhD, Professor of Orthopedic Surgery and Orthopedic Surgeon
M. W. Pagnano, MD, Professor of Orthopedic Surgery and Orthopedic Surgeon
Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota, USA.

J. Victor, MD, PhD, Professor of Orthopaedic Surgery, Department of Orthopaedics and Traumatology, Ghent University Hospital, Ghent, Belgium.

F. S. Haddad, BSc MD (Res), FRCS (Tr&Orth), Professor of Orthopaedic Surgery, University College London Hospitals, The Princess Grace Hospital, and The NIHR Biomedical Research Centre at UCLH, London, UK.

Funding statement:
Although none of the authors has received or will receive benefits for personal or professional use from a commercial party related directly or indirectly to the subject of this article, benefits have been or will be received but will be directed solely to a research fund, foundation, educational institution, or other non-profit organization with which one or more of the authors are associated.

ICMJE COI statement
M. P. Abdel reports consultancy fees and royalties paid by Stryker, and grants/grants pending by the US National Institutes of Health, unrelated to this article. J. Victor reports patents and royalties paid by Smith & Nephew, also unrelated to this article.

This article was primary edited by J. Scott.