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ORIGINAL PAPER

Femoral flexion position is a highly variable factor in total knee arthroplasty: an analysis of 593 conventionally aligned total knee replacements

Paola Koenen[1] · **Deha Murat Ates**[1] · **Thomas R. Pfeiffer**[1] · **Bertil Bouillon**[1] · **Holger Bäthis**[1]

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Abstract

Purpose In contrast to coronal alignment, only few is known about sagittal alignment in total knee arthroplasty (TKA). The aim of this study was to identify the flexion position of the femoral component in a routine surgical setting of conventional TKA and to evaluate potential predictors for the degree of femoral flexion.

Methods A retrospective study was performed on 593 primary TKA using the conventional intramedullary alignment technique for distal femur. Femoral flexion was measured by the verification mode of a pinless navigation system. Correlations between femoral flexion and patient-specific data, surgery-related factors and measurements of a preoperative anterior–posterior long-leg X-ray were analysed.

Results The distal femoral resection showed a mean flexion of 5.5° ± 2.5° to the mechanical axis with high variation between 2.5° extension and 14° flexion. In a multivariate regression model, body height ($p = 0.023$), body weight ($p = 0.046$) and body mass index ($p = 0.026$) showed significant positive correlation to femoral flexion. There was no correlation to any preoperative alignment data from the anterior–posterior long-leg film. The sagittal position was also independent from surgery-related factors such as different knee systems or surgeons.

Conclusions Femoral flexion is a highly variable characteristic in conventionally aligned TKA. Increasing body height, body weight and body mass index were identified as predictors for a high degree of femoral flexion.

Level of evidence III.

Keywords Total knee arthroplasty · Sagittal alignment · Femoral flexion · Femoral antecurvation

Abbreviations

TKA	Total knee arthroplasty
CAS	Computer-assisted surgery
PSI	Patient-specific instruments
mFA-mTA	Mechanical tibiofemoral angle
AMA	Anatomical mechanical femoral angle
mLDFA	Mechanical lateral distal femoral angle
mMPTA	Mechanical medial proximal tibial angle
mLDTA	Mechanical lateral distal tibial angle
BMI	Body mass index
OA	Osteoarthritis

✉ Paola Koenen
Paola.Koenen@googlemail.com

[1] Department of Orthopaedics, Trauma Surgery and Sports Medicine, Cologne Merheim Medical Center, University of Witten/Herdecke, Ostmerheimer Str. 200, 51109 Cologne, Germany

Introduction

Reconstruction of limb alignment in the coronal plane has been one of the main objectives in total knee arthroplasty (TKA) within the last 2 decades. In contrast to frontal and rotational alignment, only few is known about alignment in the sagittal plane [20]. This topic has become a focus of interest only in the last decade. The optimal position of the femoral component in the sagittal plane has not been defined yet. Some authors discuss a range from 0° to 5° flexion [4, 12, 18, 21]. Other studies suggest a range between 0° and 3° flexion as favourable [6, 9].

Furthermore, measurement of femoral flexion is challenging. In conventional TKA, femoral flexion can hardly be measured during surgery as there is no accepted landmark for the sagittal femoral axis in conventional TKA [25]. It has been shown that surgeons are not able to assess the degree of flexion intraoperatively [16] and at least full-length lateral radiographs are necessary postoperatively. However, a correct identification of anatomic landmarks can be challenging, particularly in obese patients, and different distal femoral axes exist for measuring [4]. CT scan is another option for measuring femoral flexion but involves higher radiation exposure. Intraoperatively, computer navigation systems are the only opportunity to analyse sagittal alignment of the femoral component. In most of the systems the femoral canal is blocked by the fixation of the femoral reference array and, therefore, a verification of the conventional intramedullary technique is not possible. Pinless verification tools have been developed that allow a simultaneous measurement of femoral flexion when using the conventional intramedullary alignment technique. Besides that, only patient-specific instruments (PSI) may deliver a predefined sagittal alignment.

Based on these challenges in sagittal femoral alignment, the primary aim of this study was to identify the flexion position of the femoral component using the conventional intramedullary alignment technique. The secondary aim was to reveal potential predictors for femoral flexion with respect to patient-specific data, surgery-related factors and preoperative radiographic measurements.

Therefore, a cohort of 593 patients allocated for TKA in a routine surgical setting was analysed. It was hypothesised that there was a high interindividual variability in femoral flexion and that patient-specific factors such as body measurements have an influence on sagittal alignment.

Materials and methods

Study design

A retrospective study was performed on a consecutive series of patients who underwent primary TKA. Ethical approval for data collection was received from the local ethics commission (138/2018).

