ORIGINAL RESEARCH PAPER
Volume - 15 | Issue - 03 | March - 2026 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

MECHANICAL ALIGNMENT IN TOTAL KNEE ARTHROPLASTY: DOES CURRENT EVIDENCE SUPPORT A PARADIGM SHIFT?

Orthopaedics

Dr Hussain Lapia* RMO Orthopedics and Spine,Dubai, UAE. *Corresponding Author
Dr. Nikhat Khanam Case Manager, Dubai, UAE.
Dr. Uwe Johannes Nellessen Consultant Orthopedic Surgeon, Dubai UAE.

ABSTRACT

Background: Mechanical alignment (MA) has historically been the standard in total knee arthroplasty (TKA) because of its reproducibility and strong long-term registry support. Kinematic alignment (KA) was introduced to better reproduce native knee anatomy and kinematics, prompting sustained debate regarding functional benefit, durability, and safety. **Purpose:** To critically synthesize contemporary evidence comparing MA and KA in primary TKA, with emphasis on patient-reported outcome measures (PROMs), range of motion (ROM), functional recovery, patellofemoral considerations, implant survivorship, and the emerging role of phenotype-based and technology-assisted alignment strategies. **Methods:** A narrative review was conducted using PubMed, Embase, and Cochrane Library databases (January 2000–September 2025). Search terms included "total knee arthroplasty," "mechanical alignment," "kinematic alignment," "restricted kinematic alignment," "functional alignment," and "phenotype-based alignment." Priority was given to randomized controlled trials, meta-analyses, large cohort studies, and registry reports. Biomechanical and gait studies were used to support mechanistic interpretation. Studies were qualitatively synthesized with attention to effect size and clinical relevance. **Results:** Meta-analyses and comparative trials demonstrate that KA may confer small early improvements in selected PROMs and feeling of naturalness; however, these differences are frequently below established minimal clinically important differences and tend to diminish with longer follow-up. No statistical long-term differences were seen in postoperative ROM, postoperative pain and gait mechanics. Long-term implant survivorship remains most robustly supported for MA, while survivorship data for KA particularly unrestricted manual KA are limited and heterogeneous. **Conclusions:** Current evidence supports broadly equivalent mid-term clinical outcomes between MA and KA in primary TKA. MA retains the strongest long-term survivorship evidence, whereas personalized strategies such as restricted KA or functional alignment, especially when executed with enabling technologies, may offer a pragmatic balance between anatomic restoration and mechanical safety. High-quality, phenotype-stratified trials with standardized alignment definitions and long-term follow-up remain necessary.

KEYWORDS

Kinematic alignment, Mechanical alignment, Total knee arthroplasty, Patient reported outcome measures.

INTRODUCTION

Knee osteoarthritis (KOA) is the is the 11th leading cause of disability amongst adult and obese individuals globally [1]. The primary surgical management option for knee osteoarthritis is total knee arthroplasty and is gold standard when non-surgical options are ineffective. This procedure can help in restoring function and alignment, pain reduction and correction of deformities [2]. Accurate alignment minimizes aseptic loosening, enhances patient satisfaction and function, and reduces revision rates. Long-term registry analysis consistently demonstrate that alignment accuracy remains a key predictor of implant longevity extending beyond two decades [3].

MECHANICAL ALIGNMENT

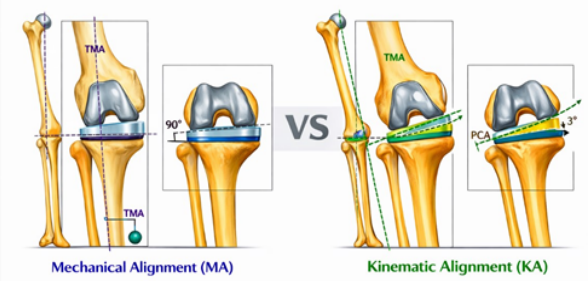

Figure 1: The Philosophy of MA vs KA [7]

