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A Comparison of Classical and Anatomical Total Knee Alignment Methods in Robotic Total Knee Arthroplasty

Classical and Anatomical Knee Alignment Methods in TKA

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ABSTRACT

The purpose of this study was to compare the clinical and radiological outcomes achieved using classical and anatomical alignment methods in primary total knee arthroplasty (TKA). One hundred and seventeen patients were randomly assigned to undergo robotic-assisted TKA using either the classical (56 patients) or the anatomical alignment method (61 patients). Clinical outcomes including varus and valgus laxities, ROM, HSS and WOMAC scores and radiological outcomes were evaluated after a minimum follow-up of 2 years. Varus and valgus laxity assessments showed no significant inter-group differences ($P > 0.05$). Moreover, no significant differences were observed in ROM, HSS and WOMAC scores ($P > 0.05$). We could not find any significant difference in mechanical alignment of the lower limb. The results of this study show that two alignment methods provide comparable clinical and radiological outcomes after primary TKA.

The success of total knee arthroplasty (TKA) depends in part on the surgeon's ability to align the extremity and position components properly. Normal anatomic alignment of the tibiofemoral joint is approximately 5° to 7° of valgus, the achievement of normal alignment or valgus overall limb alignment has been reported to be an important factor for the success and longevity of TKA [1–3]. Conversely mal-alignment is considered a principle cause of early failures due to instability and patellofemoral complications [4,5], and because it contributes to later polyethylene wear or fixation failure [5].

Overall alignment of the prosthetic knee is determined by the positions of femoral and tibial components in the coronal plane of the joint. Two basic alignment methods are used for TKA. The "classical method", introduced by Insall et al [6], involves making tibial and femoral cuts perpendicular to the mechanical axis of the tibia and femur respectively, which places the joint line perpendicular to the mechanical axis. On the other hand, the "anatomical method", introduced by Hungerford et al [7], allows for the fact that the proximal tibial plateau is actually in a few degrees of varus. Originally these authors advocated a 3° varus tibial cut and 3° valgus femoral cut to the mechanical axis, thus reconstituting the joint line parallel with respect to the ground. However, other authors have reported better alignment and results with a 2° varus tibial cut rather than 3°, for the anatomical method [8–10]. In another study, Hsu et al [9] reported even load distribution in the tibial component and a smaller incidence of radiolucent lines (8%) when the anatomical alignment method was used with a cruciate retaining (CR) implant.

However, there is always a possibility of excessive varus resection of the tibia when a 3° cut is attempted and several authors have emphasized that both varus mal-alignment of the leg and varus cut greater than 3° in the proximal tibia are associated with early failure after TKA [3,11–13], which has led most surgeons to favor a perpendicular tibial cut. On the other hand, a lack of surgical accuracy can be overcome by the use of robotic technology, which has been reported to provide excellent implant positioning and alignment errors of less than 1° [14,15].

We are not aware of any previous comparative clinical study on the classical and anatomical alignment methods in robotic TKA. Accordingly, this study was undertaken to compare the clinical and radiological outcomes achieving using these two techniques.

Materials and Methods

From January 2008 to June 2009, 117 patients with a diagnosis of unilateral osteoarthritis of knee and scheduled to undergo robotic TKA, were included in this randomized prospective study and

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followed for a minimum of two years. All patients were implanted with a NexGen, cruciate-retaining (CR) prosthesis (Zimmer, Warsaw, USA) using either the classical alignment method (the classical group; 56 patients) or the anatomical alignment method (the anatomical group; 61 patients). ROBODOC (Integrated Surgical Systems, Davis, California) was used in all cases. Preoperative planning was carried out using the ORTHODOC planning program. All operations were carried out by the senior author, who had four years of robotic TKA experience. Patients in whom robotic implantation had failed and who were scheduled for manual implantation were excluded. Similarly, patients scheduled for a posterior stabilized type of implant and patients with valgus deformity were also excluded. The study was approved by the institutional review board.

