The Swing Angle of the Intramedullary Rod in the Canal During Medial Mobile-bearing Unicompartamental Knee Arthroplasty: a Finite Element Analysis Study

Shaokui Nan

Fourth Medical Center of PLA General Hospital

Cheng Xu

Fourth Medical Center of PLA General Hospital

Dong Zhang

Fourth Medical Center of PLA General Hospital

Zhuo Zhang

Fourth Medical Center of PLA General Hospital

Yue Song

Fourth Medical Center of PLA General Hospital

Yong Li

Fourth Medical Center of PLA General Hospital

Haifeng Li (✉ lihaifengplagh@163.com)

Fourth Medical Center of PLA General Hospital <https://orcid.org/0000-0003-1708-4450>

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Abstract

Background: To determine the swing angle of the intramedullary rod in the canal during medial mobile-bearing unicompartmental knee arthroplasty (UKA), we simulated the intramedullary localization process of mobile-bearing UKA via digital technology and analyzed the swing angle of the intramedullary rod swing in the canal through finite element analysis.

Methods: Patients requiring mobile-bearing UKA in our department were prospectively selected. A three-dimensional femur model was established, and intramedullary rods of different lengths were inserted. The swing of the intramedullary rod in the canal was simulated, the angle of the moving rod was obtained, and the anatomic parameters of the femur were measured. Pearson's correlation between the swing angle of the intramedullary rod and anatomical parameters of the femur were analyzed.

Results: The longer the intramedullary rod, the smaller the swing range; this difference was statistically significant ($P < 0.05$). The maximum swing range of the same intramedullary rod was significantly larger in the sagittal than in the coronal plane ($P < 0.05$). Pearson's correlation analysis indicated that the isthmic diameter and femur length significantly correlated with the 20-cm and 25-cm and 30-cm rod swing ranges, respectively.

Conclusion: We proved that the longer the intramedullary rod, the smaller the swing angle in the femoral medullary canal. The femoral medullary canal diameter and femur length affect the swing angle; thus, in patients with a shorter femur length, we recommend 25-cm intramedullary rods.

Background

Currently, unicompartmental knee arthroplasty (UKA) is an effective procedure for treating unicompartmental diseases of the knee joint[1–6]. There are two types of UKA: fixed-bearing and mobile-bearing[7]. Mobile-bearing UKA makes the polyethylene bearing wear very low, leading to complications not found in fixed-bearing, UKA-bearing dislocations.[8] Additionally, despite positive results in Europe, the outcomes differ when applied to patients in Asian countries; for example, there is an increase in dislocation rate.[9, 10] If the femoral component is optimally positioned, complications such as dislocation can be significantly reduced.[11, 12]

To avoid perforating the trochlea, most fixed UKAs use the extramedullary technique when implanting the femoral component.[13, 14] For a more accurate alignment of the femoral component, mobile-bearing UKA uses the intramedullary (IM) positioning method.[15] In the coronal plane, the femoral component should be aligned parallel to the femoral mechanical axis; additionally the angle between the femoral mechanical and anatomical (central axis of the IM canal) axes is about 7° .[16]

Designers have created a new microplasty (MP) system in hopes of achieving a more accurate position[17, 18]; it utilizes two kinds of IM rods, with lengths of 20- and 30-cm. It exhibits a certain range

of swing within the IM canal, permitting a greater degree of error regarding distal femoral implant positioning.

We speculated that the accuracy of the IM technique in mobile-bearing UKA was related to the length of the IM rod, as well as the anatomical morphology of the femur. There is ongoing debate regarding the IM rod with respect to its usefulness.[19] In this study, a three-dimensional (3D) model of the femur and IM rods of different lengths were established using computed tomography (CT). The positioning errors for different rod lengths were obtained through finite element analysis, and correlations between the mathematical model of the femur and swing angle of the rods were evaluated.

Methods

Between January and October 2019, patients who underwent mobile-bearing UKA in our department were prospectively selected; Inclusion and exclusion criteria for mobile-bearing UKA were as defined by Pandit et al.[20] Each patient underwent preoperative femoral CT using a 64-channel CT scanner (Somatom sensation 64; Siemens Healthcare, Erlangen, Germany).

