RESEARCH ARTICLE

Improved joint line and posterior offset restoration in primary total knee replacement using a robotic-assisted surgical technique: An international multi-centre retrospective analysis of matched cohorts

Ravi Popat1*, Ali Albelooshi2, Piyush Mahapatra3, Peter Bollars4, Max Ettinger5, Simon Jennings3, Jan-Louis Van den Berg6, Dinesh Nathwani1

1 Imperial College London, London, United Kingdom, 2 Mediclinic City Hospital, Dubai, UAE, 3 London North West University Healthcare NHS Trust, London, United Kingdom, 4 St Trudo Hospital, Sint Truiden, Belgium, 5 Hannover Medical School, Annastift Hospital, Hannover, Germany, 6 Busmaed Paardevlei Private Hospital, Cape Town, South Africa

* r.popat14@imperial.ac.uk

Abstract

Background

Accurate restoration of joint line height and posterior offset in primary Total Knee Arthroplasty (TKA) have been shown to be important factors in post-operative range of movement and function. The aim of this study was to assess the accuracy of joint line and posterior offset restoration in a group of patients that underwent robotic-assisted TKA (raTKA). A matched cohort of patients that underwent a TKA using a conventional jig-based technique was assessed for comparison. The null hypothesis was that there would be no difference between groups.

Methods

This study was a retrospective analysis of a cohort of 120 patients with end-stage knee osteoarthritis that received a TKA using the Navio Surgical System (n = 60), or Conventional manual TKA (n = 60). Procedures were performed between 1 January 2019 and 1 October 2019 at six different centres. Joint line height and posterior offset was measured pre-operatively and post-operatively on calibrated weight bearing plain radiographs of the knee. Two observers performed measurements using validated measuring tools. A BMI and age-matched cohort of patients that underwent TKA using a conventional technique in the same six centres were assessed for comparison. Mean values, standard deviations and confidence intervals are presented for change and absolute change in joint line height and posterior offset. Student’s t-test was used to compare the changes between techniques.

Results

Patients that underwent robotic-assisted TKA had joint line height and posterior offset restored more accurately than patients undergoing TKA using a conventional technique. Average change from pre-operative measurement in joint line height using raTKA was
-0.38mm [95% CI: -0.79 to 0.03] vs 0.91 [0.14 to 1.68] with the conventional technique. Average absolute change in joint line height using raTKA was 1.96mm [1.74 to 2.18] vs 4.00mm [3.68 to 4.32] with the conventional technique. Average change in posterior offset using raTKA was 0.08mm [-0.40 to 0.56] vs 1.64mm [2.47 to 0.81] with the conventional technique. Average absolute change in posterior offset with raTKA was 2.19mm [1.92 to 2.46] vs 4.24mm [3.79 to 4.69] with the conventional technique. There was a significant difference when comparing absolute change in joint line height and posterior offset between groups (p < 0.01).

Conclusion

Robotic-assisted primary TKA restores the joint line height and posterior offset more accurately than conventional jig-based techniques.

Introduction

Change in anatomical joint line height can have a significant impact on post-operative function following Total Knee Arthroplasty (TKA) [1–4]. Instability associated with altered joint line is most evident in mid-flexion [1]. Change in joint line height can have a significant impact on knee flexion. Ryu et al. have demonstrated that patients with better post-operative knee flexion have had better preservation of the natural joint line [5]. This effect is potentially more significant in cruciate-retaining designs [6].

Proximal shift of the joint line can result in patella baja [7], impingement of the patella and patella tendon on the tibial component, and inefficiency of the quadriceps mechanism [8]. Distal displacement of the joint line can result in pain and subluxation [9–11]. The mechanics of the patellofemoral joint is affected by change in joint line height, with contact forces demonstrated to increase by 60% if the joint line is elevated by 10mm [8].

Functional outcomes are also influenced by change in joint line height. The seminal work by Figgie et al [12] demonstrated better functional outcomes following primary TKA when there was less than 8mm of joint line elevation. Better functional scores have been demonstrated in revision surgery when the joint line has been maintained [13].

Navigation was introduced to help surgeons achieve more accurate positioning of implants. Studies have demonstrated that computer-assisted surgery improves component alignment and mechanical axis following TKA [14–18]. Previous studies have shown that the use of computer-assisted techniques does not improve a surgeon’s ability to restore the natural joint line in primary TKA [19, 20]. Computer assisted surgery has been shown to be effective in restoring the joint line in revision surgery when compared with conventional methods [21].

