The value of postoperative prosthesis alignment and patellar height measurements on standard X-rays after Total Knee Arthroplasty: Does it relate to knee function after 5 years?☆,☆☆

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ABSTRACT

Background: The purpose of this retrospective cohort study was to investigate the influence of parameters of malalignment on knee function 5 years post TKA and, additionally, to explore alterations in patellar height after TKA.

Methods: All 661 patients undergoing TKA between 2010 and 2011 were considered for inclusion. Preoperative and 1-year postoperative short-leg radiographs were assessed for malalignment parameters: coronal tibial angle (cTA), sagittal tibial angle (sTA), femoral flexion angle (FFA) and mediolateral tibial mismatch. Patellar height was measured using the modified Insall-Salvati ratio. We determined improvements in knee function utilizing the Knee Society Score (Function score, KSS-F), Oxford Knee Score (OKS) and Algofunctional index (AI). Influences of malalignment parameters were analyzed univariate and selected (p < 0.10) for multivariate linear regression analysis. Inter-observer reproducibility was assessed by test–retest analysis of 30 randomly selected radiographs and calculation of an intra-class correlation coefficient (ICC) for all radiographic parameters.

Results: Three-hundred and four patients were included. Multivariate regression showed degrees of cTA malalignment to be significantly associated with only the KSS-F ($\beta = -3.52$). Correction of coronal deformity was stronger associated with knee function (KSS-F $\beta = 2.81$; AI $\beta = -0.36$). Patellar height was significantly reduced after TKA (1.51 vs 1.44). Decrease of patellar height was weakly associated with the OKS ($\beta = 10.69$). ICC scores were: cTA 0.81, sTA 0.57, IS 0.72, FFA 0.75.

Conclusion: Postoperative coronal tibial plate alignment and correction of preoperative coronal deformity are associated with improved knee function 5 years post TKA. Decrease in patellar height was weakly associated with knee function. Short-leg radiography can be a sufficient screening tool for prosthesis alignment.

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1. Introduction

Knee osteoarthritis (OA) is one of the most common joint diseases in the world and a major cause of pain and disability in developed countries [1–4]. Non-surgical treatment is initially preferred and includes, among others, analgesics (paracetamol, NSAIDs and/or morphine), physical therapy and intra-articular corticosteroids [5]. When debilitating symptoms such as pain and functional impairment develop, joint arthroplasty is the remaining option for relief of pain and symptoms. Total Knee Arthroplasty (TKA) is the golden standard and is known to provide satisfactory outcomes [6–10].

Pre- and postoperative work-up consists of conventional anteroposterior and lateral short-leg radiographs on which alignment of the knee is roughly assessed. There are different alignment strategies that can be utilized to acquire optimal alignment after TKA; mechanical, anatomical and kinematic alignment [11]. As kinematic alignment strives to recreate pre-arthritic location and obliquity of the joint line, mechanical and anatomical alignment focuses on establishment of the joint line perpendicular to the mechanical or anatomical axis of the tibia and femur. The traditional presumption that correct alignment is imperative to ensure long-term survival has been disproved [12–17]. However, the impact of prosthesis alignment on knee function is still a subject of discussion in the literature. A recent systematic review of 18 studies reported conflicting evidence on the relationship between parameters of malalignment and patient reported outcomes [18]. More recent studies tend to show no association between prosthesis malalignment and knee function [19–21]. However, most of the included studies had a short follow-up period, a small sample size and/or included just one or two measures of malalignment. Assessment of multiple measures of malalignment is crucial for correct clinical evaluation of the prosthesis due to the close relationship between the components in TKA [22,23].

Furthermore, problems involving the patellofemoral joint can be a cause for revision surgery. Two well-known examples are persisting anterior knee pain post-surgery and patellar luxation [24–27]. Knee arthroplasty is known to influence the patellofemoral relationship in two ways. First, recent evidence identifies excessive flexion of the femoral component to result in disruption of the patellofemoral complex [28,29]. Secondly, patellar height can significantly reduce after TKA, possibly resulting in patella baja [30–34].

The current study aims to further clarify the combined influences of multiple parameters of prosthesis alignment and patellar height on knee function, by comparing patient reported outcome measures after TKA. We attempt to improve insight on the value of present post-operative X-ray follow-up.

2. Methods

2.1. Design

Retrospective observational study.

2.2. Patients

All consecutive 661 patients who underwent TKA in 2010 and 2011 were considered for inclusion in this study. Inclusion criteria for the current study were: end-stage symptomatic knee osteoarthritis requiring TKA, availability of pre- and 1 year postoperative short-leg knee radiographs (anteroposterior and lateral) and completion of a 5-year postoperative questionnaires. There were no further exclusion criteria. All patients received pre- and postoperative care according to joint arthroplasty protocol of our hospital.

2.3. Surgery

All patients were operated using a medial parapatellar approach and a non-cemented mobile bearing total knee prosthesis without patellar prosthesis (LCS complete, DePuy, Zurich, Switzerland). A tourniquet was not used. No synovectomy was performed. After lege artis mechanically aligned TKA utilizing gap balancing, staples were used for wound closure. The wound was covered by an absorbing bandage and a tricot compression bandage was administered continuously for 2 days. Upon removal of the tricot compression bandage the wound was covered with a sterile non-woven bandage for the remaining admission period. After surgery, all patients participated in a rehabilitation program under the supervision of a physical therapist. Postoperative controls with radiographic evaluation were done after 6 weeks and 1 year in the outpatient clinic.

2.4. Baseline parameters

Preoperative age, ASA-classification, Body Mass Index (BMI), perioperative blood loss, total hospital stay (in days) and the Kellgren-Lawrence grade for severity of knee osteoarthritis [35] were extracted from the electronic hospital database. All clinical records were furthermore assessed for the presence of complications associated with the surgery for a minimum of 5 years postoperative. To prevent selection bias, age, gender, total hospital stay, ASA-classification and several radiographic parameters were compared between in- and excluded patients.

