MENTORS IN ORTHOPEDICS

TROCHLEAR SULCUS MODELING FOR FEMORAL IMPLANT POSITIONING DURING NAVIGATED TKA

https://doi.org/10.71165/3qx6-kl7t

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SUMMARY

Background: Patellofemoral complications and mid-flexion instability remain significant causes of patient dissatisfaction following total knee arthroplasty (TKA). While femoral component malpositioning and overstuffing are known contributors to anterior knee pain, the sagittal geometry of the trochlear groove in osteoarthritic patients has not been extensively characterized using intraoperative data.

Objective: This study aimed to quantify the sagittal curvature of the trochlear sulcus in patients undergoing TKA and to evaluate the clinical utility of using this geometry as an intraoperative landmark for femoral component positioning.

Key Points: Intraoperative navigation was used to map the trochlear sulcus in 110 consecutive patients. The sagittal geometry was accurately modeled as a circular arc with a mean radius of 25.5 ± 5.6 mm. The sulcus exhibited a mean external rotation of 3.2° ± 4.3° relative to the posterior condylar axis and 3.9° ± 5.3° relative to the mechanical axis. No significant correlations were found between the trochlear radius and gender or femoral length. In a clinical cohort of 60 cases where this modeling guided implant positioning, significant improvements were observed in Knee Society Scores and patellar pain scores at 12-month follow-up, with 60% of patients reporting no pain by the first postoperative month.

Conclusion: The native trochlear groove in osteoarthritic knees maintains a consistent circular sagittal profile that is independent of gender or femoral dimensions. Utilizing this geometry as an intraoperative reference allows for precise femoral component alignment, potentially reducing patellofemoral complications and improving early clinical outcomes.

KEYWORDS

Arthroplasty, Replacement, Knee; Surgery, Computer-Assisted; Femur; Osteoarthritis, Knee; Patellofemoral Joint

INTRODUCTION

Patellofemoral complications are a common cause of pain and complications after total knee arthroplasties (TKA). Femoral implant misplacement may generate overstuff, resulting in increased patellar stresses and anterior knee pain [10],[12]. A recent review on mid flexion instability included as technique-specific risk factors the distalization and anteriorization of femoral implant [5],[16]. Iranpour [6] clearly demonstrates that, in healthy knees, patella follows a circular path. This path is guided by circular shape and orientation of trochlear axis [7].

Given that, a better understanding of the relationship between the femoral component positioning, surgical technique and TKA outcomes, is related to an accurate knowledge of the femoral trochlear geometry itself. However, most of studies focused on the transverse and frontal geometry of the trochlear groove, quantifying its depths and orientation [7], while its radius in the sagittal plane has been mostly neglected [4],[11],[17]. Moreover, the few studies that investigated this aspect were limited to the use of radiological technologies such as MRI or CT-based 3D reconstructions.

During surgery the trochlear groove could be used as reference for femoral implant positioning, because it is less affected by pathology. Despite this, shape of trochlear sulcus on TKA patients has been scarcely investigated. The aim of the study was to verify if pathological trochlear sulcus, collected during intraoperative navigation, is still comparable to what is reported on healthy subjects with other methodologies. Based on literature [4],[7],[11],[17] we wanted to verify if trochlear sulcus, in TKA patients, can still be modeled with a circle and used as intraoperative parameter for implant positioning.

MATERIAL AND METHODS

Femoral sulcus was acquired on a cohort of 110 consecutive patients (34 men and 76 women) who underwent navigated TKA between October 2017 and November 2018 by a single experienced surgeon (YV). Patient characteristics such as age, gender, body mass index (BMI) and mechanical axis (HKA) were recorded (Table 1).

	Male	Female
Age (years)	72 (58–84)	74 (53–88)
Height (cm)	172.8 (158–180)	159.4 (140–173)
Weight (kg)	88.3 (71–115)	75.8 (50–132)
BMI (kg/m2)	29.6 (23.2–38.9)	29.8 (19.5–51.6)
HKA (°)	176.2 (165–190.5)	178.1 (168.5–193)
Varus/Valgus	28/6	54/22

Mean (range). BMI body mass index

Table 1 : Demographic and clinical characteristics of the cohort

Exclusion criteria of the study were: varus or valgus deformities greater than 15°.