The primary aim of this study was to determine whether raTKA more accurately restored joint line height when compared to TKA performed using a more conventional technique. The secondary outcome was to assess whether raTKA restored posterior offset more accurately, when compared to conventional surgery. The null hypothesis was that there would be no difference between raTKA and a conventional technique when assessing change in joint line height and change in posterior offset in TKAs.

Methodology

This study was a retrospective analysis of a cohort of patients with end-stage knee osteoarthritis. 60 patients received a TKA using the Navio Surgical System between 1 January and 1
October 2019 at six different centres in five countries (Imperial College Healthcare NHS Trust, London, UK; London North West University Healthcare NHS Trust, London, UK; Hannover Medical School, Annastift Hospital, Hannover, Germany; St Trudo Hospital, Sint Truiden, Belgium; Busmaed Paardevlei Private Hospital, Cape Town, South Africa, Mediclinic City Hospital, Dubai, UAE). A BMI and age-matched cohort of 60 patients that underwent TKA using a conventional technique in the same six centres were assessed for comparison.

Pre- and post-operative images (weight bearing and calibrated antero-posterior (AP) and lateral radiographs) for all 120 patients were accessed by the authors, or members of their team retrospectively. Images were then anonymised before being sent to the observers (RP and PM). Images were accessed on 1 December 2019. Computer software Osirix (Pixmeo, Bernex, Switzerland) was used to perform measurements. Joint line height was measured on pre-operative and post-operative radiographs using the Imperial Joint Line Congruency Measurement (IJLCM) Technique [22] (Figs 1 and 2). Posterior offset was measured using the technique described by Bellemans et al [23] (Fig 3). All pre-operative and post-operative images were reviewed by two Orthopaedic Surgeons. Both observers performed two full sets of measurements separately. Each set of measurements was performed two weeks apart.

Radiographic quality
All patients underwent weightbearing AP and lateral plain radiography of the affected knee joint before and after joint replacement. All radiographic images were reviewed by both observers to ensure adequate image quality and rotational profile. Exclusion criteria included images where accurate calibration could not be performed (using calibration disc on pre-operative radiographs and the tibial keel on post-operative radiographs), patients with a fixed flexion deformity pre- or post-operatively (as these deformities affect joint line height measurements), images where the most proximal point on the fibula was not visible and images where the longitudinal axis of the tibia could not be determined (i.e where tibial metaphysis and diaphysis were not visible). True lateral radiographs were required to measure posterior offset (both femoral condyles being superimposed, giving the appearance of a single femoral condyle). If any images were deemed to be inadequate, all other images belonging to the same patient were excluded from analysis and a replacement patient was found.

Formulae for the IJLCM technique
Change in joint line height =
Post-operative joint line height (mm)–pre-operative joint line height (mm)
Negative values indicate depression of the joint line height.

Formulae for the measuring change in posterior offset
Change in posterior offset =
Post-operative posterior offset (mm)–pre-operative posterior offset (mm)
The study adheres to the 1964 Helsinki declaration and its later amendments. Institutional approval was given for the retrospective assessment and analysis of medical records and radiographic images by Imperial College Healthcare NHS Trust (Reference: TRA_183) where all image and statistical analysis was performed. All radiographic images assessed as part of the study were anonymised prior to being sent for analysis at Imperial College Healthcare NHS Trust. Institutional approval was not requested from the other participating units. Institutional approval did not require patient consent for retrospective analysis of anonymised radiographic images.


**Surgical technique.** Conventional jig-based TKA was performed using intra-medullary or extra-medullary cutting guides. Gap balancing, stability and patella tracking was checked initially with trial components prior to final components being implanted.

raTKA was performed using the NAVIO Surgical System. Anatomical landmarks were registered to determine the centre of rotation of the hip and the centre of the knee and ankle. The size and position of the femoral condyles, tibial plateau and tibial slope was measured. Ligamentous laxity in each knee was also assessed. Bone cuts were performed using a surgical saw or burr and were verified. The final leg axis, stability, gap balancing and range of movement was assessed with trial components prior to final components being cemented into position.

---

**Fig 1. Pre-operative IJLCM technique.** Assessment of pre-operative joint line height calculated as the average value of the tibial height and femoral height on the least affected side. TibAx1 = the intramedullary axis of the tibia, PF1 = a line perpendicular to TibAx1 at the level of the most proximal point of the proximal fibula.

https://doi.org/10.1371/journal.pone.0272722.g001
Statistical analysis. All data were analysed using Statistical Package for Social Sciences version 26 (SPSS, Version 26 IBM Corp, 2019. IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp). All data sets were found to be normally distributed using a Shapiro-Wilk test.

