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Highly variable tibial tubercle–trochlear groove distance (TT–TG) in osteoarthritic knees should be considered when performing TKA

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Abstract

Purpose The tibial tubercle–trochlear groove distance (TT–TG) is an established measurement to assist diagnosis and treatment of patellofemoral instability. However, little is known about the distribution of TT–TG in osteoarthritic knees. The purpose of the current study is to investigate the TT–TG in a large cohort of osteoarthritic knees and to analyse, in particular, the association of knee alignment and TT–TG.

Methods Data from 962 consecutive patients [455 male, 507 female; mean age ± SD 70.8 ± 9.3 (37–96)] who had undergone 3D-CT and preoperative knee planning with validated commercial 3D planning software before total knee arthroplasty (TKA) were collected prospectively. The TT–TG, coronal hip knee ankle angle (HKA), femoral anteversion (AVF), external tibial torsion (ETT), and femorotibial rotation (Rot FT) were analysed. Pearson correlations were performed to assess correlations between TT–TG, mechanical axis, and rotational parameters ($p < 0.05$).

Results HKA showed a strong correlation with TT–TG ($r = 0.488$; $p < 0.001$) with 98 (67.1%) and 45 (30.8%) of valgus knees having respective abnormal and pathological TT–TG values. There were no significant correlations between parameters of rotational alignment (AVF, ETT, Rot FT) and TT–TG. Mean TT–TG was 12.9 ± 5.6 mm, ranging from 0.0 to 33.7 mm. 325 (33.8%) of all patients had abnormal (> 15 mm) and 101 (10.5%) had pathological (> 20 mm) values. A varus alignment was present in 716 (74.4%) of the cases (HKA < − 1.5°), a neutral alignment in 100 (10.4%), and a valgus alignment in 146 (15.2%) (HKA > 1.5°).

Conclusion A wide variation of TT–TG values in osteoarthritic knees was shown by our results. There was a relevant influence of coronal limb alignment on the TT–TG—the more valgus the higher and more pathological the TT–TG. With the aim of having a more personalised TKA, the individual TT–TG should be taken into account to improve the outcome.

Level of clinical evidence III. Retrospective cohort study.

Keywords Patellofemoral joint · PFJ · TT–TG · Tibial tubercle · Trochlear groove · Knee · Alignment · Anatomy · Functional bone phenotypes

Introduction

A well-established and reliable measurement to assess patellar maltracking radiographically is the distance between the tibial tubercle and trochlear groove (TT–TG) [5, 16, 20, 23]. TT–TG was originally described by Goutallier et al. [11] on axial radiographs, but it is nowadays mainly measured on computerised tomography (CT) and magnetic resonance imaging (MRI) scans. Increased TT–TG distance is generally accepted as a predictor for patellofemoral instability [7, 25] and used as an important criterion for decision-making in realignment surgery of the patella [22, 26]. Based on axial CT imaging, TT–TG values > 15 mm and > 20 mm

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are considered as, respectively, abnormal and pathological [1, 2, 7, 17].

While many prior studies have identified pathological TT–TG distances in patients with a history of patellar dislocations and anterior knee pain [6], the potential role and prevalence of this parameter in patients with osteoarthritic knees is unclear. However, measuring individual TT–TG might be an important parameter in preoperative planning of total knee arthroplasty (TKA) to reduce anterior knee pain and improve outcome by, e.g., reducing lateral patellofemoral joint contact pressure and increasing patellar stability. Considering the TT–TG distance which could support decision-making as far as the surgical approach, a tibial tubercle osteotomy to realign patellar tracking or rotational positioning of the tibial component [4] is concerned. To address this gap in understanding, the present study was conducted using 3D-CT data to quantify coronal and rotational limb parameters in osteoarthritic knees. The primary aim of this study was to analyse the distribution of the TT–TG in a large collective of osteoarthritic knees, in particular the association of coronal knee alignment and the TT–TG. The hypothesis was that there is higher prevalence of pathological TT–TG values in osteoarthritic valgus knees compared to osteoarthritic varus knees.