Preoperative Planning

The patients underwent pinless robotic implantation, which required a helical computed tomography (CT) scan of the femoral head, distal femur, proximal tibia, and ankle. CT scan data were transferred to the ORTHODOC working station and transformed in each case into a three-dimensional reconstruction. Necessary anatomic landmarks were identified at the level of the center of the femoral head, distal femur, proximal tibia, and center of the ankle, and these were used to determine the mechanical axis. Virtual implantation of the NexGen CR prosthesis was carried out; the central axis of the implant was defined and identified, implant size was selected, and the implant was positioned into the corresponding bone. In the classical group, a perpendicular tibial cut was planned in the coronal plane with 7° of posterior slope to the mechanical axis of the tibia (Fig. 1A and B). The distal femoral cut was also planned perpendicularly to the mechanical axis, and rotational alignment of the femoral component was planned parallel to the transepicondylar axis. In the anatomical group, the tibial cut was planned at 2° of varus to the mechanical axis of the tibia (Fig. 2A and B), and the femoral cut was planned at 2° of valgus to the mechanical axis. We set rotational alignment of the femoral component at 2° of internal rotation from the transepicondylar axis. All data were saved on disc, and subsequently transferred to the ROBODOC controlling computer.

Surgery

A standard incision with medial parapatellar arthrotomy and lateral eversion of the patella were performed. The patient's leg (placed in a leg holder), was flexed and rigidly connected to the robot by two transverse Steinmann pins inserted through the proximal tibia and distal femur. These two pins were connected to a frame, which was linked to the robot. Registration was then performed using a ball tip probe, and involved the registering of bones and anatomical points and matching findings with CT data. After successful registration, ROBODOC performed intraoperative precise 3-dimensional cutting for the implant according to the preoperative plan using a milling cutter, with constant normal saline irrigation for cooling and debris removal. After the bone cuts had been made, ROBODOC was disconnected and components were manually inserted.

Soft tissue balancing was performed in a stepwise manner by releasing only what was required to achieve balance. The order of release for medial soft tissues was, as follows, the deep MCL, the posterior medial capsule, and the superficial MCL. No lateral releases were needed because no knee in this study had a valgus deformity. Patellar resurfacing was not performed in any patient, and all implants were fixed with cement.

Evaluation

All patients were evaluated preoperatively and at follow up visit using the Hospital for Special Surgery (HSS) and Western Ontario and McMaster Universities (WOMAC) scoring systems, and range of motion (ROM) assessment. Patient demographics and body mass index (BMI) were recorded preoperatively. Radiographic evaluations were performed preoperatively and postoperatively using standing full-leg radiographs to determine overall coronal plane alignment, which was determined by measuring the angle between a line