3D model reconstruction

The femoral CT data (DICOM format, slice thickness: 0.625-mm) were imported into the Mimics software (Materialise NV, Leuven, Belgium) to reconstruct a 3D model of the femoral cortical bone; three IM rod models were established (Figure 1a, b). To better understand the relationship between errors of the IM guides and the length of the rods, we built three kinds of IM rods with lengths of 20-, 25-, 30-cm and a diameter of 4.2-mm (Figure 1c); the inserted lengths of the IM rods were 16-, 21-, and 26-cm, respectively.

Model assembly

The coronal plane was defined by three points; namely, the posteriormost points of the medial and lateral femoral condyles, and the greater trochanter. Subsequently, an anteromedial insertion point (1-cm anterior to the anteromedial corner of the intercondylar notch) was selected (Figure 1d). The IM rod was inserted into the femur from the insertion point using 3-Matics 13.0 software (Materialise NV, Leuven, Belgium); the position of the rod was adjusted to ensure that it did not coincide with the cortex (Figure 1e). After optimizing and fitting the surface using Geomagics 2014 software, the models were exported in IGES format. The assembled and optimized models were imported into ANSYS Workbench 19.1 software, and the display dynamics module was used for further analysis.

Measurement of the maximum swing angles of the three IM rods

Using the ANSYS Workbench 19.1 software, the maximum swing angles of the three IM rods were measured. First, the femoral cortex and rods were assumed to be rigid. The surface of femoral cortex was constrained (Figure 2); 18 directional forces were then applied to the top of the rod (Figure 3a, b, c), with 20° between each direction. When the IM rod met the inner wall of the femur and stopped, the maximum

moving distances of the rod were recorded. We visualized the moving range maps of the three kinds of IM rods' swing in the canal (Figure 3a, b, c). The maximum swing angle of the rods could be calculated (Figure 3d).

Measurement of femoral anatomical parameters

Radius of the femoral curvature (RFC)

Using the Mimics software to reconstruct the femoral bone marrow cavity model, the length was measured from below the small trochanter to the distal femoral expansion using the 'centerline' function to automatically reconstruct the centerline of the IM canal; the centerline was an approximate circular arc shape (Figure 4a). Referring to the method of Su et al.,[21] the center line was fit to a circle. The radius of the circle was the radius of the anterior arch of the femur.

Femur length (FL)

FL was defined as the distance between the uppermost point of the femoral head and lowermost point of the distal femoral condyle (medial femoral condyle), measured using the 3D model of the femur (Figure 4c).

Femoral isthmic diameter (ID)

After using the 'best fit diameter' function of the Mimics software to create the best fit circle of each point of the center line in the canal, we selected the circle with the smallest radius. This circle was considered the isthmus and was measured in both the sagittal and coronal planes (Figure 4c).

Femoral isthmus to insertion point distance (IPD)

This was defined as the distance between the center of the best fit circle of the femur isthmus and the insertion point of the distal femur (Figure 4c).

All parameters were evaluated using the Kolmogorov-Smirnov test for normality. Paired t-tests were performed on the coronal and sagittal planes of the three IM rods in the femoral cavity; $P < 0.05$ was considered statistically significant. Both Pearson and Spearman correlation analyses were performed between the swing angle of the rods and anatomical parameters of the femur to obtain a corresponding correlation coefficient. All statistical analyses were performed using SPSS version 19 software (SPSS Inc., Chicago, Illinois).

Results

A total of 30 patients were enrolled in this study, with an average age of 64.1 ± 10.6 years; detailed case data and measured femoral anatomical parameters are shown in Table 1. Both the length of the femur and distance from the isthmus to the opening point were significantly larger in male patients than in female patients; no differences were observed regarding other parameters.

