Original Article

Relationships between position of patellar ridge high point and morphology of resected surface for patellar resurfacing in total knee arthroplasty

Changzhao Li[1,2#], Xinyu Wang[1#], Lihang Zhang[1#], Peiheng He[2], Yong Liu[2], Cong Wang[3], Tsung-Yuan Tsai[3], Pingyue Li[1], Dongliang Xu[2]

[1]Guangdong Key Lab of Orthopedic Technology and Implant, General Hospital of Southern Theater Command of PLA, The First School of Clinical Medicine, Southern Medical University, Guangzhou, China; [2]Department of Joint Surgery, The First Affiliated Hospital of Sun Yat-sen University, Guangzhou, China; [3]Shanghai Key Laboratory of Orthopaedic Implants, Department of Orthopaedic Surgery, Shanghai Ninth People's Hospital, Shanghai Jiao Tong University School of Medicine, School of Biomedical Engineering, Shanghai Jiao Tong University, Shanghai, China

Contributions: (I) Conception and design: C Li, X Wang, L Zhang, P Li, D Xu; (II) Administrative support: P Li, D Xu; (III) Provision of study materials or patients: P Li, X Wang, D Xu; (IV) Collection and assembly of data: C Li, L Zhang, P He, Y Liu, C Wang, TY Tsai; (V) Data analysis and interpretation: C Li, X Wang, L Zhang, P He, Y Liu, C Wang, TY Tsai; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

[#]These authors contributed equally to this work and should be considered as co-first authors.

Correspondence to: Dongliang Xu, MD. Department of Joint Surgery, The First Affiliated Hospital of Sun Yat-sen University, Zhongshan 2nd Road, Yuexiu District, Guangzhou 510080, China. Email: dddrxu@163.com; Pingyue Li, PhD. Guangdong Key Lab of Orthopedic Technology and Implant, General Hospital of Southern Theater Command of PLA, The First School of Clinical Medicine, Southern Medical University, 111 Liuhua Road, Yuexiu District, Guangzhou 510030, China. Email: lipingyue09@126.com.

Background: Reproducing the native patellar ridge high point while maximizing osseous coverage is important for the success of patellar replacement, but it cannot always be achieved simultaneously. This study aimed to thoroughly investigate the relationships and their influencing factors between the positions of the high point of patellar ridge (HPPR) and the morphology of the patellar resected surface.

Methods: Four hundred seventy-three patients (265 men, 208 women) aged 18 to 50 years with knee injuries before arthroscopy were retrospectively collected for this cross-sectional study. Computed tomography (CT) and magnetic resonance imaging (MRI) were used to construct 3D computer models of the patella and patellar cartilage. The morphometric characteristics of the patellar cut after virtual resection and the HPPR position relative to the patellar cut centre were measured and analyzed.

Results: The medial displacements of the HPPR were positively correlated with Wiberg's classification and index (all $P<0.001$). The mean values of HPPR's medial displacements were 0.15 of the medial width of patellar cut, and 93.2% of all patella ranged from 0 to 0.3. When the implant's apex were placed at 0.15 of the medial width of patellar cut medialized, the proportion of implant placement errors within 1 mm of the native high point was 12% more in female patella ($P=0.01$), and 7% more in all patella ($P=0.03$) than 3 mm medialized.

Conclusions: Wiberg's system can roughly predicted the medial-lateral position of the HPPR. The HPPR was mainly medially located at the 0.15 of the medial patellar width approximately, and 15% medialized of the implant's apex can better reproduce the native patellar high point than 3 mm medialized. The current results provide basic data for patellar implant selection, preoperative planning, and implant design to reproduce the native patellar high point better while maximizing osseous coverage for patellar resurfacing.

Keywords: Arthroplasty; anatomy; morphometry; patella

Submitted Jun 28, 2022. Accepted for publication Jun 05, 2023. Published online Jul 31, 2023.
doi: 10.21037/qims-22-691
View this article at: https://dx.doi.org/10.21037/qims-22-691

Introduction

Numerous surgeons have advocated resurfacing the patella during total knee arthroplasty (TKA) to significantly reduce the revision rate, relieve pain, and improve patient-reported outcomes while remaining cost-effective (1-4). In contrast, a suboptimal surgical technique for resurfacing increases the risk of complications, such as patellar instability and clunk syndrome, anterior knee pain, or abnormal wear leading to prothesis loosening (1,5,6). Several principles should be followed to obtain satisfactory results, and replicating the original patellar ridge high point is one of them (7,8). The ridge high point acts as a fulcrum for patellar tracking, and changes in its position can influence the normal patellofemoral kinematics after resurfacing (9).