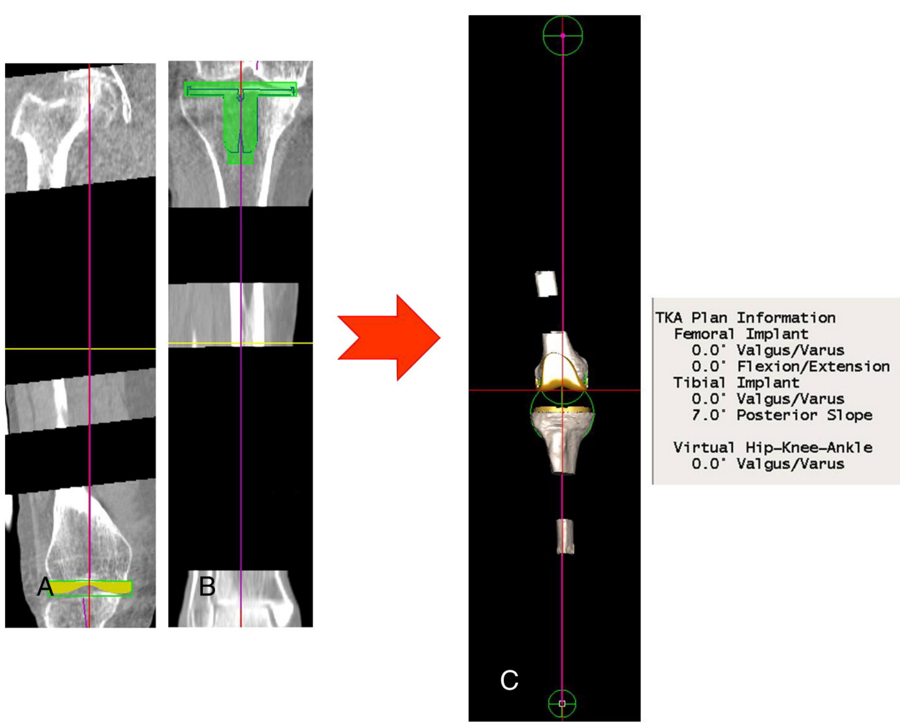

Fig. 1. Preoperative planning classical method. (A) Femoral component alignment and resection planned on CT scan data. Femoral mechanical axis (magenta line) and implant axis (red line) are parallel to each other and femoral bone cut is perpendicular to mechanical axis. (B) Tibial component alignment. Proximal tibial cut is planned at 90° to mechanical axis and implant axis is parallel to mechanical axis. (C) Virtual implant placement in knee and the final plan information.

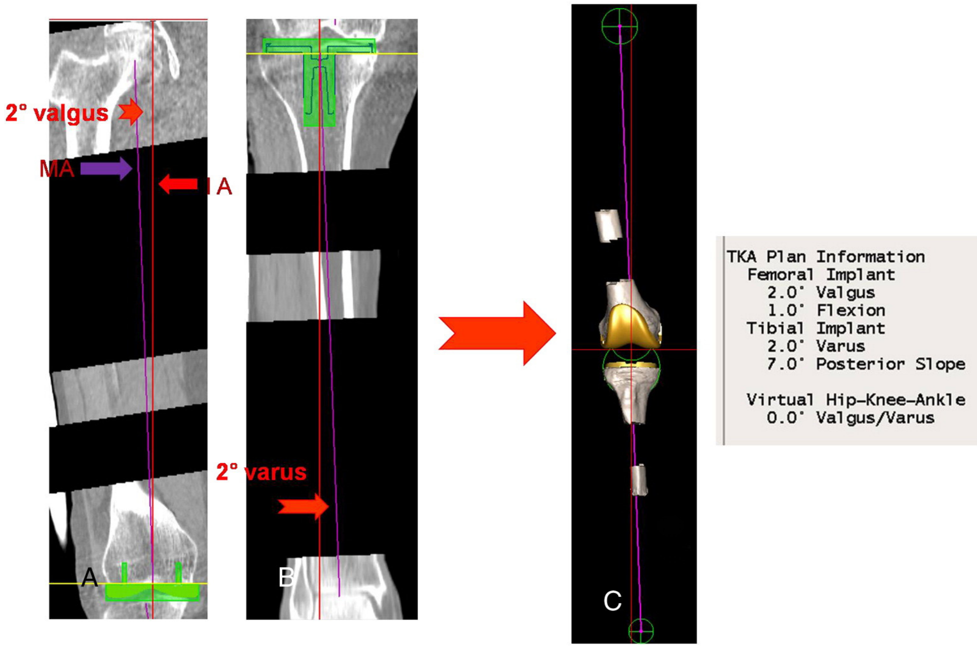

Fig. 2. Preoperative planning anatomical method. (A) Femoral component planning. Femoral bone resection planned in 2° valgus. This angle also evident between the implant axis (IA) and the mechanical axis (MA). (B) Proximal tibia bone resection in 2° varus. Note also the 2° varus angle between the MA and IA. (C) Virtual implant placement and final TKA plan information.

connecting the center of the femoral head and the center of the knee and a line connecting the center of the knee to the center of the ankle. Femoral component alignment in the coronal plane and tibial component alignment in the coronal plane were measured on standing full-leg films and defined as the angles between the respective prosthetic resection planes and the mechanical axis. In addition, we measured tibial component alignment in the sagittal plane on lateral radiograph of the knee. The PACS digital radiographic software (Infinitt Healthcare, Seoul, Korea) was used for all measurements. This software system enables precise measurements, as images can be magnified and the software tools can provide the measurement to the second decimal point.