2.5. Radiographic measurements

Radiographic parameters that encompass prosthesis alignment included: coronal tibial angle (cTA, coronal angle between the tibial plate and the anatomical axis of the tibia, ideally between 87° and 93°), sagittal tibial angle (sTA, sagittal angle between the tibial plate and the anatomical axis of the tibia, ideally between 83° and 90°), the degrees flexion/extension of the femoral component with respect to the femoral anatomical axis (Femoral flexion angle, FFA, ideally <7°), mediolateral tibial mismatch (coronal mismatch between the borders of the prosthesis and the tibial bone, sagittal placement was not assessed) and patellar height (modified Insall-Salvati ratio) [36] (Figures 1 & 2). Decrease in patellar height was compared to knee function.

We furthermore determined the amount of degrees of malalignment and operative deformity correction for both tibial angles (cTA and sTA). For example, a knee with a cTA of 97° (or 83°) with the prosthesis in situ has a malalignment (e.g. deviation from normal) of 4° (normal range for cTA is 87–93°). If the preoperative valgus deformity was 100° (or 80° varus), the operative correction is 3°.

All radiographic parameters were measured on preoperative and 1-year postoperative short-leg radiographs. All weight-bearing anteroposterior (AP) and supine lateral (LAT) radiographs were assessed by three different authors (RR, FB, PN). Inter-observer reproducibility was assessed by test–retest analysis of 30 randomly selected radiographs and calculation of an intra-class correlation coefficient (ICC) for all radiographic parameters.

2.6. Predictors

We selected radiographic and clinical parameters for inclusion in the regression analysis. Radiographic parameters included cTA (degrees of malalignment and deformity correction), sTA (degrees of malalignment and deformity correction), decrease in patellar height (modified Insall-Salvati ratio), FFA and tibial mismatch (with medial overhang and lateral overhang separately analyzed). Clinical parameters included age, BMI, operation time, ASA-classification and Kellgren-Lawrence grade.

2.7. Patient reported outcome measures

We compared the previously described radiographic parameters to several patient reported outcome measures (PROMs). PROMs included the Oxford Knee Score (OKS), Knee Society Score for function (KSS-F) and Algofunctional index (AI). The Oxford Knee Score is a reliable and sensitive score derived from a 12-item questionnaire that focuses on subjective knee function and pain [37]. Resulting scores range from 0 (worst outcome) to 48 (best outcome). The OKS is one of the first questionnaires to focus on satisfactory elements of the patient instead of the surgeon and provides an international measure of outcome that is
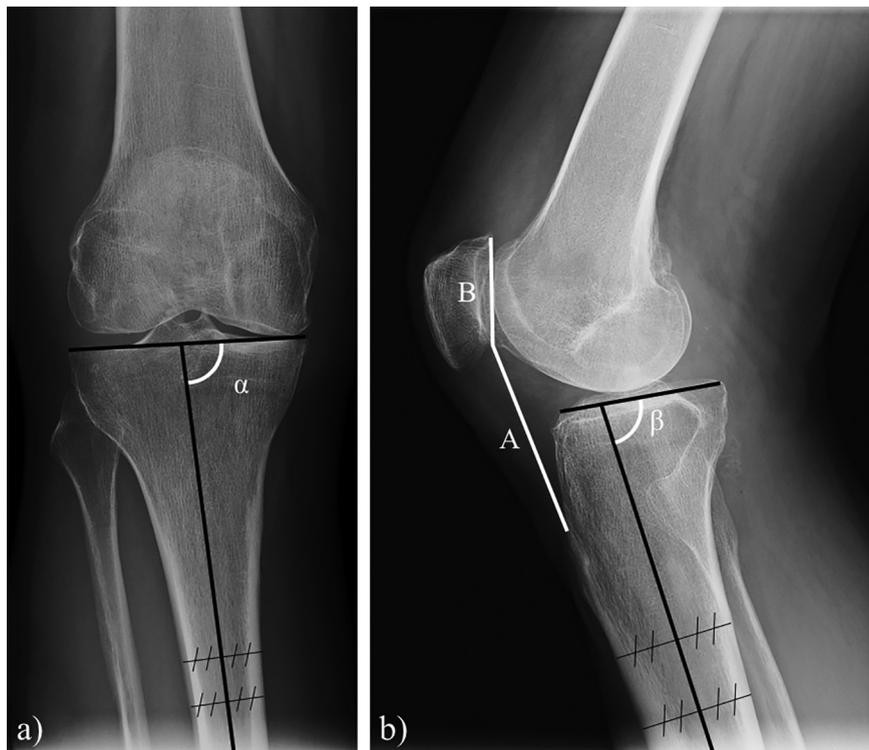

Figure 1. Preoperative measurements of deformity. a) AP radiograph. α = coronal tibial angle (cTA, i.e. valgus angle + 90º). b) Supine lateral radiograph. β = sagittal tibial angle (sTA), A/B = modified Insall-Salvati ratio.