To reproduce the native high point, surgeons choose to place the implant's high point over the points on the patellar-cut surface projected from the high point of patellar ridge (HPPR) (5,10). This technique decreased the need for lateral retinacular release and improved patellofemoral prognosis (5,10). The HPPR positions vary widely, but mainly toward the medial aspect of the patellar cut (5,10,11). For patients with a small medial patellar facet (often found in East Asian patients), intentional medialization of the patellar implant according to the HPPR position may lead to an overhang of the medial part of the implant. If a smaller implant is used to prevent overhang, the overhang of the lateral bone surface beyond the implant will occur (1,12). Therefore, reproducing the native patellar high point while maximizing osseous coverage for patellar resurfacing is not always satisfied simultaneously. To better solve this problem, it is essential to understand the relationship between the HPPR positions and the anatomy of the patellar cut. However, limited knowledge is available for their relationships (5,10,13,14) and till now, factors influencing their relationships have not been evaluated.

Therefore, the aim of this study was to thoroughly investigate the correlations and their influencing factors between HPPR position and anatomy of the patellar cut. Since a previous study showed that placing the patellar component in two-thirds of the width of the patella reduces the need for lateral release during TKA (1), we hypothesized that HPPR may be proportionally distributed according to the size of the patellar cut. In addition, the HPPR is determined by the patellar ridge, and Wiberg's system is used to describe the shape of the patella mainly according to the ridge position (15). Our second hypothesis is that the Wiberg's system may influence or predict HPPR positions. We present this article in accordance with the STROBE reporting checklist (available at https://qims.amegroups.com/article/view/10.21037/qims-22-691/rc).

Methods

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The ethics committee of the First Affiliated Hospital of Sun Yat-sen University approved the study protocol (No. [2011]57). Written informed consent was obtained from all subjects before the study. All patients included in this study were scheduled to undergo primary arthroscopy for sports knee injuries at our hospital between January 2019 and December 2021. All patients were aged between 18 and 50 years. Patients were excluded if they presented with advanced patellofemoral arthritis, patellar dysplasia, patellar instability, patellar fracture, or had undergone previous knee surgery (*Figure 1*). A total of 473 patients (265 men and 208 women; mean age, 29±13 years) were retrospectively collected for this cross-sectional study.

Computed tomography (CT) scanning (Siemens SOMATOM 16, Germany; slice thickness =1 mm) and magnetic resonance imaging (MRI) scan (GE 3.0T, USA; series of O Sag 3D-FS-SPGR, matrix =256×256, flip angle =15°, slice thickness =1 mm) were performed for all subjects' injured knees (16). Both CT and MRI images were imported into Amira 6.7 (Thermo Fisher Scientific, Rockford, IL, USA) to construct patellar models. Then, the 3D models of the patella were imported into MATLAB (Mathworks Inc., Natick, MA, USA), and the 3 dimensional (3D) model of patellar cartilage was moved as a float to share physical space with the 3D model of the bony patella (the fixed object) using the best fit method (16).

The 3D models of the patella were then imported into Rhinoceros 5.0 software (Robert McNeel & Assoc., Seattle, USA) to establish the anatomical coordinate systems of the patella (13). Multiple points were selected on the patellar

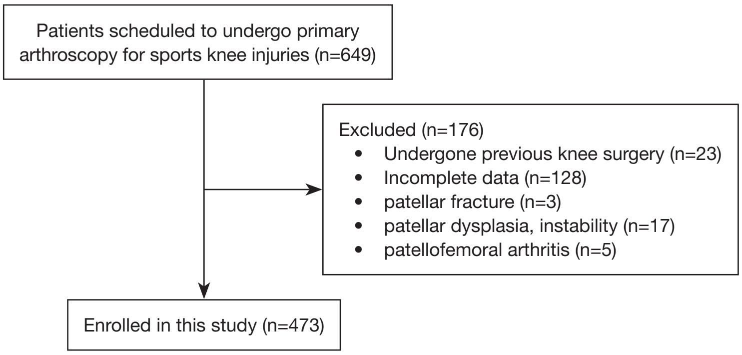


Figure 1 Patient selection flowchart.