At final follow-up visits, we determined flexion laxity as the sum of laxity to varus and valgus stress with the knee at 90° of flexion. To do so, we combined the methods described by Kanekasu et al [16] and Stahelin et al [17]. Briefly, the patient was asked to sit on a wooden

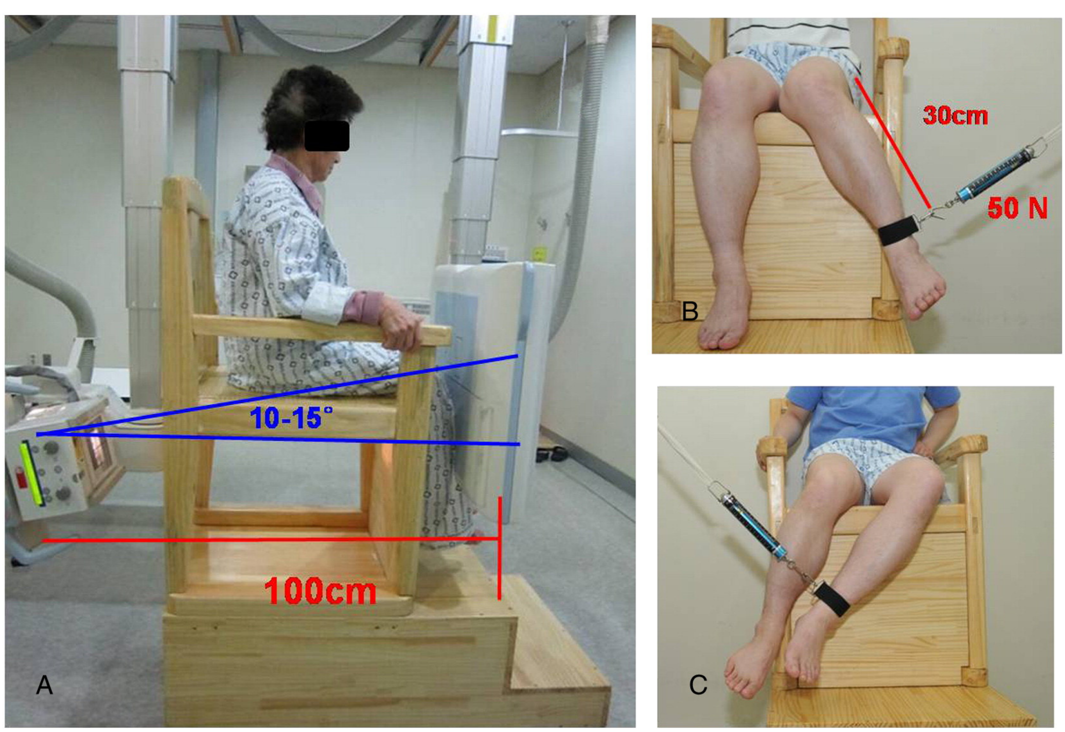

Fig. 3. Measurement of varus and valgus laxity. (A) Positioning of patient for the radiograph. Beam is projected at an angle of 10°–15° and 100 cm is the distance between the x-ray tube and film cassette. Both epicondyles, posterior condyles and joint line are clearly visible by this method. Valgus (B) and Varus (C) stress views being taken to assess the laxity. 50 Newton (N) force being used, approximately 30 cm from the joint line using a spring scale.

Table 1
Preoperative Patient Demographics.

	Classic	Anatomic	*P*-Value
Cases	56	61	
Gender (M:F)	8:48	4:57	0.32
Age (year)[e]	66.1 (51–84)	69 (58–85)	0.53
ROM[a] (°)	9.2–124.9	8.8–125.4	0.86
Mean Varus (°)	9.57	9.88	0.78
BMI[b] (kg/m^2)[e]	26.3 (20–37.2)	25.7 (18–32.5)	0.23
HSS[c,e]	56.4	56.2	0.88
WOMAC[d,e]	59.9	57.3	0.47

[a] ROM, range of motion.
[b] BMI, body mass index.
[c] HSS, hospital for special surgery score.
[d] WOMAC, Western Ontario and McMaster Universities.
[e] The values are given as the mean and range in parentheses for age and BMI.

chair with the knee in 90° of flexion. An x-ray beam was then directed 10°–15° upward at a distance of one meter from the knee (Fig. 3A). A force of 50 N was applied on 30 cm distal from the knee joint using a spring scale to obtain varus and valgus stress radiographs (Fig. 3B and C). Laxity was assessed by measuring opening angles on lateral and medial sides on varus and valgus stress radiographs, respectively. We also calculated total flexion laxity by summing valgus and varus laxities.