Between 11/2012 and 08/2018, all patients allocated for primary TKA with the surgical technique described below were initially included in the study ($n=719$). Due to failed backup, 111 patients (05/2014–12/2014) had to be excluded as verification data of the navigation system were lacking ($n=608$). Another 15 patients were excluded from the study due to incomplete data for body measurements or missing long-leg X-ray, resulting in a cohort of 593 patients.

All surgeries were performed by four surgeons with extensive experience in TKA. The conventional alignment technique was used supplemented by the pinless verification tool of a navigation system. The distal femoral cut was intramedullary aligned. The pinless verification workflow was then used to measure the flexion position of the distal femoral resection. These data were recorded in degrees of flexion to the mechanical femoral axis. Verification data for femoral flexion were then analysed with respect to potential correlations with (1) patient-specific data such as gender, age, body weight, body height and body mass index (BMI); (2) surgery-related factors like type of osteoarthritis (OA), type of knee system and surgeon; and (3) measurements of a preoperative long-leg X-ray in the coronal plane.

Surgical technique

For all knee arthroplasties, either the DePuy Synthes Sigma® knee system or the DePuy Synthes Attune® knee system was used (DePuy Synthes, Johnson & Johnson medical GmbH, Umkirch, Germany). A standard midline skin incision, medial parapatellar approach and tibia-first technique were performed. Using the intramedullary alignment technique at distal femur, the entry point of the intramedullary alignment rod was defined at 7–10 mm anterior to the origin of the posterior cruciate ligament (PCL) as described within the surgical technique manual of both systems. A standard intramedullary rod (300 × 8 mm) was introduced to the femoral isthmus. The distal femoral cut in the sagittal plane was then directed by the fixed rectangular geometry of the standard intramedullary alignment devices (Fig. 1). After completion of the distal femoral resection, the final alignment data of the resection plane were measured using the pinless verification workflow of the navigation system DASH (Brainlab, Munich, Germany). This surgical technique has been used for all primary TKA cases since 2012 with a maximum of two cases per day.

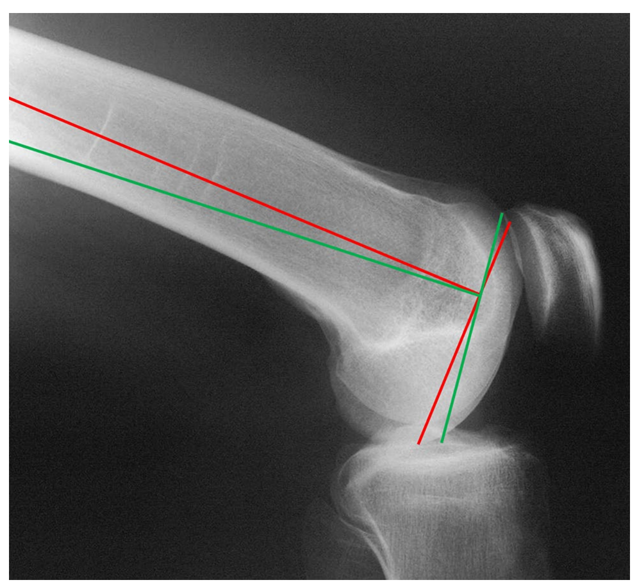

Fig. 1 Distal femoral resection is shown schematically on a true lateral radiograph of the knee. Using the intramedullary alignment technique, the anatomical distal femoral axis is referenced (red). In navigated TKA and PSI, the sagittal mechanical femoral axis is taken as a reference (green)

Measurements of the navigation system

The DASH system (Brainlab, Munich, Germany) is an image-free, optoelectronic navigation device. Using an infrared camera, all joint information is digitised within the surgery without the need for special preoperative diagnostics or fixation of static reference arrays to femur and tibia. Central to the hardware concept is a sterile draped Apple iPod touch® that is included into a handheld cradle and serves as the operating unit. The iPod touch® works remotely with the separated computer platform that is included into the infrared camera stand using secured wireless-LAN network connection. In earlier studies, a comparable accuracy has been shown between the pinless DASH system and conventional computer-assisted surgery with bony references [2, 11]. The DASH system can either be used as navigation device in its classical meaning or as verification tool when using the conventional alignment technique. In this study, it was used only as verification tool when using the conventional alignment technique. The femoral cutting block is oriented using the conventional intramedullary alignment and fixed to the bone in the desired position. After removal of the intramedullary rod, a cutting block slot adapter equipped with optical spheres is rigidly inserted into the cutting block. Due to the stable fixation of the cutting block to the bone, a coordinate system can now be defined. Using the pointer attached to the iPod touch® anatomic landmarks are digitised and defined in the respective coordinate system to acquire an accurate 3D position. These landmarks are for the tibia, the medial and lateral malleolus, tibial mechanical axis point and tibial ap-direction and for the femur, the femoral mechanical axis point and the Whiteside line. In addition, a circumduction of the leg is performed to identify the femoral head centre. Besides data on coronal alignment, sagittal alignment of the femoral component is then displayed in degrees of flexion to the mechanical femoral axis with an accuracy of 0.5°. Positive values are defined as flexion position and negative values as extension position. Then, the distal femoral cut is done. For verification of the resection plane, a bone verification plate equipped with optical spheres is positioned at the distal femoral cut and the centre of the femoral head is digitised again by hip pivoting. As a result, the final flexion position of the distal femoral cut is displayed in degrees of flexion on the iPod touch®.