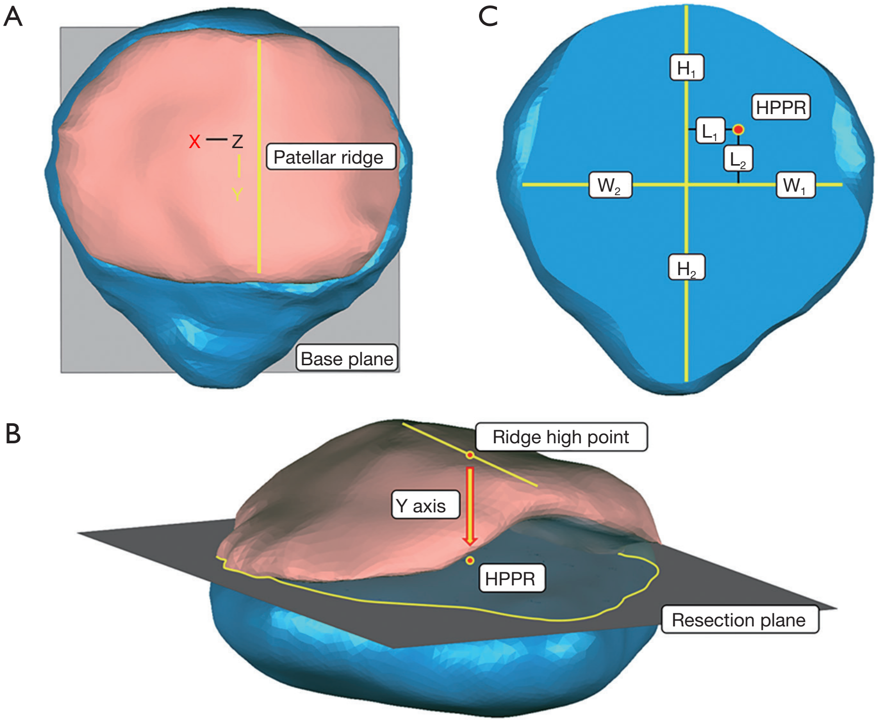


Figure 2 Schematic representation of the morphological parameters of the patella. (A) Set up the Coordinate system of the patellar 3D model; (B) virtually resected the patellar and defined the HPPR; (C) measured the morphology of the patellar cut and HPPR position. H_1, superior height; H_2, inferior height; L_1, lateral HPPR distance; L_2, superior HPPR distance; W_1, medial width; W_2, lateral width; HPPR, high point of patellar ridge.

anterior surface patella to fit the base plane using the least-squares method. Subsequently, the deepest points on the median ridge were selected to fit a line. Then the patellar 3D models were aligned to the XY surface and Y-axes to simultaneously parallel to the fitting base plane and line (*Figure 2A*) (13).

Next, the patellar resection plane was created parallel to the fitting base plane. The resected plane was set at the deepest level of the lateral facet to virtually cut the patella, simulating the subchondral resection method for routine patellar resurfacing (13). A patellar cartilage ridge line was drawn. The midpoint of the ridge line projected on the resected surface along the z-axis was defined as the HPPR (*Figure 2B*). Two cross lines were drawn on the resected surface, intersecting the horizontal and vertical axes, where width (W) and height (H) represent the width

Table 1 Comparison of the anatomy of patellar resected surface and HPPR position between genders

Patellar parameters	Male	Female	P
W (mm)	44.27±2.87	37.52±3.63	<0.001
W_1 (mm)	21.30±1.60	17.80±1.86	<0.001
W_2 (mm)	21.33±1.51	18.12±1.85	<0.001
H (mm)	40.26±2.75	34.88±2.89	<0.001
H_1 (mm)	17.94±1.34	16.18±1.13	<0.001
H_2 (mm)	20.59±1.51	17.78±1.49	<0.001
L_1 (mm)	3.15±1.61	2.65±1.59	<0.001
L_2 (mm)	3.32±1.27	1.87±1.19	<0.001
L_1/W_1	0.15±0.08	0.15±0.09	0.74
L_2/H_1	0.19±0.07	0.12±0.07	<0.001

Values are reported as mean ± SD. W, width of patellar cut; W_1, medial width; W_2, lateral width; H, height of patellar cut; H_1, superior height; H_2, inferior height; L_1, lateral HPPR distance; L_2, superior HPPR distance; L_1/W_1, The ratio of lateral HPPR distance and medial width of patellar cut; L_2/H_1, the ratio of superior HPPR distance and superior height of patellar cut. HPPR, high point of patellar ridge; SD, standard deviation.

and height of the patellar cut, respectively. The cross point of two lines were defined as the centre of the patellar cut. The location of the HPPR to the centre of the patellar cut was then measured via the horizontal axis (medial-lateral distance) and vertical axis (proximal-distal distance) (5). The medial width (W_1), lateral width (W_2), superior height (H_1), inferior height (H_2), lateral HPPR distance (L_1), and superior HPPR distance (L_2) relative to the centre of the patellar cut were measured. The HPPR positions normalized by the medial width (L_1/W_1) and superior height (L_2/H_1) were calculated (*Figure 2C*). The shape of the patella was classified according to Wiberg (15) and Baumgartl (17) into types I, II and III. Wiberg index were measured at the axial level of the greatest patellar width slice (18) (Table S1, Figure S1).

Gender differences were statistically analyzed using the Student's *t*-test. The correlations between Wiberg's index and L1 were evaluated using Pearson's correlations. One-way analysis of variance (ANOVA) and post hoc pairwise comparison (Newman-Keuls test) were used to analyze the L_1 differences among different patellar types according to the Wiberg classification. The chi-squared and Fisher's exact test were used for frequency distribution differences. All parameters were measured twice and blindly by two experienced orthopedic surgeons. The inter- and intra-observer reliabilities were evaluated using intraclass correlation coefficients (ICCs) and all ICC were greater than 0.8. P<0.05 were considered statistically significant differences. All statistical analyses were performed using SPSS version 24 software (SPSS Inc., Chicago, IL, USA).

Results

The mean values of the patellar cut parameters and HPPR positions relative to the patellar cut centre are shown in *Table 1*. The mean proximal and medial displacements of the HPPR were significantly greater in men than in women (both P<0.001). When HPPR positions were normalized by the medial width and proximal height of the patellar cut, greater proximal displacements were found in males than that in females (P<0.001), but no significant difference were found in medial displacement (P=0.74).

