

Differences between native and prosthetic knees in trochlear groove tracking based on a morphometric measurement of three-dimensional reconstruction models in Chinese people

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Research article

Keywords: Total knee arthroplasty, Femoral trochlear groove, Prosthetic design, Morphological analysis, Computed tomography

Posted Date: March 20th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-18143/v1>

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Abstract

Background Prosthetic trochlear design is important to ideal postoperative patellofemoral kinematics and knee function. But there has been little research on the differences of trochlear groove trackings between the native and prosthetic knees. We aimed to investigate the differences between native and prosthetic knees through the entire trochlear length by three-dimensional computerized quantification.

Methods Virtual total knee arthroplasty was performed, using three-dimensional models of 42 healthy knees that were matched to the femoral components of five different prosthesis systems. Coaxial planes were created along the trochlear groove in 3° increments, and the deepest points of the trochlear groove were marked in each plane. Taking the lower extremity mechanical axis as reference line, the differences in the mediolateral location of the groove tracking were analyzed between the native and prosthetic knees.

Results From the proximal to the distal end, the native tracking started from 0° cross section and extended laterally and then medially with its turning point located in 69° cross section, while the prosthetic knees showed medial orientation throughout the trochlear length. Compared with the proximal portion of the native tracking, the prosthetic trackings extended along a paradoxical orientation and started from a more proximal and lateral position, with maximal discrepancy to, 3.2 mm in the 0° cross section. Distally, the prosthetic trackings were located significantly medial, with maximal discrepancy, to 2.4 mm in the 69° cross section.

Conclusion The prosthetic trochlear design varies among different types, and does not conform to that of the native knee in terms of shape, orientation, and location, which may cause soft tissue tension imbalance and abnormal patellofemoral biomechanics during knee flexion. This study may be helpful for prosthetic trochlear design that accords with native anatomy so as to optimize patellofemoral biomechanics and decrease the risk of patellofemoral complications.

Background

Total knee arthroplasty (TKA) is effective for improving knee functions in patients with end-stage knee joint disease. Despite recent advances in component design, surgical technique, and management, patellofemoral complications (i.e., anterior knee pain, patellar component dislocation, and wearing/loosening) are still commonly observed postoperatively, which are responsible for disappointing functional outcomes and revision surgeries [1–3], with similar rates of patellar replacement and non-replacement [4, 5].

Abnormal patellofemoral biomechanics and patellar tracking play important roles in postoperative patellofemoral dissatisfaction, and the trochlear design is considered to be the main determinant [4, 6–9]. Compared to conventional designs with a neutral or symmetrical trochlear groove, the currently used femoral components with a lateral orientation or asymmetrical trochlear groove (“patella-friendly” design, with trochlear grooves that extend more proximally and orient more valgus compared to the native one)

are believed to favor early patella capture and promote patellofemoral stability; however, the physiological patellofemoral kinematics, patellar tracking, and stability are not provided [6, 10–13]. Some biomechanical studies have shown that when influential factors such as component positioning, alignment, soft tissue balancing, and patellar resurfacing are controlled, the patellofemoral biomechanics are not fully restored to normal anatomy [11, 12]. A comparative study of one type of prosthetic femoral component in 21 knees found that prosthetic trochlear groove tracking was more lateral than in native knees, while it was medial relative to its position in native knees [11]. The patellofemoral anatomical morphology changed postoperatively, and the patellar motion followed an unphysiological trochlear track.

The bearing geometry and kinematic pattern of different guided-motion prosthetic designs can affect the clinical and functional outcomes and complication type in TKA [8, 9]. The exact prosthetic morphological parameters vary with respect to the trochlear groove angle, groove depth, groove length, and condylar height [14, 15]. The various characteristics of femoral trochlear designs of different prosthetic systems should not be overlooked [16]. In a study by Dejour et al., the differences in trochlear designs of 14 different femoral models were identified at specific flexion angles (0°, 15°, 30°, and 45°)¹⁶, but the curve features of the entire trochlear groove tracking were not well characterized, and the differences between the native and prosthetic trackings are unknown. Quantitative evaluation of the trochlear geometry in native and prosthetic knees is critical for a better understanding of and improvement in the existing implant designs.

In the present study, we performed virtual TKA using computed tomography (CT) knee models of 42 healthy Chinese adults matched to 5 different commercially available prosthetic femoral components. With 3° increments, several coaxial planes were created along the trochlear groove in order to mark the deepest points of the trochlear groove; the mediolateral location of the groove tracking was then analyzed between the native and prosthetic knees, by establishing the lower extremity mechanical axis as the reference line. It was hypothesized that the trochlear design varies among different components in terms of shape, orientation, and location; the morphological differences in the trochlear groove tracking between the native and prosthesis showed different characteristics along the full length of the trochlear groove.