Radiological assessment

Preoperative standardised anterior–posterior, full-length–weight-bearing radiographs were performed. Radiographs were performed using an internal standardised protocol according to the recommendations described by Cooke et al. [5]. Measurements were performed by one observer using the digital planning software mediCAD version 5.1.0.10 (mediCAD Hectec GmbH, Altdorf, Germany). The following parameters were analysed: mFA-mTA (= mTFA, mechanical tibiofemoral angle), AMA (anatomical mechanical femoral angle), mLDFA (mechanical lateral distal femoral angle), mMPTA (mechanical medial proximal tibial angle), and mLDTA (mechanical lateral distal tibial angle). In general, radiographic measurements are subject to interobserver errors especially when identification of anatomic landmarks is difficult [29]. In an earlier study, measurements on full-length–weight-bearing radiographs were shown to be very reliable with an interobserver reliability that was “almost perfect” [11].

Statistical analysis

Statistical analysis was performed using GraphPad Prism 7.0 (La Jolla, California, USA) and SPSS Statistics Version 24.0.0.0 (IBM Corporation, IBM Inc., Armonk, New York, USA).

Linear regression analysis was performed to reveal correlations between femoral flexion position and metric variables. Differences between groups were tested using either an unpaired t test (2 groups) or one-way analysis of variance with Tukey’s post hoc test (> 2 groups), when following normal distribution and Kruskal–Wallis test with Dunn’s post hoc analysis (> 2 groups), when not passing normality test.

Multivariate regression analysis was performed to identify variables that were significant in independently predicting femoral flexion. Unstandardized regression coefficient B, standard error, the standardised regression coefficient Beta, t statistics and p value were calculated.

A p value < 0.05 was considered statistically significant.

Results

593 patients were included in the study. Demographic data and surgery-related factors are shown in Table 1. Measurements of the preoperative anterior–posterior long-leg X-ray are shown in Table 2.

Using the intramedullary alignment technique, sagittal alignment of the distal femoral cut showed a mean flexion of 5.5° ± 2.5° to the mechanical femoral axis. A high variation existed between 2.5° extension and 14° flexion (Fig. 2).

While men had a mean femoral flexion of 5.8° ± 2.6° women showed a mean flexion of 5.3° ± 2.4°, which was proven to be statistically significant in a univariate analysis ($p = 0.016$). Body height ($r = 0.115$, $p = 0.006$), body weight ($r = 0.127$, $p = 0.002$) and BMI ($r = 0.087$, $p = 0.036$) showed a statistically significant positive correlation with femoral flexion (Fig. 3), meaning that the degree of femoral flexion increased with increasing body height, body weight and BMI.

Table 1 Descriptive statistics for demographics and surgery-related factors shown as n (%) or mean ± SD and range. $n = 593$

Gender	
Male	243 (41%)
Female	350 (59%)
Race	
Caucasian	593 (100%)
Age (years)	
66.8 ± 10.1	27–91
Body height (m)	
1.69 ± 0.09	1.42–1.96
Body weight (kg)	
86.7 ± 17.5	50–181
Body mass index (kg/m^2)	
30.2 ± 5.4	18.6–55.9
Type of osteoarthritis	
Idiopathic	542 (91.4%)
Posttraumatic	51 (8.6%)
Side of surgery	
Right	287 (48.4%)
Left	306 (51.6%)
Type of knee system	
DePuy Synthes Attune®	452 (76.2%)
DePuy Synthes Sigma®	141 (23.8%)
Surgeon	
Surgeon 1	411 (69.3%)
Surgeon 2	72 (12.1%)
Surgeon 3	38 (6.4%)
Surgeon 4	72 (12.1%)