The scatter plot of HPPR on the patellar cut is shown in *Figure 3*. The medial and proximal distances of HPPR relative to the patellar cut centre ranged from −2.1 to 7.3 mm and −2.6 to 7.3 mm, respectively. 94% of all HPPRs were proximal medial to the centre of the patellar cut. All male HPPRs were proximal, whereas 4.8% of all female HPPRs were distal to the patellar cut centre (P<0.001).

With the Wiberg index increased, more medial displacements of the HPPR relative to the patellar cut centre were found in both males (r=0.793, P<0.001) and females (r=0.692, P<0.001) (*Table 2*). More medial displacements of the HPPR were observed from type I to type III patella according to Wiberg's classification (both P<0.05) (*Figure 4*).

After normalized by the medial width of the patellar cut, the mean values of HPPR's medial displacements (L_1/W_1) were 0.15 in both males and females (*Table 1*). L_1/W_1 of 94.3% of all male patella and 91.8% of all female patella ranged from 0 to 0.3 (*Figure 5*).

When the position of the patellar implant apexes was 0.15 of W_1 medialized to the patellar cut centre, 7% more patella (P=0.03) and 12% more female patella (P=0.01) had the apexes positioned within ±1 mm of the native patellar high point than the implant's apexes were 3 mm medialized (*Table 3*).

Discussion

The major finding of the current study was that the HPPR was mainly located at the medial around 0.15 of medial

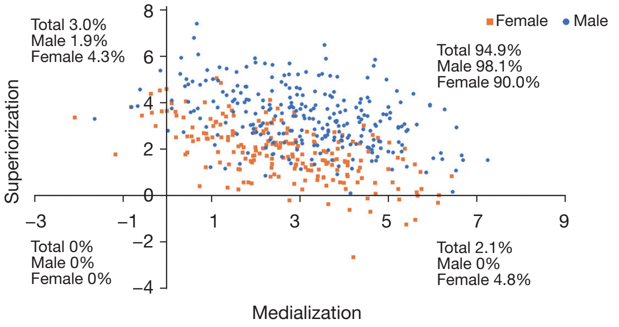


Figure 3 Scatter-plot graph of the HPPR. HPPR, high point of patellar ridge.

Table 2 Correlation coefficient between medial displacement of HPPR and Wiberg index

Parameters	Male	Female	Total
r	0.793	0.692	0.715
Adjusted R^2	0.627	0.476	0.51
P	<0.001	<0.001	<0.001

HPPR, high point of patellar ridge.

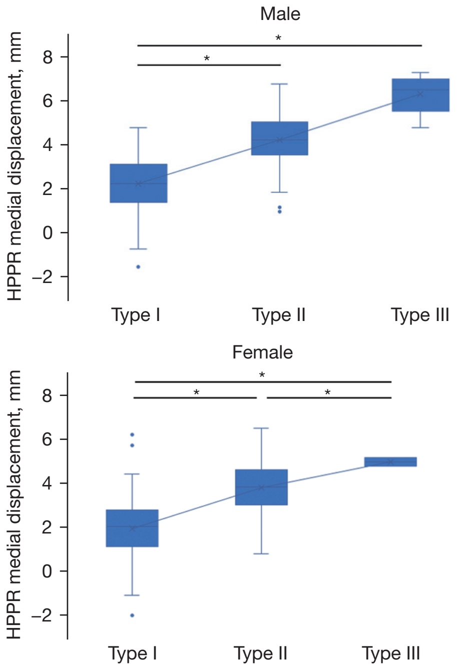


Figure 4 Correlation between HPPR medial displacement and patellar types according to Wiberg in male and female. *, P<0.05. HPPR, high point of patellar ridge.

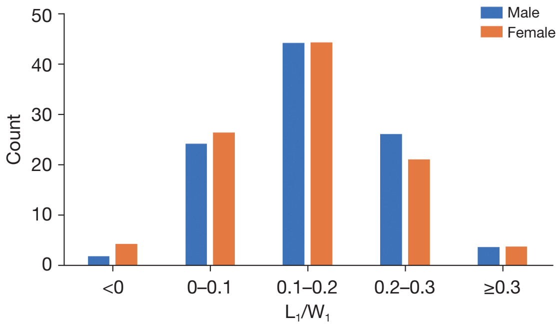


Figure 5 Histograms of the ratio of lateral HPPR distance and medial width of patellar cut (L_1/W_1). HPPR, high point of patellar ridge.

width of the patellar cut. Fifteen percent of medial patellar cuts medialized of the implant's apex can reproduce the native patellar high point better than 3 mm medialized. The medial displacements of the HPPR were positively correlated with Wiberg's classification and index.