Insall and his colleagues [4] first introduced the philosophy of mechanical alignment (MA) (figure 1) in the late 1970s where the aim was to position the femoral and tibial components perpendicular to the mechanical axis of the femur and tibia. This was further supported by radiographic studies such as Jeffrey et al [5] that established a safe zone of ± 3° from neutral in the coronal plane and reinforced the strong association between improved longevity of implants and neutral hip-knee-ankle axis (HKA axis). Deviation beyond this threshold-particularly into varus-has been associated with asymmetric loading, increased medial compartment stress, and accelerated wear [6]. This principle of alignment configuration of achieving a neutral hip-knee axis (HKA axis) of 180° ± 3° remained the gold standard for over 30 years. It allows even distribution of joint load resulting in reduced eccentric wear and enhanced survivorship of prosthesis which at 15-20 years exceed 95% as documented In several long-term registries [8,9]

Patient perceived outcomes remained unsatisfactory with almost 20-25% of the patients described the knee as unnatural with MA[10,11]. Beverland et al while reviewing the relative patient satisfaction at 10 year follow up following knee replacement found out that around 7% of the patients were never happy [12]. The dogma of uniform mechanical neutrality was challenged by the recognition of constitutional varus and valgus morphotypes found in nearly 30% of the normal population [13].

KINEMATIC ALIGNMENT

The concept of Kinematic alignment (KA) was introduced in 2008 by Howell et al. The principle was to restore the patient's pre-arthritic joint line aiming at a more enhanced natural proprioception and more natural feeling knee [14]. 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 posterior condylar axis, 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[15].

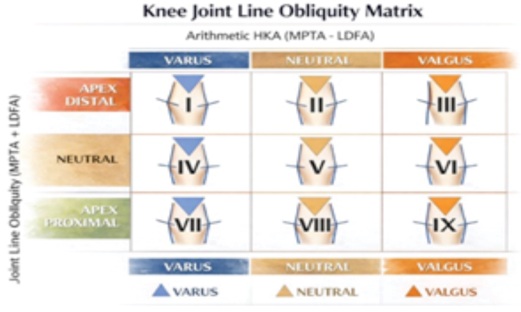

Figure 2: Arithematic HKA

MacDessi et al [16] introduced the Coronal Plane alignment of the knee (CPAK) classification by categorizing the knees into 9 subtypes on the basis of the HKA angles (fig 2), joint line obliquity and limb morphology. With the recent advancements in computer navigation, robotic assistance and patient specific instrumentation that allow reduced variability by facilitating millimetre level accuracy in bone resection and component placement [17], The debate amongst these alignment strategies is more active than ever amongst the orthopaedic community.

The crux is if native kinematics can be restored by KA as opposed to MA, does this translate clinically to happier patients postoperatively? This review aims to integrate the biomechanical, clinical and technical perspectives by emphasizing on patient reported outcomes, implant survivorship, gait restoration and patellofemoral mechanics to synthesize contemporary evidence comparing kinematic and mechanical alignment philosophies in TKA.

Comparison Of Functional And Biomechanial Outcomes In MA vs KA

Subjective recovery after TKA can be measured by patient reported outcome measures (PROMs) that include measures such as but not limited to Oxford knee score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Forgotten Joint score (FJS) and Knee Injury and Osteoarthritis Outcome Score (KOOS) [18]. Van Essen el at [19] in their meta-analysis concluded that although KA produced slightly better short term OKS and FJS than MA, this difference fell below the minimum clinical important difference (MCID). Stove et al. [20] and Miglioini et al [21] in their analysis of 39 and 30 clinical studies respectively found no significant differences between PROMs between the KA and MA group. Rahman et al. [22] observed the modest early benefits that KA can yield especially in constitutional varus knees, but long-term outcomes converged with MA. A 6-month transient improvement in KOOS and FJS for KA knees was reported by Jeremic et al [23]. A review of 26 clinical studies conducted by Karasvvidis el at [24] concluded that the early satisfaction differences favoring KA were small, inconsistent and not sustained.

