MENTORS IN ORTHOPEDICS

INVERSE KINEMATIC ALIGNMENT FOR TOTAL KNEE ARTHROPLASTY: A NEW CONCEPT FOR PERSONALIZED ALIGNMENT

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SUMMARY

Background: Total knee arthroplasty (TKA) aims for optimal patient satisfaction, yet outcomes remain inconsistent despite advancements in implant design. Traditional mechanical and anatomical alignment strategies have dominated clinical practice for decades but may not account for individual morphological variations.

Objective: This article reviews contemporary alignment philosophies in TKA, with a specific focus on the methodology, surgical principles, and clinical outcomes associated with inverse kinematic alignment (iKA).

Key Points: Mechanical alignment (MA) utilizes perpendicular resections to the mechanical axes to achieve a neutral hip-knee-ankle (HKA) angle, often necessitating soft tissue releases. Kinematic alignment (KA) seeks to restore native anatomy through bone resurfacing, though restricted KA (rKA) is often employed to avoid extreme component orientations. Inverse kinematic alignment (iKA) prioritizes the restoration of native tibial joint line obliquity, targeting a medial proximal tibia angle (MPTA) between 84° and 92°. Subsequent femoral resections are performed using gap-balancing techniques to achieve ligamentous stability without soft tissue release. Postoperative HKA is maintained within 6° varus and 3° valgus. Clinical evidence indicates that iKA achieves higher patient satisfaction and superior Oxford Knee Score (OKS) thresholds compared to MA at 12-month follow-up. Successful implementation requires a far-medial subvastus approach to preserve the soft tissue envelope and an accurate assessment of rotatory stability.

Conclusion: Transitioning from systematic to patient-specific alignment strategies like iKA allows for the preservation of native joint kinematics and soft tissue integrity. Precise execution of these techniques, supported by a thorough understanding of knee anatomy, may enhance functional outcomes and patient-reported success in TKA.

KEYWORDS

Arthroplasty, Replacement, Knee; Bone Malalignment; Knee Joint; Biomechanical Phenomena; Patient Satisfaction

INTRODUCTION

Achieving optimal patient satisfaction with total knee arthroplasty (TKA) is the goal for knee replacement surgeons. Over the past four decades, better implant designs, enhanced surgical techniques, and optimized perioperative patient management were installed. However, patient satisfaction after TKA is still in need for improvement. In this perspective, the positioning or alignment of the implant components could further enhance functional outcomes. The two classical concepts of mechanical and anatomical alignment have been used for the last 40 years with no changes. To further improve patient's outcome several new alignment philosophies had been proposed during the last decade.

1. Mechanical alignment (MA)

Described by Insall et al [20] (Figure 1) has the advantage of simplicity. In the coronal plane, perpendicular cuts are made to the tibial and femoral mechanical axes. The aim postoperatively is a straight leg (HKA 180°). Yet, MA does not consider the variability of existing morphotypes and requires soft tissue release to balance the ligament balance. It does not restore the natural varus joint line obliquity. These elements possibly contribute to the imperfect functional results [21],[36].