To determine the effect of flexion laxity on clinical outcomes, patients were dichotomized based on the amount of total flexion laxity about a cutoff of 10°, that is, laxity ≤ 10° and > 10°.

Statistical Methods

Power analysis was performed using flexion laxities of the first 20 patients (10 patients in each group). Based on the results obtained, 56 patients per group were found to be required to detect a 1.3° difference with a 2.5° standard deviation in flexion laxity between the classical and anatomical groups (power = 0.8; confidence level = 0.05).

The chi-square test was used to compare the categorical values and the independent t-test was used to analyze all other continuous variables. In addition, the independent t-test was used to compare clinical outcomes in patients with flexion laxities of ≤ 10° and > 10°. SPSS for windows (version 16; SPSS, Chicago, Illinois) was used for the analysis, and statistical significance was accepted for *P* values of <0.05.

Results

Patient Demographics

No significant difference in preoperative patient demographics, age, BMI, or mean varus deformity was evident between the classical and anatomical groups (Table 1), and group preoperative functional assessments (HSS score, WOMAC score and ROM) were not significantly different.

Table 2
Comparison of Clinical Results.

	Classic	Anatomic	*P-Value*
ROM[a] (°)	129 ± 11.5	125 ± 11.5	0.07
HSS[b] score	94.8 ± 5.5	93.2 ± 8.1	0.28
WOMAC[c] score	20.4 ± 6.7	19.3 ± 8.6	0.64

[a] ROM, range of motion.
[b] HSS, hospital for special surgery score.
[c] WOMAC, Western Ontario and McMaster Universities.

Table 3
Comparison of Radiological Results.

	Classic	Anatomic	*P-Value*
Mechanical axis (°)	−0.71 ± 1.73	−0.39 ± 2.01	0.47
Coronal inclination, femur (°)	89.5 ± 0.39	91.71 ± 1.93	0.03
tibia (°)	90.1 ± 0.37	87.48 ± 1.68	0.04
Sagittal inclination, tibia (°)	84.1 ± 0.66	85.42 ± 1.66	0.82

Clinical Assessment

At final follow up, mean ROMs in the classical and anatomical groups were 129° ± 11.5° and 125° ± 11.5° respectively. HSS and WOMAC scores at final follow-up were 94.8 ± 5.5 and 20.4 ± 1.8 points in the classical group and 93.2 ± 8 and 19.3 ± 1.9 points in the anatomical group, respectively. No significant intergroup differences were found in terms of final clinical measures (Table 2).

Radiological Assessment

Mean mechanical axes were similar in the classical and anatomical groups (−0.71° ± 1.73° (range, −3.0°–2.8°) and −0.39° ± 2.01° (range, −3.7°–3.0°), respectively; *P* = 0.76), as were tibial component alignments in the sagittal plane (*P* = 0.82) (Table 3). However, significant intergroup difference was observed in the coronal alignments of femoral and tibial components. In the classical group, femoral components were placed at 89.5° ± 0.39° while in the anatomical group they were placed at 91.71° ± 1.93° (*P* = 0.03), whereas tibial components were implanted at 90.1° ± 0.37° in the classical group and at 87.48° ± 1.68° in anatomical group with a significant difference (*P* = 0.04).

Flexion Laxity

Mean varus and valgus laxities in the classical group were 6.75° ± 3.34° and 3.49° ± 2.57°, respectively, and in the anatomical group were 5.89° ± 3.25° and 3.17° ± 2.54°, which were not significantly different (*P* = 0.16 and 0.49, respectively). Total laxity also showed no significant intergroup difference (10.3° vs. 9.1°, *P* = 0.18). No significant differences were found between knees with flexion laxities of ≤ 10° and > 10° in terms of ROM, HSS or WOMAC scores (*P* = 0.78, 0.45, and 0.31, respectively) (Table 4).