Methods

Subjects

We collected data on 42 healthy Chinese adults (11 men and 31 women) from our previous study [17]. This study was approved by the ethical committee of our institute, and informed consent was obtained from all subjects. Participants had an average age of 45.8 years (range, 34-57 years), height of 161.4 cm (range, 150-179 cm), body mass index of 23.7 Kg/m² (range, 16.5-29.6 Kg/m²), and mechanical axis of the lower limb of 179.7° (range, 174.7-184.4°). None of the subjects had experienced trauma or previous

knee surgery, or had a clinical record of osteoarthritis-related knee pain. This was verified with a clinical examination and CT images.

Five TKA prosthetic systems, namely the Advance Medial-Pivot (MP) Knee System, Advance Stature Knee System (MicroPort Orthopedics Co., Arlington, TN), Triathlon Knee System (Stryker Co., Kalamazoo, MI), NRG Knee System (Stryker Co., Mahwah, NJ), and NexGen Complete Knee Solution (Zimmer Inc., Warsaw, IN), were evaluated in the current study. Stature femoral component is morphology-specific knee implant that is designed based on standard MP implant and accommodates femora in men or women with relatively narrower femoral condyle. For a given anteroposterior dimension, the Stature femoral component was 5 mm smaller in the mediolateral dimension than that of the MP.

For the convenience of this study, we intentionally selected subjects who had similar distal femur anteroposterior dimensions (the distance between the anterior femoral cortex and the posterior surface of the condyle: 56.9 ± 1.5 mm), 42 subjects were included from previous database. Based on the anteroposterior dimension of the distal femur and femoral component [18], size 3 of the MP (56.5 mm) and Stature (56.1 mm), size 7+ of the Triathlon (57.0 mm) and NRG (55.8 mm), and size E of the NexGen (56.9 mm) most closely matched the sizes of the distal femurs and were evaluated in the present study (Fig. 1).

Data Scanning

Three-dimensional (3D) knee models were reconstructed using CT images (Light speed 16, GE Medical System, Milwaukee, WI), with a slice thickness of 0.625 mm and resolution of 512×512 pixels. The entire length of the femur was included in the scanned images. A 3D laser scanner (KLS-171; Kreon Technologies, Limoges, France) was used to create 3D models of the right femoral metal components. We then introduced the scanned data into the Geomagic Studio 10.0 software (Geomagic®, Morrisville, NC, USA) for use in the 3D reconstruction of the right femur and femoral components.

Virtual Femoral Component Implantation

The femur model was aligned as follows: the mechanical axis was defined as a line connecting the center of the femoral head and the center of the knee (the midpoint of the femoral transepicondylar axis). The coronal plane was parallel to the mechanical axis and was externally rotated at 3° relative to the posterior condylar line. The sagittal plane was perpendicular to the coronal plane and passed through the mechanical axis. The horizontal plane was perpendicular to both the coronal and sagittal planes.

In the coronal plane, the femoral component was aligned perpendicular to the mechanical axis. Rotational alignment of the femoral component was set parallel to the coronal plane. In the sagittal plane, we positioned the femoral component parallel to the anterior cortex of the distal femur [19]. The femoral component was then shifted as posteriorly as possible, without notching the anterior cortex of the distal femur, and shifted transversely until the mediolateral center of the component reached the sagittal plane. The medial distal surfaces of the femoral components were consistent (Fig. 2).

Measurements and Statistical Analyses

A cylinder was established with its axis parallel to both the coronal and transverse planes, and its radius was adjusted to allow the cylindrical surface to closely fit the trochlear groove; its axis represented the trochlear groove axis. The plane passed the trochlear groove axis, and parallel to the transversal plane was defined as 0° cutting plane. Then, with 3° increments, we created coaxial cutting planes that rotated around the trochlear groove axis toward the proximal (negative direction, negative degree) and distal ends (positive direction, positive degree) of the trochlear groove. We marked the deepest points of the trochlear groove on the surfaces of the natural and prosthetic knee models in each cross section (Fig. 3A). The distance (mediolateral location) from the deepest point of the trochlear groove to the mechanical axis was measured. If the point was located at the medial side of the mechanical axis, the value was positive (d); otherwise, the value was negative (-d) (Fig. 3B).

A test-retest analysis was performed to determine intra-observer reliability, by measuring the parameters three times for all the natural and prosthetic knee models. The standard deviation of these three measurements was used to represent the accuracy of the measurement for each parameter. The intra-observer reliability analysis indicated the measurement accuracy for the d/-d values was 0.1 mm.

Student's t-test was performed to determine if the difference in the mediolateral location of the trochlear groove was significantly different between the natural and prosthetic knees. A *p* value of less than 0.05 was considered statistically significant. Based on the mean and standard deviation of the trochlear groove location of recruited subjects, a priori power analysis ($\alpha = 0.05$) indicated that 12 subjects will have more than 90% power to detect the differences between the natural and prosthetic knees. The sample size of the present study is sufficient to detect a morphological difference.