Table 1

Main characteristics of the population, and measurement of anatomical parameters of the femur

	Male (n=11)	Female (n=19)	t-test		Total (n=30)
	Mean $\pm$ SD	Mean $\pm$ SD	t	P-value	Mean $\pm$ SD
Age (years)	65.6 $\pm$ 11.5	64.6 $\pm$ 10.7	0.220	0.828	64.1 $\pm$ 10.6
Height (cm)	172.0 $\pm$ 50.1	162.3 $\pm$ 35.9	5.586	0.000**	165.5 $\pm$ 10.3
BMI	24.7 $\pm$ 2.2	22.5 $\pm$ 2.4	2.510	0.018*	25.1 $\pm$ 4.2
FL (mm)	447.9 $\pm$ 20.0	409.6 $\pm$ 14.4	6.105	0.000**	423.6 $\pm$ 24.9
IPD (mm)	240.6 $\pm$ 16.7	213.8 $\pm$ 16.9	4.204	0.000**	223.6 $\pm$ 21.1
RFC (mm)	912.9 $\pm$ 173.1	938.9 $\pm$ 184.0	-0.380	0.706	929.4 $\pm$ 177.5
ID-S (mm)	12.7 $\pm$ 1.4	13.9 $\pm$ 2.7	-1.397	0.173	13.5 $\pm$ 2.4
ID-C (mm)	10.1 $\pm$ 1.3	10.5 $\pm$ 2.0	-0.613	0.545	10.4 $\pm$ 1.8
FL: Femoral length; IPD: Femoral isthmus to insertion point distance; RFC: radius of the femoral curvature; ID-S: Isthmic diameter in the sagittal plane; ID-C: Isthmic diameter in the coronal plane					

In the sagittal plane, the maximum swing ranges of the 20-, 25-, and 30-cm rods were $4.36 \pm 0.88^\circ$, $2.47 \pm 0.74^\circ$, and $1.01 \pm 0.51^\circ$, respectively. In the coronal plane, the maximum swing ranges of the 20-, 25-, and 30-cm rods were $3.74 \pm 0.92^\circ$, $1.64 \pm 0.48^\circ$, and $0.79 \pm 0.48^\circ$, respectively.

We encountered five cases in which the 30-cm IM rod could not be fully inserted into the femoral IM canal. The maximum swing range of the same IM rod was significantly larger in the sagittal plane than in the coronal plane ($P < 0.05$; Table 2). In both planes, the longer the length of the rod, the smaller the swing range; this difference was statistically significant ($P < 0.05$). Additionally, there was a significant correlation between the swing range of each rod in the two planes (Table 3).

Table 2
Measurement of the maximum swing angles of the three IM rods

Maximum swing angles (n=30, mean $\pm$ SD, degrees)			T-test	Pearson's correlation analysis
Rod	Sagittal plane	Coronal plane	P-value	r
20-cm	4.36 $\pm$ 0.88	3.74 $\pm$ 0.92	0.000	0.846
25-cm	2.47 $\pm$ 0.74**	1.64 $\pm$ 0.48**	0.000	0.720
30-cm	1.01 $\pm$ 0.51##	0.79 $\pm$ 0.48##	0.016	0.536
**: The swing angle of the 25-cm rod was significantly smaller than that of 20-cm rod (P<0.01)				
##: The swing angle of the 30-cm rod was significantly smaller than that of 25-cm rod (P<0.01)				

Table 3
Correlation analysis between the maximum swing angle and anatomical parameters of the femur

20-cm rod			25-cm rod		30-cm rod	
Items	Sagittal plane	Coronal plane	Sagittal plane	Coronal plane	Sagittal plane	Coronal plane
FL	0.268	0.374*	0.145	0.291	0.540**	0.465**
IPD	0.260	0.332	-0.075	0.209	0.325	0.154
RFC	-0.227	-0.088	-0.247	-0.021	-0.044	0.016
FBA	-0.180	-0.099	-0.072	-0.285	0.010	0.241
ID-S	0.721**	0.520**	0.814**	0.470**	0.401*	0.135
ID-C	0.704**	0.677**	0.608**	0.659**	0.377*	0.110
*: P<0.05						
**: P<0.01						

The length of the femur positively correlated with the swing range of the 30-cm medullary rod (Table 3); conversely, the 20-cm and 25-cm rods positively correlated with the inner diameter of the isthmus of the femoral marrow cavity. The correlation coefficients between the inner diameter and swing angle in the same plane were >0.6 (P<0.01).

Discussion

We found that the length of IM rod and anatomical shape of the femur affected the swing angle; the longer the rod, the smaller the swing angle. For the 20-cm and 25-cm rods, the most relevant factor for the swing angle was the isthmus diameter of the canal; conversely, for the 30-cm IM rod, femoral length was the most relevant factor.