The advent of robotics and its integration in TKA improves the accuracy in execution of the surgery regardless of the alignment philosophy. Agarwal et al [25] demonstrated a 93% satisfaction rate among patients after robotic MA-TKA even though 86% of the patients underwent.

Similar outcomes were reported by Bertuguli et al [26] and Bollars et al [27] concluded that postoperative changes in the CPAK classification and patient's native joint line does not significantly affect functional outcomes. Bullens el al [28] and Mancuso el al [29] concluded weak correlation between global satisfaction and alignment underscoring the strong contribution of pre-operative education, psychological readiness and patient preoperative expectations in determining successful outcomes.

Meta-analyses and comparative studies demonstrate no clinically meaningful difference in postoperative flexion or extension between mechanical and kinematic alignment techniques in TKA. Pooled data show a mean flexion difference of approximately 3°, well below the MCID threshold (3.8°–6.4°), and no significant difference in extension deficit (mean difference 0.1°), indicating equivalent postoperative range of motion outcomes between alignment strategies [30-33]. Several cohort studies report lower pain scores on the visual analog scale (VAS) [34]. in the KA group. However, on longer follow up [35] and in pooled studies [21], these differences do not match statistical significance.

The patellofemoral joint significantly influences functional satisfaction following TKA. MA typically promotes stable patellar tracking by restoring neutral femoral component rotation relative to the posterior condylar axis which reduces the risk of lateral maltracking, subluxation, and anterior knee pain [36]. In contrast, KA shifts patellofemoral loading medially or laterally and alters the Q angle resulting in non-physiological patellar tilt or facet overloading, particularly in deep flexion, unless executed with robotic precision [37,38]. Reproducing a patient's native alignment might not always optimize patellar tracking, especially in cases with pre-existing deformity [39]. Karasavvidis et al [24] and Wang et al. [40] reported no significant difference in anterior knee pain or patellar complications between KA and MA, though both emphasized that KA outcomes were heavily dependent on surgical experience.

McEwen et al. demonstrated that KA-TKA replicates more natural femoral rollback and tibial internal rotation during flexion compared with MA-TKA [41]. However, In a study conducted by Bauer et al, time-discrete gait analysis variables were studied, including walking speed, stance phase, cadence, and step length which showed no significant differences between the two groups post-operatively [42]. Waterson et al [43] and Blakeney et al [44] found higher "naturalness" reports among the KA patients in the early recovery phases. However, Stöve et al. (2025) and Van Essen et al. (2023) showed these differences diminish with time. [19,20]

Implant survivorship represents the ultimate benchmark of TKA success. MA, by aligning the load vector centrally through the knee, has demonstrated exceptional durability with survivorship exceeding 95 % at 15–20 years [8]. Large registry and cohort studies report excellent survival rates for MA knees which is displayed in detail in Table 1

Source / Registry	Alignment Method	Follow-up Duration	Revision Rate (%)	Key Notes
AOANJRR (Australia, 2022) [45]	Mechanical Alignment (MA)	15+ years	3.50%	Stable over 15 years; gold standard baseline
NJR (UK, 2022) [46]	Mechanical Alignment (MA)	10+ years	4.20%	Favors MA for reproducibility and longevity
NZJR (New Zealand, 2021) [47]	Mechanical Alignment (MA)	10+ years	3.90%	Supports MA with low cumulative revision risk

Table 1: Summary of data reported in National Joint Registries

Conversely, long-term evidence for KA remains limited. Mid-term studies (2–5 years) generally report equivalent survivorship between KA and MA, with no significant differences in revision rates [48]. However, unrestricted KA-particularly when performed manually-can produce wide coronal variation, raising concerns regarding edge loading and tibial loosening [49].Howell et al reported over 95 % survivorship at 10 years in KA cases performed within ± 3° of mechanical neutrality, suggesting that precision and moderation may be more important than the alignment label itself and giving way for exploring more personalized alignment options like restricted kinematic alignment and functional alignment strategies [50].