Figure 2. Postoperative measurements of alignment. a) AP radiograph. α = coronal tibial angle (cTA, i.e. valgus angle + 90º). b) Supine lateral radiograph. β = sagittal tibial angle (sTA), A/B = modified Insall-Salvati ratio, γ = femoral flexion angle (FFA).
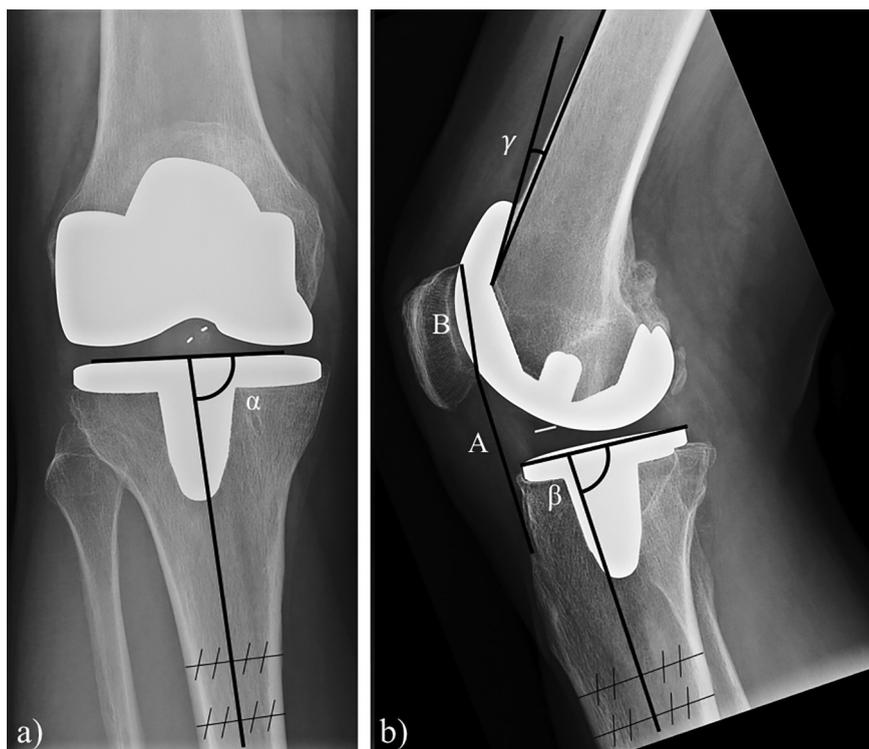
short and practical. The OKS is also a joint specific questionnaire, which results in specific outcomes and minimalizes influences from other comorbidities [38]. The KSS is a clinical rating system and is divided into 2 domains (knee score (KSS-K) and function score (KSS-F)) and is internationally considered to have a good construct validity [39,40]. Scores range from 0 (worst) and 100 (best). Due to the lack of an appointment in the outpatient clinic in case of a good functioning knee prosthesis, the KSS knee score was excluded of analysis after 5 years. The AI of knee OA consists of 3 domains objectifying pain, discomfort, morning stiffness and activities of daily living [41]. Every domain contributes up to 8 points and is aggregated to result in a maximum score of 24, where 1 is the best outcome and 24 represents the worst outcome. These scores provide a representative image of the objective and subjective knee function, more specifically patient reported pain and satisfaction. We calculated change from baseline (CFB) values for all 5-year PROMs to use for the regression analysis. All patients received a questionnaire preoperative and 5 years postoperative. An additional questionnaire was sent to patients who did not respond to the initial one.

2.8. Statistics

Statistical analysis was done with SPSS version 24.0 (IBM Company; Chicago, Illinois). All associations with potential predictive factors (radiographic and clinical) were initially approached with a univariate linear regression analysis for all three PROMs. We selected all significant variables (with adjusted significance level of 0.10) for each PROM to include in the multivariate linear regression. Due to a mediating role of deformity correction in the outcome of degrees of malalignment (for cTA and sTA), we made separate models for each. Moreover, we performed a subgroup analysis (linear regression) separately for preoperative varus and valgus deformed knees. A power analysis with an alpha-error of 5%, 85% power and a maximum of 5 predictors resulted in a minimal sample size of N = 102. P-values <0.05 were considered statistically significant.

3. Results

After in- and exclusion of participants, a remaining population of 304 patients (304 knees; 157 right knees, 147 left knees) were included in the analysis. Distribution of age, gender, total hospital stay, ASA-classification, preoperative alignment angles (cTA, sTA and patellar height), postoperative alignments angles (cTA, sTA, patellar height and FFA) and all baseline PROMs were comparable among in- and excluded patients. All patients had a radiographically proven diagnosis of knee osteoarthritis. The population consisted of 103 males and 201 females. Fifty-four patients (17.8%) had an ASA classification of I, 218 (71.7%) were classified as ASA II and 32 patients (10.5%) as ASA III. One patient had a radiographic osteoarthritis classification according to Kellgren and Lawrence of I (0.3%), 53 were classified as II (17.4%), 221 as III (72.7%) and 29 as IV (9.5%). Two-hundred twenty-three knees showed preoperative varus deformity of the

Table 1
Baseline clinical and radiographic characteristics (n = 304).

	Mean (SD)	Median (Range)
Age (years)	68.4 (9.2)	68.0 (41.0–89.0)
BMI (kg/m^2)	28.9 (4.7)	28.4 (16.5–47.7)
Operation time (minutes)	50.7 (12.1)	51.0 (22.0–83.0)
Total hospital stay (days)	4.5 (2.7)	4.0 (0.4–42.0)
Perioperative blood loss (ml)	159.0 (84.4)	150.0 (0.0–550.0)
cTA (°)	87.2 (3.0)	87.0 (71.0–96.0)
sTA (°)	81.4 (4.2)	81.0 (70.0–90.0)
Patellar height	1.5 (0.2)	1.5 (1.1–3.0)
OKS (Preoperative)	24.9 (7.8)	26.0 (2.0–48.0)
KSS-F (Preoperative)	52.1 (21.2)	55.0 (0.0–100.0)
KSS-K (Preoperative)	51.8 (18.4)	52.0 (0.0–100.0)
AI (Preoperative)	12.1 (3.7)	12.0 (1.5–21.0)

cTA = coronal tibial angle, sTA = sagittal tibial angle, SD = standard deviation, OKS = Oxford Knee Score, KSS-F = Knee Society Score, Function score, KSS-K = Knee Society Score, Knee score, AI = Algofunctional index.

tibial plate (73.4%, range 1°–19°), 34 knees valgus deformity (11.2%, range 1°–6°) and the remaining 47 knees had neutral preoperative alignment (15.5%). The mean preoperative patellar height (modified Insall-Salvati ratio) was 1.51 ± 0.19, which reduced significantly after TKA to 1.44 ± 0.19 (p = 0.00). The remaining baseline characteristics and preoperative knee function scores are summarized in Table 1. Postoperative radiographic characteristics and knee function scores after 5 years are shown in Table 2. ICC values for all radiographic measures are summarized in Table 3.

Out of the included 304 patients, a total of 34 complications (in 30 patients) were registered. Radiographic aseptic loosening was found 2 times, 1 patient needed a blood transfusion after surgery, there were 3 superficial wound infections, 2 patients developed a deep prosthetic joint infection (both underwent revision surgery), 12 knees were revised, 2 knees were re-operated for other reasons and 12 knees were Mobilized Under Anaesthetics (MUA).