Fig 2. Post-operative JILCM technique. Assessment of post-operative joint line height calculated as the average value of the Lateral Femoral Condyle (LFC) Height and the Medial Femoral Condyle (MFC) Height.

https://doi.org/10.1371/journal.pone.0272722.g002
The difference (positive values denoting an elevation in joint line height, or an increase in posterior offset) and absolute difference (non-negative values for the calculated change in joint line height and posterior offset) between pre-operative and post-operative joint line height was calculated. Average values, standard deviations and variance were calculated for each observer. Student’s T Test was used to assess for differences between Conventional and raTKA.

**Results**

Patient characteristics between groups are shown in Table 1. The inter and intra-observer reliability of the joint line height measurements was found to be >0.92 for pre-operative and post-operative radiographs.

**Change in joint line height**

As shown in Tables 2 and 3, and demonstrated graphically in Fig 4, the absolute difference in joint line height was smaller in the raTKA group. Change in joint line height was <1mm in 17 (28.3%) patients, <2mm in 27 (45.0%) patients and <5mm (100%) in all patients in the raTKA group. Change in joint line height was <1mm in 3 (5.0%) patients, <2mm in 10 (16.7%) patients and <5mm in 43 (71.7%) patients for patients in the conventional TKA group. 17 (28.3%) patients had a change in joint line height greater than 5mm.

**Change in posterior offset**

As shown in Tables 4 and 5, and demonstrated graphically in Fig 5, the absolute difference in posterior offset was smaller in the raTKA group. Change in posterior offset was <1mm in 22 (35.0%) patients, <2mm in 3 (60.0%) patients and <5mm (100%) in all patients in the raTKA group. Change in posterior offset was <1mm in 4 (6.7%) patients, <2mm in 5 (8.3%) patients and <5mm in 42 patients (70.0%). 18 (30.0%) patients had a change in posterior offset greater than 5mm.

**Discussion**

**Change in joint line height–raTKA vs conventional technique**

The most important outcome from this study is that raTKA (using the NAVIO Surgical System) restores the pre-operative joint line in TKA more accurately than when the procedure is performed using a conventional jig-based techniques.

Furthermore, all patients in the raTKA group had their joint line height restored to within 5mm of the pre-operative level. With conventional TKA techniques, joint line height changes were more than 5mm in approximately 30% of patients.

No outcome scores were collected as part of this study. Previous studies have demonstrated a link between joint line height restoration and clinical outcomes. Van Lieshout et al have presented a systematic review demonstrating a statistically significant negative correlation between joint line elevation and post-operative Knee Society Scores (p<0.001) [3]. A deviation of more than 2mm in joint line height has also been shown to have a negative impact on post-operative range of movement [1, 4, 5, 24, 25].

Previous studies have assessed whether raTKA improved joint line height restoration. Jawhar et al used the measurement technique described by Snider & Macdonald [19, 26]. Average change in joint line height was reported as 0.6mm. There was no difference in joint line height restoration between conventional TKA and raTKA. The authors used a measurement tool with an accuracy of 1mm which may lead to inaccuracies in the results presented. Babazadeh et al presented the result of a randomised controlled trial in a smaller cohort than is
Fig 3. Posterior offset measurement. Diagram showing the measurement of posterior condylar offset (A) before and (B) after operation.

https://doi.org/10.1371/journal.pone.0272722.g003
Table 1. Patient demographics.

| Characteristics       | Conventional TKA       | raTKA          | p-value |
|-----------------------|------------------------|----------------|---------|
| Age (range)           | 65.9 (46.3–88.2)       | 66.75 (47.2–85.5) | 0.30    |
| BMI (range)           | 29.7 (18.1–45.2)       | 30.2 (18.4–44.1) | 0.34    |
| Side (R/L)            | 27/33                  | 24/36          | 0.12    |
| Sex (M/F)             | 31/29                  | 29/32          | 0.61    |
| Pre-op anatomical axis| 4.4˚ valgus            | 4.8˚ valgus    | 0.52    |

Table 2. Absolute difference values in change in joint line height between techniques.