Anatomic data were acquired intraoperatively using a navigation system (BLU-IGS, Orthokey Italia Srl, Firenze, Italy), navigation system's protocol and accuracy are reported [1],[2], nominal accuracy of the system is 0.5°/ mm and inter-tester reliability > 0.8 (intraclass correlation coefficient ICC).

Dedicated protocol was developed for trochlear sulcus evaluation and additional acquired points were visualized, expressed and analyzed in the femur reference system to define the sagittal geometry of the sulcus (femur lateral view) (Figure 1).

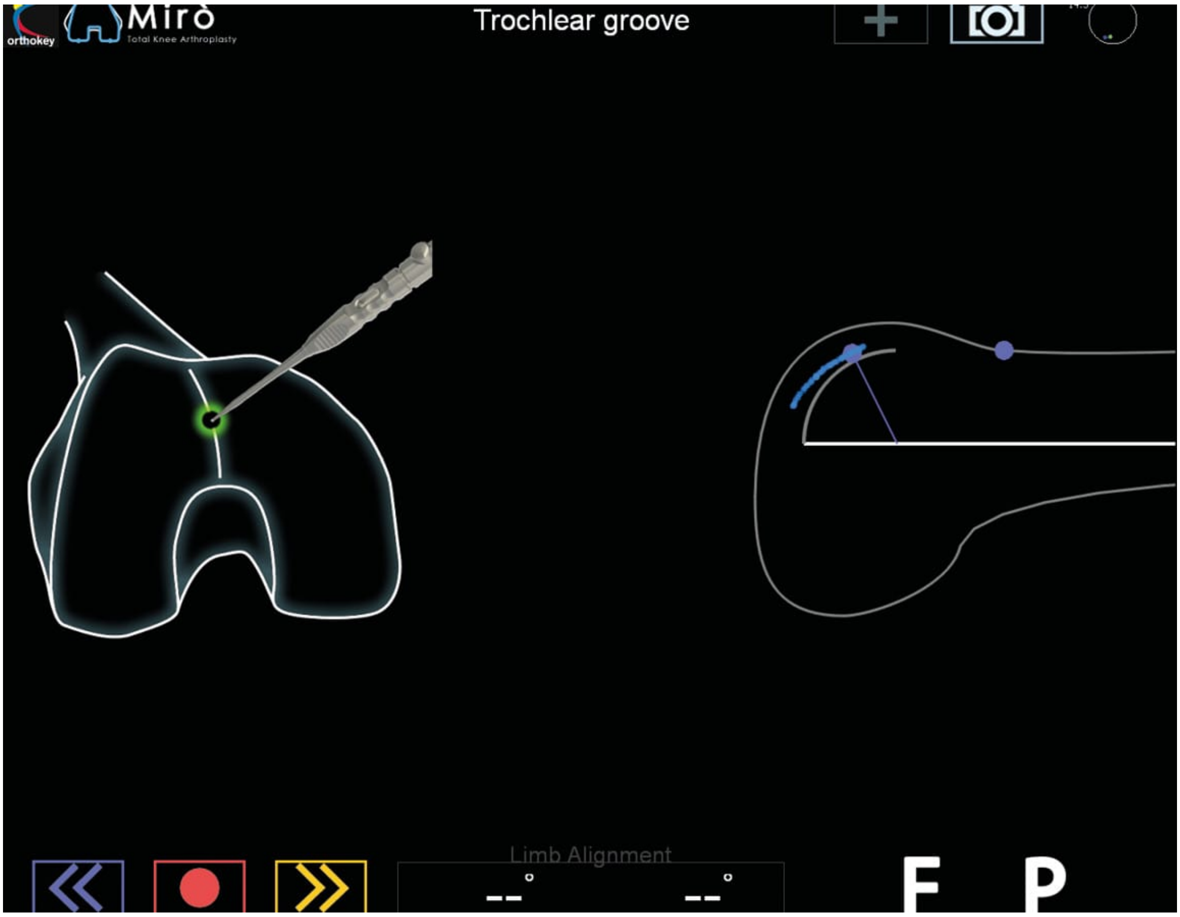

Figure 1: Module for trochlear groove registration implemented in navigated procedure