Materials and methods

Prospectively collected data from 962 consecutive patients who underwent 3D reconstructed CT scans before TKA were used for this retrospective registry study. Data were routinely collected for patient-specific instrumented TKA from Symbios, Yverdon les Bains, Switzerland. The preoperative anatomy of all patients, 455 men and 507 women, and mean age 70.9 ± 9.3 years (range 37–96 years) were analysed.

The CT protocol was modified according to the Imperial Knee Protocol, which is a low-dose CT protocol that includes high resolution 0.75 mm slices of the knee and 3 mm slices of the hip and ankle joints [13]. The protocol minimises radiation exposure by scanning only relevant regions and only the primary joint of interest is scanned in high resolution.

All measurements were done using Symbios® 3D knee preoperative planning's software (Symbios, Yverdon les Bain, Switzerland). This software has been validated by the company and is used for planning TKA as proprietary software. The same trained engineer with more than 10 years' experience in this field took all the measurements. The measurements are all within 1°. Inter- and intra-observer reliability of the software has been previously reported as excellent [10]. Patients underwent CT of the leg in full extension. TT–TG has been shown to vary significantly depending on the degree of knee flexion, decreasing by approximately 6 mm from 5° to 30° of flexion [25]. We, therefore, excluded patients with a flexion contracture prior to analysis to eliminate this bias. The TT–TG was measured from the prominence of the tibial tuberosity to the deepest point of the trochlear groove in line with the posterior condylar axis (Fig. 1). A TT–TG distance of 15–20 mm was classified as abnormal and distances > 20 mm were defined as pathological [1, 2, 7, 17]. The hip–knee–ankle angle (HKA) was measured as a line connecting the femoral head centre, the knee centre, and the ankle centre. The HKA was categorized between < 13.5° varus to > 7.5° valgus in three degree increments. Neutral alignment was defined between − 1.5° varus and 1.5° valgus. Femoral anteversion (AVF) was determined as the angle between the axis of the

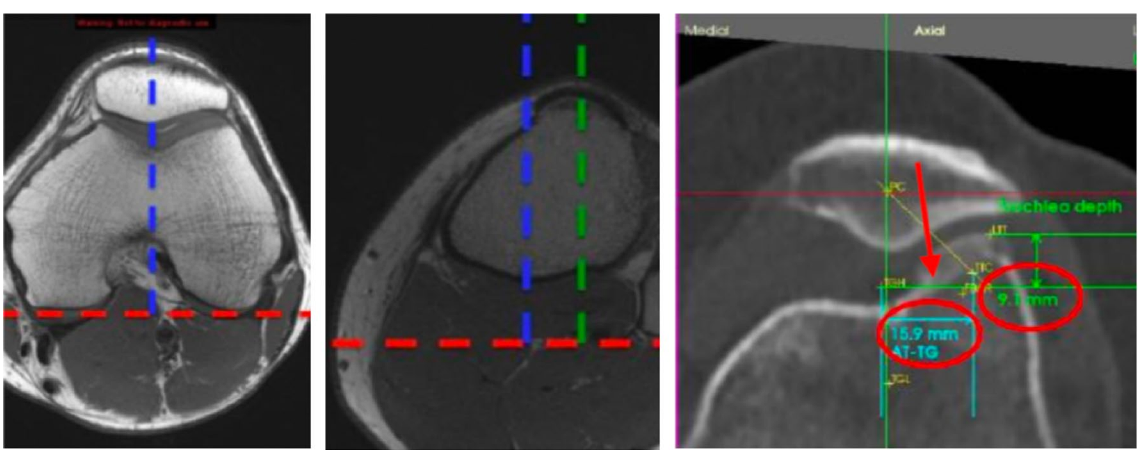

Fig. 1 Measurement of TT–TG on CT data as done in this study. **a** Axial CT scan of the left knee at the level of the femoral epicondyles, showing the perpendicular line meeting the tangent to the posterior condyles and extending through the deepest aspect of the TG. **b** Axial CT scan of the same knee at the level of insertion of the patellar tendon onto the TT **c** measuring the distance between the midpoint of the patellar tendon and the TG (TT–TG)

