



# Do Ultracongruent Inserts Reproduce the Intraoperative Sagittal Plane Kinematics of Posterior Stabilized TKR? Assessment Using a Modern Robotic System

Muhammed Shafi Thekkumpurath<sup>1</sup> · Devansh Goyal<sup>1</sup> · Arun Kannan<sup>1</sup>

Received: 28 April 2024 / Accepted: 16 November 2024  
© Indian Orthopaedics Association 2024

## Abstract

**Background** Ultracongruent (UC) total knee replacement (TKR) designs, serving as alternatives to posterior stabilized (PS) and cruciate retaining (CR) designs, lack conclusive evidence regarding posterior femoral rollback. This study aimed to compare intraoperative posterior femoral rollback and maximal knee flexion between UC and PS inserts, addressing the paucity of literature on femoral rollback achieved with UC designs in total knee replacement.

**Methods** A consecutive cohort of 20 patients undergoing robotic-assisted primary total knee replacement, posterior femoral rollback and maximal intraoperative knee flexion were assessed. Robotic imaging at varying flexion angles (0°, 45°, 90°, and 120°) was conducted after implanting femoral and tibial components with Ultracongruent and Posterior-Stabilized trial inserts. Femoral contact on the tibia was estimated as a percentage of the sagittal dimension of the tibial component with 0 representing the anterior edge and 100 representing the posterior edge of the tibial component.

**Results** In extension, UC inserts exhibited a statistically significant posterior contact point versus PS inserts (56.3 + 4.3 vs 53.5 + 5.3,  $p=0.003$ ). Between 0 and 45° flexion, 13 of 20 UC inserts showed a paradoxical anterior translation exceeding 5%, unlike the PS group. At 90° flexion, both displayed consistent posterior femoral rollback, with PS inserts having a more posterior contact point (63.5 + 6.2 vs 67.2 + 5.1,  $p=.008$ ). At 120° flexion, rollback was similar (70.1 + 8.4 vs 71.3 + 8.4,  $p=0.128$ ). Mean maximal flexion was 130° (SD = 6.87) and 133° (SD = 6.72) for UC and PS inserts, respectively ( $p=0.0001$ ).

**Conclusions** The study indicates UC inserts achieve comparable posterior femoral rollback in deep flexion, supporting their alternative use, despite minor intraoperative flexion differences. However, paradoxical anterior translation in mid-flexion with UC inserts warrants further investigation into wear and clinical outcomes.

**Keywords** Ultracongruent · Posterior-stabilized · Total knee replacement · Robotic surgery · Kinematics

## Abbreviations

CT	Computed Tomography
PCL	Posterior Cruciate Ligament
PS	Posterior stabilized
SD	Standard Deviation
TKR	Total Knee Replacement
UC	Ultracongruent

## Introduction

The Total Condylar Knee was one of the first total knee replacements that gained wide popularity. In the total condylar design, both cruciate ligaments were sacrificed [1]. However, it was recognized in a few years that it lacked posterior femoral roll back in the absence of cruciate ligaments. This, in turn, led to impingement of the tibial polyethylene on the posterior aspect of femur in deep flexion leading to restricted flexion and high rates of loosening at mid-term follow-up [1]. To address this issue, the posterior stabilized design with a cam-post mechanism was developed to ensure posterior roll back of the femur in flexion as the cam contacts the post in deeper flexion angles, generally beyond 70 degrees. The posterior stabilized TKR, like the total condylar design, required sacrifice of both the cruciate ligaments [2].