Studies demonstrated that in healthy knee, patellofemoral groove closely approximated a circular arc [4],[7],[11],[17]. The trochlear groove points were fitted by a circle in a range from 0° to 90°. The best-fit was found using a software routine that minimized the root mean-square error in relation to the acquired points. The trochlear groove varus-valgus and internal–external orientations as well as the starting and end points of the groove were even evaluated.

Femoral length was defined as the distance between femoral head center to the distal inter-condylar notch and the APk femur dimension as the distance between the anterior femoral cortex and the posterior condyle. Once modeling was validated, trochlear sulcus information has been used actively for femoral implant planning during surgery. From the comparison of sulcus modeling with used implant (U2, UOC, France) a point at 30° of sulcus arc (Figure 2) has been defined as reference during planning phase.

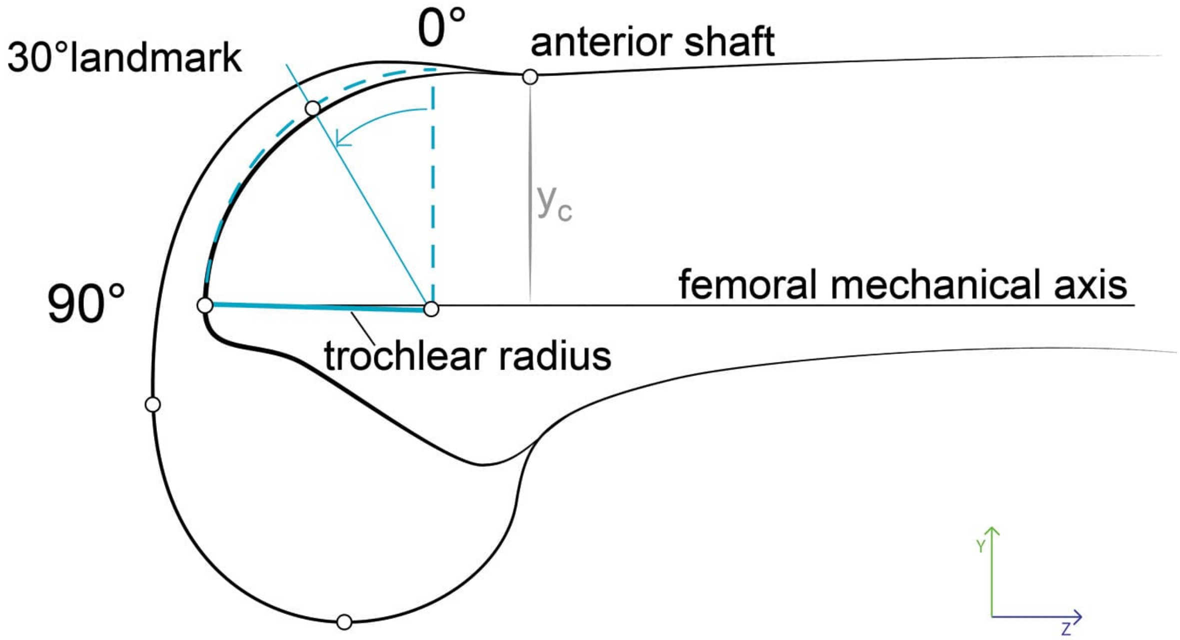

Figure 2: Representation of trochlear sulcus modeling introduced on navigation system and description of 30°-point landmark.

During planning, the use of this reference, in combination with joint spaces, implant size, notching and condylar shapes, was used to optimize implant positioning according to surgeon experience. In figure 3 an example is shown. On left side (Figure 3A) default implant position is proposed by navigation system, based on measured resection technique. Extension gap presents a laxity of 2.5mm medial and 3.0mm lateral. Implant trochlear sulcus is 1.5mm below native (indicated with a white arrow in figure), hence the surgeon decided for a distalization of femoral implant, to optimize ligament balance in extension, confident that he was not overstuffing patellar tracking, (Figure 3B yellow arrow), despite a slight overhang of 1.5mm on femoral anterior notch.

