The Knee 26 (2019) 106–114

Contents lists available at ScienceDirect

The Knee

Poor relationship between frontal tibiofemoral and trochlear anatomic parameters: Implications for designing a trochlea for kinematic alignment

Cedric Maillot [a,b], Anthony Leong [a], Ciara Harman [b], Alberto Morelli [c], Richard Mospan [a], Justin Cobb [a], Charles Rivière [a,b,*]

[a] MSK Lab, Imperial College London, Charing Cross Campus, Laboratory Block, London W6 8RP, United Kingdom of Great Britain and Northern Ireland
[b] South West London Elective Orthopaedic Center, Dorking Rd, Epsom KT18 7EG, United Kingdom of Great Britain and Northern Ireland
[c] University of Pisa, Lungarno Antonio Pacinotti, 43, 56126 Pisa, PI, Italy

ARTICLE INFO

Article history:
Received 2 August 2018
Received in revised form 12 October 2018
Accepted 7 November 2018

Keywords:
Knee replacement
Kinematic alignment
Joint line orientation
Trochlea
Implant design

ABSTRACT

Background: The kinematic alignment (KA) technique for total knee arthroplasty (TKA) is an emerging implant positioning philosophy that aims to restore constitutional knee anatomy to improve knee kinematics. At present, the KA technique aims to reconstruct native femorotibial (FT) joint alignment, however there is still insufficient consideration towards the inter-individual trochlear anatomy variability. Poor trochlear restoration may compromise clinical outcomes. Our study aimed at assessing the anatomical relationship between the native trochlea and other FT anatomical parameters.
Methods: Fifty-eight preoperative CT scans of low-grade knee arthritic patients were segmented to create 3D bone models. The FT and the PF anatomical parameters were measured using in-house software. Values were compared between different groups of lower limb and FT joint line (JL) orientation, and correlations between FT and PF anatomical parameters were assessed.
Results: We were unable to detect any significant correlation between groove orientation (frontal and axial) or groove radius and either the hip–knee–ankle (HKA), or the lateral distal femoral (LDFA), or the medial proximal tibial (MPTA), or the FTJL-mechanical axis (FTJLMAA) Angles. When considering the correlation within sub-groups of limb or JL orientation, we only found a positive correlation ($r = 0.464$, $p = 0.022$) in the varus lower limb (HKA ≤ 180°) sub-group between groove frontal orientation and LDFA.
Conclusion: Our study shows that the determination of several limb, knee, and JL parameters is of poor value to predict individual trochlea anatomy. This raises the issue of how to improve femoral component design to achieve individualised FT and PF anatomical restoration with KATKA.
Level of evidence: Level 1 – computational study.

1. Introduction

Mechanically aligned (MA) total knee arthroplasty (TKA) has been shown to have good long-term survivorship but sometimes disappointing functional outcomes [9]. Alternative more anatomical surgical techniques for TKA, the most well-known being kinematic alignment (KA), have recently been promoted, with the goal of better prosthetic knee function [12].

* Corresponding author at: MSK Lab, Imperial College London, Charing Cross Campus, Laboratory Block, London W6 8RP, United Kingdom of Great Britain and Northern Ireland.
E-mail addresses: a.leong12@imperial.ac.uk, (A. Leong), ciara.harman@nhs.net, (C. Harman), richard.mospan14@imperial.ac.uk, (R. Mospan), j.cobb@imperial.ac.uk, (J. Cobb), c.riviere@imperial.ac.uk. (C. Rivière).

https://doi.org/10.1016/j.knee.2018.11.007
0968-0160/

KA technique for TKA is an emerging implant positioning philosophy that aims to restore constitutional knee anatomy and soft tissue balance, in order to preserve native knee kinematics with improved clinical outcomes. Of the four randomised trials comparing KA to MA TKA, two have shown that KA TKA is in fact often superior (statistically significant improvement of functional outcomes) [12]. Furthermore, two in-vivo gait analysis studies found more native knee biomechanics and/or reduced abduction moment after KA TKA, compared to after MA TKA [8,10]. Finally, durability of KA TKA has been demonstrated to be similar at mid-term follow-up (mean 6.3 years) to MA TKA [3]. Although KA TKA has been proven to be safe, patellofemoral (PF) joint-related complications still remain, with a rate similar to MA TKA [2,12], the cause of which may be partially implant-related.

The KA technique has so far mainly focused on restoring the native tibiofemoral (TF) joint anatomy while neglecting true anatomical restoration of the trochlea [12]. This is because current designs of femoral components are monoblock, and thus do not allow further adjustment of trochlear parameters (groove alignment and offset) after the femoral component has been aligned with the femoral flexion and extension facets. Therefore, while the TF joint is well oriented [13], the PF one is not always [14]. It has been shown that prosthetic kinematically aligned trochleae tend to substantially under-stuff the proximal 70% of the native articular surface (due to a larger prosthetic groove radius), and also generate a mean of six degrees of excess valgus of the prosthetic groove [14]. However, as the trochlea shape guides patella kinematics, both of which have high inter-individual variability [5], inadequate restoration of constitutional trochlea anatomy may prevent optimal outcomes from KA TKA [2]. This raises the question of the relevance of new femoral implants, specifically designed for KA.