✉ Arun Kannan  
arunkannan.arun@gmail.com

<sup>1</sup> Department of Orthopaedics, Apollo Hospitals, Greams Road, Chennai 600006, India

An alternative method that was successfully adopted to preserve posterior femoral roll back was the cruciate retaining design where the posterior cruciate ligament was preserved, while the anterior cruciate ligament was sacrificed [3]. Both posterior stabilized and cruciate retaining designs of TKR have been used successfully over the last 4 decades with good long-term outcomes. Each design has its relative merits and demerits. The posterior stabilized knee has been shown to have reliable posterior femoral roll back with better flexion as compared to cruciate retaining knees [4]. However, PS TKR required removal of additional bone from the distal femur and is known to have higher risk of periprosthetic fracture of the distal femur [5]. Several studies, including registry data, have also shown a lower survivorship of the PS design when compared with the CR design [6]. The cruciate retaining TKR has been noted to have issues such as paradoxical anterior translation and reduced knee flexion when compared to the PS design [4].

In recent years, UC inserts have been introduced and have gained popularity. The UC inserts are characterized by an elevated anterior lip and a more conforming geometry that are designed to prevent anterior subluxation of femoral condyles during flexion and to provide better contact stress distribution [7](Fig. 1). They have been proposed as an alternative to the standard posterior stabilized and cruciate retaining designs. The UC designs do not require a box resection of the femoral bone as they do not have a cam-post mechanism. Additionally, the anteroposterior constraint of

the UC device is expected to be present throughout the full flexion arc, in contrast to the PS insert that does not engage until later in flexion [8]. However, the kinematics of TKR with the UC designs are not well established in current literature. The aim of our study was to compare UC and PS inserts in terms of (1) intraoperative posterior femoral roll-back in deep flexion, (2) pattern of rollback from extension to deep flexion and (3) maximal intraoperative knee flexion.

## Patients and Methods

A consecutive cohort of patients who underwent robotic-assisted (Mako, Stryker, Mahwah) posterior stabilized cemented primary TKR with a single radius femoral component (Triathlon, Stryker, Mahwah) and fixed bearing inserts, were prospectively analysed for this study. The Mako Total Knee software version 1.0 was used in the study. The UC and PS fixed bearing inserts were compared intraoperatively in the same patient to avoid individual differences. Based on the initial assessment of the first eight cases, the standard deviation of the paired differences was 7.2. To detect a 5% difference in rollback between UC and PS inserts, the sample size was found to be 20 to achieve a power of 80% and a level of significance of 5% (two-sided) [9]. The mean age of the cohort was 66 years, with a range of 52–80 years. There were 9 males and 11 females in the cohort. The diagnosis in all patients was primary osteoarthritis. An institutional