Table 2 Measurements of the preoperative long-leg X-ray; all values are reported in °, negative values are defined as varus, positive values as valgus

	Mean	SD	Min	Max
mFA-mTA	− 3.7	7.4	− 24.3	21.8
AMA	6.6	1.5	− 1.6	12.5
mLDFA	88.5	3.0	77.6	97.1
mMPTA	87.7	3.4	78.1	98.4
mLDTA	87.9	4.3	69.5	100.7

There was no statistically significant difference in femoral flexion between patients with primary and posttraumatic OA (5.5° ± 2.5° vs. 5.4° ± 2.8°, n.s.). Posttraumatic OA cases included patients with previous ligamentous injuries and tibial fractures. Due to the small number of posttraumatic cases in total ($n = 51$), a subgroup analysis was not performed. When using the Attune primary total knee system a flexion position of 5.5° ± 2.4° resulted, whereas it was 5.6° ± 2.7° in the PFC sigma group (n.s.). Differences in femoral flexion between the four surgeons were statistically not significant with a mean flexion ranging from 4.6° ± 2.4° (Surgeon 3) to 5.7° ± 2.6° (Surgeon 1) ($p = 0.055$). Details are shown in Fig. 4.

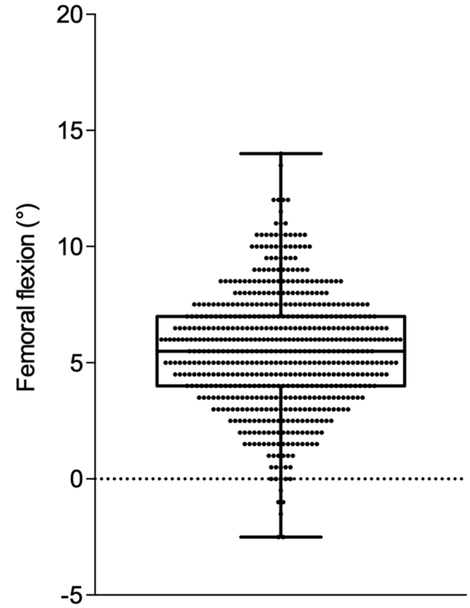

Fig. 2 Distribution of femoral flexion in degrees to the mechanical femoral axis after applying the intramedullary alignment technique. Data are presented as boxplot. Positive values are defined as flexion, negative values as extension. $n = 593$

There was neither a correlation between the flexion of the femoral component and the limb axis in the preoperative full-length–weight-bearing X-ray nor between the flexion position and preoperative mLDFA and mMPTA (Fig. 5). Preoperative mLDTA showed a weak, but statistically significant inverse correlation with femoral flexion (Fig. 5d, $p = 0.033$, $r = -0.088$).

To reveal factors that are independent in predicting femoral flexion, a multivariate regression model was created including patient-specific data (age, gender, body weight, body height, and BMI), surgery-related factors (type of OA, type of knee system, surgeon) and certain measurements of a preoperative long-leg X-ray in the coronal plane (mFA-mTA, mLDFA, mMPTA, and mLDTA). After correcting for all variables, only body height (beta = 0.565, $p = 0.023$), body weight (beta = 0.900, $p = 0.046$) and BMI (beta = 0.901, $p = 0.026$) remained significantly correlated to femoral flexion (Table 3).

Discussion

The most important finding of the present study is a very high variation of the femoral flexion position between 2.5° of extension and 14° of flexion (mean 5.5°) related to the