An improved understanding of the relationship between the orientations of the two joint lines should be of value for improving design of TKA components. Therefore, the aim of our study was to assess the relationship between native trochlea and TF anatomies. As far as we know, such an assessment has never been undertaken. The null hypothesis is that there is no relationship between trochlea and TF anatomical parameters.

2. Methods

Fifty-eight preoperative computed tomography (CT) scans of patients' hips, knees and ankles were segmented using Mimics® software (Materialize, Belgium) to generate tri-dimensional bone models (cartilage not segmented). Patients were over the age of 18 years and affected with low-grade primary medial tibiofemoral osteoarthritis (Ahlback grade ≤1), and no or slight PF arthritis

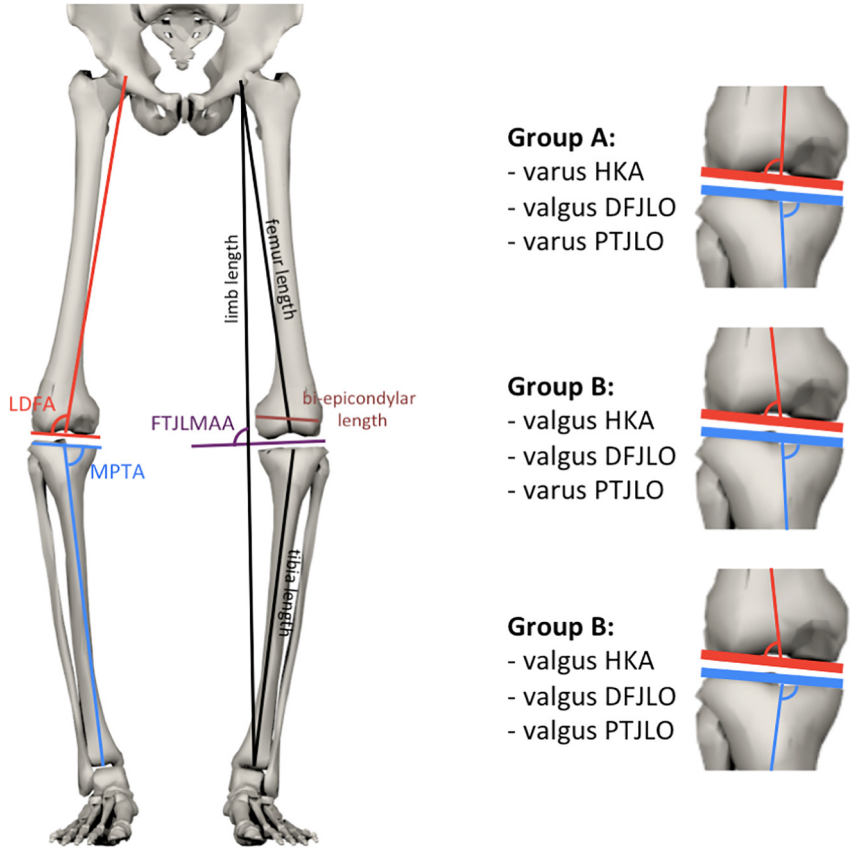

Figure 1. This figure illustrates the measured tibiofemoral joint anatomical parameters by using in-house planning software. TFJLMAA = femoro-tibial joint line mechanical axis angle, LDFA = lateral distal femoral angle, MPTA = medial proximal tibia angle.

(Iwano stage ≤2 [6]). As images were anonymised from the start, their use was not subject to approval by our institutional review board.

2.1. Measurement of TF and trochlea anatomical parameters (Figures 1 and 2)

This was performed following a method previously published [11]. Briefly, one senior consultant used an in-house implant positioning planning software to generate the TF parameters, which does an automated measure of the lateral distal femoral (LDFA), and medial proximal tibial (MPTA) angles, as well as femur, lower limb, and bi-epicondylar lengths (Figure 1). The hip–knee–ankle (HKA) angle and the angle between the TF joint line and the limb mechanical axis (TFJLMAA) were calculated. In order to ease the understanding of the results, LDFA, MPTA, and TFJLMAA were further translated to distal femoral, proximal tibial, and tibiofemoral joint line obliquity (JLO) (DFJLO, PTJLO, and TFJLO respectively), with valgus obliquity defining a LDFA <90° (DFJLO valgus) or a MPTA >90° (PTJLO valgus), or a TFJLMAA >90° (TFJLO valgus). Three sub-groups of morphotype were defined as follows: group A = morphotype with varus HKA, varus PTJLO, and valgus DFJLO; group B = valgus HKA, varus PTJLO, and valgus DFJLO; and group C = valgus HKA, valgus PTJLO, and valgus DFJLO (Figure 1). Trochlear measures relied on cutting planes revolving around the patella flexion–extension axis, which is the axis passing through the centre of the native trochlea radius and parallel to the cylindrical axis. Measurements were taken at 20° increments across the length of the groove, where 0° represents the vertical line passing through the patella axis. Trochlear parameters measured were the groove varus–valgus and internal–external orientations relative to the cylindrical axis, the groove and facet heights, as well as the start and end points and length of the groove (Figure 2).