**Fig. 1** PS insert (A), UC insert (B) (Triathlon, Stryker, Mahwah)

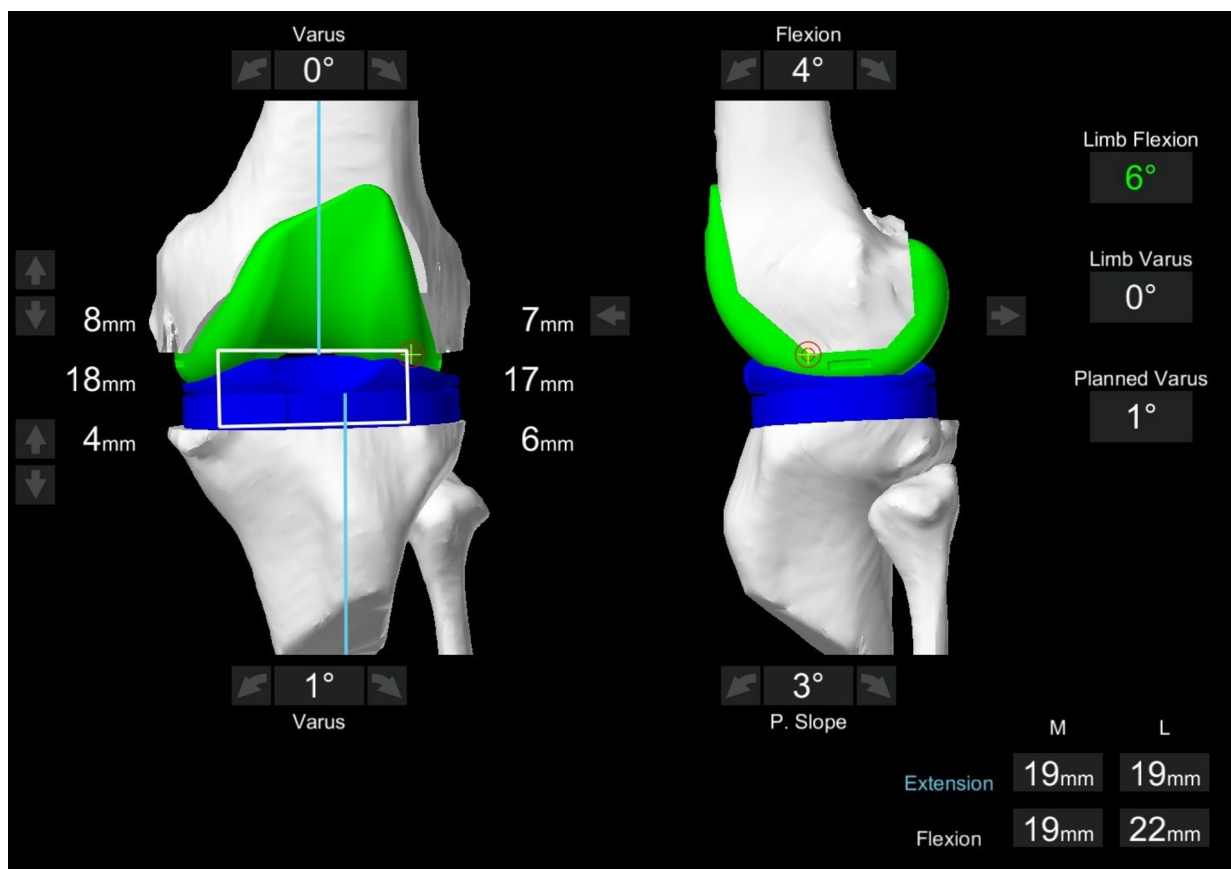
ethics board approval (AMH–DNB-054/08-22) and participant consents were obtained for the study.

A preoperative CT was performed in all patients and three-dimensional templating was done using the robotic system. All procedures were undertaken at a tertiary care hospital by a single surgeon. A medial parapatellar arthrotomy was utilized. The cruciate ligaments were sacrificed and a limited medial capsular release that was necessary for adequate exposure was performed. The landmarks required for the robotic system were captured and matched to the preoperative CT for this image based robotic system. Osteophytes were removed and the knee was balanced in extension to up to 3 degrees varus or valgus positioning of the components with respect to the mechanical axis and up to 3 degrees of varus or valgus of hip–knee–ankle angle. The knee was balanced in 90 degrees flexion by rotation of the femoral component as needed to achieve a balanced flexion gap. Equal flexion and extension gaps were aimed for by varying the position (antero-posterior) and size of the femoral component, with acceptance of up to 3–4 mm lateral laxity in 90 degree flexion. If the knee could not be balanced within these limits of component positioning, additional soft tissue

releases were performed to achieve balance in extension and 90 degrees flexion. Once balancing was done, femoral and tibial bone cuts were performed using robotic assistance. Trial components were placed and balancing conformed in extension and flexion before final component cementation.

After cementation of the components (posterior stabilized femoral component and fixed bearing tibial component), the UC and PS trial inserts were sequentially placed, and measurements made. The robotic system has the capability to display a view of the knee with TKR components as viewed from both the anterior and lateral aspects (Fig. 2). The image of the view from the lateral aspect was recorded and used for further analysis. With a holding suture on the arthrotomy, the knee was slowly moved through the range of motion and images were captured at 0, 45°, 90° and 120° flexion with the UC trial insert in place and then with the PS trial insert in place. The maximal flexion achieved with each insert was also recorded using the robotic system. The procedure was then completed by implanting PS insert.