Limitations Of Current Evidence; [51,52]

- *Lack of long-term randomized trials for KA*: Most studies report outcomes at short to mid-term follow up i.e., 5-10 years. Long term follow up with larger sample size and high volume centers are still lacking.
- *Selection bias in KA cohorts*: KA technique was conducted mostly in normal deformities with lesser bone loss and ligament balance. Most of the studies excluded severe deformities, bone loss or ligament imbalance cases leading to non-application of outcomes to all patients.
- *Heterogeneity in definitions and techniques:* Matar et al [53] highlighted methodological heterogeneity in alignment research short follow-up durations, inconsistent PROMs, and inadequate phenotype stratification limit interpretability.
- *Limited evidences in implant survival:* in KA technique early results with short term follow up had showed excellent results and satisfaction but long term implant survival and wear patterns are yet to be researched with long term studies.
- *Potential confounding factors:* Studies conducted on KA patients donot show reliable outcomes due to differences in patient anatomy, implant type or rehabilitation protocols. Psychological factors, patient expectation, and rehabilitation intensity substantially influence perceived outcomes [54,55] Consequently, alignment philosophy must be contextualized as one of several interdependent contributors to postoperative success.

Strengths of MA in TKA	Risks associated with KA in TKA
-Even load distribution	-Potential for malalignment increasing possibility of component wear and loosening
-Predictable outcomes	-Altered patellofemoral mechanics
-Suitable for all deformities	-Difficulties in severe varus/valgus deformities
-Proven long term durability	-Limited long term data

-Standardized and reproducible technique	-Surgeon learning curve
-Widely accepted benchmark; regulatory & design compatibility	-Instrumentation challenge

Table 2: Strengths of MA vs Risks associated with KA in TKA

Future Directions

The evolution of total knee arthroplasty (TKA) alignment is increasingly driven by personalized, technology-enabled execution rather than adherence to a single alignment doctrine. Image-based and imageless navigation systems provide real-time, three-dimensional visualization of limb alignment using infrared tracking, allowing accurate definition of femoral and tibial mechanical axes and precise control of coronal, sagittal, and rotational bone resections.

Robotic-assisted systems further enhance alignment accuracy by enabling incremental intraoperative adjustments to bone cuts and component positioning, resulting in fewer alignment outliers and improved consistency between surgeons. These technologies offer a framework in which mechanical alignment targets can be reliably achieved while selectively accommodating patient-specific anatomy through restricted kinematic or functional alignment strategies. [56].

Well-designed randomized trials with 10–20-year follow-up, are required to determine whether deviations from neutral alignment compromise implant survivorship. Integration of artificial intelligence driven planning, registry-level analytics, biomechanical modeling, and wearable gait assessment may further refine alignment targets and establish data-driven safety boundaries for individualized TKA.

CONCLUSION: The Debate: Longevity Versus Natural Kinematics

Mechanical and kinematic alignment should be viewed as complementary strategies along a continuum rather than opposing doctrines. Mechanical alignment remains the most biomechanically validated and registry-supported approach, offering reproducible execution and predictable long-term implant survivorship. Kinematic alignment, while conceptually appealing for restoring native joint anatomy, demonstrates at most modest early advantages in function and satisfaction that generally converge with mechanical alignment outcomes over time, with long-term durability yet to be conclusively established.

Hybrid approaches such as restricted kinematic and functional alignment, particularly when executed with navigation or robotic assistance, may provide an optimal balance by preserving mechanical safety while allowing limited personalization of soft-tissue balance and limb geometry. Until robust long-term evidence confirms the survivorship of broader departures from neutral alignment, mechanically guided or restricted kinematic strategies represent the most evidence-based and clinically reliable methods for achieving reproducible outcomes, minimizing alignment variability, and optimizing implant longevity in contemporary TKA.