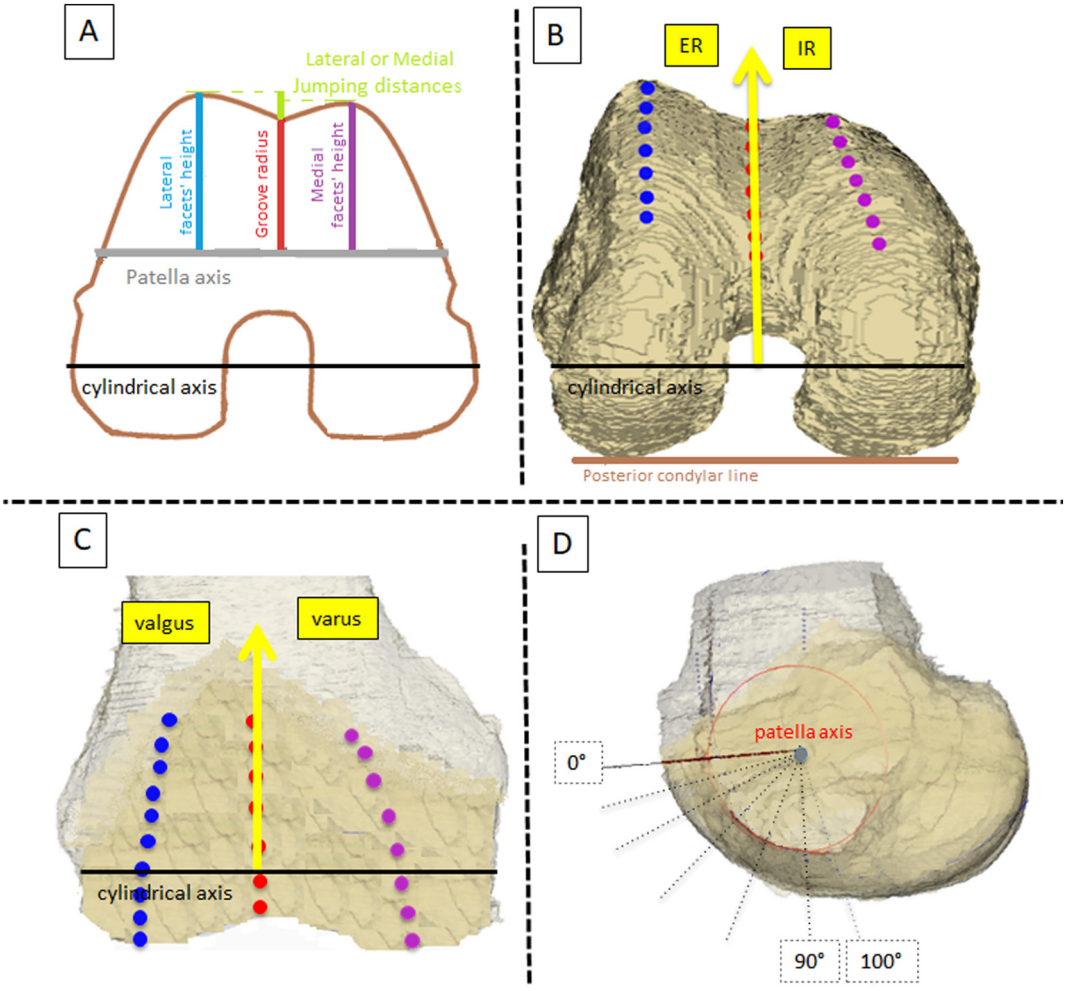

Figure 2. This figure illustrates the in-house software for measurements of patellofemoral anatomical parameters through cutting planes revolving around the patella axis (D). Medial (mauve) and lateral (blue) facets' height and groove radius (A). Axial and frontal groove alignments (B and C, respectively). ER = external rotation, IR = internal rotation.

Table 1
Comparison of tibiofemoral anatomical parameters among the different groups of combined lower limb or joint line alignments type. All results are expressed as mean (SD). A = HKA varus, PTJLO varus, DFJLO valgus, B = HKA valgus, PTJLO varus, DFJLO valgus, C = HKA valgus, PTJLO valgus, DFJLO valgus. JLO = joint line obliquity, TF = tibiofemoral, PT = proximal tibia, LDFA = lateral distal femoral angle, MPTA = Medial proximal tibia angle, HKA = hip–knee–ankle angle.