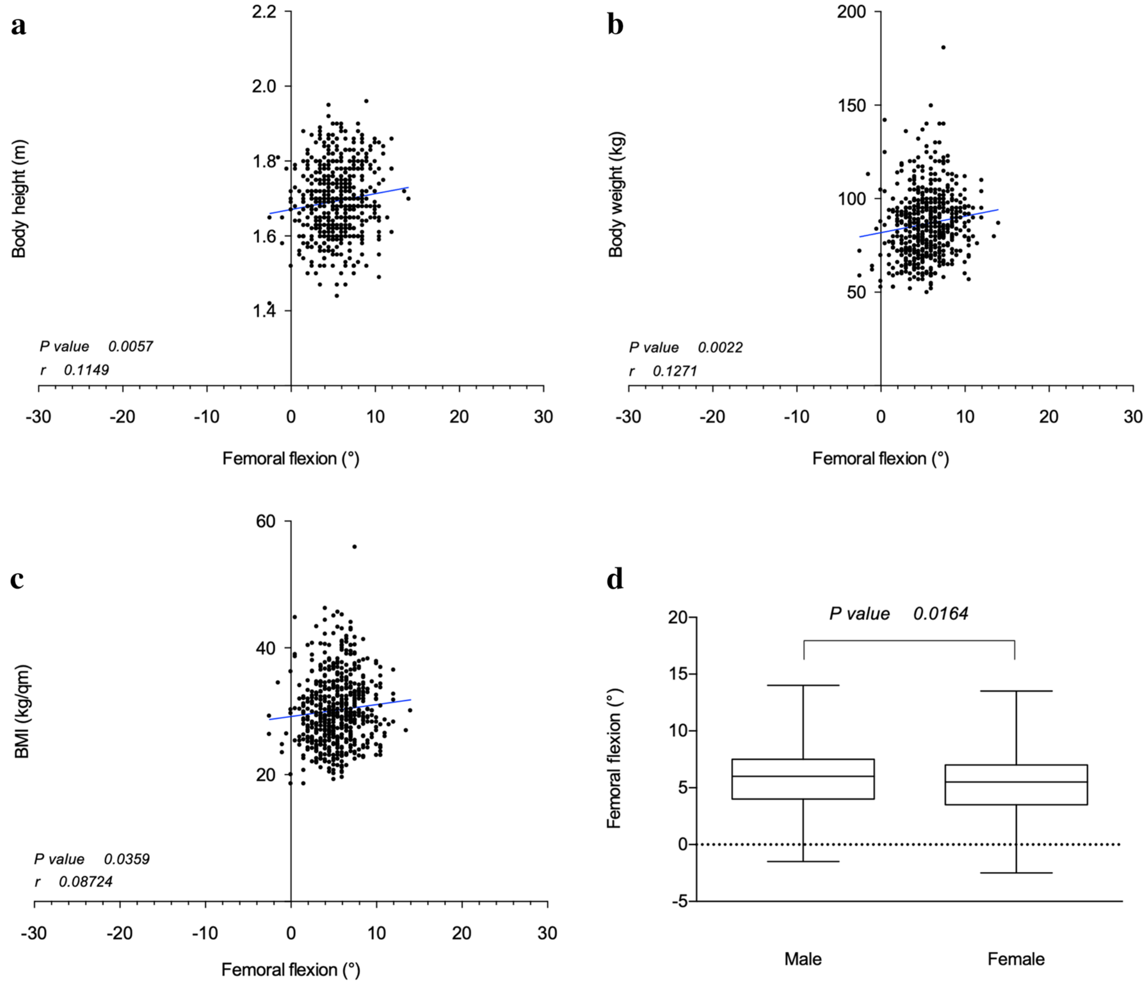

Fig. 3 Flexion of the femoral component in correlation with patient-specific factors **a** body height, **b** body weight and **c** BMI. Shown are Pearson correlation coefficient *r* and *p* values. **d** Femoral flexion dependent on patients' gender. Data are presented as boxplot and *p* values are specified. A *p* value < 0.05 was considered statistically significant. *n* = 593

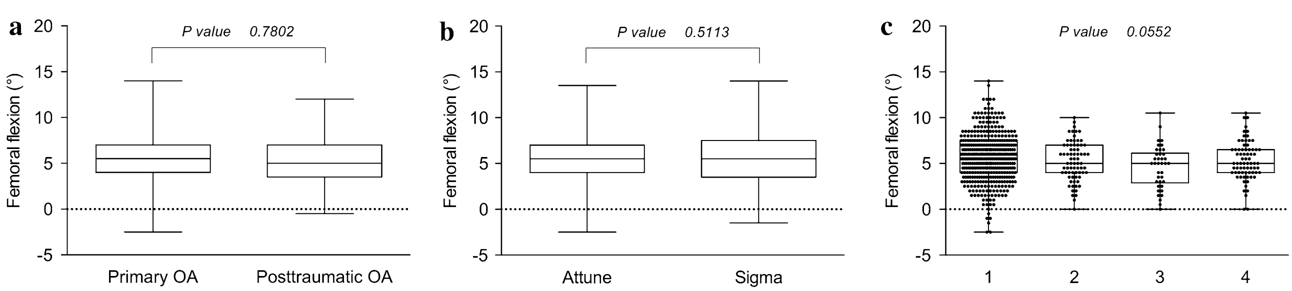

Fig. 4 Femoral flexion correlated with surgery-related factors: **a** type of OA, **b** type of knee system and **c** surgeon (1–4 means surgeon 1–4). Data are presented as boxplot and *p* values are specified. A *p* value < 0.05 was considered statistically significant. *n* = 593

sagittal mechanical femoral axis, when using a standard intramedullary alignment technique for the femur.