Declaration Of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article

Funding

The authors received no financial support for the research, authorship, and/or publication of this article

REFERENCES:

1. Dawson J, Linsell L, Zondervan K, Rose P, Carr A, Randall T, Fitzpatrick R.(2005). Impact of persistent hip or knee pain on overall health status in elderly people: A longitudinal population study. *Arthritis Rheum*, 53,368–374. doi: 10.1002/art.21180.
2. Brophy RH, Fillingham YA.(2022). AAOS Clinical practice guideline summary: Management of osteoarthritis of the Knee (Non-arthroplasty), Third edition. *J Am Acad Orthop Surg*. 30:e721–e729.
3. Karasavvidis T, Pagan Moldenhauer CA, Lustig S, Vigdorchik JM, Hirschmann MT.(2023). Definitions and consequences of current alignment techniques and phenotypes in total knee arthroplasty (TKA) - there is no winner yet. *J Exp Orthop*,10(1):120.
4. Insall JN, Ranawat CS, Aglietti P, Shine J.(1976). A comparison of four models of total knee-replacement prostheses. *J Bone Joint Surg Am,*58(6),754–765.
5. Jeffery RS, Morris RW, Denham RA.(1991).Coronal alignment after total knee replacement. J Bone Joint Surg Br,73(5),709–714.
6. Fang DM, Ritter MA, Davis KE. (2009). Coronal alignment in total knee arthroplasty: just how important is it? *J Arthroplasty* ,24(6 Suppl),39–43.
7. Scientific Committee from the Personalized Arthroplasty Society (PAS). Standardizing definitions of the total knee alignment techniques: recommendations by the Personalized Arthroplasty Society. (2025).*EFORT Open*,10(8):623-635. doi: 10.1530/EOR-2024-0120.
8. Rivière C, Iranpour F, Auvinet E, Howell S, Vendittoli P-A, Cobb J, Parratte S.(2017). Alignment options for total knee arthroplasty: a systematic review. *Orthop Traumatol Surg Res*,103(7):1047–1056.(5).
9. Segura-Nuez J Sr, Martín-Hernández C Sr, Segura-Nuez JC Sr, Segura-Mata JC Sr.(2024). Methods of alignment in total knee arthroplasty, systematic review. *Orthop Rev (Pavia)*,16,117769. doi: 10.52965/001c.117769.
10. Noble PC, Gordon MJ, Weiss JM, et al.(2005). Does total knee replacement restore normal knee function? *Clin Orthop Relat Res*,431,157–165.
11. Oussedik S, Abdel MP, Victor J, Pagnano MW, Haddad FS. (2020). Alignment in total knee arthroplasty. *Bone Joint J*, 102-B(3),276-279. doi: 10.1302/0301-620X.102B3.BJJ-2019-1729.
12. Beverland D.(2010). Patient satisfaction following TKA: Bless them all! *Orthopedics,*7,33(9),657. doi: 10.3928/01477447-20100722-23.
13. Bellemans J, Colyn W, Vandenneucker H, Victor J.(2012). The Chitranjan Ranawat award: is neutral mechanical alignment normal for all patients? *Clin Orthop Relat Res*,470(1),45–53
14. Howell SM, Howell SJ, Kuznik KT, Cohen J, Hull ML.(2013). Does a kinematically aligned total knee arthroplasty restore function without failure regardless of alignment category? *Clin Orthop Relat Res,*471(3),1000–1007