	Whole group	HKA			TF JLO			PTJLO			Morphotype			
		Varus	Valgus	p value	Valgus	Neutral	p value	Valgus	Varus	p value	A	B	C	p value
HKA (°)	180.7 (3)	177.8 (1.4)	182.8 (2)	<**0.001**	180.7 (3)	180.85 (3.2)	0.871	185.9 (1.96)	180.11 (2.51)	<**0.001**	177.79 (1.38)	182.1 (1.19)	185.92 (1.96)	<**0.001**
LDFA (°)	86.2 (1.8)	87.3 (1.5)	85.3 (1.5)	<**0.001**	85.8 (1.6)	88.1 (1.45)	<**0.001**	85.42 (1.46)	86.25 (1.81)	0.284	87.31 (1.51)	85.3 (1.55)	85.4 (1.46)	<**0.001**
MPTA (°)	86.9 (2.4)	85.1 (1.)8	88.1 (1.9)	<**0.001**	86.4 (2.28)	88.9 (1.8)	**0.002**	91.33 (0.61)	86.36 (1.93)	<**0.001**	85.1 (1.81)	87.43 (1.3)	91.33 (0.61)	<**0.001**
Calculated TF JLO (°)	3.5 (1.4)	3.7 (1.5)	3.4 (1.4)	0.43	3.9 (1.22)	1.5 (0.27)	<**0.001**	1.86 (0.6)	3.7 (1.39)	**0.002**	3.69 (1.5)	3.71 (1.32)	1.86 (0.6)	**0.010**

Bold data indicates statistical significance.

2.2. Statistical analysis

Tibiofemoral parameters (HKA, LDFA, MPTA, and TFJLMAA) were computed. Medial and lateral trochlea facets' jumping distances were calculated by the difference between the trochlear facet heights and that of the level of the sulcus of the patellar groove (groove radius). Because the bi-epicondylar length was found to more positively correlate with groove radius than femur length, facet heights and jumping distance were normalized on the former's parameters. Normal distribution was confirmed by the equality of variance test. Continuous variables were expressed as mean ± one standard deviation, and categorical data with absolute frequencies and percentages. Comparison between trochlear anatomic parameters (facet height, jumping distance, groove) and tibiofemoral parameters (HKA, LDFA, MPTA and TFJLMAA) for the whole group and within morphotype sub-groups of limbs (HKA) or JL (DF, PT and TF) alignment (valgus or varus) were performed using Student t-tests for independent samples or one-way analysis of variance (ANOVA). A Bonferroni method was used to compensate for the multiple comparison tests performed, and the level of significance (p value) was therefore set at 0.03. Correlations between groove alignment (frontal and axial) or groove radius and either the HKA, or the LDFA, or the MPTA and facet heights or jumping distance were analyzed with Pearson's linear correlation test, as all data were numerical. Finally, to measure reproducibility and repeatability, the measurements were repeated twice for 14 knees by two operators, independently. Intra-class correlation coefficient for inter-observer reproducibility and intra-observer repeatability indicated a very good agreement, with ICC = 0.9982 [0.9975 to 0.9986] and ICC = 0.9993 [0.9990 to 0.9994], respectively. Statistical analysis was performed using IBM® SPSS® Statistics 18 statistical software (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. TF anatomical parameters (Table 1)

The mean HKA in the whole group was slightly valgus (180.7° ± 3.02°); the DFJLO was always valgus oriented relative to the femoral mechanical axis (0 to eight degrees) with a mean at 3.8° ± 1.79°; the PTJLO was on average 3.1° ± 2.39° varus, ranging from two degrees valgus to eight degrees varus. The TF JLO was always valgus oriented relative to the mechanical limb axis with a mean of 3.5° ± 1.44° (1.1 to 6.6°). The valgus orientation of the TF JLO was similar between varus and valgus lower limbs (3.7° ± 1.50° vs 3.4° ± 1.41° respectively, p = 0.43) and is reduced when the proximal tibial orientation was valgus oriented. Subgroups of morphotype repartition were 24 subjects in group A, 28 in group B and six in group C.

Table 2
Comparison of trochlear anatomical parameters among the different groups of combined lower limb or joint line alignments type. All results are expressed as mean (SD). Valgus and external rotations are negative value. A = HKA varus, PTJLO varus, DFJLO valgus, B = HKA valgus, PTJLO varus, DFJLO valgus, C = HKA valgus, PTJLO valgus, DFJLO valgus. JLO = joint line obliquity, TF = tibiofemoral, PT = proximal tibia, HKA = hip–knee–ankle angle.