Poor positioning of the patellar implant can lead to patellar maltracking, possibly causing patellofemoral complications, such as anterior knee pain, patella instability, excessive wear, or aseptic loosening (1,19). Therefore, proper implant positioning is important for successful patellar tracking after resurfacing (5,10). The approach to medially place the patellar implant's apex over the HPPR to reproduce the native patellar high point is advocated by many surgeons for clinical beneficial (5). Hofmann *et al.* (10) reported that lateral retinacular release was required in 45.5% of patients whose patellar components were centralized on the patella compared with 17% whose patellar components were placed over the HPPR. Assi *et al.* (5) followed 117 patients with an implant apex placed over the HPPR for 4.5 years, and none of them experienced anterior knee pain, dislocation episodes, or patellar revision. Therefore, the HPPR positions on the patellar cut need to be investigated for implant positioning. The current study showed that HPPR medial-lateral positions relative to the patellar cut centre were wide (−2.1 to 7.3 mm), and a few HPPRs (2.96%) were located laterally. Although these results were similar to those of Assi *et al.*'s (5), they are not in line with Hofmann *et al.*'s (10) and numerous previous studies (1,12,20,21) that medialization of the implant is needed in all patients.

The wide range of the HPPR medial-lateral distribution is derived from the high variability of the ridge location (22). Wiberg's classification and index (15,18,23) can describe

Table 3 Distance range between HPPR and 3 mm or 0.15 of W_1 medialized to the patellar cut centre

Distance range	<1 (%)	1–<2 (%)	2–<3 (%)	≥3 (%)	Total (%)
Male					
3 mm	118 (44.5)	84 (31.7)	48 (18.1)	15 (5.7)	265 (100.0)
15%	126 (47.5)	71 (26.8)	50 (18.9)	18 (6.8)	265 (100.0)
Female					
3 mm	86 (41.3)	72 (34.6)	38 (18.3)	12 (5.8)	208 (100.0)
15%	111 (53.3)	48 (23.1)	42 (20.2)	7 (3.3)	208 (100.0)
Total					
3 mm	204 (43.1)	156 (33.0)	86 (18.2)	27 (5.7)	473 (100.0)
15%	237 (50.1)	119 (25.2)	92 (19.5)	25 (5.3)	473 (100.0)

Ridge variability. Thus, it is plausible to infer that the medial-lateral positions of the HPPR are correlated with Wiberg's system. The current study verified the inference that 51.0% (adjusted R^2=0.510) of the variance of the HPPR medial-lateral position is explained by the Wiberg index, and the HPPR tends to be more medial to the patellar cut centre from type I to type III patella. These correlations indicate that the Wiberg's system can roughly predict the HPPR medial-lateral position, and preoperative assessment of the Wiberg's system may be helpful for patellar implant preparation (e.g., size, type) and determining optimal patellar component positioning for later resurfacing.

Considering that the HPPR mediolateral positions differ from one patella to another, patient-based positioning of the implant is needed to reproduce the native patellar high point better (5). However, in some cases, smaller implant was required for the deliberate medialization according to HPPR positions (12), leading to the overhang of the patellar lateral bony surface beyond the implant, possibly the need of a lateral chamfer saw cut for the lateral bony impingement (12,24). The smaller patellar implant may also increase patellar instability in the trochlear groove and incidence of quadriceps tendon irritation, leading to patellar impingement, tilt, or crepitus (11,25). In some cases, it is difficult to replicate the native high point of the patellar implant while maximizing coverage. There are mainly two designs for the position of the implant's apex in the market: centralized or medialized. Since HPPR is located from near the centre to the medial aspect of the patella cut, using a centralized patellar implant when HPPR is near the central of the resected surface (*Figure 6A*), or using a medialized implant when HPPR is located medially (*Figure 6B*), may allow surgeons to use a bigger implant to better cover the lateral bone surface. Here, we provide a new technique or idea of flexibly using different types of patellar implant to better reproduce the native high point while maximize coverage. However, how to implement it should take the patellar actual condition and personal experiences into account.

As for proximal-distal positions of the HPPR, the present study showed that over 90% of all HPPR points were proximal to the centre of the patellar cut, which was similar to a previous study (5). However, two biomechanical studies showed that distal placement of the patellar implant led to decreased loading when the knee flexion angles were higher (26,27). Therefore, for patients using high flexion prosthesis or who are expected to achieve high knee flexion after TKA, placing the patellar implant more distally than the HPPR position may further improve the patellar tracking by decreasing the patellofemoral loading (11,12). Further biomechanical studies are required to verify this hypothesis. In addition, the current study further analyzed the sex differences in HPPR distribution. The results demonstrated that all distally located HPPRs relative to the patellar cut centre were female, indicating that distal placement of the patellar implant might need to be considered for the female patella.