IM positioning technology is widely used in TKA and UKA, and research on positioning accuracy during the procedures has always been a concern for surgeons. Burton et al.[22] reconstructed 20 models of the femur and built a model of the 20-cm IM rod used in mobile-bearing UKA. They found the mean rod orientation was $3.28 \pm 2.18^\circ$ of flexion and $2.58 \pm 2.08^\circ$ of valgus. Kort et al.[23] used 10 lower limb cadavers to study the IM positioning accuracy of mobile-bearing UKA. They found that the short and long IM femoral rods may result in excessive flexion alignment error of the femoral component.

To explore the influence of the length of the IM rods on IM positioning accuracy during mobile-bearing UKA, we established three kinds of IM rod models (20-, 25-, and 30-cm), and simulated the process of the IM rods' swing in the femoral canal through finite element analysis; due to the irregular shape of the femoral medullary canal and presence of an anterior arch, methods based on manual measurement cannot determine contact between the rod and femoral cortex. Burton et al.[22] evaluated rod-canal interference using a collision detection algorithm, whereas we innovatively used the finite element method to resolve this problem. We calculated the maximum swing range of the rods in the sagittal and coronal planes; this method can more accurately obtain the maximum swing angle of the IM rods in two directions.

In the sagittal and coronal planes, the maximum swing angles were: $4.36 \pm 0.88^\circ$ and $3.74 \pm 0.92^\circ$ for the 20-cm rod; $2.47 \pm 0.74^\circ$ and $1.64 \pm 0.48^\circ$ for the 25-cm rod; and $1.01 \pm 0.51^\circ$ and $0.79 \pm 0.48^\circ$ for the 30-cm rod, respectively. This may be because the medullary canal is irregular, whereas the femur possesses curvature. The longer the IM rod, the greater the restriction on the inner wall of the femoral canal; thus, the smaller the swing angle. In femurs with a larger anterior arch radius and thin medullary canal, the 30-cm rod cannot be inserted completely.

To further explore the influence of femoral anatomy on the swing angle of the IM rod swing in the canal, we measured a series of parameters, and analyzed the correlation between these parameters and the swing angle of each rod. The results show that for the 20-cm and 25-cm rods, the most relevant factor for the swing angle was the isthmus diameter of the IM canal; conversely, for the 30-cm IM rod, the femoral length was the most relevant factor (Table 3). In most cases, the tip of the 20-cm rod could not reach the femoral isthmus after insertion; conversely, the tip of the 25-cm rod was located near the isthmus (Figure 5). Therefore, when the 20-cm and 25-cm rods swing in the medullary canal, the cortex will not block the body of the rod; only the end of the rod will come into contact with the inner wall of the canal, and can cover most, or even the entire medullary canal. The inner wall of the medullary canal is a smooth curve; thus, the inner diameter of the canal at the end of the rod relates to the inner diameter of the isthmus. Regarding the 20-cm and 25-cm rods, the most relevant factor for the swing angle was the isthmus diameter of the canal; the correlation coefficients were >0.6 .

Previous studies of IM positioning during TKA demonstrate that the medullary rod tip approaches the isthmus with good positioning accuracy.[24, 25] In some cases, such as in patients who had previously undergone total hip replacement, short rods could also be used[26]; our research also supports this view. The maximum swing of the IM canal using the 25-cm rod was $2.47 \pm 0.74^\circ$ in the sagittal plane, and $1.64 \pm 0.48^\circ$ in the coronal plane; this means that the maximum force line of the femoral prosthesis was 0.82° on the coronal surface. The maximum error range of the posterior inclination on the surface was 1.24° ; for mobile-bearing UKA femoral prosthesis, this is sufficient. Kang et al.[27] found that surgeons should avoid valgus malalignment in the femoral component, especially malalignment exceeding 9° .