	Whole group	HKA			TF JLO			PTJLO			Morphotype			
		Varus	Valgus	p value	Valgus	Varus	p value	Valgus	Varus	p value	A	B	C	p value
Groove frontal alignment (°) (valgus-)	−1 (5.7)	−0.8 (5.1)	−1.1 (6.1)	0.85	−1.6 (5.57)	1.9 (5.57)	0.079	0.15 (4.49)	−1.09 ± 5.82	0.616	−0.79 (5.08)	−1.35 (6.47)	0.15 (4.49)	0.830
Groove axial alignment (°) (ER-)	−1.7 (5.2)	−2.5 (5.9)	−1.1 (4.7)	0.33	−1.92 (5.44)	−0.41 (4.1)	0.412	−0.72 (4.1)	−1.77 (5.37)	0.646	−2.46 (5.94)	−1.17 (4.86)	−0.72 (4.1)	0.614
Groove radius (mm)	22.6 (2.1)	22.5 (2.2)	22.7 (2.2)	0.9	22.82 (2.1)	21.4 (2.1)	0.064	22.52 (2.06)	22.59 (2.18)	0.937	22.48 (2.17)	22.69 (2.23)	22.52 (2.06)	0.937
Groove length (mm)	108.6 (9.5)	110.5 (7.9)	107.2 (10.4)	0.19	107.31 (9.6)	114.7 (6.6)	**0.024**	112 (10.71)	108.19 (9.37)	0.357	110.54 (7.89)	106.18 (10.2)	112 (10.71)	0.166

Bold data indicates statistical significance.

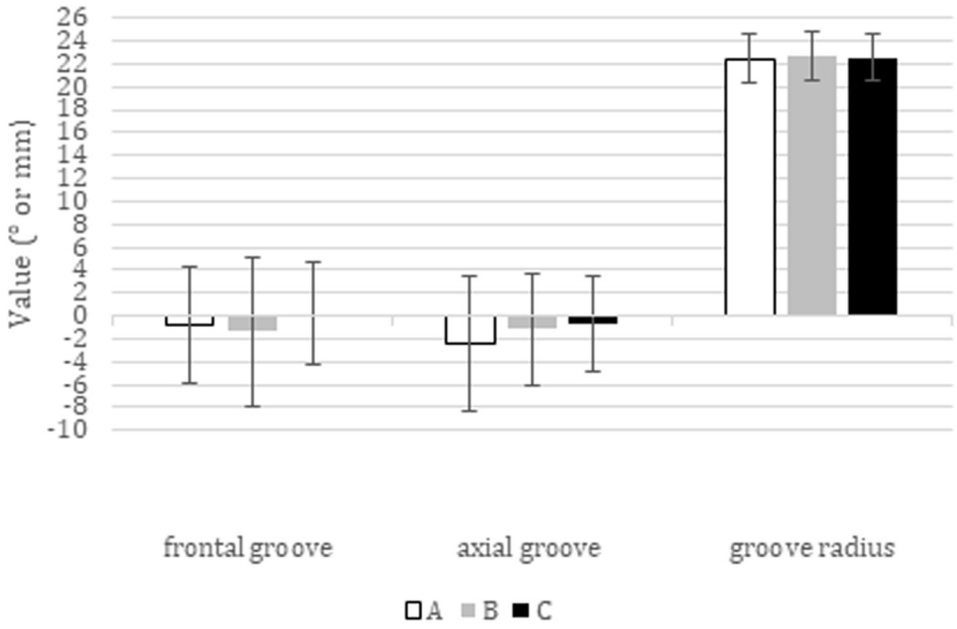

Figure 3. This figure illustrates the differences of frontal and axial groove alignment and groove radius between different lower limb morphotypes. A = varus limb (HKA) with varus PTJLO and valgus DFJLO, B = valgus limb with varus PTJLO and valgus DFJLO, C = valgus limb with valgus PTJLO and valgus DFJLO.

3.2. Trochlear anatomical parameters (Table 2)

The native groove was on average 1° ± 5.68° valgus relative to the distal femoral joint line and 1.7° ± 5.23° externally rotated relative to the posterior condylar line. We found the groove frontal and axial alignment and radius were not significantly different between the different morphotype sub-groups (A,B,C) (Figure 3). Facets' heights and jumping distances were similar between different lower limb (valgus or varus — Figure 4) or DFJLO (valgus or neutral) alignment groups. However, we found a significant decreased proximal facet height (−3.83 mm for lateral facet at 0°, $p = 0.024$) and jumping distance (−3.91 mm and −2.31 mm for the lateral facet at 0°, $p = 0.012$ and 20°, $p = 0.023$ respectively, −3.6 mm for the medial facet at 0°, $p = 0.025$) in knees with varus tibias (varus oriented PTJLO). These lateral and medial jumping distances at 0° were moderately correlated ($r = -0.33$, $p = 0.018$ and $r = -0.375$, $p = 0.006$, respectively) with axial groove alignment. We found that the normalized value of the groove radius strongly, to very strongly positively correlate with almost every measurement of the lateral and medial facet height ($r = 0.293$ to 0.830, $p < 0.026$). However, there was no significant correlation between the aforementioned parameters and the facets' jumping distances ($p = 0.034$ to 0.928).