This is in consistency to previous reports. In a small cohort of patients, Maderbacher et al. [16] found a mean flexion of 4.4° (− 1° to 18.5°) in 40 TKA whereas Ma et al. [15] showed in a computerised model of 20 cadaveric femora an average flexion of 3.2° (− 3.2 to 9.7°). Kazemi et al. [8] described in a series of 25 TKA a mean flexion of the femoral component of 8.4° ± 2.9° compared to the mechanical lateral axis measured on long-leg lateral films. Longstaff

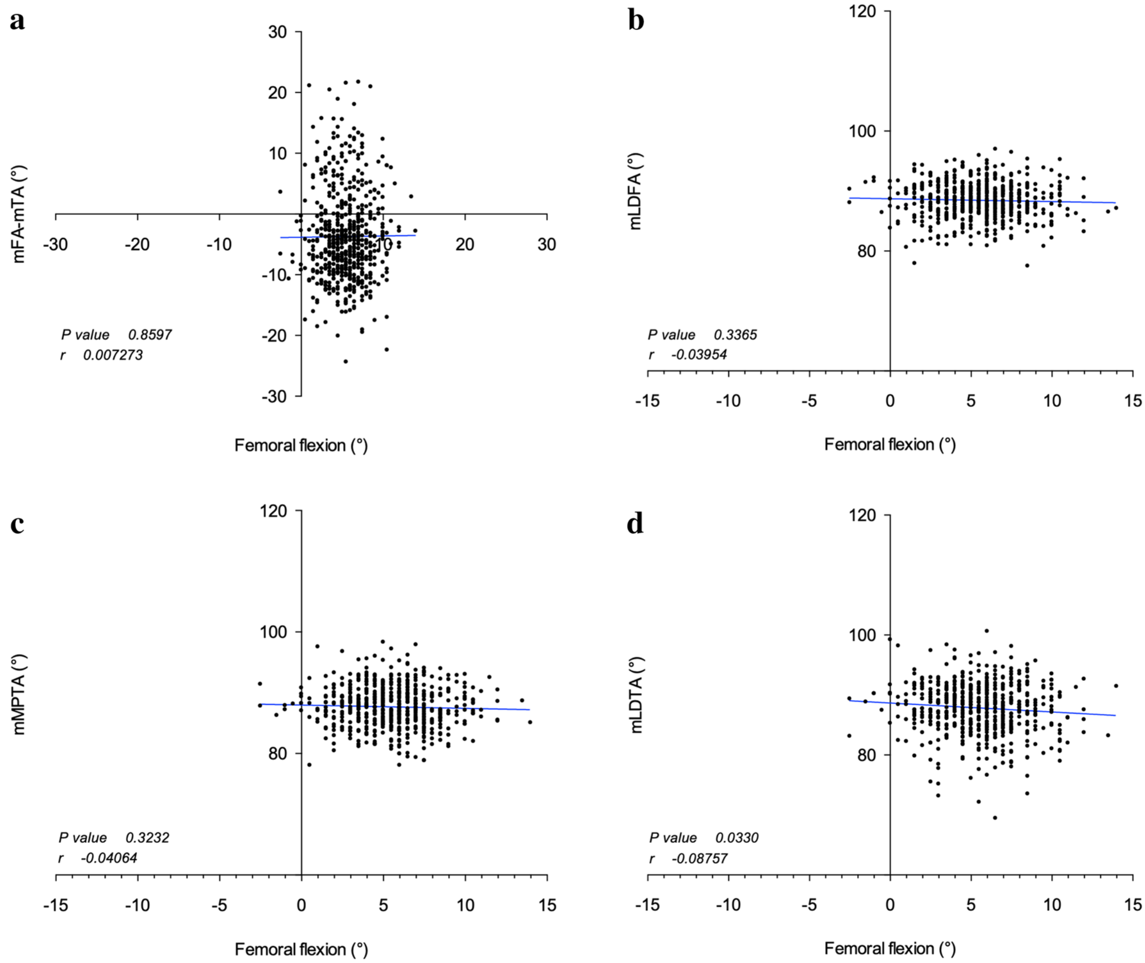

Fig. 5 Flexion of the femoral component dependent on measurements of a preoperative long-leg X-ray **a** mFA-mTA, **b** mLDFA, **c** mMPTA and **d** mLDTA. Shown are Pearson correlation coefficient *r* and *p* values. A *p* value < 0.05 was considered statistically significant. *n* = 593

also reported a high variability of femoral flexion (− 9° to 8°) in 159 conventional TKA when the intramedullary alignment technique was used in a CT-based study [12]. However, these studies have some limitations. Some included only small cohorts of patients [8, 15, 16]. Others did not use a routine setting of conventional TKA as they used cadaveric femora [15] or unusual to daily routine they planned the individual entry point on lateral radiographs preoperatively [16].