Table 1 Descriptive statistics of parameters measured ($N=962$)

	Age	TT–TG	AVF	ETT	HKA	Rot FT
Mean ± SD	70.8 ± 9.3	12.9 ± 5.6	13.5 ± 7.6	29.2 ± 8.7	− 4.4 ± 5.5	− 4.7 ± 2.9
Minimum	37	0.0	0.0	1.2	− 22.8	0.0
Maximum	96	33.7	45.2	60.2	14.5	22.3

Table 2 Descriptive statistics of categorized TT–TG distance in relation to HKA

HKA coronal	TT–TG distance categorised						Total	
	Normal		Abnormal (> 15)		Pathological (> 20)			
Varus (> 1.5°)	543	75.8%	135	18.9%	38	5.3%	716	100.0%
Neutral position	46	46.0%	36	36.0%	18	18.0%	100	100.0%
Valgus (> 1.5°)	48	32.9%	53	36.3%	45	30.8%	146	100.0%
Total	637	66.2%	224	23.3%	101	10.5%	962	100.0%

femoral head and neck with the transepicondylar femoral axis with positive values between the femoral neck and the distal femur axis indicating antetorsion and negative values indicating retrotorsion. External tibial rotation (ETT) was determined as the angle between the mediolateral axis of the tibia and the transmalleolar axis with positive angles indicating external rotation and negative values indicating internal rotation. Femorotibial rotation (Rot FT) was determined as the angle between the transepicondylar femoral axis and the mediolateral axis of the tibia with positive values indicating external tibial rotation and negative values indicating internal tibial rotation. Furthermore, the femoral size was measured. Parameters measured were displayed as mean, standard deviation (SD), and range. In addition, the parameters were shown as percentages after categorization.

Approval was obtained from the local ethics committee (Ethikkommission Nordwest- und Zentralschweiz, Project ID 2018-00223). All procedures performed were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

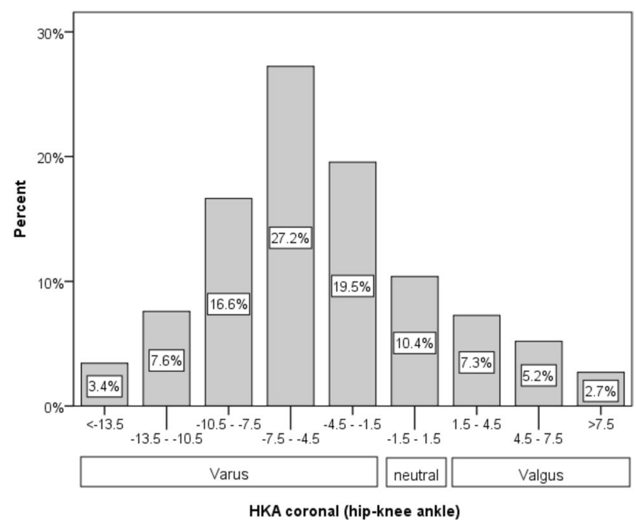

Fig. 2 Categorised distribution of HKA among the different knees showing a variation from more than 13.5° varus to more than 7.5° valgus

Statistical analysis

Pearson correlations were used to investigate the correlation of HKA and TT–TG as well as AVF, ETT, Rot FT, and TT–TG. The post hoc analysis using G*Power, version 3.1.9 (University of Kiel, Germany) tested that, for the given N of 962, a correlation of $r=0.11$ ($r^2=1.2\%$) can be found with a power of 90%. A statistical effect of 1.2% is very small and it was, therefore, concluded that the sample size was sufficient for the scientific question. All data were analysed by an independent professional statistician using IBM SPSS Statistics for Windows, version 24.0 (Armonk, NY: IBM Corp, USA.). p values were two-sided and considered statistically significant if smaller than 0.05.