Table 4 shows univariate analyses for all three PROMs (expressed as change from baseline outcomes). All variables were then selected (with adjusted significance level of 0.10) and included in a multivariate regression analysis. These results are shown in Table 5 (degrees of malalignment) and Table 6 (deformity correction). Multivariate regression showed degrees of cTA malalignment to be significantly associated with only the KSS-F (β = −3.43). Correction of coronal deformity was slightly stronger associated with knee function, showing significant β-coefficients in two of three investigated PROMs (KSS-F β = 2.87; AI β = −0.36). Change in patellar height was significantly associated with the OKS (β = 10.69). No differences in knee function were found for other radiographic parameters. Table 7 shows results of the linear regression analysis specified for preoperative varus and valgus deformity.

4. Discussion

This retrospective cohort study was designed to investigate the influences of prosthesis alignment and decrease in patellar height on knee function 5 years after TKA. We found coronal tibial component malalignment to be significantly associated with inferior improvement in KSS-F scores. Operative correction of preoperative coronal tibial plate deformity is even stronger associated with improved knee function (KSS-F and AI). Decrease in patellar height was associated with lower improvements in the OKS. Sagittal tibial component alignment, mediolateral tibial component mismatch and femoral flexion angle do not seem to compromise knee function. These findings consequently emphasize the role of current postoperative short-leg X-ray follow-up.

There have been a few studies that investigate the influence of postoperative coronal tibial component alignment on knee function [19–21,43]. All studies exclusively focus on varus-type OA. Magnussen et al. (2011) investigated the association between residual tibial component varus and inferior knee function, reporting worse outcomes in knee function after a median follow-up of 4.7 years in 553 knees [43]. The current study further supports the burden of evidence, showing a similar relationship between degrees of coronal tibial component malalignment and worse outcome after 5 years in 304 knees. Discrepancy in literature may be due to a shorter follow-up and smaller sample size used by the studies that did not report an association. An important note is

Table 2
Postoperative radiographic characteristics and PROMs at 5 year follow-up (n = 304).

	Mean (SD)	Median (Range)
cTA (°)	91.9 (2.7)	92.0 (84.0–106.0)
sTA (°)	81.2 (3.9)	81.0 (70.0–97.0)
Patellar height	1.4 (0.2)	1.4 (1.0–2.1)
FFA (°)	4.5 (3.7)	5.0 (−2.0–18.0)
OKS (5 year)	38.7 (9.6)	42.0 (6.0–48.0)
KSS-F (5 year)	67.2 (26.9)	70.0 (0.0–100.0)
AI (5 year)	5.5 (4.8)	4.5 (0.0–20.0)

cTA = coronal tibial angle, sTA = sagittal tibial angle, FFA = femoral flexion angle, SD = standard deviation, OKS = Oxford Knee Score, KSS-F = Knee Society Score, Function score, KSS-K = Knee Society Score, Knee score, AI = Algofunctional index.

Table 3

Inter-observer correlation coefficients for all measured radiographic parameters. Values >0.50 are considered moderate reliable measures, values >0.75 are considered good/excellent reliable measures [42].

Coronal tibial angle (cTA, °)	0.81
Sagittal tibial angle (sTA, °)	0.57
Patellar height (modified Insall-Salvati ratio)	0.72
Femoral Flexion angle (°)	0.75

the fact that only one of three PROMs investigated in the current study reflects these results. However, we did find this association in the KSS-F, which corresponds with the outcome used by Magnussen et al. [43].

Previous studies that have taken preoperative knee deformity into consideration focus on limb alignment, with most authors reporting non-inferior results with residual varus alignment of the limb [15,21,32,43,44]. All cited studies did not explore tibial component alignment with respect to preoperative tibial plate deformity. Our study is the first to investigate the influence of coronal tibial plate deformity correction on knee function, showing improved results after TKA (KSS-F β = 2.87; AI β = −0.36). Considering the minimal clinical important differences (MCID) of the KSS-F (6.1–6.4), a coronal tibial plate deformity correction of 2° during TKA might be of clinical relevance [45]. These results emphasize the advanced pathologic changes in the knee joint of patients with progressed OA and the importance of restoring premorbid tibial bone anatomy [46,47]. Subsequently, perioperative kinematic TKA alignment might prove superior to mechanical alignment as it restores pre-arthritic knee kinematics, but the burden of evidence is not sufficient and more research is needed [11]. Another major consideration in tibial component alignment is ligament balancing. Proper perioperative ligament balancing contributes to knee stability and function at least as much as tibial component alignment, especially in severely deformed varus or valgus knees [48–50]. Due to the small incidence of valgus deformity in the current study (n = 34), a future study including solely knees with valgus deformation should be undertaken to accurately define the impact of residual valgus orientation of the proximal tibia on knee function after TKA.

Our study found no evidence for excessive flexion of the femoral component (FFA) to be associated with worse outcomes. In contrast, a previous case–control study identified flexion of the femoral component to be more prevalent in a group with patellofemoral instability. This discrepancy is likely to be explained by the selective and small study population used (n = 52). Therefore, flexion of the femoral component might be a risk factor for post-TKA patellofemoral instability but there is insufficient evidence for an association with knee function.

We found a decrease in patellar height after TKA to be correlated to the OKS after 5 years (β = 10.69). This translates into a needed decrease of 0.47 after TKA to be of clinical importance (MCID = 5.0) (as measured with the OKS) [51]. A decrease in

Table 4

Univariate analysis of all radiographic parameters and demographic data. All values are shown as unstandardized β-values, their respective 95% confidence intervals and P-values. P-values <0.10 are included in multivariate regression. Categorial predictors (ASA classification and Kellgren-Lawrence grade) were coded using dummy variables, with the first category as reference value. All values in bold are considered statistically significant (P <0.05).