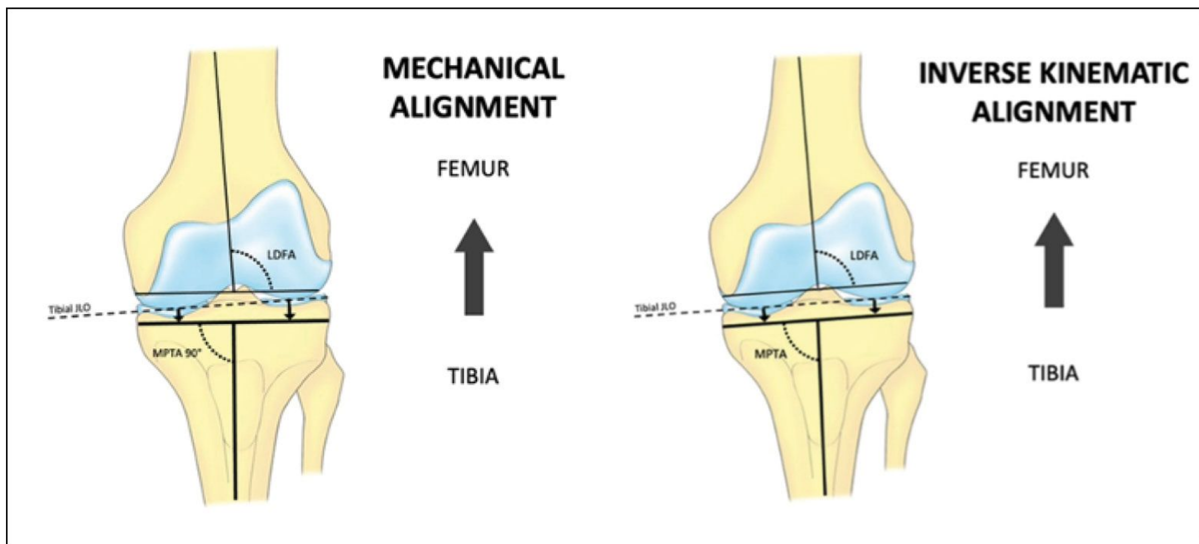

Figure 1: Alignment concepts Left: mechanical alignment (MA). Right inverse kinematic alignment (iKA).

2. Anatomical Alignment (AA)

has been proposed by Hungerford and Krackow in the late 80'ies. With AA, a systematic 3° varus joint line obliquity is created in every knee while targeting the postoperative HKA still at 180° [19]. Inconsistent functional, mainly due to the type of implant, and the lack of precision in the surgical technique have undermined this concept. They can however be considered as the precursors of kinematic alignment [21].

3. Kinematic Alignment (KA)

The individualization of the alignment and the desire to restore each patient's native anatomy is embodied in the philosophy of kinematic alignment (KA) by Howell in 2008. Bone resection, femoral and tibial, corresponds to the

metal thickness of the prosthesis. The femoral anatomy is reconstructed by pure resurfacing (cartilage and bony defects) and the balancing of the knee is achieved by adjusting the tibial resection to the soft tissue frame. The goal is to restore the native joint laxity without performing any soft tissue releases. [36]KA results sometimes in quite extreme implant orientations, therefore a restricted KA protocol had been proposed by Venditolli. This restricted kinematic alignment (rKA) philosophy [35]reduces extreme morphotypes, limb alignments and joint line obliquities by using strict boundaries for the overall alignment, lateral distal femur angle (LDFA) and medial proximal tibia angle (MPTA). The thresholds for these boundaries remain still controversial.

4. Inverse Kinematic Alignment (iKA)

More recently, Winnock de Grave introduced the inverse kinematic alignment (iKA) as new patient specific alignment concept [39]. iKA favors the restoration of tibial joint line obliquity as first step (Figure 1). This is followed by resection of the posterior and distal femur bone by using the gap balancing technique to achieve ligament balance without releasing soft tissues. By resecting equal amounts of bone on the medial and lateral tibial condyle the native tibial joint line obliquity is restored (Figures 2, 3, 4). In iKA also boundaries are set to attenuate extreme morphotypes. When the target zones of iKA, rKA and MA are compared, the iKA target zones matches a higher proportion of native knee alignment, followed by rKA and MA [40]. Analysis of the tibial position in iKA in the coronal plane shows a mean postoperative MPTA of 86,5°, corresponding to the native joint line obliquity [40]. The femoral position with the iKA shows a mean external rotation of 2° relative to the posterior condylar axis (PCA) and 2° varus position according to the native LDFA of 86° [8],[29],[39]. Whereby, when using off the shelf implants, this varus orientation of the trochlear groove leads to an optimal patellofemoral tracking [36]. A clinical study comparing iKA with MA at 12 months follow up shows that higher proportions of iKA knees are satisfied and higher proportion of iKA knees that reach the patient accepted symptom state (PASS) thresholds for the Oxford Knee Score (OKS) [39].