Results

Mean values and standard deviations of age and limb coronal and rotational alignment parameters are listed in Table 1. There were 455 (47.3%) male and 507 (52.7%) female patients. 224 (23.3%) of all patients had abnormal (> 15 mm) and 101 (10.5%) had pathological (> 20 mm) TT–TG values (Table 2). TT–TG had a highly variable distribution (Figs. 2, 3). A varus alignment was present in 716 (74.4%) of the cases (HKA < − 1.5°), a neutral alignment in 100 (10.4%) (HKA > − 1.5° and < 1.5°), and a valgus alignment in 146 (15.2%) (HKA > 1.5°). HKA showed a strong correlation

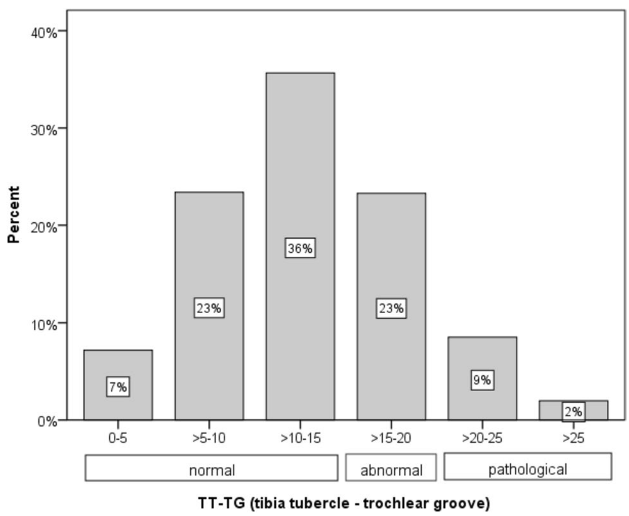

Fig. 3 Categorised distribution of TT–TG among the different knees showing a huge variation from 0 to 34 mm

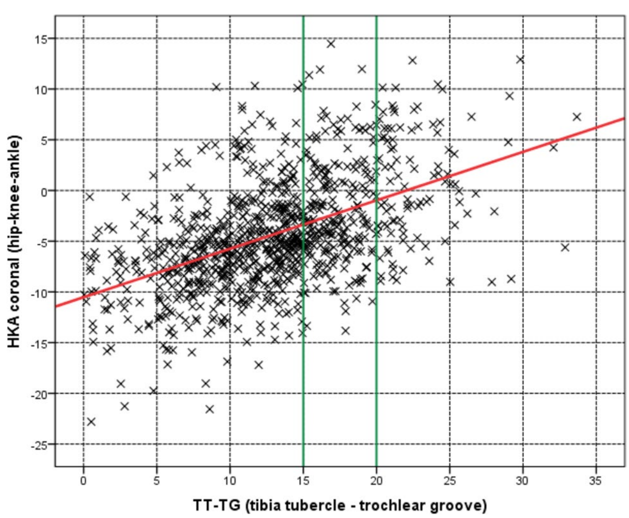

Fig. 4 Graph showing positive correlation between HKA and TT–TG. The more the valgus, the higher the TT–TG

with TT–TG ($r = 0.488$; $p < 0.01$) with 53 (36.3%) and 45 (30.8%) of valgus knees having respective abnormal and pathological TT–TG values (Table 2; Fig. 4). Therefore, 98 (67.1%) of valgus aligned knees have TT–TG values that are considered as not normal. With a valgus alignment of > 7.5° 50% of knees have pathological TT–TG values, while a varus alignment of < 10° is never associated with pathological values. TT–TG increases 0.5 mm per degree increase in valgus malalignment (Fig. 4). Regarding possible relations between rotational alignment (AVF, ETT, and Rot FT) or femoral and tibial size and TT–TG distance, there were no significant correlations of the parameters tested (Tables 3, 4).