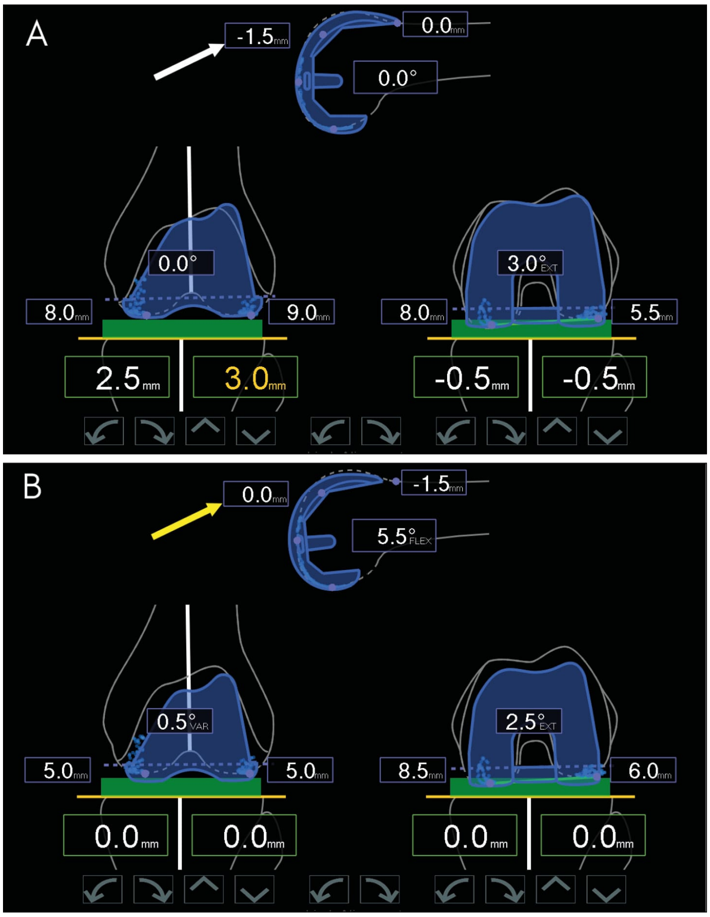

Figure 3: A. Standard measured resection planning for femoral component. In left lower corner an excessive extension gap can be noted, while white arrow indicates distance between native and implant sulcus. B. Femoral implant planning modified manually by surgeon in order to achieve a correct extension and flexion gap balancing, while controlling overstuff of implant sulcus (yellow arrow).

This approach has been applied to 60 cases, operated by a single surgeon (YV). KSS score and patellar pain score were registered at pre-operative, 1 month, 3 months and 12 months to verify the impact of approach on clinical outcomes.

The CNIL *French ethic comitee regarding personal datas* gave the authorization to collect clinical data. Patients signed informed consent for the surgical procedure the study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

STATISTICAL ANALYSIS

Data were reported as mean and standard deviation (mean ± SD). Considering the lack of studies in literature with the same methodology, the sample size was calculated with the aim to detect a significant difference between males and females of 2 mm with a standard deviation of 3 mm. The Students' t test was performed to compare the patients' gender with the radius of the trochlear groove and the APk dimension. Correlation between femur length and groove radius was analyzed with Pearson's linear correlation test. Differences on KSS scores were evaluated with ANOVA, while differences on patellar pain was evaluated with Chi-square test. A p value of less than 0.05 was considered statistically significant. Analyse-it software (Analyse-it Software Ltd., Leeds, UK) was used to perform the reported statistical analysis.

RESULTS

The geometry of the trochlear groove could be described accurately as a circle in the sagittal plane. The average radius was 25.5 ± 5.6 mm (range 14.0–37.4 mm) and the 95% CI was from 24.4 to 26.5 mm. The data points had an average root mean-square error of 0.4 ± 0.2 mm from the fitted radius in each knee.