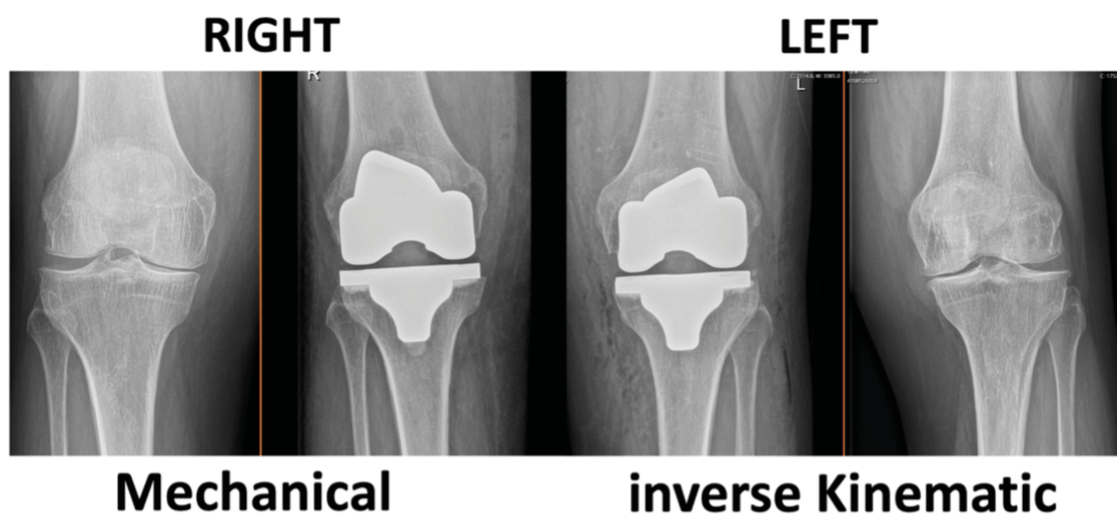

Figure 2: Bilateral TKA. Right knee: Mechanical Alignment (MA). Left knee: inverse Kinematic Alignment (iKA)

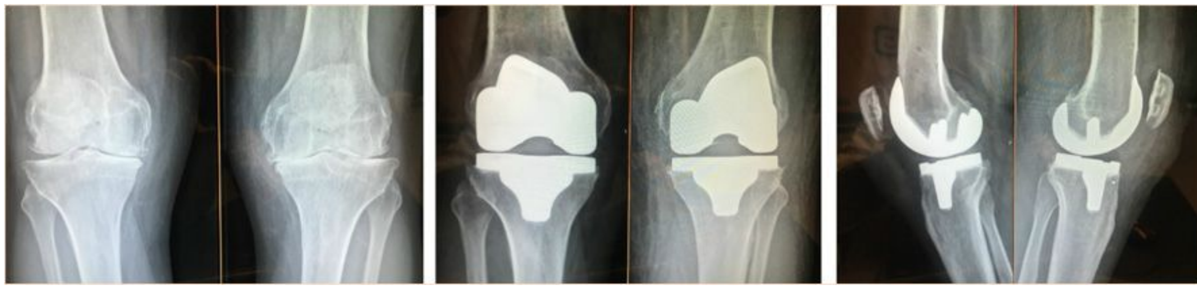

Figure 3: Bilateral TKA with iKA Restoring joint line obliquity with iKA by performing a native tibial resection