|                      | Conventional Technique (mm) | raTKA (mm)    |
|----------------------|-----------------------------|--------------|
| Absolute Difference  | 4.00 ± 1.81                 | 1.96 ± 1.21  |

Table 3. Student t test for change in joint line height with raTKA and conventional TKA.

| Observer 1 | p Value for Absolute Difference |
|------------|---------------------------------|
| Measurement a | p < 0.01                       |
| Measurement b | p < 0.01                       |
| Combined Measurements | p < 0.01                   |

| Observer 2 | p Value for Absolute Difference |
|------------|---------------------------------|
| Measurement a | p < 0.01                       |
| Measurement b | p < 0.01                       |
| Combined Measurements | p < 0.01                   |

Fig 4. Boxplot for absolute change in joint line height using conventional TKA and Navio TKA.
presented in this study [20]. The authors used an imageless computer navigation system (Ci System, Depuy) and demonstrated no significant difference when change in joint line height when compared with conventional TKA.

Herry et al demonstrated that raUKA enabled more accurate restitution of joint line height in unicompartmental knee replacements (1.4mm ± 2.6mm vs 4.7mm ± 2.4mm (p<0.05) [27]. Kawamura et al presented 73 TKAs with an average joint line elevation of 3.5mm [28], Ritter et al. demonstrated changes of 2.6mm and 2.8mm [29] and Wyss et al. reported on 106 TKAs implants using a soft tissue balancing technique where the average joint line change was 0.3mm [24].

Other authors have attempted to measure joint line height on lateral radiographs. The seminal work by Figgie et al. demonstrated an average change in joint line of 8.9mm following primary conventional TKA. The measuring technique has subsequently been demonstrated to have relatively poor inter and intra-observer reliability [22].

**Change in posterior condylar offset—Navio and conventional technique**

This study demonstrates that raTKA enables restoration of posterior condylar offset more accurately than with conventional techniques. Furthermore, all patients in the raTKA group had their posterior condylar offset restored to within 5mm of the pre-operative level. With conventional TKA techniques, posterior condylar offset was more than 5mm different in approximately 30% of patients.

Restoration of the posterior condylar offset contributes to stability and range of movement following TKA. Goutham et al. [30] demonstrated that alteration of PCO by more than 3mm had a negative impact on post-operative range of movement in cruciate-retaining TKA. Change of PCO did not impact ROM in cruciate-sacrificing TKA. Further studies have investigated the impact of change in PCO on ROM with variable results [23, 31–34].

This study had its limitations which included the use of short-leg AP and lateral radiographs. All images were reviewed by both observers for appropriateness. Furthermore, this study did not report patient reported outcomes or functional outcomes. The aim of this paper was to assess how accurately joint line height and posterior condylar offset is restored using different techniques, hence the other outcomes, although important clinically, are not relevant to this study. Due to the different methods used to measure joint line height in the literature, it

| Observer 1 | p Value for Absolute Difference |
|------------|--------------------------------|
| Measurement a | p < 0.01                        |
| Measurement b | p < 0.01                        |
| Combined Measurements | p < 0.01                    |

| Observer 2 | p Value for Absolute Difference |
|------------|--------------------------------|
| Measurement a | p < 0.01                        |
| Measurement b | p < 0.01                        |
| Combined Measurements | p < 0.01                    |
is difficult to compare our findings with those of other authors. Previous work has demonstrated the accuracy, precision and reliability of the measurement technique utilised in this study [22].

Conclusion
The NAVIO Surgical System has been shown to help surgeons reproduce the native joint line height and posterior-offset in TKA with greater accuracy than is possible with conventional techniques.

Supporting information
S1 Data.
(XLSX)

Author Contributions
Conceptualization: Ravi Popat, Dinesh Nathwani.
Data curation: Ali Albelooshi, Piyush Mahapatra.
Formal analysis: Ravi Popat, Piyush Mahapatra.
Investigation: Ravi Popat, Ali Albelooshi, Peter Bollars, Max Ettinger, Simon Jennings, Jan-Louis Van den Berg, Dinesh Nathwani.
Methodology: Ravi Popat, Piyush Mahapatra.
Supervision: Dinesh Nathwani.
Writing – original draft: Ravi Popat.
Writing – review & editing: Dinesh Nathwani.
References