Regarding the 30-cm rod, the tip extended significantly beyond the femoral isthmus (Figure 5); this was particularly prominent in female patients with shorter femurs. The shorter the length of the patient's femur, the smaller the swing range in the IM canal. In short femurs with a narrow isthmus, the tip of the rod was in contact with the cortex of the front of the femur when inserting a 30-cm rod; therefore, it could not be inserted completely. During surgery, however, we did not find this to be the case; we speculated that this discrepancy was due to the small diameter of the IM rod and slight deformation during advancement to adapt to the IM canal shape. During the operation, the medullary rod may penetrate the cortex, creating a risk of fracture. Moreover, when using a 30-cm rod, the tip is blocked by the anterolateral cortex of the femur; thus, its line of force is closer to the inner wall of the canal, deviating from the midline of the IM canal. Since women are known to have shorter femur lengths than men, using a 30-cm rod is not deemed suitable, as the positioning accuracy does not improve; rather, it imposes additional surgical risks.

There are some limitations to this study; first, we used digital technology to simulate the intramedullary positioning process. While the femur was simulated as a long, hollow bone with a smooth inner wall, bone is composed of cortical and cancellous tissues; this likely caused errors during measurement of the IM rods' swing angle. Further clinical research is required to verify our results. Second, the sample size of this study was relatively small, which makes the accuracy of correlation analysis between the swing angle and femoral anatomical parameters biased.

Conclusions

We conclude that the longer the IM rod, the smaller the swing angle in the femoral medullary canal; the diameter of the femoral medullary canal and length of the femur also affect the swing angle. In patients with a shorter femur length, such as women, 30-cm IM rods may not be fully inserted; therefore, we recommend the use of a 25-cm IM rod.

Abbreviations

FL: Femur length;

ID: Isthmic diameter;

IM: intramedullary;

IPD: insertion point distance;

MP: Microplasty;

UKA: unicompartmental knee arthroplasty;

RFC: Radius of the femoral curvature;

TKA: Total knee arthroplasty

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Institutional Committee of the sixth medical center of PLA General Hospital. Informed consent was waived from all patients for being included in this study.

Consent for publication

Informed consent was waived from all patients for being included in this study.

Availability of data and materials

The datasets used are available from the corresponding author on reasonable request.

Competing interests

The authors have no competing interests to declare.

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Authors' contributions

Shaokui Nan reconstructed 3D models, made figures and wrote the manuscript. Cheng Xu did the finite element analysis and edit the article. Dong Zhang Zhuo performed the literature search, data collection and helped write the manuscript; Zhang performed the literature search and helped to write the manuscript. Yue Song performed the literature search. Haifeng Li designed and performed the study. Yong Li performed the data collection and statistical analysis. All authors read and approved the final manuscript.

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References

1. Mohammad HR, Strickland L, Hamilton TW, Murray DW. Long-term outcomes of over 8,000 medial Oxford Phase 3 Unicompartmental Knees-a systematic review. *Acta Orthop*. 2018; 89(1):101-7. <https://doi.org/10.1080/17453674.2017.1367577>
2. Lisowski LA, van den Bekerom MP, Pilot P, van Dijk CN, Lisowski AE. Oxford Phase 3 unicompartmental knee arthroplasty: medium-term results of a minimally invasive surgical procedure. *Knee Surg Sports Traumatol Arthrosc*. 2011; 19(2):277-84. <https://doi.org/10.1007/s00167-010-1213-2>
3. Kim YJ, Kim BH, Yoo SH, Kang SW, Kwack CH, Song MH. Mid-Term Results of Oxford Medial Unicompartmental Knee Arthroplasty in Young Asian Patients Less than 60 Years of Age: A Minimum 5-Year Follow-up. *Knee Surg Relat Res*. 2017; 29(2):122-8. <https://doi.org/10.5792/ksrr.16.045>
4. Kim MS, Koh IJ, Sohn S, Jeong JH, In Y. Unicompartmental knee arthroplasty is superior to high tibial osteotomy in post-operative recovery and participation in recreational and sports activities. *Int Orthop*. 2019; 43(11):2493-501. <https://doi.org/10.1007/s00264-018-4272-5>
5. Erdem Y, Neyisci C, Yildiz C. Mid-term Clinical and Radiological Results of Oxford Phase 3 Medial Unicompartmental Knee Arthroplasty. *Cureus*. 2019; 11(9):e5674. <https://doi.org/10.7759/cureus.5674>
6. Xu T, Lao Y, Wang J, Liu F, Xiao L, Tong P. Mid-term results of Oxford phase-3 medial unicompartmental knee arthroplasty for medial arthritis in Chinese patients. *ANZ J Surg*. 2017; 87(4):287-90. <https://doi.org/10.1111/ans.13764>
7. Kim MS, Koh IJ, Kim CK, Choi KY, Baek JW, In Y. Comparison of implant position and joint awareness between fixed- and mobile-bearing unicompartmental knee arthroplasty: a minimum of five year follow-up study. *Int Orthop*. 2020; 44(11):2329-36. <https://doi.org/10.1007/s00264-020-04662-2>
8. Huang F, Wu D, Chang J, Zhang C, Qin K, Liao F, et al. A Comparison of Mobile- and Fixed-Bearing Unicompartmental Knee Arthroplasties in the Treatment of Medial Knee Osteoarthritis: A Systematic Review and Meta-analysis of 1,861 Patients. *J Knee Surg*. 2019. <https://doi.org/10.1055/s-0039-1697901>
9. Pongcharoen B, Boontanapibul K. Outcomes of mobile bearing unicompartmental knee arthroplasty in medial osteoarthritis knee with and without preoperative genu recurvatum. *World J Orthop*. 2018; 9(9):149-55. <https://doi.org/10.5312/wjo.v9.i9.149>
10. Ries MD. CORR Insights(R): Bearing Dislocation and Progression of Osteoarthritis After Mobile-bearing Unicompartmental Knee Arthroplasty Vary Between Asian and Western Patients: A Meta-analysis. *Clin Orthop Relat Res*. 2018; 476(5):961-3. <https://doi.org/10.1007/s11999-0000000000000276>
11. Kim JG, Kasat NS, Bae JH, Kim SJ, Oh SM, Lim HC. The radiological parameters correlated with the alignment of the femoral component after Oxford phase 3 unicompartmental knee replacement. *J Bone Joint Surg Br*. 2012; 94(11):1499-505. <https://doi.org/10.1302/0301-620X.94B11.29217>