3.3. Assessment of relationship between trochlea and tibiofemoral anatomical parameters

When considering every patient from the cohort, we did not find any significant correlation between groove alignment (frontal and axial) or groove radius and either the HKA, or the LDFA, or the MPTA (Figure 5). However, we found a weak relationship between groove length and LDFA ($r = 0.29$, $p = 0.026$) and JLO ($r = -0.29$, $p = 0.028$). When looking at the correlation within sub-groups of limb or JL alignment, we only found a moderate positive correlation ($r = 0.464$, $p = 0.022$) in the varus lower limb (HKA ≤ 180°) sub-groups between groove frontal alignment and DFJLO.

4. Discussion

While the KA technique has been shown to improve TKA outcomes overall, the rate of PFJ related complications has been reported to be similar between MA & KA TKAs [2,12]. This may be because KA of current femoral components has so far focused on restoring the distal condylar anatomy, while neglecting anatomical restoration of the trochlea [12]. We found the TF anatomy to be of poor value to predict the trochlea anatomy; this makes monoblock femoral components likely inappropriate to adequately restore both the native distal femoral and trochlea joint line orientation.

Before interpreting the results of this study, it is important to acknowledge some limitations. Firstly, our patients were mainly white Caucasian, and therefore our results only apply to this ethnic group. Secondly, we generated bone models as we could not segment the cartilage on the CT scans; although chondral thickness has been shown to have only a slight variability among individuals and between different areas of the distal femoral epiphysis [7,15], and therefore this limitation is not likely to significantly

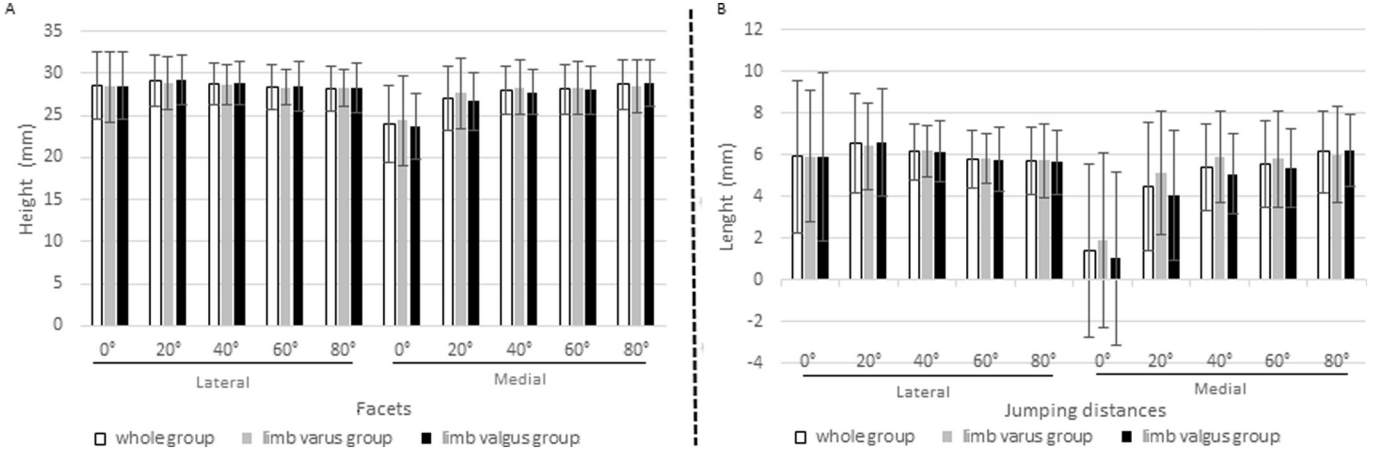

Figure 4. This figure illustrates the differences of facets heights (A) and jumping distances (B) between the whole and varus/valgus limb groups.