15. Howell SM, Roth JD, Hull ML.(2020). Principles and techniques of kinematic alignment in total knee arthroplasty. *Bone Joint J,*102-B(1),70–82.
16. MacDessi SJ, Griffiths-Jones W, Harris IA, Bellemans J. (2021).Coronal plane alignment of the knee (CPAK) classification. *Knee Surg Sports Traumatol Arthrosc*,29(11),3626–3634.
17. Cobb JP, Kannan V, Brust K, et al.(2012). Patient-specific instruments improve reproducibility of coronal alignment in total knee replacement. *J Bone Joint Surg Br*,94(12),1538–1543.
18. Noble PC, Conditt MA, Cook KF, Mathis KB.(2006). The John Insall Award: Patient expectations affect satisfaction with total knee arthroplasty. *Clin Orthop Relat Res*,452,35–43.
19. Van Essen J, et al.(2023). Comparative meta-analysis of kinematic vs mechanical alignment in total knee arthroplasty. *The Knee.* 2023;41:102–110.
20. Stöve, J., Schrednitzki, D., ReSurg, Ortwig, K., Hirschmann, M. T., & Halder, A. M. (2025). No difference in PROMs between kinematic and mechanical alignment in TKA: An umbrella review with secondary meta-analysis and GRADE assessment. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, 10.1002/ksa.70034. Advance online publication. https://doi.org/10.1002/ksa.7003
21. Migliorini, F., Maffulli, N., Pilone, M. *et al*.(2025). Mechanical versus kinematic alignment for total knee arthroplasty: a meta-analysis. *Arch Orthop Trauma Surg* 145, 212. https://doi.org/10.1007/s00402-025-05835-7
22. Rahman, W. A., Muqri, K. Y., Suhail, H. M., Shajri, M. M., Omar, Y. Z., Alahmari, M. A., Hakami, A. A., Alotaibi, R. S., Alowaimer, N. H., & Alrehaili, M. S. (2025). Functional Outcomes and Patient Satisfaction in Kinematic vs Mechanical Alignment Total Knee Arthroplasty: A Systematic Review. *Cureus*, *17*(10), e93939. https://doi.org/10.7759/cureus.93939
23. Riviere C, Jeremic D., Vendittoli PA (2021): What do you need to know about kinematic alignment for total knee arthroplasty, *Orthop Traum Surg Res* 107, 89-100.
24. Van Essen, J., Stevens, J., Dowsey, M. M., Choong, P. F., & Babazadeh, S. (2023). Kinematic alignment results in clinically similar outcomes to mechanical alignment: Systematic review and meta-analysis. *The Knee*, *40*, 24–41. https://doi.org/10.1016/j.knee.2022.11.001
25. Agarwal, S., Ayeni, F. E., & Sorial, R. (2024). Impact of change in coronal plane alignment of knee (CPAK) classification on outcomes of robotic-assisted TKA. *Arthroplasty*, *6*(1), 15.
26. Bertugli, E., Zambianchi, F., Batailler, C., Bazzan, G., Lustig, S., & Catani, F. (2025). Change of CPAK class does not affect functional outcomes in robotic arm-assisted total knee arthroplasty performed with functional alignment. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *33*(5), 1773–1783. https://doi.org/10.1002/ksa.12561.