Table 3 Pearson correlations of AVF, ETT, HKA, Rot FT, and femoral size by TT–TG

	AVF	ETT	HKA	Rot FT	Femoral size
TT–TG	0.10**	0.21***	0.49***	0.07*	0.07*

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

Table 4 TT–TG by varus–valgus

HKA coronal	TT–TG			
	N	Mean ± SD	Minimum	Maximum
Varus (< − 1.5°)	716	11.7 ± 5.2	0.0	32.9
Neutral position	100	15.7 ± 5.1	0.4	26.8
Valgus (> 1.5°)	146	17.3 ± 5.3	5.7	33.7
Total	962	12.9 ± 5.6	0.0	33.7

Discussion

The most important finding of the present study was the highly variable distribution of the TT–TG with a similar incidence of pathological values in osteoarthritic knees compared to values for healthy volunteers [1, 17]. This is the first study describing the TT–TG distribution in a large cohort of patients with osteoarthritis; thereby, our findings give new insight into the anatomical features and variable morphology of the osteoarthritic knee joint. 224 (23%) patients with end-stage osteoarthritis scheduled for TKA had abnormal and 101 (10%) had pathological TT–TG distances. The findings of the current study would support the constant preoperative measurement of the TT–TG, as it is supposed that considering the individual anatomy and phenotypes of each knee more precisely, which can improve outcome after TKA. A literature search revealed only two studies with relatively small sample sizes, analysing the TT–TG in osteoarthritic knees. Recently, Sahin et al. [19] published a study in which they measured and compared the TT–TG in patients with and without tibiofemoral osteoarthritis on MRI. One hundred and two patients had minimal or no osteoarthritis (Kellgren Lawrence osteoarthritis grade < 2) and 71 patients had advanced osteoarthritis (Kellgren Lawrence osteoarthritis grade > 2). No statistically significant difference between groups with TT–TG values of 8.7 ± 3.8 and 7.9 ± 3.4 was found, and it was argued that TT lateralization seems to be variable. Considering the different imaging methods, these results are in line with our findings. Hatayama et al. [12] compared the TT-PCL in 36 valgus and 40 varus aligned osteoarthritic knees on CT scans; this is a newer measurement described by Seitlinger et al. [21] to quantify true lateralization of the tibial tubercle. TT-PCL values differed significantly with 26.1 (18.2–36.8) and 17.2 mm (10.3–22.6) for respective valgus and varus, which is in line with our findings (17.3 ± 5.3 and 11.7 ± 5.2 for valgus and varus). In contrast to our results, the TT-PCL and, therefore, the true lateralization of the tibial tubercle did not increase with increasing valgus. The authors suggested that tibial tubercle lateralization and hypoplasia of the posterolateral femoral condyle might be congenital anomalies and predispose to developing valgus osteoarthritis. On the other hand, our results might also be a secondary phenomenon due to cartilage wear and collapse of the medial or lateral joint space or mediolateral subluxation of the femur in regard to the tibia as seen in osteoarthritic knees [15]. As little longitudinal data exist and we do not know the natural history of the valgus knee with a lateralised TT, the relevance of the TT position for the onset of valgus osteoarthritis currently remains unclear.

Another important finding of the present study was the strong correlation between TT–TG and coronal limb alignment with a higher prevalence of pathological TT–TG values in valgus osteoarthritic knees compared to varus osteoarthritic knees. The results of the present study showed that more than two-thirds of valgus aligned knees had pathological TT–TG distances. Furthermore, there was a continuum. The more pronounced the valgus, the higher the TT–TG distance; two degrees increase in valgus lead to 1 mm increase in TT–TG distance. On the other hand, a varus alignment of > 10° was never associated with pathological values. Another interesting finding was that 38 (5%) of varus and 18 (18%) of neutrally aligned knees also had pathological TT–TG distances (Fig. 5). It is important to notice this, because, with coronal realignment during TKA in a valgus situation, you could argue that TT–TG distance is "brought back to normal", but, in at least 20% coronally neutral or varus aligned knees, the TT–TG would not change or even increase during TKA. The clinical relevance of our finding is that any valgisation of coronal alignment in TKA will increase the TT–TG and, therefore, increase lateral patellofemoral joint contact pressure [24]. This should be considered during individual preoperative planning for TKA.