Results

For the native trochlear groove tracking, the average angle span was $-0.3^\circ \pm 6.2^\circ$ to $107.8^\circ \pm 5.3^\circ$ from the proximal to the distal end; for the femoral components of the MP, Stature, Triathlon, NRG, and NexGen prostheses, the angle spans were -51° to 110° , -45° to 110° , -42° to 60° , -39° to 66° , and -45° to 78° , respectively. From the proximal to distal end, the native tracking consisted of the laterally oriented proximal portion and medially oriented distal portion, with the turning point located at the 69° cross section, while the prosthetic knees showed similar medial orientation throughout the length of the trochlear, but varies in the mediolateral location. Compared with the proximal portion of the native tracking, the prosthetic tracking extended along an opposite orientation with its starting point located more proximal and lateral. Distally, the prosthetic tracking was still located significantly medial (Fig. 4A). A significant difference of the mediolateral location was observed between the native and prosthetic trackings ($p < 0.05$), except between 27°-36° (MP and Stature), 18°-24° (Triathlon and NRG), and 39°-48° (NexGen) of cross sections, respectively. The mean difference of 0° cross section for MP, Stature, Triathlon, NRG, and NexGen were 2.5 mm, 2.0 mm, 2.1 mm, 1.7 mm, and 3.2 mm, respectively; distally, the prosthetic tracking was more medial, and the corresponding mean differences of the 69° cross section

were 1.8 mm, 1.8 NRG prostheses were both set at 0 mm when analyzing the difference of the 69° cross section.

Discussion

In the present study, the geometry of the trochlear groove tracking in native and prosthetic knees was evaluated. Our results were consistent with the findings of previous researches, showing that native groove tracking followed a path that could be approximated by two consecutive straight lines: a bilinear approximation, composed of a laterally oriented proximal portion, and a medially oriented distal portion [20, 21]. The prosthetic tracking was relatively consistent and smooth among different types, showed proximal-lateral to distal-medial orientation throughout the length of the trochlea, and had a prolonged proximal part compared to the native knee.

Current femoral trochlear geometry has evolved from symmetrical to asymmetrical, and the main design difference was considered existing on the anterior flange. Compared with traditional symmetrical component, in TKA with an asymmetrical component with a laterally orientated trochlear groove (more parallel to the orientation of the quadriceps force) and asymmetrical trochlear flanges, patellar “capture”, more stable and physiological patellar tracking could be expected during early stage of flexion (0°-30°; the supracondylar pouch/anterior flange) [6, 10, 12]. However, symmetrical and asymmetrical TKAs both have altered physiological patellofemoral kinematics. When compared with a symmetrical prosthesis, the asymmetrical component did not provide more patellar stability and improve the non-physiological tracking of the patella [6, 12]. This indicated that the groove of the prosthetic trochlea may still be different from that of the normal trochlea [10, 11].

Previously, Varadarajan et al. compared the groove morphology of 21 knee models and NexGen cruciate retaining femoral components via virtual TKA. Proximally, between 43.5–58.7% of the trochlear length, the prosthetic groove was more lateral than in the native knees (difference, 0.6–3.5 mm; average, 2.0 mm; $p < 0.034$) [11]. Similarly, in the present study, when compared with the proximal portion of the native tracking, the prosthetic tracking extended along an opposite orientation, with its starting point located more proximal and lateral, with maximal discrepancy of 3.2 mm in the 0° cross section. It was found that soft tissue had an overriding influence, and the patella was disengaged from the trochlea by the medial patellofemoral ligament in the native knee near extension [12, 22]. Thus, the prosthetic patellar initial position and engagement area might differ from that of the native patella, which might affect early stage patellar tracking and contribute to changes in the patellofemoral kinematics after TKA [12, 23].

It was believed that patellar tracking and patellofemoral kinematics could be affected by changes of the groove location after TKA [24, 25]. During knee flexion, patellar medial shift might lead to patellar periphery soft tissue imbalance and patellar lateral tilt, which may lead to pain impingement on the lateral edge of the trochlea (in the situation of a non-resurfaced patellar) and a laterally directed force on the patella [26, 27]. A biomechanical study by Barink et al. showed that an unsurfaced TKA patella was significantly displaced in high flexion angles, with about 3 mm more medially at 80°-90° of flexion

compared with intact knees [6]. In the present study, for the distal trochlear groove, the prosthetic tracking was more medial than that in the native knees, with maximal discrepancy of 2.4 mm in the 69° cross section. Aside from prosthetic design, the mediolateral position of the femoral and patellar button and how the surgeon should judge the best mediolateral position may also affect the groove position and patellar tracking [12, 24].