27. Bollars, P., Feyen, H., Nathwani, D., Albelooshi, A., Ettinger, M., De Corte, R., & Schotanus, M. G. M. (2025). Postoperative changes in CPAK-classification do not significantly influence patient-reported outcome measures following conventional or robotic-assisted total knee arthroplasty: A randomised controlled trial. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *33*(9), 3333–3340. https://doi.org/10.1002/ksa.12740.
28. Bullens, P. H., van Loon, C. J., de Waal Malefijt, M. C., Laan, R. F., & Veth, R. P. (2001). Patient satisfaction after total knee arthroplasty: a comparison between subjective and objective outcome assessments. *The Journal of arthroplasty*, *16*(6), 740–747. https://doi.org/10.1054/arth.2001.23922
29. Mancuso, C. A., Sculco, T. P., Wickiewicz, T. L., Jones, E. C., Robbins, L., Warren, R. F., & Williams-Russo, P. (2001). Patients' expectations of knee surgery. *The Journal of bone and joint surgery. American volume*, *83*(7), 1005–1012. https://doi.org/10.2106/00004623-200107000-00005
30. Akinari Tokiyoshi, Yusuke Akaoka. Comparison of mechanical and restricted kinematic alignment in robotic-assisted total knee arthroplasty: A retrospective single-surgeon study. Orthopedics and Tissue Engineering 025320009. https://doi.org/10.36922/OTE025320009
31. Nucci, N., Chakrabarti, M., DeVries, Z., Ekhtiari, S., Tomescu, S., & Mundi, R. (2025). Kinematic Alignment Does Not Result in Clinically Important Improvements After TKA Compared With Mechanical Alignment: A Meta-analysis of Randomized Trials. *Clinical orthopaedics and related research*, *483*(6), 1020–1030. https://doi.org/10.1097/CORR.0000000000003356
32. Alhifzi Z. (2024). Systematic review and meta-analysis of long term outcomes and innovations in Total Knee Arthroplasty: KINEMATIC, PERSONALIZED KNEE vs. CONVENTIONAL. *Orthopedic reviews*, *16*, 122318. https://doi.org/10.52965/001c.122318.
33. Silva, M. D. C., Woodward, A. P., Fearon, A. M., Perriman, D. M., Spencer, T. J., Couldrick, J. M., & Scarvell, J. M. (2024). Minimal clinically important change of knee flexion in people with knee osteoarthritis after non-surgical interventions using a meta-analytical approach. *Systematic reviews*, *13*(1), 50. https://doi.org/10.1186/s13643-023-02393-0
34. Elbuluk, A. M., Jerabek, S. A., Suhardi, V. J., Sculco, P. K., Ast, M. P., & Vigdorchik, J. M. (2022). Head-to-Head Comparison of Kinematic Alignment Versus Mechanical Alignment for Total Knee Arthroplasty. *The Journal of arthroplasty*, *37*(8S), S849–S851. https://doi.org/10.1016/j.arth.2022.01.052
35. Reinisch, F., Ioannou, A., Eberle, A., & Ioannou, M. (2024). Comparison of Six-Week, Three-Month, and One-Year Postoperative Clinical Results of Kinematic and Mechanical Alignment in Primary Medial Pivot Total Knee Arthroplasty. *Cureus*, *16*(7), e64517. https://doi.org/10.7759/cureus.64517
36. Harris AB, Vigdorchik JM.(2025). Correlation between alignment deviation and failure in joint arthroplasty. *J Bone Joint Surg Am*,107(2),165–173.
37. Howell SM, Hull ML.(2017). Outcomes of kinematically aligned total knee arthroplasty at ten years. *J Arthroplasty*,32(11),3304–3310.