The design and shape of the patellar implant are critical for the success of patellar replacement (28). Patellar implants come in various shapes and designs over time owing to increasing knowledge of the anatomy and biomechanics of the patellofemoral joint. The current study showed that the mean medialized distance of the HPPR relative to the patellar cut centre was approximately

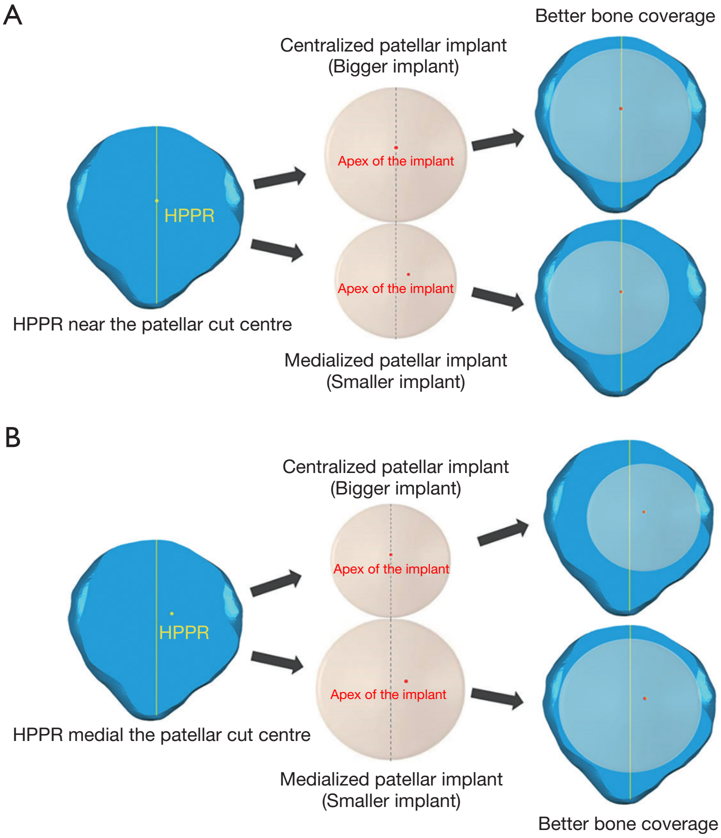
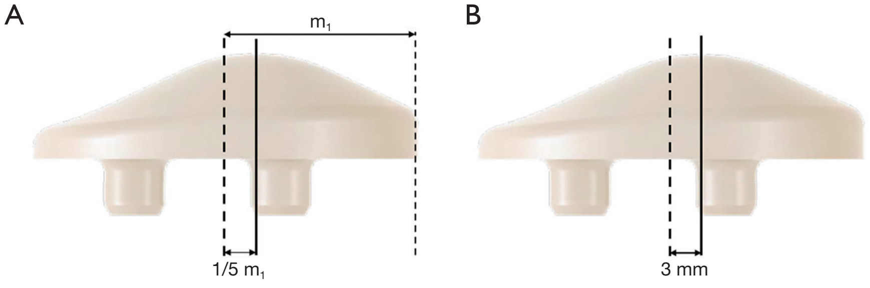


Figure 6 Flexibly using different types of patellar component according to the HPPR position. (A) Choosing centralized patellar component when HPPR is near to the centre of the patellar cut; (B) choosing medialized patellar component when there is an obvious medialization of the HPPR relative to the patellar cut's center. HPPR, high point of patellar ridge.

3 mm. This result is in line with the design of the market's most used medialized patellar implant, where the implant's apex is 3 mm medialized (*Figure 7A*). However, since the positions of the HPPR showed wide variability, the implant's apex with fixed medialized values were expected to be unable to reproduce the native high point well in some patellae. The current results verified this and showed that over 50% of patellae had an apex positioned over ±1 mm of the patellar native high point with a 3 mm medialized apex. When normalizing the position of the HPPR with the size of the patellar cut, we observed that the HPPR was mainly distributed on approximately 15% of the medial patellar cut from the centre. According to this new finding, if the implant's apex was designed to be 15% of the medial patellar cut from the centre (*Figure 7B*), the current results demonstrated that significantly fewer patellae (7%) had an apex positioned over ±1 mm of the native high point than 3 mm medialized, particularly for female patellae (12%). Knee OA is also more common in women than in men. The Hofmann *et al.*'s study (10) showed that differences in duplication of the native high point within 1–2 mm increased the need for lateral retinacular release during TKA. Anglin *et al.* (12) reported that patellar tilt and shift change with the amount of medialization change of the implant. Since 15% medialization of the implant's apex is more fit to the patellar native high point than 3 mm medialization, it is plausible to infer that 15% medialization of the implant's apex may require less lateral retinacular release and obtain better patellofemoral tracking than 3 mm medialization for patellar resurfacing. Of course, this new design idea of proportionally medializing the implant's apex requires more biomechanical and clinical research to verify its clinical applications. Still, we believe it may expand the design philosophy of patellar implants to reproduce the high point better while maximizing coverage.