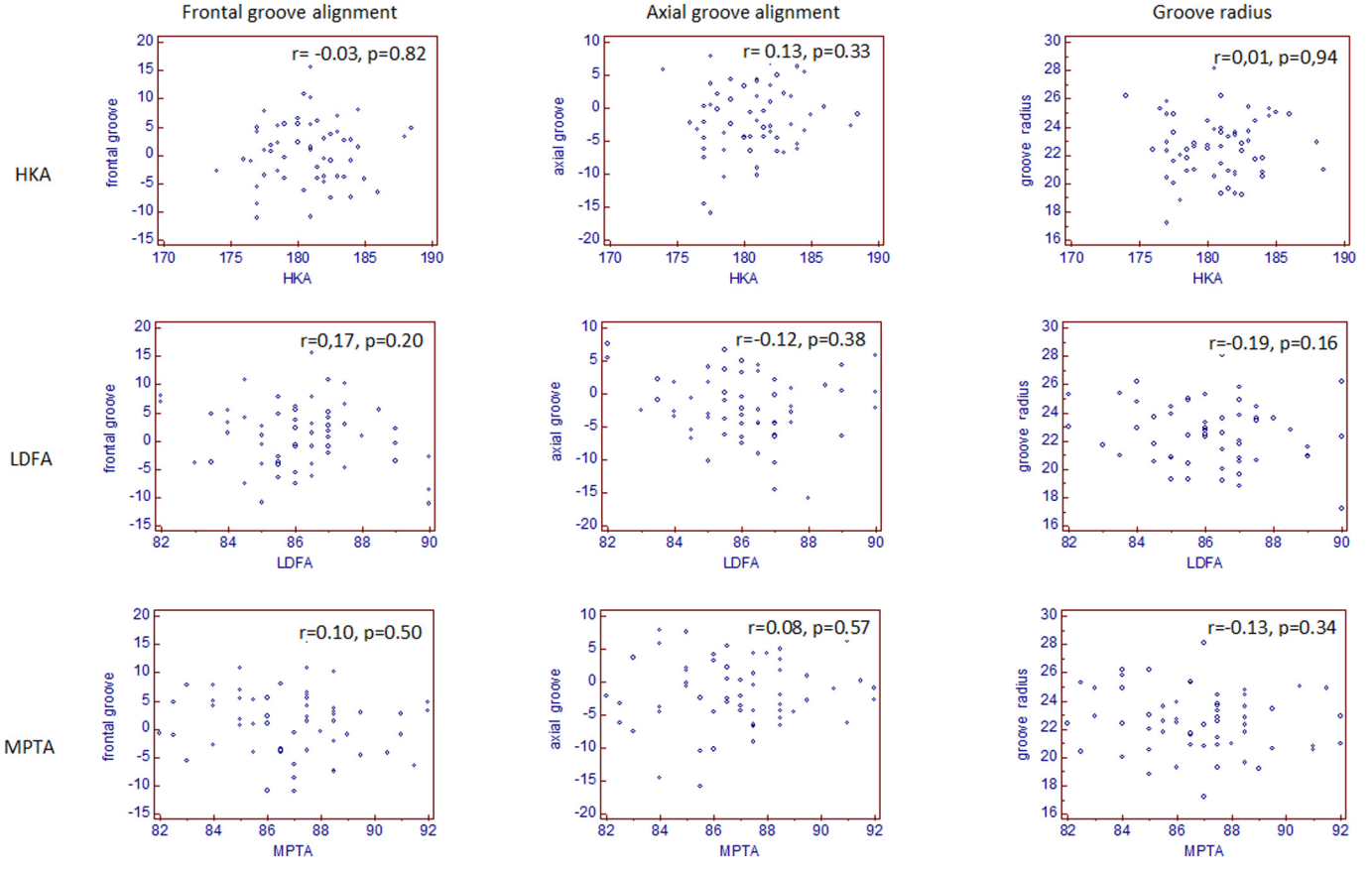

Figure 5. This figure illustrates the scatter diagrams of correlations between groove alignment (frontal and axial) or groove radius and either the hip–knee–ankle (HKA), or the lateral distal femoral (LDFA), or the medial proximal tibia (MPTA) angles.

affect our comparisons. Finally, we lacked power for some inter-group comparisons and correlation statistical tests that might have been responsible of type 2 errors.

Our data regarding native TF (HKA, LDFA, MPTA) and trochlea (groove alignment and radius, facet heights) anatomies are in line with those from previous studies [1,5]. However, we had several findings that have not been widely discussed in past studies, including: 1) Trochlear anatomy was similar within different lower limb alignment groups (HKA, DFJL, PTJL, and TFJLO), the only exception being we found a more constraining proximal trochlea (larger lateral facet and facets' jumping distance) in valgus proximal tibia. The latter observation may be a compensatory factor given that valgus alignment of the proximal tibia could increase the tibial tuberosity–trochlear groove distance, constituting a risk factor for patella instability. 2) The TFJLO was always valgus oriented relative to the femoral mechanical axis. As the lower limb usually tends to adduct during the stance phase in normal gait, a valgus orientation would contribute to having the TFJL horizontal to the ground no matter what the patient's lower limb axis is [4,10]. And 3) the facets' jumping distance was similar between knees, whatever their size was after normalization. In other words, the lateral and medial facets' jumping distances were almost the same whatever the size of the trochlea.

When looking at correlation tests, we only found the groove frontal alignment to be strongly correlated to the DFJLO in the varus limb sub-group. As shown in Figure 5, we were far from having significant correlations regarding the other groups and other anatomical parameters, making the relationship between TF and trochlear anatomies overall very poor. These findings surprised us, and probably indicate that TF and trochlear anatomies are relatively independent from one another, therefore parameters such as HKA, LDFA, and MPTA angles are of poor value in predicting trochlea anatomy. PF biomechanics would therefore be less influenced by TF anatomy than traditionally thought.