1. Martin JW, Whiteside LA. The influence of joint line position on knee stability after condylar knee arthroplasty. Clin Orthop Relat Res. 1990 PMID: 2208849
2. Rota A, De Santis P, Rota P, Aureli A. Joint line restoration after primary and revision total knee arthroplasty. J Orthop Traumatol. 2013; 1
3. van Lieshout WAM, Valkering KP, Koenraadt KLM, van Etten-Jamaludin FS, Kerkhoffs GMMJ, van Geenen RCI. The negative effect of joint line elevation after total knee arthroplasty on outcome. Vol. 27, Knee Surgery, Sport Traumatol Arthrosc. 2019.
4. Partington PF, Sawyer J, Rorabeck CH, Barrack RL, Moore J. Joint line restoration after revision total knee arthroplasty. Clin Orthop Relat Res. 1999. PMID: 10546611
5. Ryu J, Saito S, Yamamoto K, Sano S. Factors influencing the postoperative range of motion in total knee arthroplasty. Vol. 53, Bulletin: Hosp Joint Dis. 1993. PMID: 8012266
6. Emodi GJ, Callaghan JJ, Pederse DR, Brown TD. Posterior cruciate ligament function following total knee arthroplasty: the effect of joint line elevation. Iowa Orthop J. 1999; 19. PMID: 10847521
7. Grelsmager RP. Patella baja after total knee arthroplasty: Is it really patella baja? J Arthroplasty. 2002; 17(1). https://doi.org/10.1016/s0883-5403(11)80013-6 PMID: 1875209
8. Konig C, Sharenkov A, Matziolis G, Taylor WR, Perka C, Duda GN, et al. Joint line elevation in revision TKA leads to increased patellofemoral contact forces. J Orthop Res. 2010; 28(1). https://doi.org/10.1002/jor.20952 PMID: 19637213
9. Yoshii I, Whiteside LA, White SE, Milliano MT. Influence of prosthetic joint line position on knee kinematics and patellar position. J Arthroplasty. 1991; https://doi.org/10.1016/s0883-5403(11)80013-6 PMID: 1875209
10. Insall J, Goldberg V, Salvati E. Recurrent dislocation and the high-riding patella. Clin Orthop Relat Res. 1972; https://doi.org/10.1097/00003086-197210000-00012 PMID: 5085683
11. Cope MR, O’Brien BS, Nunu AM. The influence of the posterior cruciate ligament in the maintenance of joint line in primary total knee arthroplasty: A radiologic study. J Arthroplasty. 2002; 17(2). https://doi.org/10.1054/arth.2002.29396 PMID: 11847621
12. Figgie HE, Goldberg VM, Heiple KG, Moller HS, Gordon NH. The influence of tibial-patellofemoral location on function of the knee in patients with the posterior stabilized condylar knee prosthesis. J Bone Jt Surg—Ser A. 1986; PMID: 3745240
13. Porteous AJ, Hassaballa MA, Newman JH. Does the joint line matter in revision total knee replacement?. J Bone Joint Surg Br. 2008; 90(7):879–84. https://doi.org/10.1302/0301-620X.90B7.20566 PMID: 18591596
14. Mason JB, Fehring TK, Estok R, Banel D, Fahrbach K. Meta-Analysis of Alignment Outcomes in Computer-Assisted Total Knee Arthroplasty Surgery. J Arthroplasty. 2007; 22(8). https://doi.org/10.1016/j.arth.2007.08.001 PMID: 18078876
15. van der List JP, Chawla H, Joskowicz L, Pearle AD. Current state of computer navigation and robotics in unicompartimental and total knee arthroplasty: a systematic review with meta-analysis. Vol. 24, Knee Surgery, Sport Traumatol Arthrosc. 2016. https://doi.org/10.1007/s00167-016-4305-9 PMID: 27600634
16. Shihab Z, Clayworth C, Nara N, Handheld, accelerometer-based navigation versus conventional instrumentation in total knee arthroplasty: a meta-analysis. ANZ J Surg. 2020; 90(10). https://doi.org/10.1111/ans.15925 PMID: 32479702
17. Thienpont E, Fennema P, Price A. Can technology improve alignment during knee arthroplasty. Knee. 2013. https://doi.org/10.1097/knee.0b013e32836c0fba PMID: 24034591
18. Shatrov J, Parker D. Computer and robotic–assisted total knee arthroplasty: a review of outcomes. Vol. 7, J Exp Orth. 2020. https://doi.org/10.1186/s40634-020-00278-y PMID: 32974864
19. Jawhar A, Shah V, Sohoni S, Scharf HP. Joint line changes after primary total knee arthroplasty: Navigated versus non-navigated. Knee Surgery, Sport Traumatol Arthrosc. 2013; https://doi.org/10.1007/s00167-013-2580-2 PMID: 23794005
20. Babazadeh S, Dowsey MM, Swan JD, Stoney JD, Choong PFM. Joint line position correlates with function after primary total knee replacement: A randomised controlled trial comparing conventional and computer-assisted surgery. J Bone Jt Surg—Ser B. 2011; https://doi.org/10.1302/0301-620X.93B9.26950 PMID: 21911534
21. de Ladoucette A. Computer-assisted revision of total knee arthroplasty. Knee Surgery, Sport Traumatol Arthrosc. 2009; 17(10). https://doi.org/10.1007/s00167-009-0769-1 PMID: 19305973
22. Popat R, Dhillon K, Mahapatra P, Khan H, Nathwani D. The Imperial Joint Line Congruency Measurement is a valuable tool in total knee arthroplasty. PLoS One. 2021; 16(9):e0257325. https://doi.org/10.1371/journal.pone.0257325 PMID: 34506586
23. Bellemans J, Banks S, Victor J, Vandenneucker H, Moemans A. Fluoroscopic analysis of the kinematics of deep flexion in total knee arthroplasty. Influence of posterior condylar offset. J Bone Joint Surg Br. 2002; https://doi.org/10.1302/0301-620X.84b1.12432 PMID: 11837832