The optimal position of the femoral component in the sagittal is still unclear. In literature, a range from 0° to 5° flexion is discussed [4, 6, 9, 12, 18, 21]. However, earlier studies have demonstrated that using the conventional alignment technique a femoral flexion within this range is achieved in only 25% and 48% of TKA, respectively [10, 16]. Moreover, it remains unclear whether sagittal alignment has an influence on clinical long-term results. In a retrospective analysis of 3048 TKA, Kim et al. [9] showed a higher revision rate for sagitally malaligned femoral components compared to neutrally aligned. Longstaff et al. [12] showed a trend to better function with good sagittal alignment at 1-year follow-up. A positive correlation between femoral flexion and maximum flexion angle as well as total range of motion could be demonstrated by Antony et al. [1] at 1-year follow-up. An inadequate flexion of the femoral component might be attributed to a limited range of motion. Even small changes in the degree of the femoral flexion lead to a reduction of the flexion gap [17] and might, therefore, cause flexion contracture [14]. On the other hand, placing the femoral component in an overly extended position may lead to anterior notching with the risk for supracondylar fractures [24]. In this study, we did not measure clinical outcomes, but this is subject of further studies.

The intramedullary alignment technique allows for an individual adjustment of the coronal plane orientation according to measurements on preoperative long-leg radiographs (e.g. AMA). In contrast, sagittal alignment of the femoral component is directed by the fixed rectangular connection between the intramedullary rod and the resection

Table 3 Multivariate regression analysis for femoral flexion as dependent variable

	B	Standard error	Beta	*t*	*p* values
Age	−0.006	0.012	−0.025	−0.546	n.s.
Gender	−0.242	0.290	−0.047	−0.834	n.s.
Body weight	−0.130	0.065	−0.900	−2.000	0.046
Body height	15.372	6.762	0.565	2.273	0.023
BMI	0.417	0.187	0.901	2.226	0.026
Type of OA	−0.331	0.405	−0.037	−0.817	n.s.
Type of knee system	0.042	0.253	0.007	0.165	n.s.
Surgeon	0.183	0.100	−0.077	−1.834	n.s.
mFA-mTA	0.019	0.029	0.056	0.658	n.s.
mLDFA	0.000	0.051	0.000	0.006	n.s.
mMPTA	−0.051	0.052	−0.069	−0.993	n.s.
mLDTA	−0.040	0.025	0.067	−1.584	n.s.

Shown are the unstandardized regression coefficient B, standard error, the standardised regression coefficient beta, t statistics and p value. A p value ≥ 0.05 is considered as statistically non-significant (n.s.)

block. Due to this fixed geometry, sagittal position of the femoral component is influenced by the surgical technique (e.g. entry point, depth of penetration) as well as patient-related factors like the individual anatomy of the distal femur (e.g. degree of antecurvation).

With respect to the surgical technique, the choice of entry point and the depth of penetration of the intramedullary rod have to be considered. A variation of the entry point at the distal femur significantly changes sagittal alignment: while an anterior deviation leads to an increase of femoral extension, a posterior deviation results in increased flexion. In a radiographic study of 29 cadaveric femora, the real position of a predefined femoral entry point was verified. In more than 80%, a significant deviation from the desired entry point could be shown in the sagittal plane [28]. The depth of penetration or length of the intramedullary rod, respectively, has also been shown to have an impact on sagittal alignment [15, 23]. In a CT-based study, a deviation of the intramedullary rod of 1.1° in both flexion and extension relative to the anatomical axis could be shown [7]. Novotny et al. [23] demonstrated in a cadaveric study that increasing the rod length from 101.6 to 228.6 mm the potential error in the sagittal plane decreases from 4.74° to 1.22° as a longer rod rather matches the anatomic axis. In this study, the variability in femoral flexion was independent from surgery-related factors like type of OA (primary vs. posttraumatic), type of knee system and surgeon. No significant differences in femoral flexion could be detected between the four surgeons. All surgeons were experienced in TKA and the surgical settings were identical. The entry point at distal femur was standardly chosen 7–10 mm anterior to the origin of the posterior cruciate ligament (PCL). To mimic daily routine, it was identified by standard practice without preoperative planning. The standard intramedullary rod of both knee systems with a dimension of 300 × 8 mm was used, and the rod was introduced to the femoral isthmus.