	OKS (CFB)		KSS-F (CFB)		AI (CFB)	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
cTA (°)						
Degrees of malalignment	−0.46 (−1.19; 0.28)	0.22	**−3.97 (−6.43; −1.51)**	**0.00**	0.26 (−0.11; 0.63)	0.17
Deformity correction[a]	0.40 (−0.14; 0.93)	0.15	**3.04 (1.28; 4.80)**	**0.00**	**−0.37 (−0.64; −0.10)**	**0.01**
sTA (°)						
Degrees of malalignment	−0.27 (−0.68; 0.14)	0.20	0.19 (−1.19; 1.57)	0.79	0.09 (−0.12; 0.30)	0.40
Deformity correction[a]	0.09 (−0.24; 0.43)	0.58	0.43 (−0.69; 1.56)	0.45	−0.06 (−0.23; 0.11)	0.47
Patellar height (decrease)	**−9.92 (−0.32; −19.51)**	**0.04**	−29.14 (−61.65; 3.37)	0.08	0.05 (−4.83; 4.92)	0.99
FFA (°)	0.07 (−0.77; 0.91)	0.87	−0.83 (−3.66; 1.99)	0.56	−0.04 (−0.20; 0.11)	0.60
Tibial mismatch (±)	1.63 (−0.94; 4.19)	0.21	1.50 (−7.21; 10.22)	0.74	−0.68 (−1.97; 0.61)	0.30
Medial overhang (±)	−0.64 (−5.51; 4.22)	0.80	−5.73 (−22.20; 10.73)	0.49	−1.01 (−3.45; 1.43)	0.42
Medial underhang (±)	1.46 (−4.06; 6.99)	0.60	5.91 (−12.79; 24.61)	0.54	−0.03 (−2.81; 2.74)	0.98
Lateral overhang (±)	−0.91 (−5.78; 3.96)	0.71	−9.03 (−25.96; 7.89)	0.29	−1.05 (−2.55; 2.34)	0.93
Lateral underhang (±)	3.83 (−0.38; 8.04)	0.12	9.05 (−5.23; 23.33)	0.21	−0.39 (−2.51; 1.74)	0.72
Age (years)	**−0.14 (−0.26; −0.02)**	**0.03**	**−1.13 (−1.53; −0.74)**	**0.00**	0.06 (−0.01; 0.12)	0.07
BMI (kg/m^2)	0.03 (−0.21; 0.27)	0.80	**−1.15 (−1.94; −0.35)**	**0.01**	0.06 (−0.06; 0.19)	0.30
Operation time (minutes)	0.04 (−0.06; 0.14)	0.42	0.10 (−0.22; 0.42)	0.53	−0.01 (−0.06; 0.04)	0.64
ASA Classification (I-III)						
I vs II	−2.34 (−5.33; 0.64)	0.12	**−14.06 (−23.57; −4.56)**	**0.00**	1.12 (−0.38; 2.62)	0.14
I vs III	−2.90 (−7.28; 1.48)	0.19	**−43.71 (−57.66; −29.76)**	**0.00**	**2.22 (0.01; 4.42)**	**0.05**
Kellgren-Lawrence grade (I-IV)						
I vs II	−0.43 (−20.34; 19.48)	0.97	0.66 (−66.31; 67.62)	0.99	1.04 (−8.97; 11.06)	0.84
I vs III	0.23 (−19.54; 20.00)	0.98	6.67 (−59.81; 73.16)	0.84	1.05 (−8.89; 10.99)	0.84
I vs IV	1.51 (−18.55; 21.58)	0.88	1.14 (−66.33; 68.61)	0.97	−0.37 (−10.46; 9.72)	0.94

cTA = coronal tibial angle, sTA = sagittal tibial angle, FFA = femoral flexion angle, OKS = Oxford Knee Score, KSS-F = Knee Society Score, Function score, AI = Algofunctional index, CFB = change from baseline.

[a] Deformity correction = preoperative angle of deformity (°) – postoperative angle of malalignment (°).

Table 5

Multivariate regression analysis with degrees of malalignment for cTA as independent variable. All values are shown as unstandardized β-values and their respective 95% confidence intervals (95% CI). Categorial predictors (ASA classification) were coded using dummy variables, with the first category as reference value.

	OKS (CFB)		KSS-F (CFB)		AI (CFB)	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
cTA, Degrees of malalignment (°)	NI		−3.43 (−5.70; −1.17)	0.00	NI	
Patellar height (decrease)	10.69 (1.14; 20.24)	0.03	NS		NI	
Age (years)	−0.14 (−0.26; −0.01)	0.04	−1.00 (−1.40; −0.60)	0.00	NS	
BMI (kg/m^2)	NI		−1.05 (−1.80; −0.29)	0.01	NI	
ASA Classification (I-III)						
I vs II	NI		NS		NS	
I vs III	NI		−21.51 (−33.26; −9.75)	0.00	NS	

cTA = coronal tibial angle, sTA = sagittal tibial angle, FFA = femoral flexion angle, OKS = Oxford Knee Score, KSS-F = Knee Society Score, Function score, AI = Algofunctional index, CFB = change from baseline, NI = not included, NS = not significant.

patellar height of this magnitude is very unusual after conventional TKA. Our findings support the evidence found in the recent study performed by Davies and colleagues [52]. These results do not infer that decrease in patellar height after TKA should be considered irrelevant, as there still is a specific population of patients with a preoperative low-riding patella that is at risk for developing patella baja. A large addition with the current study is the use of the modified Insall-Salvati ratio. In contrary to the conventional Insall-Salvati ratio, the modified ratio accounts for patella morphology. This approach identifies the population suffering with patellar symptoms significantly more accurately [36]. Unfortunately, cut-off points for patella baja using the modified Insall-Salvati ration have not yet been defined. Future research is needed to define this cut-off point and thereby increasing the utility of the modified ratio to identify clinical significant decreases in patellar tendon length after TKA.

Mediolateral tibial component mismatch was found not to influence knee function after 5 years in the current study. Previous literature reports conflicting results [53], more recent studies show mediolateral overhang to be associated with worse function after 1 year [54,55] and one other study describes no differences in knee function after 5 years [56] This could be explained due to inadequate determination of the location of over-underhang (side-specification), resulting in pooling of data and subsequently possible diluted p-values.