Furthermore, in the present study, distally, Triathlon, NRG, and NexGen (the angle spans extended to 60°, 66°, and 78°, respectively) have shorter trochlear groove compared to that of the native one, MP and Stature (the angle spans both extended to 110°) showed similar trochlear groove length compared to that of the native one. Femoral components with a shorter trochlea appear to have increased incidence of patellar clunk syndrome, which has been associated with posterior-stabilized TKA [28, 29, 30]. In the study of Maloney et al., the prevalence of patellar clunk was 3.9% in 179 consecutive Insall-Burstein posterior-stabilized TKA, while with a longer trochlear groove extended distally, no patellar clunks developed in the patients with Advanced posterior-stabilized TKA [28]. In a recently published series, an incidence of 2.76% was observed with a modern posterior-stabilized implant, whereas an incidence of 6% was seen with the use of a different posterior stabilized design [30]. Lengthening the trochlea groove distally make it more difficult for a nodule to develop and become entrapped [28]. Besides, patella baja or alta, abnormal patellar tracking, anterior placement of the tibial tray, and an increased degree of postoperative knee flexion have also been associated with the development of patellar clunk syndrome [30, 31].

The knee joint is a well balanced system, and good function relies on coordination and cooperation of the femur, tibia, patella, and soft tissue during dynamic motion. A main limitation of the study was the static analysis of the femoral trochlea separately. The present study did not provide evidence to support the use of one prosthetic design over another, just showed the differences of the trochlear groove trackings between various prosthetic systems and between the native and prosthetic knees. As the sensitivity of ligaments and tendons to applied tensile loads, such that stretching of these structures at very low loads may induce major changes in the response of their sensory receptors [32], better patellofemoral function may be expected by a femoral component designed with physiological values in trochlear groove tracking; however, further studies are needed. Another limitation was that physiological features (e.g. the width and height of the lateral and medial femoral condylar facet, and trochlear bisector angle) are also important in prosthetic design and patellofemoral kinematics were not evaluated [11, 16]. Further studies are needed to explore these parameters. Third, CT-scanned knee models were used in the present study, neglecting the geometry of the articular cartilage. Although the difference was small (less than 1 mm) in the location between the osseous and cartilaginous grooves [33], the effect of articular cartilage on the morphology of the trochlear groove should be evaluated in further studies.

Conclusions

Our study revealed the variations in trochlear design parameters among different types, and the current prosthetic trochlear design does not conform to that of the native knee. The prosthetic tracking was

different from that of the native knee in terms of shape, orientation, and location, which may cause soft tissue tension imbalance during knee flexion, and lead to abnormal patellofemoral biomechanics. This study may be helpful for prosthetic trochlear design that accords with native anatomy so as to optimize patellofemoral biomechanics and decrease the risk of patellofemoral complications.

Abbreviations

TKA: Total knee arthroplasty; CT: Computed tomography; MP: Medial-Pivot; 3D: Three-dimensional

Declarations

Acknowledgements

N/A

Funding

No funding was obtained for this study.

Availability of data and material

All the necessary information is contained in the manuscript. Each participant's raw data is only available in hospital archive. Therefore digital availability of each patient's data is limited.

Authors' contributions

CC designed the study, analyzed the data and wrote and revised the manuscript. HX designed the study, performed measurements and reviewed the manuscript. SG designed the study and reviewed the manuscript. All authors read and approved the final manuscript.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Shanghai Baoshan Hospital of Integrated Traditional Chinese and Western Medicine, and written informed consent for participation was obtained from all subjects.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