12. Hopkins AR, New AM, Rodriguez-y-Baena F, Taylor M. Finite element analysis of unicompartmental knee arthroplasty. *Medical Engineering & Physics*. 2010; 32(1):14-21. <https://doi.org/10.1016/j.medengphy.2009.10.002>
13. Levine B, Rosenberg AG. The simple unicondylar knee: extramedullary technique. *Clin Sports Med*. 2014; 33(1):77-85. <https://doi.org/10.1016/j.csm.2013.06.003>
14. Matziolis G, Mueller T, Layher F, Wagner A. The femoral component alignment resulting from spacer block technique is not worse than after intramedullary guided technique in medial unicompartmental knee arthroplasty. *Arch Orthop Trauma Surg*. 2018; 138(6):865-70. <https://doi.org/10.1007/s00402-018-2911-3>
15. Dunn AS, Petterson SC, Plancher KD. Unicondylar knee arthroplasty: intramedullary technique. *Clin Sports Med*. 2014; 33(1):87-104. <https://doi.org/10.1016/j.csm.2013.08.004>
16. Gulati A, Weston-Simons S, Evans D, Jenkins C, Gray H, Dodd CA, et al. Radiographic evaluation of factors affecting bearing dislocation in the domed lateral Oxford unicompartmental knee replacement. *Knee*. 2014; 21(6):1254-7. <https://doi.org/10.1016/j.knee.2014.08.008>
17. Tu Y, Xue H, Ma T, Wen T, Yang T, Zhang H, et al. Superior femoral component alignment can be achieved with Oxford microplasty instrumentation after minimally invasive unicompartmental knee arthroplasty. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2016; 25(3):729-35. <https://doi.org/10.1007/s00167-016-4173-3>
18. Koh IJ, Kim JH, Jang SW, Kim MS, Kim C, In Y. Are the Oxford((R)) medial unicompartmental knee arthroplasty new instruments reducing the bearing dislocation risk while improving components relationships? A case control study. *Orthop Traumatol Surg Res*. 2016; 102(2):183-7. <https://doi.org/10.1016/j.otsr.2015.11.015>
19. Zhang Q, Wang W, Liu Z, Yue D, Cheng L, Wang B, et al. A novel extramedullary technique to guide femoral bone preparation in mobile unicompartmental knee arthroplasty based on tibial cut and overall alignment. *J Orthop Surg Res*. 2020; 15(1):92. <https://doi.org/10.1186/s13018-020-01598-6>
20. Pandit H, Jenkins C, Barker K, Dodd CA, Murray DW. The Oxford medial unicompartmental knee replacement using a minimally-invasive approach. *J Bone Joint Surg Br*. 2006; 88(1):54-60. <https://doi.org/10.1302/0301-620X.88B1.17114>
21. Su XY, Zhao Z, Zhao JX, Zhang LC, Long AH, Zhang LH, et al. Three-Dimensional Analysis of the Curvature of the Femoral Canal in 426 Chinese Femurs. *Biomed Res Int*. 2015; 2015:318391. <https://doi.org/10.1155/2015/318391>
22. Ma B, Long W, Rudan JF, Ellis RE. Three-dimensional analysis of alignment error in using femoral intramedullary guides in unicompartmental knee arthroplasty. *J Arthroplasty*. 2006; 21(2):271-8. <https://doi.org/10.1016/j.arth.2004.07.012>
23. Kort NP, van Raay JJ, Thomassen BJ. Alignment of the femoral component in a mobile-bearing unicompartmental knee arthroplasty: a study in 10 cadaver femora. *Knee*. 2007; 14(4):280-3. <https://doi.org/10.1016/j.knee.2007.04.007>