Post-arthroplasty follow-up using short-leg radiographs is currently standard clinical practice in most European orthopedic clinics due to lower costs and capability to identify crude anomalies. Even though ICC values for coronal measurements in the current study were good (Table 3, 0.81 for cTA), there are limitations to the usage of short-leg films in the accuracy of determining these angles. A study performed by Park et al. (2016) showed anatomical tibial component alignment on short-leg radiography to not always correlate to the true mechanical alignment on long-leg radiographs (r = 0.62) [57]. However, means and standard deviations for cTA on postoperative short-leg radiographs did not differ much from the true cTA on long-leg radiographs in the study by Park and colleagues (88.75 ± 2.18° and 89.99 ± 1.91° respectively) [57]. As the current study analyzed data on a continuous scale in a large group of patients, the limitations of short-leg radiography were minimalized and external validity to clinical practice was maximized. It is true, however, that weight bearing long-leg radiography allow for more accurate determination of the mechanical axis and assessment of whole-limb interaction of the prosthesis. However, one would still need an additional X-ray for assessing patellar height (in 30° knee flexion) and incorporating long-leg radiography in standard TKA follow-up would be cost inefficient and time-consuming. We therefore recommend continuation of standard TKA follow-up with short-leg radiography, as this modality allows for patellar assessment and can be a rough screening tool for prosthesis malalignment. When malalignment is suspected, an additional long-leg radiograph needs to be performed to accurately assess prosthesis alignment.

A limitation of the current study was its retrospective character. All retrospective studies suffer from risk of selection bias. This risk was minimized by conducting a lost to follow-up analysis, showing comparable demographics of both the included and excluded patients in our population. Another possible limitation might be the fact that the current study focused on coronal tibial

Table 6

Multivariate regression analysis with deformity correction for cTA as independent variable. All values are shown as unstandardized β-values and their respective 95% confidence intervals (95% CI). Categorial predictors (ASA classification) were coded using dummy variables, with the first category as reference value.

	OKS (CFB)		KSS-F (CFB)		AI (CFB)	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
cTA, Deformity correction[a] (°)	NI		2.87 (1.26; 4.49)	0.00	−0.36 (−0.64; −0.10)	0.01
Patellar height (decrease)	10.69 (1.14; 20.24)	0.03	NS		NI	
Age (years)	−0.14 (−0.26; −0.01)	0.04	−1.03 (−1.43; −0.64)	0.00	NS	
BMI (kg/m^2)	NI		−1.05 (−1.80; −0.30)	0.01	NI	
ASA Classification (I-III)						
I vs II	NI		NS		NS	
I vs III	NI		−21.38 (−33.06; −9.69)	0.00	NS	

cTA = coronal tibial angle, sTA = sagittal tibial angle, FFA = femoral flexion angle, OKS = Oxford Knee Score, KSS-F = Knee Society Score, Function score, AI = Algofunctional index, CFB = change from baseline, NI = not included, NS = not significant.

[a] Deformity correction = preoperative angle of deformity (°) – postoperative angle of malalignment (°).

Table 7

Multivariate linear regression with exclusive varus knees (n = 223) and valgus knees (n = 34) respectively. All values are shown as unstandardized β-values and their respective 95% confidence intervals (95% CI). Categorial predictors (ASA classification) were coded using dummy variables, with the first category as reference value. All values in bold are considered statistically significant (P <0.05).

	OKS (CFB)		KSS-F (CFB)		AI (CFB)	
Varus knees (n = 223)	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
Varus (cTA) correction[a] (°)	0.31 (−0.31; 0.93)	0.32	**2.03 (0.16; 3.91)**	**0.03**	**−0.36 (−0.67; −0.06)**	**0.02**
Age (years)	−0.10 (−0.24; 0.04)	0.16	**−1.07 (−1.55; −0.59)**	**0.00**	0.04 (−0.03; 0.12)	0.24
BMI (kg/m^2)	NI		**−1.06 (−1.98; −0.13)**	**0.03**	NI	
ASA Classification (I-III)						
I vs II	NI		−4.14 (−15.30; 7.02)	0.47	0.77 (−0.95; 2.50)	0.38
I vs III	NI		**−22.28 (−39.76; −4.80)**	**0.01**	1.13 (−1.62; 3.88)	0.42
Valgus knees (n = 34)						
Valgus (cTA) correction[a] (°)	0.01 (−1.99; 2.01)	0.99	−0.07 (−2.19; 2.05)	0.95	−0.05 (−0.96; 0.86)	0.91
Age (years)	−0.16 (−0.59; 0.27)	0.45	−0.14 (−0.65; 0.36)	0.57	0.01 (−0.22; 0.23)	0.95
BMI (kg/m^2)	NI		−0.28 (−1.19; 0.63)	0.53	NI	
ASA Classification (I-III)						
I vs II	NI		−0.24 (−13.43; 12.95)	0.97	−1.05 (−6.23; 4.13)	0.68
I vs III	NI		−0.12 (−21.03; 20.80)	0.99	1.61 (−7.16; 10.37)	0.71

cTA = coronal tibial angle, BMI = Body Mass Index, OKS = Oxford Knee Score, KSS-F = Knee Society Score, Function score, AI = Algofunctional index, CFB = change from baseline, NI = not included.

[a] Varus/valgus correction = preoperative varus/valgus (°) – postoperative varus/valgus (°).

alignment and deformity correction rather than overall alignment (tibiofemoral angle; TFA). However, preoperative knee deformities are mostly due to arthritic changes at the tibial plate rather than the femoral bone [47]. If gap balancing is properly performed during TKA, overall alignment (and therefore femoral component alignment) is expected to adhere to tibial measurements, as mechanical alignment is achieved mainly through proximal tibial bone resections.

In conclusion, we found coronal tibial plate alignment to be significantly associated with knee function 5 years after TKA, with a positive effect of preoperative deformity correction and a negative effect of postoperative magnitude of malalignment. These results are, however, not reflected in all 3 investigated PROMs. Decrease in patellar height was weakly associated with only the OKS. All other component angles and measurements showed no significant association with knee function. Follow-up with short-leg radiography after TKA is a sufficient screening tool for prosthesis malalignment and allows patellar height measurements. Long-leg radiography needs to be performed when malalignment is suspected.

Acknowledgement

References

[1] Arden N, Nevitt MC. Osteoarthritis: epidemiology. Best Pract Res Clin Rheumatol 2006;20:3–25.