References

1. Barrack RL, Schrader T, Bertot AJ, Wolfe MW, Myers L. Component rotation and anterior knee pain after total knee arthroplasty. *Clin Orthop Relat Res.* 2001;(392):46-55.
2. Eisenhuth SA, Saleh KJ, Cui Q, Clark CR, Brown TE. Patellofemoral instability after total knee arthroplasty. *Clin Orthop Relat Res.* 2006;446:149-60.
3. Patel J, Ries MD, Bozic KJ. Extensor mechanism complications after total knee arthroplasty. *Instr Course Lect.* 2008;57:283-94.
4. Kulkarni SK, Freeman MA, Poal-Manresa JC, Asencio JI, Rodriguez JJ. The patellofemoral joint in total knee arthroplasty: is the design of the trochlea the critical factor? *J Arthroplasty.* 2000;15:424-9.
5. Robertsson O, Knutson K, Lewold S, Lidgren L. The Swedish Knee Arthroplasty Register 1975-1997: an update with special emphasis on 41,223 knees operated on in 1988-1997. *Acta Orthop Scand.* 2001;72:503-13.
6. Barink M, Meijerink H, Verdonschot N, van Kampen A, de Waal Malefijt M. Asymmetrical total knee arthroplasty does not improve patella tracking: a study without patella resurfacing. *Knee Surg Sports Traumatol Arthrosc.* 2007;15:184-91.
7. Akbari Shandiz M, Boulos P, Saevarsson SK, Yoo S, Miller S, Anglin C. Changes in knee kinematics following total knee arthroplasty. *Proc Inst Mech Eng H.* 2016;230:265-78.
8. Matz J, Howard JL, Sisko ZW, Teeter MG, Lanting BA. Differences in trochlear surface damage and wear between three different total knee arthroplasty designs. *J Arthroplasty.* 2017;32:3763-70.
9. 9. Mugnai R, Digennaro V, Ensini A, Leardini A, Catani F. Can TKA design affect the clinical outcome? Comparison between two guided-motion systems. *Knee Surg Sports Traumatol Arthrosc.* 2014;22:581-9.
10. 10. Barink M, Van de Groes S, Verdonschot N, De Waal Malefijt M. The difference in trochlear orientation between the natural knee and current prosthetic knee designs; towards a truly physiological prosthetic groove orientation. *J Biomech.* 2006;39:1708-15.
11. 11. Varadarajan KM, Rubash HE, Li G. Are current total knee arthroplasty implants designed to restore normal trochlear groove anatomy? *J Arthroplasty.* 2011;26:274-81.
12. 12. Stoddard JE, Deehan DJ, Bull AM, McCaskie AW, Amis AA. No difference in patellar tracking between symmetrical and asymmetrical femoral component designs in TKA. *Knee Surg Sports Traumatol Arthrosc.* 2014;22:534-42.
13. Shervin D, Pratt K, Healey T, Nguyen S, Mihalko WM, El-Othmani MM, Saleh KJ. Anterior knee pain following primary total knee arthroplasty. *World J Orthop.* 2015;6:795-803.
14. Rivière C, Dhaif F, Shah H, Ali A, Auvinet E, Aframian A, Cobb J, Howell S, Harris S. Kinematic alignment of current TKA implants does not restore the native trochlear anatomy. *Orthop Traumatol*

- Surg Res. 2018;104:983-95.
15. Keshmiri A, Maderbacher G, Baier C, Sendtner E, Schaumburger J, Zeman F, Grifka J, Springorum HR. The influence of component alignment on patellar kinematics in total knee arthroplasty. *Acta Orthop.* 2015;86:444-50.
 16. 16. Dejour D, Ntagiopoulos PG, Saffarini M. Evidence of trochlear dysplasia in femoral component designs. *Knee Surg Sports Traumatol Arthrosc.* 2014;22:2599-607.
 17. 17. Chen S, Du Z, Yan M, Yue B, Wang Y. Morphological classification of the femoral trochlear groove based on a quantitative measurement of computed tomographic models. *Knee Surg Sports Traumatol Arthrosc.* 2017;25:3163-70.
 18. 18. Dai Y, Scuderi GR, Penninger C, Bischoff JE, Rosenberg A. Increased shape and size offerings of femoral components improve fit during total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc.* 2014;22:2931-
 19. 19. Tsukeoka T, Lee TH. Sagittal flexion of the femoral component affects flexion gap and sizing in total knee arthroplasty. *J Arthroplasty.* 2012;27:1094-9.
 20. 20. Barink M, van de Groes S, Verdonschot N, de Waal Malefijt M. The trochlea is bilinear and oriented medially. *Clin Orthop Relat Res.* 2003;(411):288-95.
 21. 21. Varadarajan KM, Gill TJ, Freiberg AA, Rubash HE, Li G. Gender differences in trochlear groove orientation and rotational kinematics of human knees. *J Orthop Res.* 2009;27:871-8.
 22. 22. Senavongse W, Amis AA. The effects of articular, retinacular, or muscular deficiencies on patellofemoral joint stability: a biomechanical study in vitro. *J Bone Joint Surg Br.* 2005;87:577-82.
 23. 23. Merican AM, Amis AA. Iliotibial band tension affects patellofemoral and tibiofemoral kinematics. *J Biomech.* 2009;42:1539-46.
 24. 24. Meijerink HJ, Barink M, van Loon CJ, Schwering PJ, Donk RD, Verdonschot N, de Waal Malefijt MC. The trochlea is medialized by total knee arthroplasty: an intraoperative assessment in 61 patients. *Acta orthop.* 2007;78:123-7.
 25. 25. Ahmed AM, Duncan NA. Correlation of patellar tracking pattern with trochlear and retropatellar surface topographies. *J Biomech Eng.* 2000;122:652-60.
 26. 26. Anglin C, Brimacombe JM, Wilson DR, Masri BA, Greidanus NV, Tonetti J, Hodgson AJ. Biomechanical consequences of patellar component medialization in total knee arthroplasty. *J Arthroplasty.* 2010;25:793-802.
 27. 27. Kessler O, Patil S, Colwell CW, Jr., D'Lima DD. The effect of femoral component malrotation on patellar biomechanics. *J Biomech.* 2008;41:3332-9.
 28. Maloney W, Schmidt R, Sculco T. Femoral component design and patellar clunk syndrome. *Clin Orthop Relat Res.* 2003;410:199-202.
 29. Choi WC, Ryu KJ, Lee S, Seong SC, Lee MC. Painful patellar clunk or crepitation of contemporary knee prostheses. *Clin Orthop Relat Res.* 2013;471:1512–22.