In the sagittal view, the average center of the fitted trochlear groove was at 24.0 ± 4.6 mm proximally along the mechanical axis and 2.2 ± 5.2 mm posteriorly along the AP axis. A weak correlation was found between the groove radius and the anterior femoral cortex (r = 0.27). No correlation was found between the femur length and the trochlear groove radius (r = – 0.02).

For men, the radius of the curvature of the femoral trochlear groove was 24.7 ± 4.9 mm, while for women it was 25.6 ± 5.8 mm. On axial plane, the trochlear groove was 3.2° ± 4.3° externally rotated, with respect to the posterior condylar axis. On frontal plane, it was 3.9° ± 5.3° externally rotated, with respect to femoral mechanical axis. With no statistical difference between genders for radius and orientation. A positive moderate correlation was found between the APk dimension and the trochlear groove radius (r = 0.36).

Clinical follow-up showed reduction of patellar pain, with more than 60% of patients reporting no pain since first month. After 3 months patellar pain remained stable (Fig.4). Similarly, KSS knee and functional scores improved at early follow-up. In particular Knee score reached optimal (>80) results at 1m follow up (Figure 5).

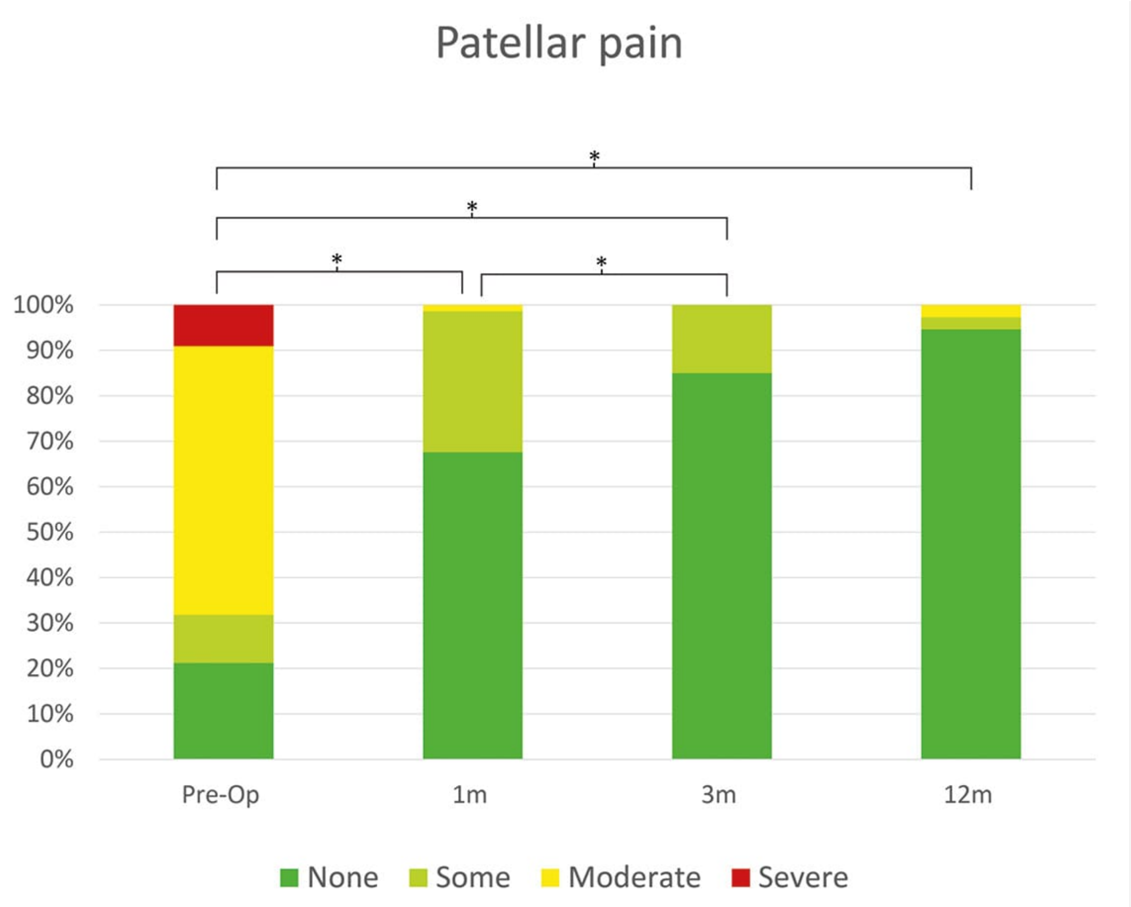

Figure 4: Patellar pain reported by patients at preoperative, 1 month, 3 months and 12 months follow up. * indicates statistical difference ($p<0.05$)

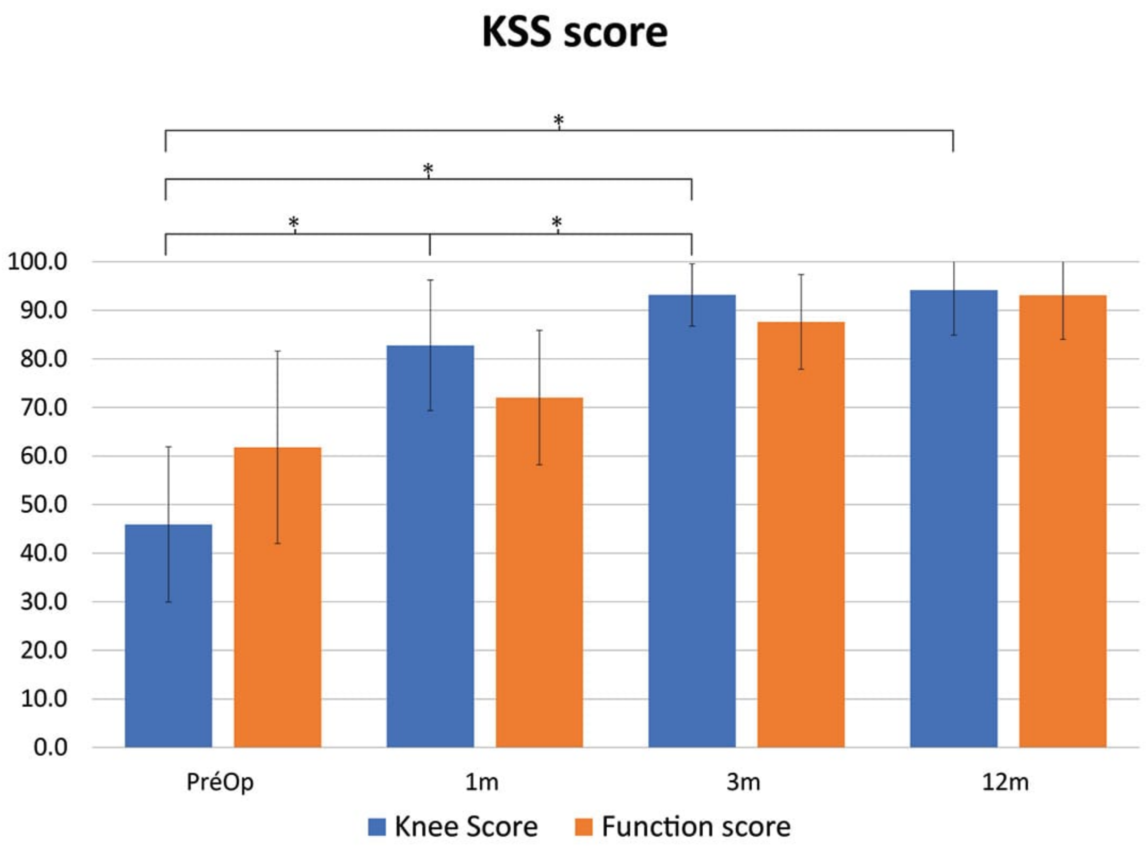

Figure 5: KSS knee and function scores reported by patients at preoperative, 1 month, 3 months and 12 months follow up (range 0-100, with 100 optimal result). * indicates statistical difference ($p<0.05$).