38. Matar, H. E., Platt, S. R., Gollish, J. D., & Cameron, H. U. (2020). Overview of randomized controlled trials in total knee arthroplasty (47,675 patients): what have we learnt?. *The Journal of Arthroplasty*, *35*(6), 1729-1736.
39. Rivière, C., Iranpour, F., Harris, S., Auvinet, E., Aframian, A., Chabrand, P., & Cobb, J. (2017). The kinematic alignment technique for TKA reliably aligns the femoral component with the cylindrical axis. *Orthopaedics & traumatology, surgery & research : OTSR*, *103*(7), 1069–1073. https://doi.org/10.1016/j.otsr.2017.06.016
40. Weber, P., & Gollwitzer, H. (2021). Kinematic alignment in total knee arthroplasty. *Operative Orthopädie und Traumatologie*, *33*(6), 525-537.
41. McEwen P, et al. Patellofemoral contact mechanics in kinematic vs mechanical alignment. Bone Joint Res. 2020;9(6):267
42. Howell, S. M., Shelton, T. J., & Hull, M. L. (2018). Implant Survival and Function Ten Years After Kinematically Aligned Total Knee Arthroplasty. *The Journal of arthroplasty*, *33*(12), 3678–3684. https://doi.org/10.1016/j.arth.2018.07.020
43. Bauer, L., Layher, F., Kirschberg, J., Heinecke, M., Woiczinski, M., & Matziolis, G. (2026). No differences in functional and clinical outcomes after rehabilitation between modified kinematic and mechanical alignment in total knee arthroplasty: A randomized controlled trial. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *34*(2), 596–607. https://doi.org/10.1002/ksa.70004
44. Blakeney W, Beaulieu Y, Kiss MO, Rivière C, Vendittoli PA. Less gap imbalance with restricted kinematic alignment than with mechanically aligned total knee arthroplasty: simulations on 3-D bone models created from CT-scans. *Acta Orthop*. 2019;90(6):602-609. doi:10.1080/17453674.2019.1675126
45. Waterson, H. B., Clement, N. D., Eyres, K. S., Mandalia, V. I., & Toms, A. D. (2016). The early outcome of kinematic versus mechanical alignment in total knee arthroplasty: a prospective randomised control trial. *The bone & joint journal*, *98-B*(10), 1360–1368. https://doi.org/10.1302/0301-620X.98B10.36862
46. Australian Orthopaedic Association National Joint Replacement Registry (AOANJRR). Annual Report. Adelaide: AOA; 2022.
47. New Zealand Joint Registry. 20-Year Report. Wellington: NZ Orthopaedic Association; 2022.
48. Ben-Shlomo Y, Blom A, Boulton C, et al. The National Joint Registry 19th Annual Report 2022 [Internet]. London: National Joint Registry; 2022 Oct. Available from: https://www.ncbi.nlm.nih.gov/books/NBK587525/
49. Boutros, M., Awad, G., Mouawad, A., & Mansour, E. (2025). Kinematic versus Mechanically Aligned Total Knee Arthroplasty: A Meta-analysis of Randomized Controlled Trials. *The journal of knee surgery*, 10.1055/a-2741-1246. Advance online publication. https://doi.org/10.1055/a-2741-1246
50. Howell SM, et al.(2022). Kinematic alignment in Total Knee Arthroplasty: long-term outcomes and lessons learned. *J Arthroplasty*,37(7),1324–1331.
51. Howell SM, et al. Ten-year outcomes of kinematically aligned total knee arthroplasty performed with manual instrumentation. J Arthroplasty. 2017;32(11):3304–3310.
52. Rivière, C., Dhaif, F., Shah, H., Ali, A., Auvinet, E., Aframian, A., Cobb, J., Howell, S., & Harris, S. (2018). Kinematic alignment of current TKA implants does not restore the native trochlear anatomy. *Orthopaedics & traumatology, surgery & research : OTSR*, *104*(7), 983–995. https://doi.org/10.1016/j.otsr.2018.05.010
53. Lei, K., Liu, L., Chen, X., Feng, Q., Yang, L., & Guo, L. (2022). Navigation and robotics improved alignment compared with PSI and conventional instrument, while clinical outcomes were similar in TKA: a network meta-analysis. *Knee surgery, sports traumatology, arthroscopy : official journal of the ESSKA*, *30*(2), 721–733. https://doi.org/10.1007/s00167-021-06436-8
54. Seo, S. S., & Roh, S. M. (2021). How to Make a Strategy for Knee Arthritis Treatment. In *A Strategic Approach to Knee Arthritis Treatment: From Non-Pharmacologic Management to Surgery* (pp. 365-392). Singapore: Springer Singapore.
55. Bullens, P. H., van Loon, C. J., de Waal Malefijt, M. C., Laan, R. F., & Veth, R. P. (2001). Patient satisfaction after total knee arthroplasty: a comparison between subjective and objective outcome assessments. *The Journal of arthroplasty*, *16*(6), 740–747. https://doi.org/10.1054/arth.2001.23922
56. Mancuso, C. A., Sculco, T. P., Wickiewicz, T. L., Jones, E. C., Robbins, L., Warren, R. F., & Williams-Russo, P. (2001). Patients' expectations of knee surgery. *The Journal of bone and joint surgery. American volume*, *83*(7), 1005–1012. https://doi.org/10.2106/00004623-200107000-00005
57. Bollars, P., Nathwani, D., Albelooshi, A., Ettinger, M., Verheyden, F., Mievis, J., Meshram, P., & Schotanus, M. (2025). Imageless handheld robotic-assisted total knee arthroplasty showed better clinical outcomes than conventional total knee arthroplasty: A randomized controlled trial with preliminary results at 1-year follow up. *The Knee*, *56*, 232–240. https://doi.org/10.1016/j.knee.2025.05.028