30. Peralta-Molero JV, Gladnick BP, Lee YY, Ferrer AV, Lyman S, González Della Valle A. Patellofemoral crepitation and clunk following modern, fixed-bearing total knee arthroplasty. *J Arthroplasty*. 2014;29:535-40.
31. Snir N, Schwarzkopf R, Diskin B, Takemoto R, Hamula M, Meere PA. Incidence of patellar clunk syndrome in fixed versus high-flex mobile bearing posterior-stabilized total knee arthroplasty. *J Arthroplasty*. 2014;29:2021-4.
32. Delpont H, Labey L, De Corte R, Innocenti B, Vander Sloten J, Bellemans J. Collateral ligament strains during knee joint laxity evaluation before and after TKA. *Clin biomech*. 2013;28:777-82.
33. Shih YF, Bull AM, Amis AA. The cartilaginous and osseous geometry of the femoral trochlear groove. *Knee Surg Sports Traumatol Arthrosc*. 2004;12:300-6.

Figures

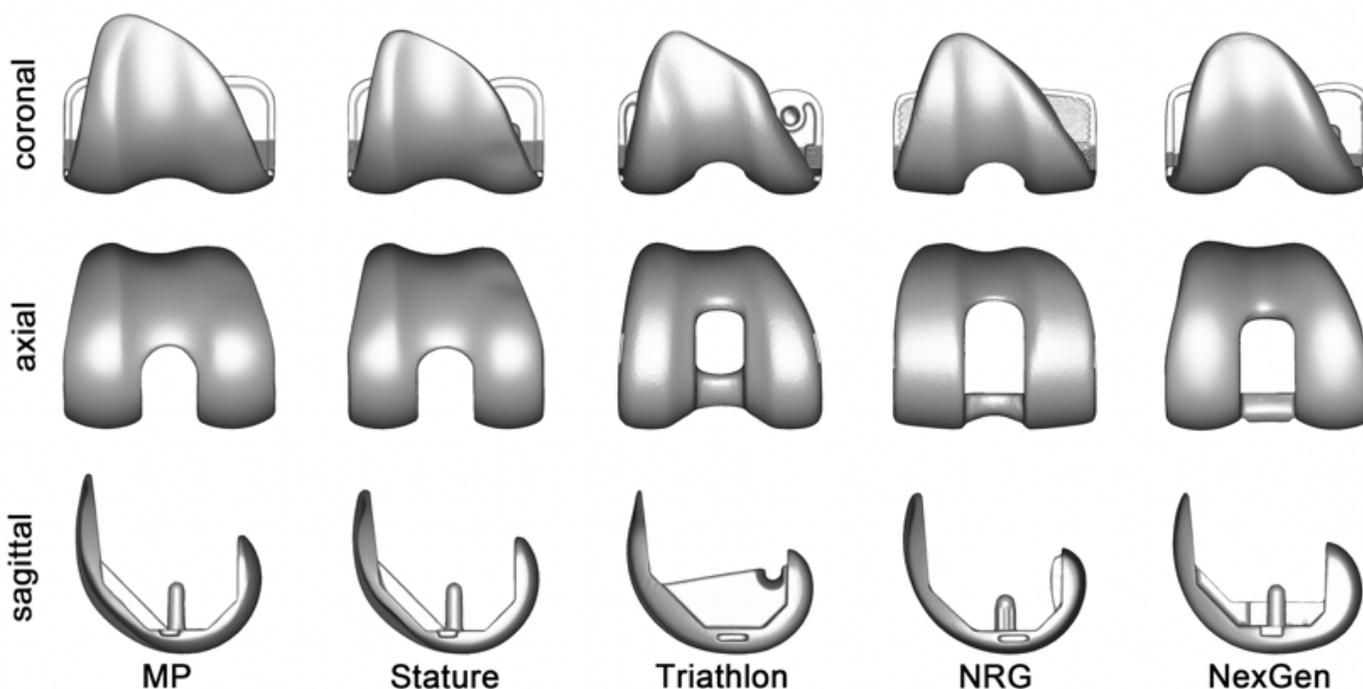


Figure 1

The femoral components used in this study

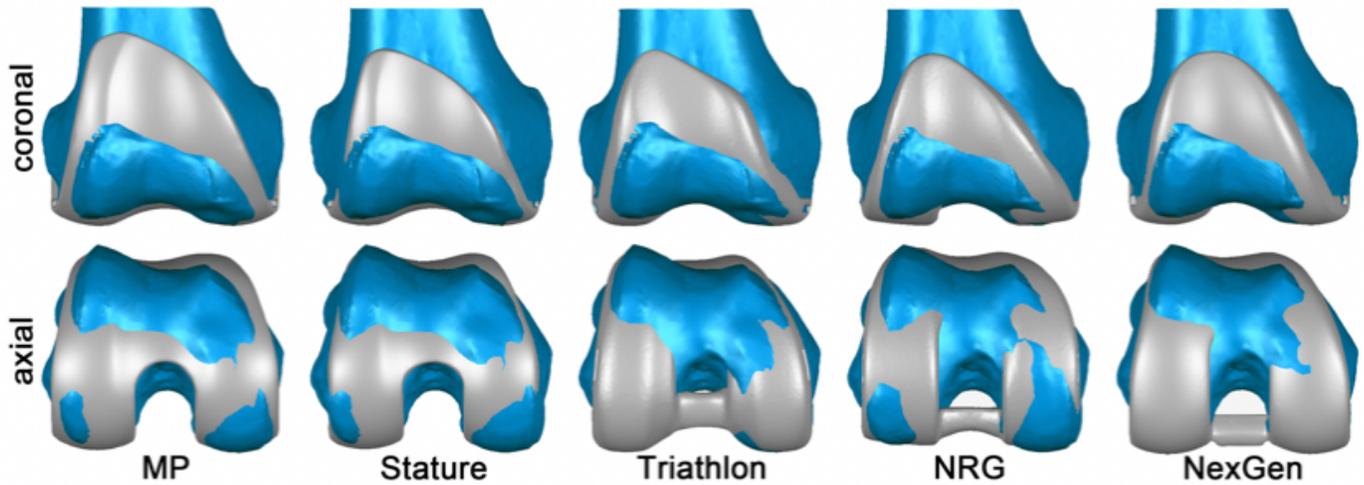


Figure 2

Coronal and axial views of the knee after virtual total knee arthroplasty

