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Is limb overcorrection following total knee arthroplasty compromising functional outcome?

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ABSTRACT

Purpose: Many patients remain unsatisfied after total knee arthroplasty (TKA). Personalized alignment strategies have gained popularity in the search to improve patient satisfaction and function. This study aimed to examine the impact of limb overcorrection in the coronal plane on patient satisfaction and functional outcome. The secondary aim was to investigate how a change in knee phenotype following TKA affects clinical outcome.
Methods: A retrospective matched case-control study was designed between patients with limb overcorrection (N = 37) and a control group (N = 104). Mean follow-up was 68 months. Satisfaction and function were compared by means of the new 2011 Knee Society Score (KSS) and the Knee Injury and Osteoarthritis Outcome Score (KOOS). Radiological evaluation was performed on weight-bearing full-leg radiographs. Overcorrection was defined as a mechanical HKA (mHKA) angle of 2° or more and opposite to the preoperative alignment. The control group consisted of TKAs that were corrected to neutral or left in slight undercorrection. Finally, component alignment (lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA)) and Coronal Plane Alignment of the knee (CPAK) phenotypes were evaluated.
Results: The overcorrection group performed better than the control group in terms of KSS subscores satisfaction and functional activities, total KSS score, all KOOS subcategories, and total KOOS score. Subdivision of the control group into a neutral and undercorrection group, and the overcorrection group into mild and severe overcorrection, revealed similar findings.
A chance in knee phenotype as per aHKA, JLO or CPAK did not result in worse clinical outcomes.
Conclusion: Accidental limb overcorrection after TKA does not result in inferior clinical outcomes or patient satisfaction at midterm follow-up.
The present study could not identify an optimal coronal alignment target. This suggests that coronal alignment as a predictor of patient satisfaction and function is likely less important than previously believed.
Level of evidence: Level III, retrospective case-control study.

1. Introduction

Total knee arthroplasty (TKA) is established as a successful treatment for advanced osteoarthritis of the knee joint.[1] Nevertheless, up to 20 % of patients are not completely satisfied with their outcome after surgery.[2,3] Several preoperative and postoperative factors including age, preoperative pain at rest, range of motion, postoperative complications, persistent pain after TKA, component rotational malalignment and soft tissue balance were found to correlate with postoperative satisfaction and function.[2–5]

Restoration of a mechanical neutral limb alignment, defined as a mechanical hip-knee-ankle angle (mHKA) of 0° ± 3°, has been the golden standard in TKA because of its perceived promotion of implant durability due to equal force distribution over the whole surface of the joint.[6–8] It has long been accepted as a prerequisite for a successful outcome, but the effect of neutral alignment on patient satisfaction and function remains controversial, with existing literature presenting conflicting findings. Traditionally, alignment is defined as a dichotomous variable, aligned or malaligned, while disregarding the patient's preoperative knee phenotype. An increasing number of studies have called into question the concept of neutral mHKA. Vanlommel et al.[9] evaluated patients with preoperative varus alignment and noticed improved

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clinical outcome scores if the overall mHKA was left in mild varus without compromising implant survival. Others have claimed that placing TKA in the patient's physiologic alignment with residual malalignment could be beneficial from a functional perspective.[9,10] In recent years, a more personalized alignment approach has gained popularity.

It is accepted that the help of technology, like robot assisted TKA, is required for such personalized alignment strategies. Robot assisted TKA has shown improved precision in component positioning and overall alignment.[11] But optimal alignment targets for TKA are still lacking and the impact of limb malalignment after TKA on patient satisfaction and function remains unanswered.

To our knowledge, the effect of accidental surgical overcorrection of the limb following TKA has never been properly examined. Therefore, the primary objective of this study was to evaluate the effect of limb overcorrection in the coronal plane on clinical outcome and patient satisfaction. The secondary objective was to assess the effect of a change in knee phenotype after TKA. The research hypothesis of this study is twofold: Patients with overcorrection have inferior clinical outcome scores and poorer patient satisfaction compared to patients who are corrected to neutral or left in slight undercorrection and preserving the knee phenotype after TKA would result in superior clinical outcomes.

2. Materials and methods

2.1. Patient population

A retrospective matched case-control study was conducted after approval of the local ethics committee. All primary TKAs performed between 2013 and 2019 in a single institution were screened for accidental overcorrection in the coronal plane following surgery (Fig. 1). Overcorrection was identified when the postoperative mechanical HKA (mHKA) angle crossed the neutral axis with 2° or more (an example is shown in Fig. 2).