In each image, the lateral femoral condyle contact point on the tibia was marked. The relative distance of the femoral contact point from the anterior and posterior edges



**Fig. 2** Computerized display of TKR components with the robotic system. The view from the lateral side (on the right) was used to assess the femorotibial contact point

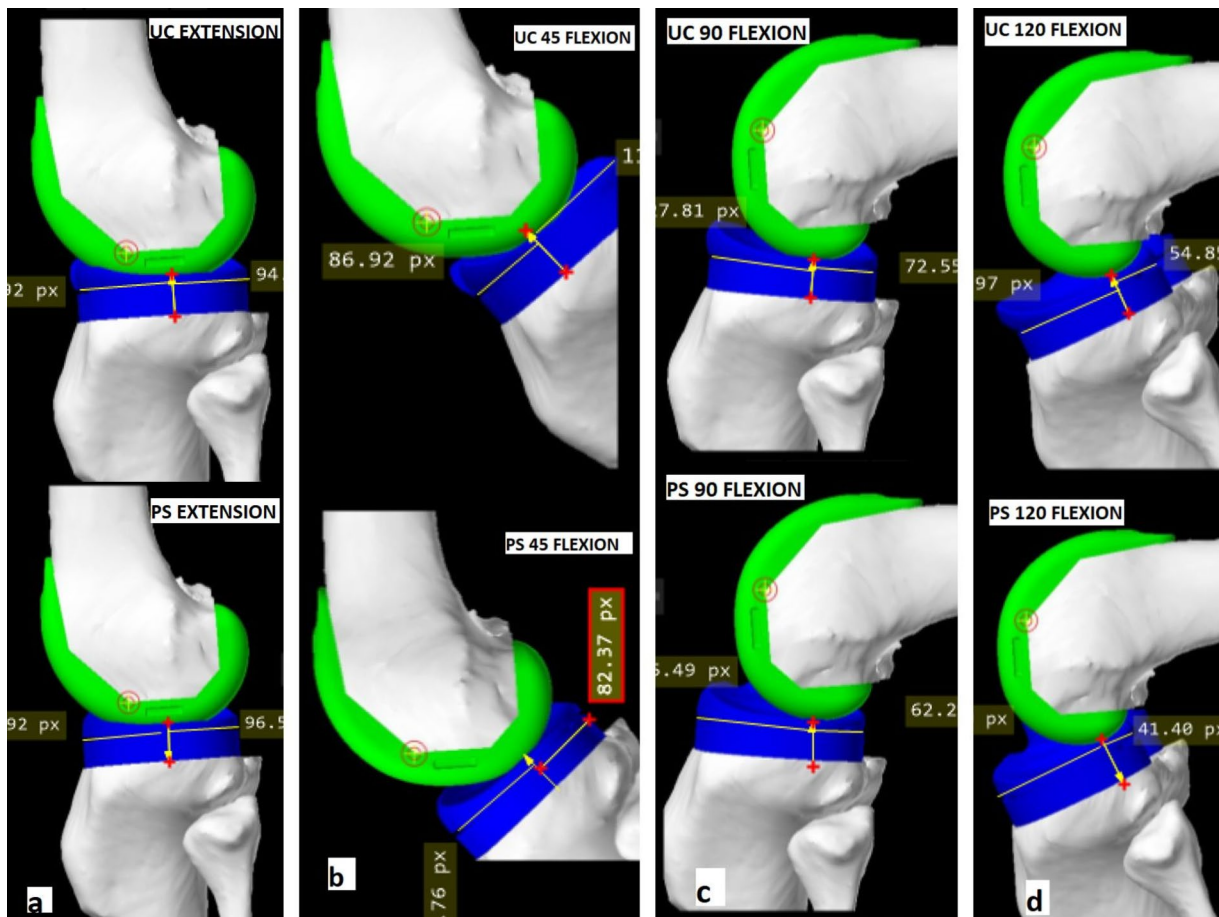
of the distal aspect of the tibial component was recorded using an image processing software (microDICOM image viewer, Microsoft). The femoral contact point on the tibia was calculated as a percentage of sagittal dimension of the tibial component with 0 representing the anterior edge and 100 representing the posterior edge of the tibial component. This method, rather than absolute distance in millimetres, was used to ensure comparability across various implant sizes (Fig. 3). The contact point values were calculated by two independent blind observers at two different time points 2 months apart to ensure inter-observer reliability.