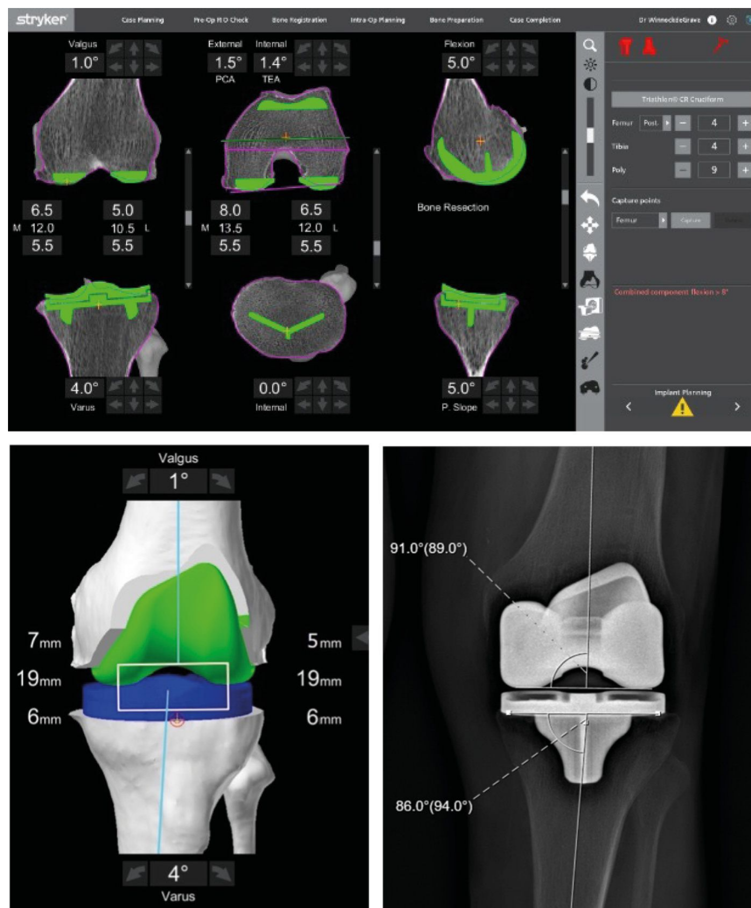

Figure 4: Typical iKA case with robotic system

IKA PRINCIPLES OF IMPLANT POSITIONING AND BALANCING

1. In the coronal plane

With iKA, the aim is to restore the native joint line obliquity (JLO), by restoring the individual MPTA and to restore the native limb alignment (HKA axis). The native MPTA is restored by performing equal bony resections medial and lateral on the tibial plateau. The MPTA is restored within the boundaries of 84° (varus) and 92° (valgus) preventing extreme implant positions. These boundaries represent native tibial alignment in 93% of Caucasian knees. [40] The postoperative coronal limb alignment (HKA) is restored within the boundaries of 6° varus and 3° valgus. Postoperative limb alignment up to 6° varus have shown no deleterious effect on implant survival in long term survival studies. [1],[19],[35] On the femoral side, the femoral component is positioned using the gap

balancing technique to gain a symmetric extension gap. Furthermore the femoral implant restores the native medial joint line height as good as possible which will result in MCL isometry and prevent mid-flexion instability [24].

2. In the sagittal plane

The slope of the tibial resection is performed parallel to the native medial tibial slope, with a maximum of 8° posterior slope [11]. The femoral flexion is set to match the native anatomy, yet it is a compromise between femoral posterior offset, respecting the posterior condyle and avoiding notching the anterior cortex. The adjustment of the femur component size and flexion between 0 and 8° enable us to optimize this positioning in the sagittal plane [42].

3. In the axial plane

The rotation of the femoral component determines the balancing of the flexion gap by using the balanced gap technique. Concerning the medial compartment in flexion, the target is to restore the native joint line level. When the PCL is retained, a slight over resection of the posterior condyles is sometimes necessary to open up the flexion gap and enable the entrance of the minimal insert thickness. This is allowed in iKA, but not in KA. The medial compartment in flexion must be balanced, with a remaining laxity of 1 or 2mm. On the lateral side however, the native laxity is reproduced with a joint opening up to 4 mm according to the native patient's laxity. Rotation of the tibial component is set to Akagi's line [2].

IKA PRINCIPLES FOR SURGICAL APPROACH

When performing iKA or any kind of patient specific alignment, it is key to maintain and respect the patient's unique soft tissue envelope and ligaments. On the contrary, an adequate exposure and access to all corners of the knee is mandatory to properly implant the components.