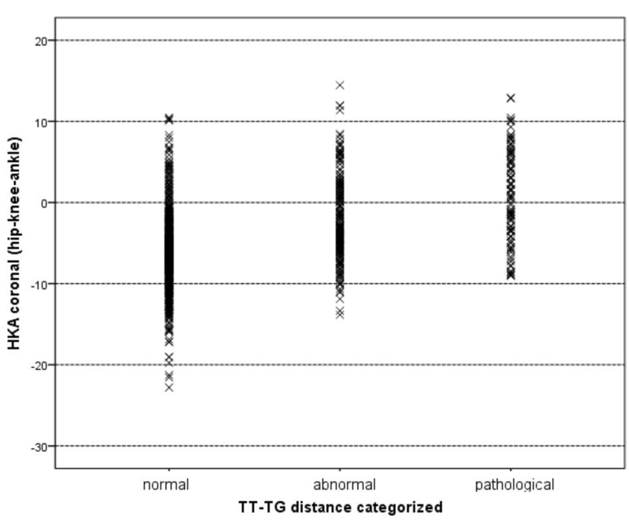

Fig. 5 Graph showing that 5% of varus and 15% of neutrally aligned knees also had pathological TT–TG distances

A literature search revealed a small number of studies, showing the effect of varus/valgus on TT–TG. Yao et al. [28] found an increase of 38% in the TT–TG distance with 5° of simulated valgus and a decrease of 51% with 5° of varus while performing MRI scans on 12 healthy subjects. Ho et al. [14] compared TT–TG distances on CT and MRI scans of 59 patients with a special focus on patient positioning and found that knees were positioned in varus on the MRI compared to the CT examination, resulting in lower TT–TG values.

As it has been hypothesised that the TT–TG is influenced by femoral anteversion, external tibial rotation, and femorotibial rotation, these parameters were also analysed in our study [7, 8, 18, 27]. A number of studies investigating rotational alignment in healthy patients using CT scans presented similar results to our study [7, 8, 18]. No significant correlations between rotational parameters and TT–TG were found in the current study. Therefore, the TT–TG in the osteoarthritic knee is mainly influenced by true lateralisation of the tibial tubercle and coronal alignment of the knee.

Considering the existing literature, in preoperative planning for TKA, the TT–TG so far has had no or only little significance. The TT–TG distance is widely used and helpful in selecting appropriate patients for distal patellar realignment procedures in the situation of patellar instability and may also guide operative decisions whether or not and to what extent the tibial tuberosity should be corrected when performing TKA. Furthermore, the surgical approach might be planned differently if a pathological TT–TG is present, i.e., in choosing a lateral approach and if applicable combining it with a tibial tuberosity osteotomy and thereby realigning patellar tracking. Stephen et al. [24] showed, in a recent cadaveric study, that tibial tuberosity lateralisation significantly elevated lateral patellofemoral joint contact pressures, increased lateral patellar tracking, and reduced patellar stability. Considering that patellar maltracking has been shown to be associated with a high incidence of complications and persistent pain after TKA [3, 9], it might be important to include the TT–TG in the standard planning process to account for the individual constitutional phenotypes.

The clinical relevance of this study is that it provides evidence for the importance of considering the individual TT–TG before performing TKA, recommending a preoperative 3D-CT scan if pathological values are suspected clinically. As any valgisation of coronal alignment in TKA will increase the TT–TG and may lead to worse outcome, realignment procedures should be considered if the TT–TG is pathological.