[2] Herrero-Sanchez MD, Garcia-Inigo Mdel C, Nuno-Beato-Redondo BS, Fernandez-de-Las-Penas C, Alburquerque-Sendin F. Association between ongoing pain intensity, health-related quality of life, disability and quality of sleep in elderly people with total knee arthroplasty. Cien Saude Colet 2014;19:1881–8.

[3] Bijlsma JW, Berenbaum F, Lafeber FP. Osteoarthritis: an update with relevance for clinical practice. Lancet (London, England) 2011;377:2115–26.

[4] Tambascia RA, Vasconcelos RA, Mello W, Teixeira PP, Grossi DB. Pre-operative functional parameters of patients undergoing total knee arthroplasty. Physiother Res Int 2016;21:77–83.

[5] McAlindon TE, Bannuru RR, Sullivan MC, Arden NK, Berenbaum F, Bierma-Zeinstra SM, et al. OARSI guidelines for the non-surgical management of knee osteoarthritis. Osteoarthr Cartil 2014;22:363–88.

[6] Rissanen P, Aro S, Slatis P, Sintonen H, Paavolainen P. Health and quality of life before and after hip or knee arthroplasty. J Arthroplasty 1995;10:169–75.

[7] Dawson J, Fitzpatrick R, Murray D, Carr A. Comparison of measures to assess outcomes in total hip replacement surgery. Qual Health Care 1996;5:81–8.

[8] Rissanen P, Aro S, Sintonen H, Slatis P, Paavolainen P. Quality of life and functional ability in hip and knee replacements: a prospective study. Qual Life Res 1996;5:56–64.

[9] Norman-Taylor FH, Palmer CR, Villar RN. Quality-of-life improvement compared after hip and knee replacement. J Bone Joint Surg 1996;78:74–7.

[10] Rasanen P, Paavolainen P, Sintonen H, Koivisto AM, Blom M, Ryynanen OP, et al. Effectiveness of hip or knee replacement surgery in terms of quality-adjusted life years and costs. Acta Orthop 2007;78:108–15.

[11] Cherian JJ, Kapadia BH, Banerjee S, Jauregui JJ, Issa K, Mont MA. Mechanical, anatomical, and kinematic axis in TKA: concepts and practical applications. Curr Rev Muscoskelet Med 2014;7:89–95.

[12] Bonner TJ, Eardley WG, Patterson P, Gregg PJ. The effect of post-operative mechanical axis alignment on the survival of primary total knee replacements after a follow-up of 15 years. J Bone Joint Surg 2011;93:1217–22.

[13] Howell SM, Howell SJ, Kuznik KT, Cohen J, Hull ML. Does a kinematically aligned total knee arthroplasty restore function without failure regardless of alignment category? Clin Orthop Relat Res 2013;471:1000–7.

[14] Parratte S, Pagnano MW, Trousdale RT, Berry DJ. Effect of postoperative mechanical axis alignment on the fifteen-year survival of modern, cemented total knee replacements. J Bone Joint Surg Am 2010;92:2143–9.

[15] Vanlommel L, Vanlommel J, Claes S, Bellemans J. Slight undercorrection following total knee arthroplasty results in superior clinical outcomes in varus knees. Knee Surg Sports Traumatol Arthrosc 2013;21:2325–30.

[16] Malkani AL, Rand JA, Bryan RS, Wallrichs SL. Total knee arthroplasty with the kinematic condylar prosthesis. A ten-year follow-up study. J Bone Joint Surg Am 1995;77:423–31.

[17] Matziolis G, Adam J, Perka C. Varus malalignment has no influence on clinical outcome in midterm follow-up after total knee replacement. Arch Orthop Trauma Surg 2010;130:1487–91.

[18] Hadi M, Barlow T, Ahmed I, Dunbar M, McCulloch P, Griffin D. Does malalignment affect patient reported outcomes following total knee arthroplasty: a systematic review of the literature. Springerplus 2016;5:1201.

[19] Stucinskas J, Robertsson O, Sirka A, Lebedev A, Wingstrand H, Tarasevicius S. Moderate varus/valgus malalignment after total knee arthroplasty has little effect on knee function or muscle strength. Acta Orthop 2015;86:728–33.

[20] Slevin O, Amsler F, Hirschmann MT, Stucinskas J, Robertsson O, Sirka A, et al. No correlation between coronal alignment of total knee arthroplasty and clinical outcomes: a prospective clinical study using 3D-CT. Knee Surg Sports Traumatol Arthrosc 2017;25:3892–900.

[21] Nishida K, Matsumoto T, Takayama K, Ishida K, Nakano N, Matsushita T, et al. Remaining mild varus limb alignment leads to better clinical outcome in total knee arthroplasty for varus osteoarthritis. Knee Surg Sports Traumatol Arthrosc 2017;25:3488–94.

[22] Berend ME, Ritter MA, Meding JB, Faris PM, Keating EM, Redelman R, et al. Tibial component failure mechanisms in total knee arthroplasty. Clin Orthop Relat Res 2004:26–34.

[23] Ritter MA, Davis KE, Meding JB, Pierson JL, Berend ME, Malinzak RA. The effect of alignment and BMI on failure of total knee replacement. J Bone Joint Surg Am 2011;93:1588–96.

[24] de Oliveira V, de Souza V, Cury R, Camargo OP, Avanzi O, Severino N, et al. Medial patellofemoral ligament anatomy: is it a predisposing factor for lateral patellar dislocation? Int Orthop 2014;38:1633–9.

[25] Aglietti P, Buzzi R, Gaudenzi A, Patel J, Ries MD, Bozic KJ, et al. Patellofemoral functional results and complications with the posterior stabilized total condylar knee prosthesis. J Arthroplasty 1988;3:17–25.

[26] Patel J, Ries MD, Bozic KJ. Extensor mechanism complications after total knee arthroplasty. Instr Course Lect 2008;57:283–94.

[27] Petersen W, Rembitzki IV, Bruggemann GP, Ellermann A, Best R, Koppenburg AG, et al. Anterior knee pain after total knee arthroplasty: a narrative review. Int Orthop 2014;38:319–28.

[28] Brar AS, Howell SM, Hull ML, Nedopil AJ, Howell SM, Hull ML. What are the bias, imprecision, and limits of agreement for finding the flexion-extension plane of the knee with five tibial reference lines? Knee 2016;23:406–11.