Discussion

The goal of primary total knee arthroplasty is to reestablish a normal mechanical axis using a well-fixed stable prosthesis. Jeffery et al [18] concluded that the mechanical axis should pass through the middle third of the prosthesis, and other authors have reported better results for neutral or slight valgus mechanical axis alignment [2,11,19]. Historically, total knee alignment methods have been classified as classical or anatomical alignment methods. For classical alignment methods, which are the most commonly used, the goal is to establish a joint line perpendicular to the mechanical axis. As a result, the proximal tibial cut is perpendicular to the overall tibial shaft axis, and the distal femoral cut is perpendicular to the femoral portion of

Table 4
Comparisons of Clinical Outcomes Based on the Flexion Laxity.

	Flexion laxity ≤10°	Flexion laxity >10°	*P-Value*
Number (patients)	71	46	
Range of motion (°)	131.8 ± 9.0	133.3 ± 9.8	0.78
HSS score	93.5 ± 4.9	94.2 ± 5.4	0.45
WOMAC score	15.5 ± 8.7	14.0 ± 6.5	0.31

the mechanical axis. Because the mechanical axis at the femur is oriented at an angle of from 5° to 7° of valgus relative to the femoral anatomic axis, intramedullary femoral instrumentation is used most commonly. The successful use of an intramedullary guide is dependent on its starting point, particularly when the distal femoral canal is capacious or has a significant bow [20]. Furthermore, it should be remembered that 1 mm mediolateral placement errors of a femoral head will lead to 3°–4.5° errors in the orientation of the femoral cut.

Hungerford et al [7] proposed the anatomical alignment method because it mimics the normal anatomical characteristics of knee and produces better kinematics. Normal tibial plateaus are inclined at 3° with respect to the tibial mechanical axis [21,22] and the anatomical alignment method tries to recreate this joint line obliquity by resecting the tibial plateau at 3° of varus with respect to the mechanical axis. And the femoral cut at 3° of valgus with respect to the mechanical axis of femur was made to create 9°–10° of valgus with respect to the femoral shaft. However, play in instruments, especially, inadvertent movement of fixation pins, can lead to realistic errors of 1°–4°. Even when sophisticated instruments and cutting jigs are used, excessive varus may result because the correct assessment of 3° of varus is difficult to achieve, and this could lead to overall varus malalignment of the lower limb, which is deleterious for prosthesis survival and mechanical function [1,3,11–13,23].

However, computer assisted navigation has dramatically reduced the incidence of malalignment and more than 90% of cases so treated have achieved a mechanical axis within ± 3° [24,25]. Robotic systems, combine computer navigation technology with the robotic preparation of bone cuts and produce highly accurate component implantations with mechanical alignments within ± 1° in almost all cases [15,26]. Therefore to achieve accurate coronal, sagittal and rotational alignments of components and to avoid mechanical errors during assessments of the anatomical and classical alignment methods, we conducted this study using robotic assisted surgery. The accuracy associated with this type of surgery is reflected by our results, as we achieved a mechanical axis of the leg within 3° of neutral in all patients in both groups. Femoral and tibial component placements were also within ± 2°.

The two alignment methods have been compared in cadaveric series [9,27,28], but as far as we are aware, no comparative clinical study has been previously undertaken, which may be due to a lack of high accuracy in terms of achieving a 3° varus tibial cut or a fear of creating proximal tibial varus greater than 3°.