Some limitations are presented in our study. First of all, measurements were taken by a single analyst and we, therefore, did not determine interobserver bias. However, inter-rater reliability has been reported to be excellent, especially for TT–TG measurement on CT scans [5], and thus, interobserver bias was assumed to be minimal. Furthermore, our cohort is quite diverse and we did not collect any clinical information about the scanned knees, i.e., posttraumatic situation, patella dislocation, or instability, prior realignment procedures. Since the cohort is quite large, some posttraumatic or postoperative situations would not be of consequence. Inclusion of clinical outcome data would have been of further interest.

Conclusion

In the osteoarthritic knee, the TT–TG is highly variable. Our results show a relevant influence of coronal limb alignment on the TT–TG in osteoarthritic knees—the more valgus the higher and more pathological the TT–TG. With the aim of having a more personalised TKA, the individual TT–TG should be taken into account.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All investigations were conducted in conformity with ethical principles of research and that institutional approval of the human protocol for this investigation was obtained.

Informed consent Informed was waived by ethical committee.

References

1. Alemparte J, Ekdahl M, Burnier L, Hernandez R, Cardemil A, Cielo R, Danilla S (2007) Patellofemoral evaluation with radiographs and computed tomography scans in 60 knees of asymptomatic subjects. Arthroscopy 23:170–177
2. Anley CM, Morris GV, Saithna A, James SL, Snow M (2015) Defining the role of the tibial tubercle–trochlear groove and tibial tubercle-posterior cruciate ligament distances in the work-up of patients with patellofemoral disorders. Am J Sport Med 43:1348–1353
3. Barrack RL, Bertot AJ, Wolfe MW, Waldman DA, Milicic M, Myers L (2001) Patellar resurfacing in total knee arthroplasty. A prospective, randomized, double-blind study with five to seven years of follow-up. J Bone Joint Surg 83–A:1376–1381
4. Barrack RL, Schrader T, Bertot a J, Wolfe MW, Myers L (2001) Component rotation and anterior knee pain after total knee arthroplasty. Clin Orthop Relat Res 392:46–55
5. Camp CL, Stuart MJ, Krych AJ, Levy BA, Bond JR, Collins MS, Dahm DL (2013) CT and MRI measurements of tibial tubercle–trochlear groove distances are not equivalent in patients with patellar instability. Am J Sport Med 41:1835–1840
6. Carlson VR, Boden BP, Shen A, Jackson JN, Yao L, Sheehan FT (2017) The tibial tubercle–trochlear groove distance is greater in patients with patellofemoral pain: implications for the origin of pain and clinical interventions. Am J Sport Med 45:1110–1116
7. Dejour H, Walch G, Nove-Josserand L, Guier C (1994) Factors of patellar instability: an anatomic radiographic study. Knee Surg Sport Traumatol Arthrosc 2:19–26
8. Diederichs G, Kohlitz T, Kornaropoulos E, Heller MO, Vollnberg B, Scheffler S (2013) Magnetic resonance imaging analysis of rotational alignment in patients with patellar dislocations. Am J Sport Med 41:51–57
9. Dye SF (2005) The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. Clin Orthop Relat Res 436:100–110
10. Figueroa J, Guarachi JP, Matas J, Arnander M, Orrego M (2016) Is computed tomography an accurate and reliable method for measuring total knee arthroplasty component rotation? Int Orthop 40:709–714
11. Goutallier D, Bernageau J, Lecudonnec B (1978) The measurement of the tibial tuberosity. Patella groove distanced technique and results (author's transl). Rev Chir Orthop Reparatrice Appar Mot 64:423–428
12. Hatayama K, Terauchi M, Saito K, Hagiwara K, Higuchi H (2016) Tibial tubercle in valgus osteoarthritic knees is more laterally positioned than in varus knees. J Arthroplasty 31:2303–2307
13. Henckel J, Richards R, Lozhkin K, Harris S, Rodriguez y Baena FM, Barrett AR, Cobb JP (2006) Very low-dose computed tomography for planning and outcome measurement in knee replacement. The imperial knee protocol. J Bone Joint Surg 88:1513–1518
14. Ho CP, James EW, Surowiec RK, Gatlin CC, Ellman MB, Cram TR, Dornan GJ, LaPrade RF (2015) Systematic technique-dependent differences in CT versus MRI measurement of the tibial tubercle–trochlear groove distance. Am J Sport Med 43:675–682
15. Khamaisy S, Zuiderbaan HA, Thein R, Gladnick BP, Pearle AD (2016) Coronal tibiofemoral subluxation in knee osteoarthritis. Skelet Radiol 45:57–61
16. Paiva M, Blond L, Holmich P, Steensen RN, Diederichs G, Feller JA, Barfod KW (2017) Quality assessment of radiological measurements of trochlear dysplasia; a literature review. Knee Surg Sport Traumatol Arthrosc. https://doi.org/10.1007/s00167-017-4520-z
17. Pandit S, Frampton C, Stoddart J, Lynskey T (2011) Magnetic resonance imaging assessment of tibial tuberosity–trochlear groove distance: normal values for males and females. Int Orthop 35:1799–1803
18. Reikeras O (1992) Patellofemoral characteristics in patients with increased femoral anteversion. Skelet Radiol 21:311–313
19. Sahin N, Atici T, Ozkaya G (2018) Tibial tuberosity–trochlear groove distance shows no change in patients with or without knee osteoarthritis. Eurasian J Med 50:38–41
20. Schoettle PB, Zanetti M, Seifert B, Pfirrmann CW, Fucentese SF, Romero J (2006) The tibial tuberosity–trochlear groove distance; a comparative study between CT and MRI scanning. Knee 13:26–31
21. Seitlinger G, Scheurecker G, Hogler R, Labey L, Innocenti B, Hofmann S (2012) Tibial tubercle–posterior cruciate ligament distance: a new measurement to define the position of the tibial tubercle in patients with patellar dislocation. Am J Sport Med 40:1119–1125