Generally, during a classic anteromedial approach to the knee (parapatellar, midvastus, subvastus) a quite important medial release is already performed during the approach by releasing the fibers of the deep MCL (meniscotibial band) and peeling off the soft tissues attached to the anteromedial tibia. In our opinion, the best approach to get an adequate access to the joint, without the need of a medial soft tissue release, is the far medial subvastus approach. Exposure is made by a subvastus approach and the medial joint capsule is incised in 2 distinct layers. (Fig 5) The eventual arthrotomy is performed far-medial, just in front of the medial collateral ligament (MCL). When reaching the medial tibia with this vertical arthrotomy (from proximal to distal), the longitudinal capsular incision (vertical) is redirected 90 degrees (horizontal) parallel to the tibial plateau in the anterolateral direction. No soft-tissues are peeled off from the anteromedial tibia [13]

<table>
<tr><td rowspan="9">BALANCING</td><td>TIGHT IN EXTENSION AND FLEXION</td><td>Recut tibia</td></tr>
<tr><td>TIGHT IN EXTENSION</td><td>Recut distal femur
or recut tibia and posteriorize femroal component</td></tr>
<tr><td>TIGHT IN FLEXION</td><td>antriorize femroal component
or recut tibia and distalize femur</td></tr>
<tr><td>LOOSE IN EXTENSION AND FLEXION</td><td>use thicker insert</td></tr>
<tr><td>LOOSE IN EXTENSION</td><td>distalize femoral component</td></tr>
<tr><td>LOOSE IN FLEXION</td><td>postriorize femoral component
or proximalize tibia (or use thicker insert) + recut distal femur</td></tr>
<tr><td>EXTENSION
(tight medial - loose lateral)</td><td>add varus to distal femur</td></tr>
<tr><td>EXTENSION
(tight medial - tight lateral)</td><td>add valgus to distal femur</td></tr>
<tr><td>FLEXION IMBALANCE</td><td>adjust femoral rotation</td></tr>
<tr><td colspan="2">SOFT TISSUE RELEASE (<5%)</td><td>if HKA>6° varus: medial release
if HKA>3° valgus: lateral release</td></tr>
</table>

Table 1: Guidelines for preoperative positioning of implants according iKA principles

<table>
<tr><td rowspan="4">ALIGNEMENT</td><td rowspan="2">TIBIA</td><td>CORONAL varus/valgus</td><td>• parallel to the native joint line
• equal bone resections, taking into account bony wear when present</td></tr>
<tr><td>SAGITAL Slope</td><td>• parapllel to native slope of medial tibial plateau in cruciate retaining design
• reduced slope in cruciate sacrficing designs</td></tr>
<tr><td rowspan="2">FEMUR</td><td>CORONAL varus/valgus (extension gap)</td><td>• parallel to tibial resection with soft tissue envelope tensioned in extension
• equel gaps medial and lateral in extension
• medial distal resection according to implant thickness</td></tr>
<tr><td>AXIAL rotation (flexion gap)</td><td>• parallel to tibai resection with soft tissue envelope tensioned in flexion (90°)
• equal gaps medial and lateral in flexion or slighty more loose lateral gap
• medial posterior resection according implant thickness</td></tr>
</table>

Table 2: Guidelines for balancing during TKA surgery according iKA principles

CONCLUSION

Rotatory instabilities are more difficult to assess and interpret. Their diagnosis requires an examiner to be skilled, systematic and detailed in his physical examination. Accurate diagnosis is the stepping stone on which pillars of successful treatment are built. It is of outmost importance to understand the contribution of anatomic structures to the stability of the knee. By being thorough in the anatomy of the knee esp the posteromedial and the posterolateral corner of the knee and taking into consideration the function of these structures an orthopedic surgeons ability to clinically diagnose patterns of knee injuries and various types of knee instabilities can be greatly enhanced.