Sample size was calculated using an online application (Select statistical services, Exeter, UK). To detect a difference of 5% in the posterior femoral roll back between the two groups with a confidence interval of 95% and power of 80%, the estimated sample size was 20. Data were collected and entered in Microsoft Excel. The statistical analysis was done by using GraphPad (Dotmatix, Boston, Massachusetts) online application. The mean femoral contact point at each flexion angle was compared between UC and PS inserts

using paired *t* test. *p* value of  $<0.05$  was taken as statistically significant.

## Results

In extension, UC inserts had a significantly posterior contact point as compared to PS inserts ( $56.3 \pm 4.3$  vs  $53.5 \pm 5.3$ ,  $p=0.003$ ). At 45 degrees flexion, UC inserts had a significantly anterior contact point as compared to PS inserts ( $49.2 \pm 5.9$  vs  $56.8 \pm 5.7$ ,  $p=0.0001$ ) (Table 1). Between 0 and 45° flexion, a paradoxical anterior translation of more than 5% was noted with 13 of 20 UC inserts, as compared to none in the PS group (Fig. 4). Between 45 and 90° flexion, both UC and PS inserts showed consistent posterior femoral rollback with PS inserts having a more posterior contact point as compared to UC inserts at 90-degree flexion ( $63.5 \pm 6.2$  vs  $67.2 \pm 5.1$ , 0.008, Table 1). At 120° flexion, there was no significant difference in the contact point between UC and PS inserts ( $70.1 \pm 8.4$  vs  $71.3 \pm 8.4$ ,  $p=0.128$ , Fig. 4). The mean maximal flexion with UC and

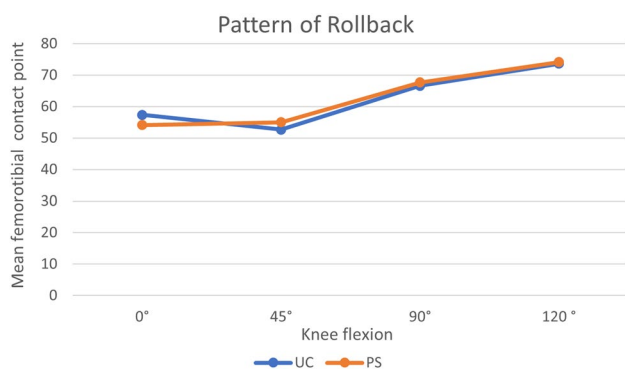


**Fig. 3** Illustration of the femorotibial contact points for UC (top row) and PS (bottom row) inserts for the same knee in extension (a), 45 degrees flexion (b), 90 degrees flexion (c) and 120 degrees flexion (d)

**Table 1** Mean femoral contact point on tibia at different knee flexions\*

Flexion	UC	PS	<i>p</i> value
0	56.3	53.5	0.003
45	49.2	56.8	0.0001
90	63.5	67.2	0.008
120	70.1	71.3	0.128

\*Femoral contact point is expressed as a percentage of sagittal dimension of the tibial component with 0 representing the anterior edge and 100 representing the posterior edge of the tibial component



**Fig. 4** Comparison of femorotibial contact points compared between UC and PS inserts. The paradoxical anterior translation between 0- and 45-degree flexion with UC inserts is seen

PS inserts were 130° (SD=6.87) and 133° (SD=6.72), respectively (*p*=0.0001).