24. Wyss TF, Schuster AJ, Münger P, Pfleger D, Wehrli U. Does total knee joint replacement with the soft tissue balancing surgical technique maintain the natural joint line? Arch Orthop Trauma Surg. 2006; https://doi.org/10.1007/s00402-006-0171-0 PMID: 16799793

25. Hofmann AA, Kurtin SM, Lyons S, Tanner AM, Bolognesi MP. Clinical and Radiographic Analysis of Accurate Restoration of the Joint Line in Revision Total Knee Arthroplasty. J Arthroplasty. 2006; 21(8). https://doi.org/10.1016/j.arth.2005.10.026 PMID: 17162175

26. Snider MG, MacDonald SJ. The Influence of the Posterior Cruciate Ligament and Component Design on Joint Line Position After Primary Total Knee Arthroplasty. J Arthroplasty. 2009; https://doi.org/10.1016/j.arth.2008.08.009 PMID: 19027265

27. Herry Y, Batailler C, Lording T, Servien E, Neyret P, Lustig S. Improved joint-line restitution in unicompartmental knee arthroplasty using a robotic-assisted surgical technique. Int Orthop. 2017; 41(11). https://doi.org/10.1007/s00264-017-3633-9 PMID: 28913557

28. Kawamura H, Bourne RB. Factors affecting range of flexion after total knee arthroplasty. J Orthop Sci. 2001; https://doi.org/10.1007/s007760100043 PMID: 11484119

29. Ritter MA, Faris PM, Keating EM, Meding JB. Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res. 1994 Feb;(299):153–6. PMID: 8119010

30. Goutham GDV, Jain VK, Sinha S, Arya RK. Effect of posterior condylar offset in post operative range of motion in cruciate retaining and sacrificing TKR: A comparative analysis. J Orthop. 2020; 20. https://doi.org/10.1016/j.jor.2020.06.012 PMID: 32684670

31. Malviya A, Lingard EA, Weir DJ, Deehan DJ. Predicting range of movement after knee replacement: The importance of posterior condylar offset and tibial slope. Knee Surgery, Sports Traumatol Arthrosoc. 2009; 17(5). https://doi.org/10.1007/s00167-008-0712-x PMID: 19139846

32. Hanratty BM, Thompson NW, Wilson RK, Beverland DE. The influence of posterior condylar offset on knee flexion after total knee replacement using a cruciate-sacrificing mobile-bearing implant. J Bone Jt Surg—Ser B. 2007; 89(7). https://doi.org/10.1302/0301-620X.89B7.18920 PMID: 17673585

33. Ishii Y, Noguchi H, Takeda M, Sato J, Toyabe SI. Posterior condylar offset does not correlate with knee flexion after TKA. Clin Orthop Relat Res. 2013;471(9).

34. Voleti PB, Stephenson JW, Lotke PA, Lee G-C. No sex differences exist in posterior condylar offsets of the knee. Clin Orthop Relat Res. 2015; 473(4):1425–31. https://doi.org/10.1007/s11999-014-4066-z PMID: 25448325