24. Maderbacher G, Schaumburger J, Baier C, Zeman F, Springorum HR, Birkenbach AM, et al. Appropriate sagittal femoral component alignment cannot be ensured by intramedullary alignment rods. *Knee Surg Sports Traumatol Arthrosc.* 2016; 24(8):2453-60. <https://doi.org/10.1007/s00167-015-3541-8>
25. Haruta Y, Kawahara S, Tsuchimochi K, Hamasaki A, Hara T. Deviation of femoral intramedullary alignment rod influences coronal and sagittal alignment during total knee arthroplasty. *Knee.* 2018; 25(4):644-9. <https://doi.org/10.1016/j.knee.2018.04.011>
26. Webb BT, Ulrich SD, MacKinlay KGW, Smith LS, Malkani AL. Use of Shorter Intramedullary Guide for Ipsilateral Total Knee Arthroplasty following Prior Total Hip Arthroplasty. *J Knee Surg.* 2018; 31(4):348-51. <https://doi.org/10.1055/s-0037-1603796>
27. Kang K-T, Son J, Baek C, Kwon O-R, Koh Y-G. Femoral component alignment in unicompartmental knee arthroplasty leads to biomechanical change in contact stress and collateral ligament force in knee joint. *Archives of Orthopaedic and Trauma Surgery.* 2018; 138(4):563-72. <https://doi.org/10.1007/s00402-018-2884-2>

Figures

Figure 1

3D models of the femur and intramedullary rods

Computed tomography data were imported into the Mimics software to reconstruct 3D models of the femoral cortical bone (a, b); three IM rod models were established (c). The intramedullary rod was inserted

into the femur from the insertion point (e), while the position of the rod was adjusted to ensure that it did not coincide with the cortex (f).

Figure 2

Finite Element model of the femur and intramedullary rod

After meshing, the model was imported into the ANSYS software (a); 18 directional forces were applied to the top of the rod to obtain a moving range map (b).

Figure 3

The moving range map of three kinds of intramedullary rods swing in the canal (a, b, and c)

The maximum moving distance in the two planes was measured: A is in the coronal plane and B is the sagittal plane. According to the results, the maximum swing angle of the rods was calculated. The swing angle was defined as α , $\sin(\alpha/2) = (A/2)/P$; therefore, $\alpha = 2 \cdot \arcsin(A/2/P)$, where P is the length of the intramedullary rod inserted into the canal, and A (or B) is the maximum moving distance (d).

Figure 4

Anatomical parameters of the femur were measured after the 3D models of the femoral cortical bone and canal were reconstructed

The centerline of the medullary canal was established (a), and a circle was fitted into the centerline of the medullary canal (b). Best fit circles at each control point on the centerline were built, and the smallest circle was selected as the isthmus; the isthmic diameter in the coronal and sagittal planes were also measured (c).

Figure 5

Images of the three kinds of intramedullary rods inserted into the femoral medullary canal; (a) is in the coronal plane and (b) is in the sagittal plane.