### Discussion

Ultracongruent inserts have been proposed as alternative to posterior stabilized designs with theoretical advantages of bone preservation in the distal femur and reduced risk of intraoperative fracture[7]. Whether UC inserts can replicate the kinematics of the PS knee, particularly femoral roll back and knee flexion, is not well established in current literature. The Literature is conflictive in this regard. Several studies have shown comparable clinical outcomes between UC and PS TKRs [10–13]. Several studies have evaluated the kinematics of UC inserts but only a few have analysed the pattern of rollback in fixed bearing UC TKRs [11, 14]. In our study, UC inserts produced similar intraoperative posterior femoral rollback as PS inserts in deep flexion.

In deep flexion of 120 degrees, we observed similar posterior rollback between UC and PS inserts. Here, we differ from the findings of Fritzsche et al. who have noted that in deep flexion, UC inserts have less posterior rollback as

compared to PS inserts [15]. The differences in design of the UC insert may have played a role in this. The UC insert used in our study has an elevated anterior lip while the posterior lip remains the same as a PS insert (Fig. 1). Some UC inserts have an elevated posterior lip as well, and this may be a factor in limiting rollback in deep flexion in such designs. The UC insert used in our study lacks an elevated posterior lip and this may have allowed posterior rollback similar to the PS inserts. The equivalent posterior rollback provided by UC inserts in our study is consistent with the results seen on isokinetic testing by Akti et al. [8].

In extension, we noted a more posterior contact point for UC inserts as compared to the PS inserts. This has been noted by previous studies [15] and is attributable to the elevated anterior lip in UC inserts. However, at midflexion angle of 45 degrees, UC inserts had a more anterior contact point than PS inserts. This combination of a more posterior contact in extension and a more anterior contact point in 45-degree flexion resulted in a midflexion paradoxical anterior translation of more than 5% of the anteroposterior width in 13 out of 20 knees with UC inserts. A paradoxical anterior translation in midflexion was not seen in any of the knees with PS inserts. Our results showing paradoxical anterior translation with UC inserts is consistent with prior studies that have shown this phenomenon in mobile bearing [16] as well as fixed bearing [15] UC inserts. One plausible explanation for this paradoxical translation during early flexion could be a more posterior initial contact point in extension in the UC insert group due to the anteriorly elevated lip as compared to less conforming geometry of the PS insert. Hence, as the knee goes into mid flexion, both PS and UC inserts achieve similar contact points at 45 degrees flexion after a small paradoxical anterior translation in the UC insert group. While UC inserts have shown good midterm clinical outcomes [17], the effect of this paradoxical anterior translation in midflexion on wear and long term implant survival remains to be seen.

Between 45 and 90 degrees of flexion both UC and PS inserts exhibited consistent posterior femoral rollback. It is in this degree of flexion where the cam-post mechanism of the PS design comes into play and ensures rollback of the femur. The UC inserts, in the absence of PCL, were able to achieve posterior rollback in this range of flexion.

We observed a 3-degree difference in maximal knee flexion between UC and PS inserts. In comparison, Fritzsche et al. noted a 5-degree lower mean flexion with UC inserts compared to PS inserts [15]. Posterior femoral rollback is one of the variables affecting maximal knee flexion. In our study, the rollback achieved with UC inserts in deep flexion was comparable to PS inserts. This likely explains the low difference in maximal flexion between UC and PS inserts in our study. Lutzner et al. in their randomized controlled trial between UC and PS TKR found the no difference in

intraoperative maximal flexion between the two groups with mean intraoperative ROM being 125.2° (SD 9.6°) in the UC group and 127.3° (SD 9.3°) in the PS group [11].

**Limitations:** Our study is based on intraoperative findings and does not account for the dynamic changes that happen in vivo during activities. Dynamic muscle forces can affect the balance and rollback that happen during daily activities. Our study has a small sample size is based on one specific design of UC insert used with a single radius femoral component and this may not be generalizable to all TKR designs with UC inserts. Thirdly, we used a functional alignment philosophy with robotic assistance that is a middle path between mechanical and kinematic alignment principles. Whether these findings are applicable to knees with strict mechanical or kinematic alignment is unknown. We utilized trial PS and UC inserts to record the intra-operative biomechanics on the robotic system. The trial inserts are geometrically identical to the actual inserts but have different material characteristics and this can be a potential confounding factor when assessing the biomechanics, and hence is another limitation of our study.