[29] Nedopil AJ, Howell SM, Hull ML. What clinical characteristics and radiographic parameters are associated with patellofemoral instability after kinematically aligned total knee arthroplasty? Int Orthop 2017;41:283–91.

[30] Floren M, Davis J, Peterson MG, Laskin RS. A mini-midvastus capsular approach with patellar displacement decreases the prevalence of patella Baja. J Arthroplasty 2007;22:51–7.

[31] Koshino T, Ejima M, Okamoto R, Morii T. Gradual low riding of the patella during postoperative course after total knee arthroplasty in osteoarthritis and rheumatoid arthritis. J Arthroplasty 1990;5:323–7.

[32] Meneghini RM, Ritter MA, Pierson JL, Meding JB, Berend ME, Faris PM. The effect of the Insall-Salvati ratio on outcome after total knee arthroplasty. J Arthroplasty 2006;21:116–20.

[33] Weale AE, Murray DW, Newman JH, Ackroyd CE. The length of the patellar tendon after unicompartmental and total knee replacement. J Bone Joint Surg 1999;81:790–5.

[34] Fern ED, Winson IG, Getty CJ. Anterior knee pain in rheumatoid patients after total knee replacement. Possible selection criteria for patellar resurfacing. J Bone Joint Surg 1992;74:745–8.

[35] Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis 1957;16:494–502.

[36] Grelsamer RP, Meadows S. The modified Insall-Salvati ratio for assessment of patellar height. Clin Orthop Relat Res 1992:170–6.

[37] Dawson J, Fitzpatrick R, Murray D, Carr A. Questionnaire on the perceptions of patients about total knee replacement. J Bone Joint Surg 1998;80:63–9.

[38] Murray DW, Fitzpatrick R, Rogers K, Pandit H, Beard DJ, Carr AJ, et al. The use of the Oxford hip and knee scores. J Bone Joint Surg 2007;89:1010–4.

[39] Insall JN, Dorr LD, Scott RD, Scott WN. Rationale of the Knee Society clinical rating system. Clin Orthop Relat Res 1989:13–4.

[40] Lingard EA, Katz JN, Wright RJ, Wright EA, Sledge CB. Validity and responsiveness of the Knee Society Clinical Rating System in comparison with the SF-36 and WOMAC. J Bone Joint Surg Am 2001;83-A:1856–64.

[41] Lequesne MG. The algofunctional indices for hip and knee osteoarthritis. J Rheumatol 1997;24:779–81.

[42] Portney LG, Watkins MP. Foundations of clinical research: Applications to practice. Prentice Hall; 2000.

[43] Magnussen RA, Weppe F, Demey G, Servien E, Lustig S. Residual varus alignment does not compromise results of TKAs in patients with preoperative varus. Clin Orthop Relat Res 2011;469:3443–50.

[44] Salzmann M, Fennema P, Becker R, Hommel H. Does postoperative mechanical axis alignment have an effect on clinical outcome of primary total knee arthroplasty? A retrospective cohort study. Open Orthop J 2017;11:1330–6.

[45] Lee WC, Kwan YH, Chong HC, Yeo SJ. The minimal clinically important difference for Knee Society Clinical Rating System after total knee arthroplasty for primary osteoarthritis. Knee Surg Sports Traumatol Arthrosc 2017;25:3354–9.

[46] Haverkamp DJ, Schiphof D, Bierma-Zeinstra SM, Weinans H, Waarsing JH. Variation in joint shape of osteoarthritic knees. Arthritis Rheum 2011;63:3401–7.

[47] Baker-LePain JC, Lane NE. Role of bone architecture and anatomy in osteoarthritis. Bone 2012;51:197–203.

[48] Meere PA, Schneider SM, Walker PS, Meneghini RM, Ziemba-Davis MM, Lovro LR, et al. Accuracy of balancing at total knee surgery using an instrumented tibial trial can intraoperative sensors determine the "Target" ligament balance? Early outcomes in total knee arthroplasty can we really "Feel" a balanced total knee arthroplasty? J Arthroplasty 2016;31:1938–42.

[49] Elmallah RK, Mistry JB, Cherian JJ, Chughtai M, Bhave A, Roche MW, et al. Can we really "feel" a balanced total knee arthroplasty? J Arthroplasty 2016;31:102–5.

[50] Meneghini RM, Ziemba-Davis MM, Lovro LR, Ireland PH, Damer BM. Can intraoperative sensors determine the "target" ligament balance? early outcomes in total knee arthroplasty. J Arthroplasty 2016;31:2181–7.

[51] Clement ND, MacDonald D, Simpson AH, Lee WC, Kwan YH, Chong HC, et al. The minimal clinically important difference in the Oxford knee score and Short Form 12 score after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2014;22:1933–9.

[52] Davies GS, van Duren B, Shorthose M, Garfjeld Roberts P, Morley JR, Monk AP, et al. Changes in patella tendon length over 5 years after different types of knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2016;24:3029–35.

[53] Gromov K, Korchi M, Thomsen MG, Husted H, Troelsen A. What is the optimal alignment of the tibial and femoral components in knee arthroplasty? Acta Orthop 2014;85:480–7.

[54] Bonnin MP, Saffarini M, Shepherd D, Bossard N, Dantony E. Oversizing the tibial component in TKAs: incidence, consequences and risk factors. Knee Surg Sports Traumatol Arthrosc 2016;24:2532–40.

[55] Nielsen CS, Nebergall A, Huddleston J, Kallemose T, Malchau H, Troelsen A. Medial overhang of the tibial component is associated with higher risk of inferior knee injury and osteoarthritis outcome score pain after knee replacement. J Arthroplasty 2018;33:1394–8.

[56] Abram SG, Marsh AG, Brydone AS, Nicol F, Mohammed A, Spencer SJ. The effect of tibial component sizing on patient reported outcome measures following uncemented total knee replacement. Knee 2014;21:955–9.

[57] Park A, Stambough JB, Nunley RM, Barrack RL, Nam D. The inadequacy of short knee radiographs in evaluating coronal alignment after total knee arthroplasty. J Arthroplasty 2016;31:878–82.