22. Sherman SL, Erickson BJ, Cvetanovich GL, Chalmers PN, Farr J II, Bach BR Jr, Cole BJ (2014) Tibial tuberosity osteotomy: indications, techniques, and outcomes. Am J Sport Med 42:2006–2017
23. Smith TO, Davies L, Toms AP, Hing CB, Donell ST (2011) The reliability and validity of radiological assessment for patellar instability. A systematic review and meta-analysis. Skelet Radiol 40:399–414
24. Stephen JM, Lumpaopong P, Dodds AL, Williams A, Amis AA (2015) The effect of tibial tuberosity medialization and lateralization on patellofemoral joint kinematics, contact mechanics, and stability. Am J Sport Med 43:186–194
25. Tanaka MJ, Elias JJ, Williams AA, Carrino JA, Cosgarea AJ (2015) Correlation between changes in tibial tuberosity–trochlear groove distance and patellar position during active knee extension on dynamic kinematic computed tomographic imaging. Arthroscopy 31:1748–1755
26. Tecklenburg K, Feller JA, Whitehead TS, Webster KE, Elzarka A (2010) Outcome of surgery for recurrent patellar dislocation based on the distance of the tibial tuberosity to the trochlear groove. J Bone Joint Surg 92:1376–1380
27. Tensho K, Akaoka Y, Shimodaira H, Takanashi S, Ikegami S, Kato H, Saito N (2015) What components comprise the measurement of the tibial tuberosity–trochlear groove distance in a patellar dislocation population? J Bone Joint Surg 97:1441–1448
28. Yao L, Gai N, Boutin RD (2014) Axial scan orientation and the tibial tubercle–trochlear groove distance: error analysis and correction. AJR 202:1291–1296