This study has several limitations. First, only Asian



Proportionally medialized patellar implant

3 mm medialized patellar implant

Figure 7 Position of the apex for patellar implant. (A) The apex of the patellar implant to be proportionally medialized based on the component size; (B) the apex of the patellar implant to be 3 mm medialized.

patients were included in the study, and racial disparities in the patellar morphological parameters may exist. Caution should be taken when applying the current results to populations of different ethnicities. Second, all patients in this study were 20 to 50 years old, but TKA and patellar resurfacing are common in elderly patients with OA. Previous three-dimensional patellar studies (13,14,23,29-31) have demonstrated that the positions of the patellar ridge (approximately 0.42) and shape are similar in young, healthy subjects and elderly patients with osteoarthritic knees. Thus, we do not expect the current results to differ significantly from those of elderly patients with OA.

In terms of clinical relevance, the present study highlights that although the position of the patellar high point showed wide variability, it can be roughly predicted by Wiberg's system and was mainly proportionally distributed after normalizing by the size of the patellar cut. These findings may be important for patellar component selection, implant design, and preoperative planning of patellar resurfacing in TKA.

Conclusions

The positions of the patellar ridge high points showed wide variability, but Wiberg's system can roughly predict its medial-lateral position. After normalization by the size of the patellar cut, ridge high points were mainly located at the medial, around 15% of the medial patellar cut. A 15% proportionally medialized apex of the implant can better reproduce the native patellar high point than the 3 mm medialized commonly seen in the market. For patellar resurfacing, patient-based selection of the implant type, preoperative assessment of the patellar shape according to Wiberg's system, and implant design with a proportionally medialized apex could better replicate the native patellar high point while maximizing osseous coverage, which may further improve patellar tracking and prognosis after resurfacing.

Acknowledgments

The authors would like to thank all the staff of the Department of Joint Surgery in The First Affiliated Hospital of Sun Yat-sen University for giving all kinds of support and help for this study.
Funding: This work was supported by the 5010 Clinical Research Project of Sun Yat-sen University (No. 2010005).

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://qims.amegroups.com/article/view/10.21037/qims-22-691/rc

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://qims.amegroups.com/article/view/10.21037/qims-22-691/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The ethics committee of the First Affiliated Hospital of Sun Yat-sen University approved the study protocol (No. [2011]57). Written informed consent was obtained from all subjects before the study.

References

1. Lewonowski K, Dorr LD, McPherson EJ, Huber G, Wan Z. Medialization of the patella in total knee arthroplasty. J Arthroplasty 1997;12:161-7.
2. Migliorini F, Eschweiler J, Niewiera M, El Mansy Y, Tingart M, Rath B. Better outcomes with patellar resurfacing during primary total knee arthroplasty: a meta-analysis study. Arch Orthop Trauma Surg 2019;139:1445-54.
3. Maney AJ, Koh CK, Frampton CM, Young SW. Usually, Selectively, or Rarely Resurfacing the Patella During Primary Total Knee Arthroplasty: Determining the Best Strategy. J Bone Joint Surg Am 2019;101:412-20.
4. Weeks CA, Marsh JD, MacDonald SJ, Graves S, Vasarhelyi EM. Patellar Resurfacing in Total Knee Arthroplasty: A Cost-Effectiveness Analysis. J Arthroplasty 2018;33:3412-5.
5. Assi C, Kheir N, Samaha C, Deeb M, Yammine K. Optimizing patellar positioning during total knee arthroplasty: an anatomical and clinical study. Int Orthop 2017;41:2509-15.
6. Johnson TC, Tatman PJ, Mehle S, Gioe TJ. Revision surgery for patellofemoral problems: should we always resurface? Clin Orthop Relat Res 2012;470:211-9.
7. Kim JH, Yoo BW, Kim CW. Influence of the Rotational Alignment of the Femoral and Patellar Components on Patellar Tilt in Total Knee Arthroplasty. Knee Surg Relat Res 2015;27:163-7.
8. Keshmiri A, Springorum H, Baier C, Zeman F, Grifka J, Maderbacher G. Is it possible to re-establish pre-operative patellar kinematics using a ligament-balanced technique in total knee arthroplasty? A cadaveric investigation. Int Orthop 2015;39:441-8.
9. Kim TK, Chung BJ, Kang YG, Chang CB, Seong SC. Clinical implications of anthropometric patellar dimensions for TKA in Asians. Clin Orthop Relat Res 2009;467:1007-14.
10. Hofmann AA, Tkach TK, Evanich CJ, Camargo MP, Zhang Y. Patellar component medialization in total knee arthroplasty. J Arthroplasty 1997;12:155-60.
11. Yang CC, Dennis DA, Davenport PG, Kim RH, Miner TM, Johnson DR, Laz PJ. Patellar component design influences size selection and coverage. Knee 2017;24:460-7.
12. 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.
13. Huang AB, Luo X, Song CH, Zhang JY, Yang YQ, Yu JK. Comprehensive assessment of patellar morphology using computed tomography-based three-dimensional computer models. Knee 2015;22:475-80.
14. Park DY, Ji HM, Kwak KS, Nair SG, Won YY. Three dimensional CT-based virtual patellar resection in female patients undergoing total knee replacement: a comparison between tendon and subchondral method. Clin Orthop Surg 2012;4:193-9.
15. Wiberg G. Roentgenographs and anatomic studies on the femoropatellar joint: with special reference to chondromalacia patellae. Acta Orthop Scand 1941;12:319-410.
16. Yang Y, Zeng X, Jin Y, Zhu Z, Tsai TY, Chen J, Shen H, Li P. The Presence of Cartilage Affects Femoral Rotational Alignment in Total Knee Arthroplasty. Front Surg 2022;9:802631.
17. Baumgartl F. Das Kniegelenk. Berlin: Springer; 1944.
18. Fucentese SF, von Roll A, Koch PP, Epari DR, Fuchs B, Schottle PB. The patella morphology in trochlear dysplasia--a comparative MRI study. Knee 2006;13:145-50.
19. Gasparini G, Familiari F, Ranuccio F. Patellar malalignment treatment in total knee arthroplasty. Joints 2013;1:10-7.
20. Lachiewicz PF, Soileau ES. Patella maltracking in posterior-stabilized total knee arthroplasty. Clin Orthop Relat Res 2006;452:155-8.
21. Yoshii I, Whiteside LA, Anouchi YS. The effect of patellar button placement and femoral component design on patellar tracking in total knee arthroplasty. Clin Orthop Relat Res 1992;(275):211-9.
22. Tecklenburg K, Dejour D, Hoser C, Fink C. Bony and cartilaginous anatomy of the patellofemoral joint. Knee Surg Sports Traumatol Arthrosc 2006;14:235-40.
23. Li Z, Liu G, Tian R, Kong N, Li Y, Li Y, Wang K, Yang P. The patellofemoral morphology and the normal predicted value of tibial tuberosity-trochlear groove distance in the Chinese population. BMC Musculoskelet Disord