Several studies have shown comparable clinical outcomes with UC and PS TKR with satisfactory short and mid-term results [11–13, 18]. The observed kinematic distinctions between the two designs do not appear to exert any discernible impact on clinical outcomes in the short to mid-term. Consequently, it can be inferred that UC TKR stands as a viable alternative to the well-established PS TKR design. Nevertheless, a more extended study is imperative to assess potential implications on polyethylene wear, warranting a comprehensive exploration of long-term results.

## Conclusions

Our study shows that UC inserts achieve posterior femoral rollback similar to PS TKR in deep flexion and lends credence to their usage as an alternative to PS designs. The difference in maximal intraoperative flexion between UC and PS inserts is small and unlikely to represent a clinically consequential difference. However, majority of UC inserts exhibited paradoxical anterior translation in mid-flexion; its effect on wear and clinical outcomes needs further analysis.

**Author Contributions** MST carried out execution of the study, data collection and analysis; DG carried out data analysis, drafted and edited the manuscript; AK conceived the study idea and design, carried out the surgical procedures and editing of manuscript.

**Funding** None.

**Data availability** The data supporting the findings of this study are available from the corresponding author upon reasonable request. Access to the data may be subject to institutional approval.

## Declarations

**Conflict of Interest** Muhammed Shafi Thekkumpurath, Devansh Goyal & Arun Kannan declare that they have no conflict of interest.

**Ethical Approval** Cleared by Institutional Ethics board (Application number: AMH – DNB-054/08-22).

**Informed Consent** For this type of study informed consent is not required.

**Consent to Participate** All patients provided informed consent to participate in this study.

**Consent for Publication** All participants provided informed consent for the publication of this study.

## References

1. Insall, J., Scott, W. N., & Ranawat, C. S. (1979). The total condylar knee prosthesis. A report of two hundred and twenty cases. *The Journal of Bone & Joint Surgery*, 61, 173–80.
2. Insall, J. N., Lachiewicz, P. F., & Burstein, A. H. (1982). The posterior stabilized condylar prosthesis: a modification of the total condylar design. Two to four-year clinical experience. *The Journal of Bone & Joint Surgery*, 64, 1317–23.
3. Scott, R. D. (1982). Duopatellar total knee replacement: The Brigham experience. *Orthopedic Clinics of North America*, 13, 89–102.
4. Dennis, D. A., Komistek, R. D., Mahfouz, M. R., Haas, B. D., & Stiehl, J. B. (2003). Multicenter determination of in vivo kinematics after total knee arthroplasty. *Clinical Orthopaedics & Related Research*. <https://doi.org/10.1097/01.blo.0000092986.12414.b5>
5. Alden, K. J., Duncan, W. H., Trousdale, R. T., Pagnano, M. W., & Haidukewych, G. J. (2010). Intraoperative fracture during primary total knee arthroplasty. *Clinical Orthopaedics*, 468, 90–95. <https://doi.org/10.1007/s11999-009-0876-9>
6. Vertullo, C. J., Lewis, P. L., Lorimer, M., & Graves, S. E. (2017). The effect on long-term survivorship of surgeon preference for posterior-stabilized or minimally stabilized total knee replacement: An analysis of 63,416 prostheses from the Australian orthopaedic association national joint replacement registry. *Journal of Bone and Joint Surgery. American Volume*, 99, 1129–1139. <https://doi.org/10.2106/JBJS.16.01083>
7. Ng, J. W. G., Bloch, B. V., & James, P. J. (2019). Sagittal radius of curvature, trochlea design and ultracongruent insert in total knee arthroplasty. *EFORT Open Reviews*, 4, 519–524. <https://doi.org/10.1302/2058-5241.4.180083>
8. Akti, S., Karakus, D., Sezgin, E. A., & Cankaya, D. (2021). No differences in clinical outcomes or isokinetic performance between cruciate-substituting ultra-congruent and posterior stabilized total knee arthroplasties: A randomized controlled trial. *Knee Surgery Sports Traumatology Arthroscopy Official Journal ESSKA*, 29, 3443–3449. <https://doi.org/10.1007/s00167-020-06275-z>
9. Dhand, N. K., & Khatkar, M. S. Statulator: An online statistical calculator. Sample size calculator for comparing two paired means (2014)
10. Bae, J.-H., Yoon, J.-R., Sung, J.-H., & Shin, Y.-S. (2018). Posterior-stabilized inserts are preferable to cruciate-substituting ultra-congruent inserts due to more favourable kinematics and stability. *Knee Surgery, Sports Traumatology, Arthroscopy*, 26, 3300–3310. <https://doi.org/10.1007/s00167-018-4872-z>