REFERENCES

1. Abdel M, Ollivier M, Parratte S, Trousdale R, Berry D, Pagnano M. Effect of post-operative mechanical axis alignment on survival and functional outcomes of modern

2. Akagi M, Oh M, Nonaka T, et al. An anteroposterior axis of the tibia for total knee arthroplasty. Clin Orthop. 2004:213–219.

3. Almaawi AM, Hutt JRB, Masse V, Lavigne M, Vendittoli PA. The impact of mechanical and restricted kinematic alignment on knee ana- tomy in total knee arthroplasty. J Arthroplasty 2017;32:2133–40, http://dx.doi.org/10.1016/j.arth.2017.02.028 [Epub 2017 Feb 20. PMID: 28302462].

4. Begum FA, Kayani B, Magan AA, Chang JS, Haddad FS. Current concepts in total knee arthroplasty. Bone Jt Open. 2021; 2: 397-404 https://doi.org/10.1302/2633-1462.26.BJO-2020-0162.R1

5. Blakeney WG, Vendittoli PA. Restricted kinematic alignment: the ideal com- promise? 2020 Jul 1. In: Rivière C, Vendittoli PA, editors. Personalized Hip and Knee Joint Replacement [Internet]. Cham (CH): Springer; 2020 [Chapter 17. PMID: 33347126].

6. Calliess T, Ettinger M. Limits of kinematic alignment and recom- mendations for its safe application. Orthopade 2020;49:617–24, http://dx.doi.org/10.1007/s00132-020-03931-7 [PMID: 32494904].

7. Calliess T, Ettinger M, Savov P, Karkosch P, Windhagen H. Individualized align- ment in total knee arthroplasty using image-based robotic assistance: Video article. Orthopade 2018;47(10):871–9.

8. Chao TW, Geraghty L, Dimitriou P, Talbot S. Averaging rotational landmarks during total knee arthroplasty reduces component malro- tation caused by femoral asymmetry. J Orthop Surg Res 2017;12:74, http://dx.doi.org/10.1186/s13018-017-0575-2 [PMID: 28499396; PMCID: PMC5429545].

9. Dong Oh Ko, Song Lee, Jin Hak Kim, Il Chan Hwang, Sung Jun Jang, Jin Jung. The Influence of Femoral Internal Rotation on Patellar Tracking in Total Knee Arthroplasty Using Gap Technique. Clin in Orthop Surg 2021;13:352-357. https://doi.org/10.4055/cios20168

10. Dossett HG, Estrada NA, Swartz GJ, LeFevre GW, Kwasman BG. A ran- domised controlled trial of kinematically and mechanically aligned total knee replacements: two-year clinical results. Bone Joint J 2014;96-B:907–13, http://dx.doi.org/10.1302/0301-620X.96B7.32812.

11. Farooq H, Deckard ER, Carlson J, Ghattas N, Meneghini RM, Coronal and Sagittal Component Position in Contemporary TKA: Targeting Native Alignment Optimizes Clinical Outcomes, J Arthroplasty (2023), https://doi.org/10.1016/j.arth.2023.04.040.

12. Gao ZX, Long NJ, Zhang SY, Yu W, Dai YX, Xiao C. Comparison of kinematic ali- gnment and mechanical alignment in total knee arthroplasty: a meta-analysis of randomized controlled clinical trials. Orthop Surg 2020;12:1567–78, http://dx.doi.org/10.1111/os.12826 [Epub 2020 Oct 25. PMID: 33099892; PMCID: PMC7767667].

13. Ghijselings I. 13th International Conference on Arthroplasty, Paris, France; February 21-22, 2020. https://arthroplasty.cmesociety.com/2020/abstract/the-eeklo-modified-subvastus-approach-for-total-knee-arthroplasty

14. Gillespie D, Mandziak D, Howie C (2015) Influence of posterior lateral femoral condyle geometry on patellar dislocation. Arch Orthop Trauma Surg 135(11):1503–1509

15. Graichen H, Lekkreusuwan K, Eller K. Graus T, Hirschmann MT, Scior W. A single type of varus knee does not exist: morphotyping and gap analysis in varus OA. Knee Surgery, Sports Traumatology, Arthroscopy. https://doi.org/10.1007/00167-021-06688-4

16. Hayasaka S, Newman C, Walter WL, Talbot S. Coronal tibial alignment is linked to femoral rotational asymmetry: Implications for total knee arthroplasty surgery. Knee 2019;26:435–43, http://dx.doi.org/10.1016/j.knee.2019.01.008 [Epub 2019 Feb 10. PMID:30745220].