2021;22:575.
24. Doerr TE, Eckhoff DG. Lateral patellar burnishing in total knee arthroplasty following medialization of the patellar button. J Arthroplasty 1995;10:540-2.
25. Joseph L, Batailler C, Roger J, Swan J, Servien E, Lustig S. Patellar component size effects patellar tilt in total knee arthroplasty with patellar resurfacing. Knee Surg Sports Traumatol Arthrosc 2021;29:553-62.
26. Lee TQ, Budoff JE, Glaser FE. Patellar component positioning in total knee arthroplasty. Clin Orthop Relat Res 1999;(366):274-81.
27. Reithmeier E, Plitz W. A theoretical and numerical approach to optimal positioning of the patellar surface replacement in a total knee endoprosthesis. J Biomech 1990;23:883-92.
28. Sharma A, Grieco TF, Zingde SM, Dennis DA, Anderle MR, Komistek RD. In Vivo Three-Dimensional Patellar Mechanics: Normal Knees Compared with Domed and Anatomic Patellar Components. J Bone Joint Surg Am 2017;99:e18.
29. Shang P, Zhang L, Hou Z, Bai X, Ye X, Xu Z, Huang X. Morphometric measurement of the patella on 3D model reconstructed from CT scan images for the southern Chinese population. Chin Med J (Engl) 2014;127:96-101.
30. Baldwin JL, House CK. Anatomic dimensions of the patella measured during total knee arthroplasty. J Arthroplasty 2005;20:250-7.
31. Iranpour F, Merican AM, Amis AA, Cobb JP. The width:thickness ratio of the patella: an aid in knee arthroplasty. Clin Orthop Relat Res 2008;466:1198-203.

Cite this article as: Li C, Wang X, Zhang L, He P, Liu Y, Wang C, Tsai TY, Li P, Xu D. Relationships between position of patellar ridge high point and morphology of resected surface for patellar resurfacing in total knee arthroplasty. Quant Imaging Med Surg 2023;13(9):6129-6138. doi: 10.21037/qims-22-691

Supplementary

Table S1 Wiberg classification of the patella

Wiberg classification	Classification criteria
Wiberg type I	The ridge was seen to be situated approximately in the center of the patella
Wiberg type II	The ridge was situated slightly toward the medial border of the patella, and the medial facet was smaller than the lateral
Wiberg type III	The ridge was displaced medially to such a degree that there was hardly any room left over for the medial facet

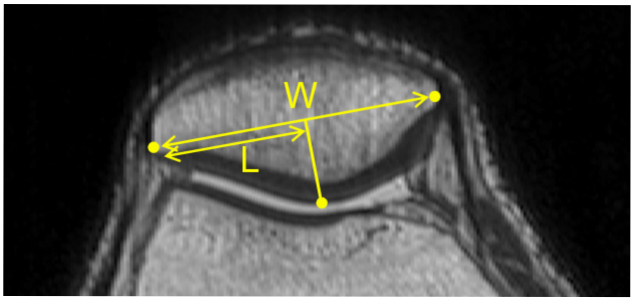


Figure S1 Wiberg's index of the patella. Patellar width (W) was measured between the medial and lateral patellar margins at the level of the greatest patellar width. The lateral patellar width (L) is the distance from the lateral patellar margin to the line perpendicular to the patellar width and crossing the ridge point. Wiberg index = L/W.

https://dx.doi.org/10.21037/qims-22-691