11. Lützner, J., Beyer, F., Dexel, J., Fritzsche, H., Lützner, C., & Kirschner, S. (2017). No difference in range of motion between ultracongruent and posterior stabilized design in total knee arthroplasty: A randomized controlled trial. *Knee Surgery, Sports Traumatology, Arthroscopy*, *25*, 3515–3521. <https://doi.org/10.1007/s00167-016-4331-7>
12. Scott, D. F. (2018). Prospective randomized comparison of posterior-stabilized versus condylar-stabilized total knee arthroplasty: Final report of a five-year study. *Journal of Arthroplasty*, *33*, 1384–1388. <https://doi.org/10.1016/j.arth.2017.11.037>
13. Wenzel, A. N., Hasan, S. A., Chaudhry, Y. P., Mekkawy, K. L., Oni, J. K., & Khanuja, H. S. (2023). Ultracongruent designs compared to posterior-stabilized and cruciate-retaining tibial inserts – what does the evidence tell us? A systematic review and meta-analysis. *Journal of Arthroplasty*, *38*, 2739–2749.e7. <https://doi.org/10.1016/j.arth.2023.05.064>
14. Fritzsche, H., Beyer, F., Postler, A., & Lützner, J. (2018). Different intraoperative kinematics, stability, and range of motion between cruciate-substituting ultracongruent and posterior-stabilized total knee arthroplasty. *Knee Surgery, Sports Traumatology, Arthroscopy*, *26*, 1465–1470. <https://doi.org/10.1007/s00167-017-4427-8>
15. Fritzsche, H., Beyer, F., Postler, A., & Lützner, J. (2018). Different intraoperative kinematics, stability, and range of motion between cruciate-substituting ultracongruent and posterior-stabilized total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA.*, *26*, 1465–1470. <https://doi.org/10.1007/s00167-017-4427-8>
16. Kim, T. W., Lee, S. M., Seong, S. C., Lee, S., Jang, J., & Lee, M. C. (2016). Different intraoperative kinematics with comparable clinical outcomes of ultracongruent and posterior stabilized mobile-bearing total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA.*, *24*, 3036–3043. <https://doi.org/10.1007/s00167-014-3489-0>
17. Dalton, P., Holder, C., Rainbird, S., & Lewis, P. L. (2022). Survivorship comparisons of ultracongruent, cruciate-retaining and posterior-stabilized tibial inserts using a single knee system design: Results from the Australian Orthopedic Association National Joint Replacement Registry. *Journal of Arthroplasty*, *37*, 468–475. <https://doi.org/10.1016/j.arth.2021.11.001>
18. Sur, Y.-J., Koh, I.-J., Park, S.-W., Kim, H.-J., & In, Y. (2015). Condylar-stabilizing tibial inserts do not restore anteroposterior stability after total knee arthroplasty. *Journal of Arthroplasty*, *30*, 587–591. <https://doi.org/10.1016/j.arth.2014.11.018>

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.