17. Hirschmann MT, Moser LB, Amsler F, Behrend H, Leclerq V, Hess S (2019) Functional knee phenotypes: a novel classification 79 for phenotyping the coronal lower limb alignment based on the native alignment in young non-osteoarthritic patients. Knee Surg Sports Traumatol Arthrosc 27(5):1394–1402

18. Howell S, Shelton T, Hull M. Implant survival and function ten years after kine- matically aligned total knee arthroplasty. J Arthroplasty 2018;33:3678–84.

19. Hungerford DS, Krackow KA.Total joint arthroplasty of the knee. Clin Orthop Relat Res. 1985; 192: 23-33 https://doi.org/10.1097/00003086-198501000-00004

20. Insall JN, Binazzi R, Soudry M, Mestriner LA. Total knee arthroplasty.Clin Orthop Relat Res. 1985; 192: 13-22. https://doi.org/10.1097/00003086-198501000-00003

21. Karasavvidis T, Pagan C, Haddad F, Hirschmann M, Pagnano M, Vigdorchik J, Current Concepts in Alignment in Total Knee Arthroplasty, J Arthroplasty (2023), https://doi.org/10.1016/j.arth.2023.01.060.

22. Lawrence JM, Keggi JM, Impact of Component Alignment and Soft Tissue Release on 2 Year Outcomes in TKA, J Arthroplasty (2022), https://doi.org/10.1016/j.arth.2022.04.042).

23. Luyckx T, Vandenneucker H, Ing LS, Vereecke E, Ing AV, Victor J. Raising the joint line in TKA is associated with mid-flexion laxity: a study in cadaver knees. Clin Orthop Relat Res 2018;476:601–11.

24. MacDessi SJ, Griffiths-Jones W, Harris IA, Bellemans J, Chen DB. The arithmetic HKA (aHKA) predicts the constitutional alignment of the arthritic knee compared to the normal contralateral knee, a matched-pairs. Bone Joint Open 2020;1-7:339–345. doi: 10.1302/2633-1462.17.

25. Mathon P, Micicoi G, Seil R, Kacaoglu B, Cerciello S, Ahmad F, LiArno S, Teitge R, Ollivier M (2021) Healthy middle-aged Asian and Caucasian populations present with large intra- and inter-individual variations of lower limb torsion. Knee Surg Sports Traumatol Arthrosc 29(4):1083–1089

26. Matsuda S, Miura H, Nagamine R, Mawatari T, Tokunaga M, Nabeyama R, Iwamoto Y (2004) Anatomical analysis of the femoral condyle in normal and osteoarthritic knees. J Orthop Res 22(1):104–109

27. McEwen P, Balendra G, Doma K. Medial and lateral gap laxity differential in computer-assisted kinematic total knee arthroplasty. Bone Jt J. 2019;101-B:331–339.

28. Micicoi G, Jacquet C, Sharma A, LiArno S, Faizan A, Kley K, Parratte S, Ollivier M (2021) Neutral alignment resulting from tib- ial vara and opposite femoral valgus is the main morphologic pat- tern in healthy middle-aged patients: an exploration of a 3D-CT database. Knee Surg Sports Traumatol Arthrosc 29(3):849–858

29. Ng CK, Chen JY, Yeh JZY, Ho JPY, Merican AM, Yeo SJ. Distal femoral rotation correlates with proximal tibial joint line obliquity: a considera- tion for kinematic total knee arthroplasty. J Arthroplasty 2018;33:1936–44, http://dx.doi.org/10.1016/j.arth.2017.12.025 [Epub 2017 Dec 28. PMID: 29395720].