DISCUSSION

The most important finding of the present study was that the geometry of the trochlear groove, in patients who underwent a TKA implant, could be described accurately as a circle in the sagittal plane with an average radius of 25.5 ± 5.6 mm centered 2.2 ± 5.2 mm posterior to mechanical axis, and 24.0 ± 4.6 mm proximal to inter-condylar notch. Sulcus line has 3.2° ± 4.3° of external rotation, with respect to the posterior condyles axis and a 3.9° ± 5.3° of external rotation, with respect to the mechanical axis. Moreover, no differences were found between genders or based on femoral length.

Native trochlear groove modeling groove geometry, in combination with conventional landmarks and ligament balancing, can be used intraoperatively to bet position femoral component with the result of reducing patellar pain and obtain satisfactory KSS score at early follow-up. This is the first study that describes sagittal geometry of trochlear groove intraoperatively using a navigation system and its intraoperative use to finetune femoral implant positioning. Despite the different methodology our results were comparable to literature. In fact Iranpour, with a 3D CT-based model on 40 healthy knees, described the trochlear groove as a circle with a radius of 23 mm [7]. Considering that CT is able to capture only osseous anatomy, including a cartilage layer of 2 mm [3],[14], it is consistent to the value of 25 mm reported in the present study. An inferior value of 19–20 mm was instead found in 100 healthy Chinese subjects, again using 3D CT-based reconstructions [17]. The authors imputed the differences with previous studies to the variation in reference axis, measurement methods and racial differences. On the other hand, no differences were found between males and females. This is important, because it confirms the hypothesis that femoral groove shape is independent from gender. Furthermore, the patient's height seems irrelevant as well, since no correlation was found between radius and femoral length. Thus, in the view of patient specific TKA positioning and TKA design, gender and patient's femoral length does not represent relevant variables to be taken into account to optimize patellofemoral anatomy.

Our results confirm that the orientation of trochlear sulcus on axial plane is about 3° externally rotated with respect to posterior condylar tangent. This confirms what expressed by Riviere et al. [13], kinematically aligned implants might lead to overstuff of lateral trochlea, and also in works of Talbot et al.[15].

From a clinical perspective, the present study offers important insights. First of all, it confirms that intraoperatively it is still possible to map the trochlear groove shape [7],[9],[17]. Trochlear sulcus can be used as reference to customize implant positioning based, to avoid potential complications [5],[8]. Further studies should be performed in this direction to assess its reliability and verify the influence of femoral implant positioning, according to this landmark, and clinical outcomes after TKA.

The present study has several limitations. First, the measurements were not obtained in healthy patients but in those with OA requiring TKA, without considering the amount of patellofemoral disease that could bias the results. If from one side this could not allow to generalize the findings to general population, on the other hand those are applicable to osteoarthritic patients, which are those that effectively need knee replacement and thus represent the ideal population to investigate the patellofemoral anatomy. Secondly, all measurements were obtained manually by a single examiner. However, the small average root mean square error demonstrates a good reliability in such measurements, thus discarding bias in the method of measurement. Finally, the lack of MRI or CT evaluation did not allow to correlate and validate the navigation measurement with common radiological methods. However, it was not the aim of the study, which was instead designed to assess the in vivo trochlear shape and its correlation with gender and femoral dimension. Lastly, this is a single cohort study with no control group: the correlation between the obtained postoperative scores and surgical strategy defined by the investigator is not demonstrated. Anyway, the addition of an additional landmark, not previously described in literature, resulted to be safe: did not led to complication or unsatisfactory results. Further studies will be recommended to verify this hypothesis.

CONCLUSION

Modeling of native trochlear groove for intraoperative implant positioning has been demonstrated to be safe and useful. The geometry of the trochlear groove in patients with osteoarthritis could be described accurately as a circle in the sagittal plane with an average radius of 25.5 ± 5.6 mm and a 3.2° ± 4.3° of external rotation, with respect to the posterior condyle axis and a 3.9° ± 5.3° of external rotation, with respect to the mechanical axis.