In order to improve prosthetic PF biomechanics, it would be appropriate to develop custom implants or to increase modularity of implants by creating femoral components with various trochlea shapes. This would raise the concern of having more inventory, however could be solved with better preoperative planning and logistics management. The relevance of our results is that, if such implants were made available, preoperative measurement of limb, knee, and JL alignments would be of poor value to predict (or plan) individual trochlea anatomy. Therefore, the surgeon would need to get individual trochlear anatomy data either from preoperative three-dimensional (3D) planning or intra-operative landmarks, in order to make an informed decision on the correct implant to use.

5. Conclusion

Our study shows that determining limb, knee, and JL parameters is of poor value in predicting the shape of the trochlea. Restoration of individual trochlear anatomy, in addition to the TF joint, would probably further improve the currently good clinical outcomes of KA TKA by optimization of whole-knee kinematics. This would require either custom or new modular femoral component designs, which enable the surgeon to replicate native trochlea anatomy after TF joint alignment. Higher implant modularity would bring logistical and inventory challenges, highlighting the need for more sophisticated preoperative planning.

Authors' contributions

All authors give their final approval of the version to be published, and their agreement to be accountable for all aspects of the work.

Disclosure of interest

The authors declare that they have no competing interest. Outside the current study Charles Rivière declares being a consultant to Medacta, and received fees from Corin. Justin Cobb declares being a consultant to Biomet-Zimmer, Mathortho, and receives fees from Microport. CR owns an IP regarding a new TKA component design specific for kinematic implantation.

Source of funding

None.

Acknowledgements

We would like to thank Edouard Auvinet, Stefan Lazic, and Giacomo Petrucci for their help in this study.

References

[1] Almaawi AM, Hutt JRB, Masse V, Lavigne M, Vendittoli P-A. The impact of mechanical and restricted kinematic alignment on knee anatomy in total knee arthroplasty. J Arthroplasty 2017;32:2133–40.
[2] Dossett HG, Estrada NA, Swartz GJ, LeFevre GW, Kwasman BG. A randomised controlled trial of kinematically and mechanically aligned total knee replacements: two-year clinical results. Bone Joint J 2014;96:907–13.
[3] Howell SM, Papadopoulos S, Kuznik K, Ghaly LR, Hull ML. Does varus alignment adversely affect implant survival and function six years after kinematically aligned total knee arthroplasty? Int Orthop 2015;39:2117–24.
[4] Hutt J, Massé V, Lavigne M, Vendittoli P-A. Functional joint line obliquity after kinematic total knee arthroplasty. Int Orthop 2016;40:29–34.

[5] Iranpour F, Merican AM, Dandachli W, Amis AA, Cobb JP. The geometry of the trochlear groove. Clin Orthop Relat Res 2010;468:782–8.
[6] Iwano T, Kurosawa H, Tokuyama H, Hoshikawa Y. Roentgenographic and clinical findings of patellofemoral osteoarthrosis. With special reference to its relationship to femorotibial osteoarthrosis and etiologic factors. Clin Orthop 1990:190–7.
[7] Kazam JK, Nazarian LN, Miller TT, Sofka CM, Parker L, Adler RS. Sonographic evaluation of femoral trochlear cartilage in patients with knee pain. J Ultrasound Med 2011;30:797–802.
[8] McNair PJ, Boocock MG, Dominick ND, Kelly RJ, Farrington BJ, Young SW. A comparison of walking gait following mechanical and kinematic alignment in total knee joint replacement. J Arthroplasty 2018;33:560–4.
[9] Nam D, Nunley RM, Barrack RL. Patient dissatisfaction following total knee replacement: a growing concern? Bone Joint J 2014;96:96–100.
[10] Niki Y, Nagura T, Nagai K, Kobayashi S, Harato K. Kinematically aligned total knee arthroplasty reduces knee adduction moment more than mechanically aligned total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2018;26(6):1629–35.
[11] Rivière C, Iranpour F, Auvinet E, Aframian A, Asare K, Harris S, et al. Mechanical alignment technique for TKA: are there intrinsic technical limitations? Orthop Traumatol Surg Res 2017;103:1057–67.
[12] Rivière C, Iranpour F, Auvinet E, Howell S, Vendittoli P-A, Cobb J, et al. Alignment options for total knee arthroplasty: a systematic review. Orthop Traumatol Surg Res 2017;103:1047–56.
[13] Rivière C, Iranpour F, Harris S, Auvinet E, Aframian A, Chabrand P, et al. The kinematic alignment technique for TKA reliably aligns the femoral component with the cylindrical axis. Orthop Traumatol Surg Res 2017;103:1069–73.
[14] Rivière C, Iranpour F, Harris S, Auvinet E, Aframian A, Parratte S, et al. Differences in trochlear parameters between native and prosthetic kinematically or mechanically aligned knees. Orthop Traumatol Surg Res 2018;104(2):165–70.
[15] Schub DL, Frisch NC, Bachmann KR, Winalski C, Saluan PM. Mapping of cartilage depth in the knee and elbow for use in osteochondral autograft procedures. Am J Sports Med 2013;41:903–7.