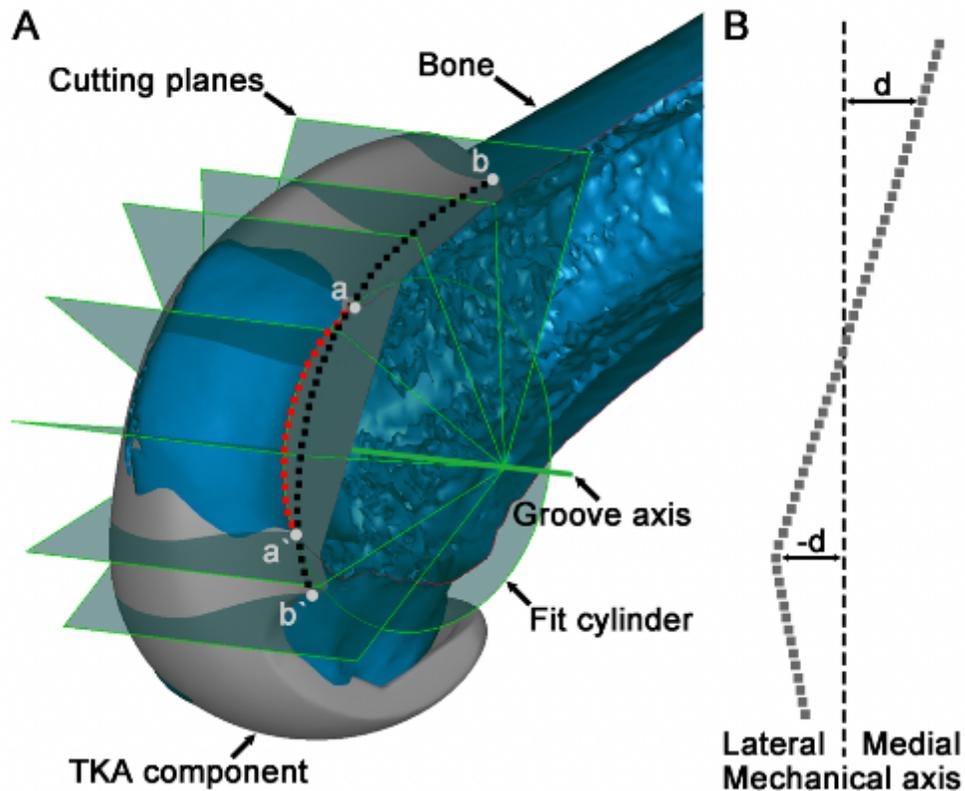


Figure 3

The cutting planes and measurement of the mediolateral location of the trochlear groove tracking. A. A cylinder was established to allow the cylindrical surface to closely fit the trochlear groove; its axis

represented the trochlear groove axis. Coaxial cutting planes rotating around the trochlear groove axis were created throughout the arc of the groove, with 3° increments. The red and black dash lines indicate natural and prosthetic groove trackings, respectively. Dots *a* and *b* indicate the proximal ends of the natural and prosthetic groove trackings, respectively; dots *a* and *b* indicate the distal ends of the natural and prosthetic groove trackings, respectively. B. A positive *d* value (*d*) indicates that the point was located at the medial side of the mechanical axis; a negative *d* value (*-d*) indicates that the point was located at the lateral side of the the mechanical axis