Romano et al [27] conducted a cadaveric study to assess the varus and valgus flexion laxities of the two methods in relation to femoral component malrotation. In their study, the "combined alignment method" was mentioned, which involves resection of the tibia perpendicular to the mechanical axis and removal of equal amounts of bone at the posterior condyles medially and laterally. This method was found to produce 3° of inherent internal rotation of the femoral component and a trapezoidal flexion gap. In addition, the amount of femoral component rotational malalignment, which produced maximum instability, was assessed. The authors concluded that the classical and anatomical alignment methods produce comparable stabilities, and that significant varus laxity occurs at 6° of internal malrotation of the femoral component at 60° of knee flexion. This result is supported by our finding, as we also found no significant difference between the two methods in terms of varus or valgus laxities. At 90° of flexion, Romano et al [27] reported varus laxities ranging from 1.8° ± 0.3° to 2.6° ± 1.2° and valgus laxities from 1.4° ± 0.6° to 1.9° ± 0.8°, which are much less than our findings (varus laxities, 6.72° ± 3.19° and 5.88° ± 2.25°, in the classical and anatomical group, respectively, and valgus laxities, 3.34° ± 1.63° and 2.94° ± 1.23°, respectively). However, direct comparison with our results was not possible because they conducted studies on cadaveric knees with no previous deformity or ligamentous imbalance and their measurement was made under time zero conditions.

Hsu et al [9] compared the two methods with two implants, that is, the total condylar posterior stabilized (PS) type and the kinematic cruciate retaining (CR) type, in polyurethane foam artificial bone models. For the PS type a 0° tibial cut and 7° of valgus tilt of the femoral component were found to lead to the most even load distribution, and for the CR type a 2° varus tibial component and 9° of valgus tilt the femoral component produced the best results. Furthermore, it was suggested that the different total knee designs had different ideal component alignment positions. In the present study, only one implant model was used, and thus, we suggest that a larger-scale study should be undertaken to assess the two alignment methods clinically using different implant types. Regarding radiological outcomes, the only significant finding in the present study was the coronal alignments of femoral and tibial components in the two groups. However, this was expected because a 2° difference was purposefully created to assess the two alignment methods. Nevertheless, we found no significant clinical or functional outcome differences between the two groups. Various authors have examined the relationship between laxity and ROM and between laxity and clinical outcome [29–32]. Some have reported a better postoperative ROM with less pain in lax knee prostheses [29–31], whereas others found no differences between acceptable and loose knee prosthesis in terms of functional outcomes [32]. Similarly, we found no significant effects of flexion laxities on the clinical outcomes.

Certain limitations of the present study should be mentioned. First, patients with valgus deformities were excluded, because it has been reported that these patients do not have a normal 3° of varus inclination, and that a 3° varus cut using the anatomical method may place the lower limb in varus. On the other hand, we used robotic TKA, and performed preoperative planning using CT scan data, and thus, this limitation is not believed to have substantially affected outcomes. Second, the follow up period was too short to assess radiolucencies or TKA failure in either group, especially in the anatomical group.

In this study, we compared the outcomes of the classical and anatomical alignment methods in robotic TKA and found no clinical differences between the two study groups. In fact, both methods provided good mechanical and component alignments. We emphasize that the most important requirements are a good preoperative plan and its intraoperative execution. Accordingly, we conclude that robotic TKA achieves treatment goals regardless of whether anatomical or classical alignment methods are used.

References

1. Bargren JH, Blaha JD, Freeman MAR. Alignment in total knee arthroplasty: correlated biomechanical and clinical observations. Clin Orthop 1983;173:178.
2. Tew M, Waugh W. Tibiofemoral alignment and the results of knee replacement. J Bone Joint Surg Br 1985;67B:551.
3. Windsor RE, Scuderi GR, Moran MC, et al. Mechanisms of failure of the femoral and tibial components in total knee arthroplasty. Clin Orthop 1989;248:15.
4. Fehring TK, Odum S, Griffin WL, et al. Early failures in total knee arthroplasty. Clin Orthop 2001;392:315.
5. Sharkey PF, Hozack WJ, Rothman RH, et al. Why are total knee arthroplasties failing today? Clin Orthop 2002;404:7.
6. Insall J, Scott WN, Ranawat CS. The total condylar knee prosthesis: a report of two hundred and twenty cases. J Bone Joint Surg Am 1979;61A:173.
7. Hungerford DS, Kenna RV, Krackow KA. The porous-coated anatomic total knee. Orthop Clin North Am 1982;13:103.
8. Townley CO. The anatomic total knee resurfacing arthroplasty. Clin Orthop 1985;192:82.
9. Hsu HP, Garg A, Walker PS, et al. Effect of knee component alignment on tibial load distribution with clinical correlation. Clin Orthop 1989;248:135.
10. Laskin RS. Flexionspace configuration in total knee arthroplasty. J Arthroplasty 1995;10(5):657.
11. Lotke PA, Ecker ML. Influence of positioning of prosthesis in total knee replacement. J Bone Joint Surg Am 1977;59A:77.
12. Insall JN, Hood RW, Flawn LB, et al. The total condylar knee prosthesis in gonarthrosis. A five to nine-year follow-up of the first one hundred consecutive replacements. J Bone Joint Surg Am 1983;65(5):619.