With respect to patient-specific factors, a recent study demonstrated the high variability of distal femoral geometry in a very large study population [19]. Natural femoral sagittal bowing has been subject to human evolution [3]. In a cadaveric study, it was shown that human femora have become longer and straighter since the Middle Ages [3]. However, the functional role remains unclear. The individual, physiological antecurvation has been demonstrated to differ between race and gender. Femoral bowing is more distinct in the Asian than in the Caucasian population [26, 27, 30]. Previous studies in an Asian population have shown an inverse correlation between the distal angle of femoral curvature and body height and body weight, respectively [27, 30]. Accordingly, men have been shown to have less distal bowing of the femur than women [13, 30]. Based on the natural bowing of the femur, differences between sagittal mechanical femur axis and anatomical distal femur axes have to be discussed. Chung et al. described the degree of femoral bowing as predictor for differences between the sagittal femoral mechanical and the distal femoral axes. For each degree of femoral bowing, the deviation between the sagittal distal femoral axis and mechanical axis increased by nearly 0.5° [4]. Recent anatomic and radiologic studies have shown a strong correlation between sagittal femoral bowing, intramedullary sagittal alignment and the flexion position of the femoral component [8, 10]. In this study, body height, body weight and BMI were significantly correlated to femoral flexion. This difference might be explained by the fact that the aforementioned studies have been performed in the Asian population and femoral bowing has been demonstrated to differ between races [26, 27, 30]. Another explanation for an increasing femoral flexion position with increasing body height and weight might be that the entrance point is chosen slightly more posterior in large knees. This is underlined by the finding of Maderbacher et al. [16] who showed a positive correlation between the dorsoventral diameter of the distal femur and femoral flexion. Performing univariate analysis, a significantly higher femoral flexion could be shown in men. However, this could not be confirmed using multivariate analysis. The higher degree of flexion in men might, therefore, be due to an increased body height and weight compared to women.

Intraoperatively computer navigation systems are the only opportunity to analyse sagittal alignment of the femoral component. Besides that, only PSI may result in a predefined femoral flexion position. However, sagittal femoral alignment in CAS as well as PSI is planned based on the mechanical femur axis [22] but notable differences were observed between sagittal femoral anatomical and mechanical axes. Furthermore, most studies using CAS have defined the flexion position of the femur to 0° [4]. In this study, a high variability of femoral flexion between 2.5° of extension and 14° of flexion could be demonstrated. Considering the results of this study, defining femoral flexion to 0° might lead to an inadequate flexion position of the femoral component in the majority of patients.

The present study design has some limitations. Sagittal alignment is influenced by femoral antecurvation, femoral entry point and rod length. However, neither femoral antecurvation nor the exact femoral entry point was measured in this study which might be limitations of the study.

Femoral antecurvation has not been measured due to no access to lateral long-leg X-rays. However, it was not aim of the study to show the relation between femoral antecurvation and sagittal alignment but to describe the interindividual variability of femoral flexion in conventional TKA. The femoral entry point was not precisely marked on purpose as the aim of study was to analyse the results of conventional TKA in daily practice without special preoperative planning not to show the relation between the entry point of the rod and sagittal alignment. Measurements of femoral flexion were performed using a pinless navigation system. Therefore, measurement errors cannot be fully excluded. However, in earlier studies, a good accuracy has been shown for the pinless DASH system [2, 11]. Furthermore, pinless navigation devices provide the only opportunity to analyse sagittal alignment of the femoral component during surgery as there is no interference of reference arrays with the intramedullary rod in contrast to "conventional computer-assisted surgery".

Conclusion

Femoral flexion is a very individual characteristic in conventionally aligned TKA with a high variability. It has been shown to be independent from surgery-related factors and preoperative alignment data in the coronal plane. Body weight, body height and BMI have been identified as patient-specific factors that correlate with the sagittal flexion position.

Author contributions PK participated in the design of the study, collected data, performed the statistical analysis and drafted the manuscript. TP participated in the design of the study and helped to collect data. DA and HB have been involved in drafting the manuscript and revising it critically. HB performed most surgeries. DA and TP helped to perform the statistical analysis and interpretation of data. BB participated in the design and coordination of the study. HB conceived of the study and participated in its design. All the authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest HB has a consultant agreement with the companies BrainLAB and DePuy Synthes. DA received reimbursement of travel expenses by DePuy Synthes. All the other authors declare that there is no conflict of interests.

Ethical approval Ethical approval for data collection was received from the local ethics commission (138/2018). All procedures involving human participants were in accordance with the 1964 Helsinki declaration and its later amendments.

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