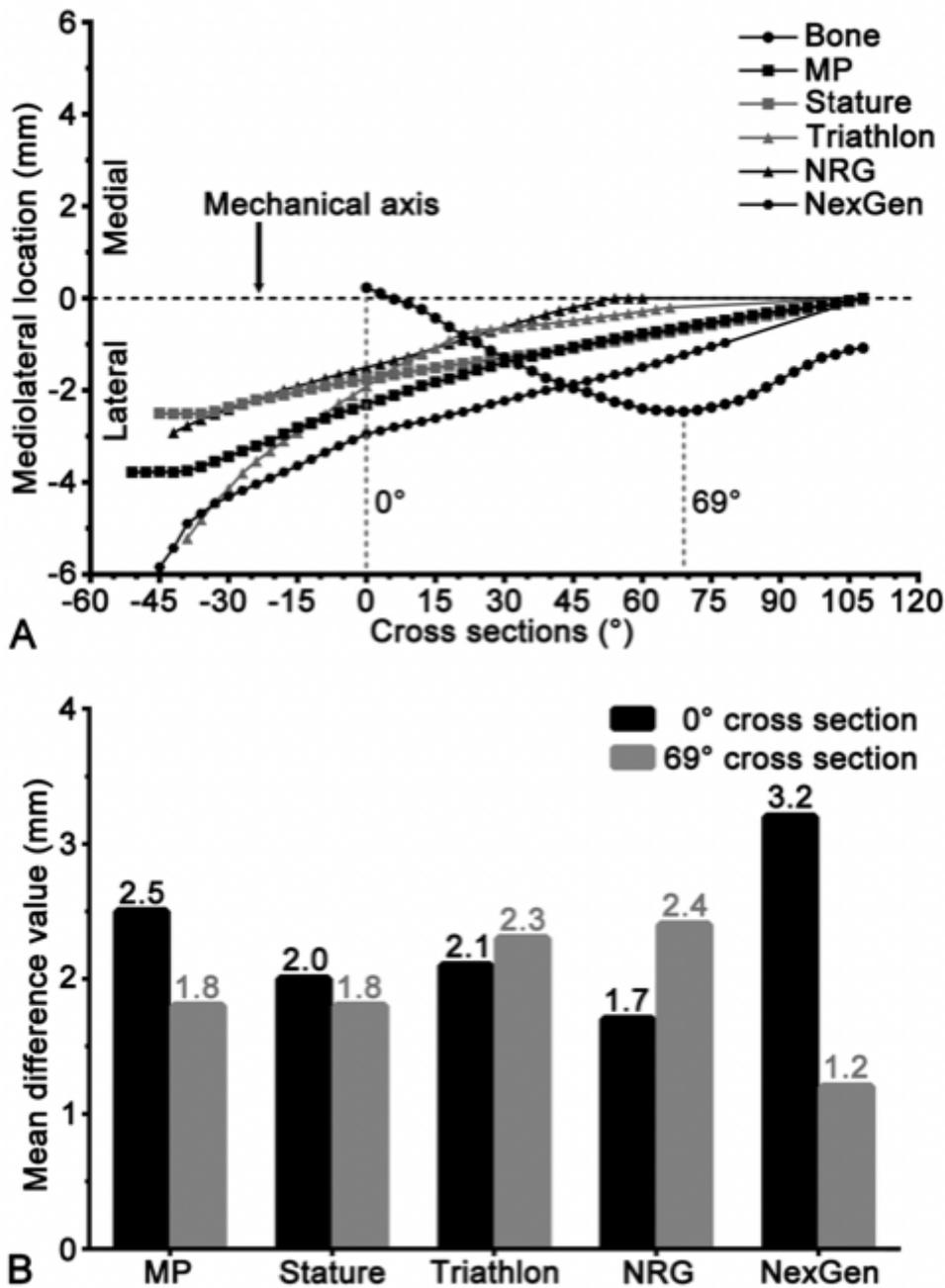


Figure 4

Differences of the trochlear groove trackings between the native and prosthetic knees. A. Difference in the mediolateral location of the entire length trackings between the native and prosthetic knees. B. Mean difference in the mediolateral location between the native and prosthetic knees in the 0° and 69° cross sections