REFERENCES

1. Bignozzi S, Lopomo N, Zaffagnini S, Martelli S, Bruni D, Marcacci M (2008) Accuracy, reliability, and repeatability of navigation systems in clinical practice. Oper Tech Orthop 18:154–157

2. Casino D, Zaffagnini S, Martelli S, Lopomo N, Bignozzi S, Iacono F, Russo A, Marcacci M (2009) Intraoperative evaluation of total knee replacement: kinematic assessment with a navigation system. Knee Surg Sports Traumatol Arthrosc 17:369–373

3. Culvenor AG, Eckstein F, Wirth W, Lohmander LS, Frobell R (2019) Loss of patellofemoral cartilage thickness over 5 years following ACL injury depends on the initial treatment strategy: results from the KANON trial. Br J Sports Med 53:1168–1173

4. Du Z, Chen S, Yan M, Yue B, Zeng Y, Wang Y (2017) Do size, shape, and alignment parameters of the femoral condyle affect the trochlear groove tracking? A morphometric study based on 3D- computed tomography models in Chinese people. BMC Musculoskelet Disord 18:1–7

5. Evangelista PJ, Laster SK, Lenz NM, Sheth NP, Schwarzkopf R (2018) A computer model of mid-flexion instability in a balanced total knee arthroplasty. J Arthroplasty 33:S265–S269

6. Iranpour F, Merican AM, Baena FRY, Cobb JP, Amis AA (2010) Patellofemoral joint kinematics: the circular path of the patella around the trochlear axis. J Orthop Res 28:589–594

7. Iranpour F, Merican AM, Dandachli W, Amis AA, Cobb JP (2010) The geometry of the trochlear groove. Clin Orthop Relat Res 468:782–788

8. Mihalko W, Fishkin Z, Krakow K (2006) Patellofemoral overstuff and its relationship to flexion after total knee arthroplasty. Clin Orthop Relat Res 449:283–287

9. Monk AP, Choji K, O'Connor JJ, Goodfellow JW, Murray DW (2014) The shape of the distal femur: a geometrical study using MRI. Bone Jt J 96B:1623–1630

10. Nam D, Nunley RM, Barrack RL (2014) Patient dissatisfaction following total knee replacement: a growing concern? Bone Jt J 96B:96–100

11. O'Connor JJ, Shercliff TL, Biden E, Goodfellow JW (1989) The geometry of the knee in the sagittal plane. Proc Inst Mech Eng Part H J Eng Med 203:223–233

12. Petersen W, Rembitzki IV, Brüggemann GP, Ellermann A, Best R, Koppenburg AG, Liebau C (2014) Anterior knee pain after total knee arthroplasty: a narrative review. Int Orthop 38:319–328

13. Rivière C, Dhaif F, Shah H, Ali A, Auvinet E, Aframian A, Cobb J, Howell S, Harris S (2018) Kinematic alignment of current TKA implants does not restore the native trochlear anatomy. Orthop Traumatol Surg Res 104:983–995

14. Schub DL, Frisch NC, Bachmann KR, Winalski C, Saluan PM (2013) Mapping of cartilage depth in the knee and elbow for use in osteochondral autograft procedures. Am J Sports Med 41:903–907

15. Talbot S, Dimitriou P, Radic R, Zordan R, Bartlett J (2015) The sulcus line of the trochlear groove is more accurate than Whiteside's Line in determining femoral component rotation. Knee Surg Sports Traumatol Arthrosc 23:3306–3316

16. Vajapey SP, Pettit RJ, Li M, Chen AF, Spitzer AI, Glassman AH (2020) Risk factors for mid-flexion instability after total knee arthroplasty: a systematic review. J Arthroplasty. https ://doi. org/10.1016/ j.arth.2020.05.026

17. Wang J, Yue B, Wang Y, Yan M, Zeng Y (2012) The 3D analysis of the sagittal curvature of the femoral trochlea in the Chinese population. Knee Surg Sports Traumatol Arthrosc 20:957–963