13. Berend ME, Ritter MA, Meding JB, et al. Tibial component failure mechanisms in total knee arthroplasty. Clin Orthop 2004;428:26.
14. Park SE, Lee CT. Comparison of robotic-assisted and conventional manual implantation of a primary total knee arthroplasty. J Arthroplasty 2007;22(7):1054.
15. Bellemans J, Vandenneucker H, Vanlauwe J. Robot-assisted total knee arthroplasty. Clin Orthop 2007;464:111.
16. Kanekasu K, Kondo M, Kadoya Y. Axial radiography of the distal femur to assess rotational alignment in total knee arthroplasty. Clin Orthop Relat Res 2005; 434:193.
17. Stähelin T, Kessler O, Pfirrmann C, et al. Fluoroscopically assisted stress radiography for varus-valgus stability assessment in flexion after total knee arthroplasty. J Arthroplasty 2003;18(4):513.
18. Jeffery RS, Morris RW, Denham RA. Coronal alignment after total knee replacement. J Bone Joint Surg Br 1991;73B:709.
19. Insall JN, Binazzi R, Soudry M, et al. Total knee arthroplasty. Clin Orthop 1985;192:13.
20. Teter KE, Bregman D, Colwell CW. The efficacy of intramedullary femoral alignment in total knee replacement. Clin Orthop 1995;321:117.
21. Kapandji IA. The physiology of the joints. 2nd ed. New York: Churchill Livingstone; 1970.
22. Moreland JR, Bassett LW, Hanker GJ. Radiographic analysis of the axial alignment of the lower extremity. J Bone Joint Surg Am 1987;69A:745.
23. Aglietti P, Buzzi R. Posteriorly stabilised total-condylar knee replacement. Three to eight years' follow-up of 85 knees. J Bone Joint Surg Br 1988;70(2):211.
24. Ensini A, Catani F, Leardini A, et al. Alignments and clinical results in conventional and navigated total knee arthroplasty. Clin Orthop Relat Res 2007;457:156.
25. Chin PL, Yang KY, Yeo SJ, et al. Randomized control trial comparing radiographic total knee arthroplasty implant placement using computer navigation versus conventional technique. J Arthroplasty 2005;20:618.
26. Siebert W, Mai S, Kober R, et al. Technique and first clinical results of robot-assisted total knee replacement. Knee 2002;9(3):173.
27. Romero J, Duronio JF, Sohrabi A, et al. Varus and valgus flexion laxity of total knee alignment methods in loaded cadaveric knees. Clin Orthop 2002;394:243.
28. Green GV, Berend KR, Berend ME, et al. The effects of varus tibial alignment on proximal tibial surface strain in total knee arthroplasty: the posteromedial hot spot. J Arthroplasty 2002;17(8):1033.
29. Ishii Y, Matsuda Y, Ishii R, et al. Sagittal laxity in vivo after total knee arthroplasty. Arch Orthop Trrauma Surg 2005;125:249.
30. Yamakado K, Kitaoka K, Yamada H, Hashiba K, Nakamura R, Tomita K. Influence of stability on range of motion after cruciate-retaining TKA. Arch Orthop Trauma Surg 2003;123:1.
31. Warre PJ, Olanlokun TK, Cobb AG, Walkers PS, Iverson BF. Laxity and function in knee replacements. A comparative study of three prosthetic designs. Clin Orthop Trauma Surg 1994;305:200.
32. Itokazu M, Masuda K, Wafa E, et al. Influence of anteroposterior and mediolateral instability on range of motion after total knee arthroplasty: an ultrasonographic study. Orthopedics 2000;23:49.