30. Oussedik S, Abdel MP, Victor J, Pagnano MW, Haddad FS. Alignment in total knee arthroplasty. Bone Joint J. 2020;102-B(3):276-279. doi:10.1302/0301-620X.102B3.BJJ-2019-1729

31. Rivière C, Villet L, Jeremic D, Vendittoli PA. What you need to know about kinematic alignment for total knee arthroplasty. Orthop Traumatol Surg Res 2021;107:102773, http://dx.doi.org/10.1016/j.otsr.2020.102773.

32. Roger J, Lustig S, Cerciello S, Bruno CF, Neyret P, Servien E (2019) Short lateral posterior condyle is associated with trochlea dysplasia and patellar dislocation. Knee Surg Sports Traumatol Arthrosc 27(3):731–739

33. Thienpont E, Schwab PE, Paternostre F, Koch P (2014) Rotational alignment of the distal femur: anthropometric measurements with CT-based patient-specific instruments planning show high vari-ability of the posterior condylar angle. Knee Surg Sports Traumatol Arthrosc 22(12):2995–3002

34. Vanlommel L, Vanlommel J, Claes S, Bellemans J. Slight undercorrection fol- lowing total knee arthroplasty results in superior clinical outcomes in varus knees. Knee Surg Sports Traumatol Arthrosc 2013;21(10):2325–30.

35. Vendittoli PA, Martinov S, Blakeney WG. Restricted kinematic alignment, the fundamentals, and clinical applications. Front Surg. 2021; 8: 697020. https://doi.org/10.3389/fsurg.2021.697020

36. V Vigdorchik JM, Wakelin EA, Koenig JA, Ponder CE, Plaskos C, DeClaire JH,Lawrence JM, Keggi JM, Impact of Component Alignment and Soft Tissue Release on 2 Year Outcomes in TKA, J Arthroplasty (2022), https://doi.org/10.1016/j.arth.2022.04.042.

37. Lawrence JM, Keggi JM, Impact of Component Alignment and Soft Tissue Release on 2 Year Outcomes in TKA, J Arthroplasty (2022), https://doi.org/10.1016/j.arth.2022.04.042.

38. Winnock de Grave P, Kellens J, Luyckx T, Tampere T, Lacaze F, Claeys K (2022). Inverse kinematic alignment for total knee arthroplasty. Orthopaedics & Traumatology: Surgery & Research, 108(5), 103305.

39. Winnock de Grave, P., Luyckx, T., Claeys, K. et al. Higher satisfaction after total knee arthroplasty using restricted inverse kinematic alignment compared to adjusted mechanical alignment. Knee Surg Sports Traumatol Arthrosc 30, 488–499 (2022). https://doi.org/10.1007/s00167-020-06165-4

40. Winnock de Grave, P., Luyckx, T., Van Criekinge, T. et al. Inverse kinematic alignment accommodates native coronal knee alignment better in comparison to adjusted mechanical alignment and restricted kinematic alignment. Knee Surg Sports Traumatol Arthrosc (2023). https://doi.org/10.1007/s00167-023-07326-x

41. Woon JTK, Zeng ISL, Calliess T, Windhagen H, Ettinger M, Waterson HB, et al. Outcome of kinematic alignment using patient-specific instrumentation versus mechanical alignment in TKA: a meta-analysis and subgroup ana- lysis of randomised trials. Arch Orthop Trauma Surg 2018;138:1293–303, http://dx.doi.org/10.1007/s00402-018-2988-8 [Epub 2018 Jun 30. PMID: 29961093].

42. Yoshinori O, Shuhei O, Mikio N, Tsuyoshi J, Hitoshi W, Masashi N. Sagittal Alignment of the Femoral Component and Patient Height Are Associated With Persisting Flexion Contracture After Primary Total Knee Arthroplasty. J Arthroplasty 34 (2019) 1476e1482