Inclusion criteria were patients with preoperative valgus or varus alignment of the knee and primary osteoarthrosis of the knee as the main indication for TKA. The exclusion criteria included: preoperative neutral alignment of the knee (mHKA ± 3°), indications for TKA other than primary osteoarthrosis, revision knee arthroplasty, unavailability of preoperative or postoperative full-leg radiographs, previous knee surgery other than meniscectomy, intraoperative fractures and/or postoperative infection or fractures. A total of 64 patients (70 TKAs) fulfilled inclusion criteria. Thirty-one patients (33 TKAs) were not available for follow-up due to various reasons (Fig. 1). The final study population

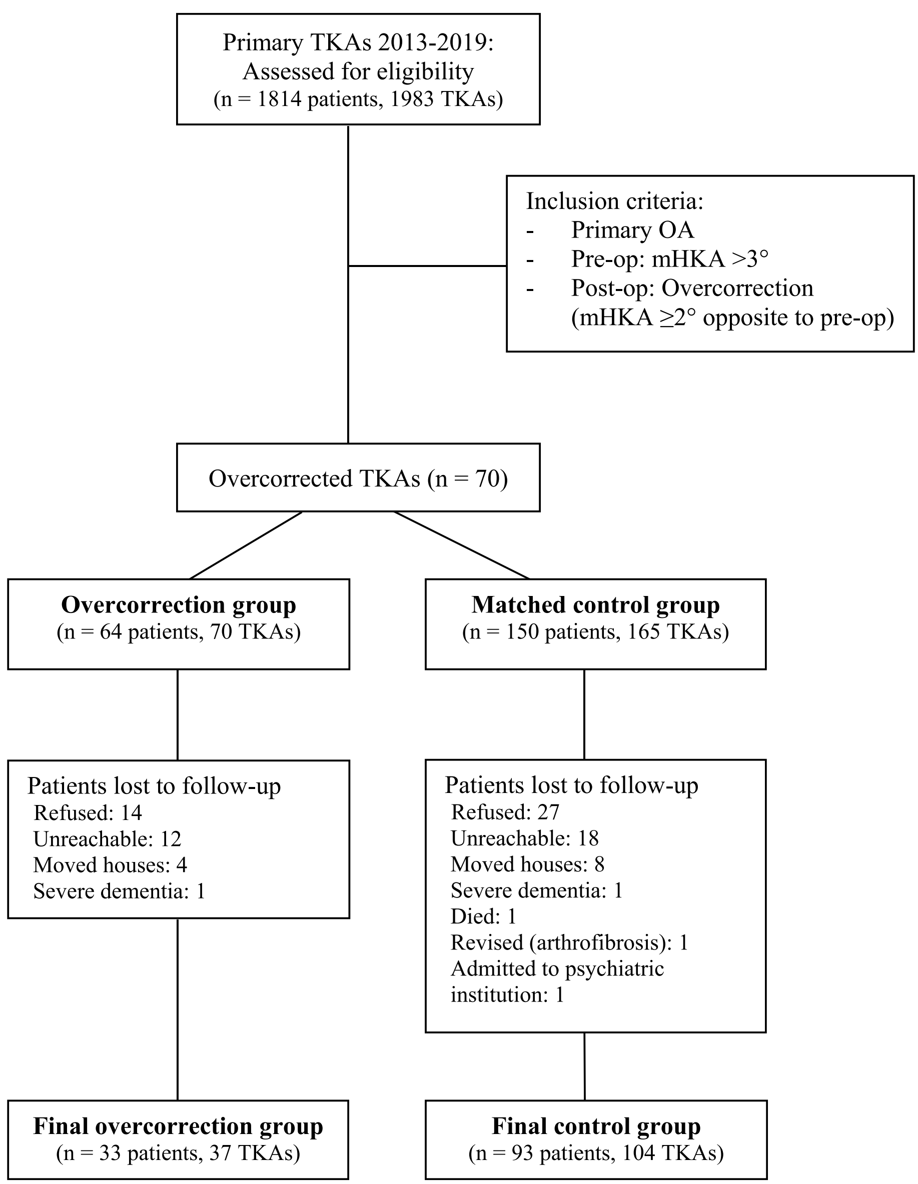

Fig. 1. CONSORT diagram showing the flow of the patient inclusion process.

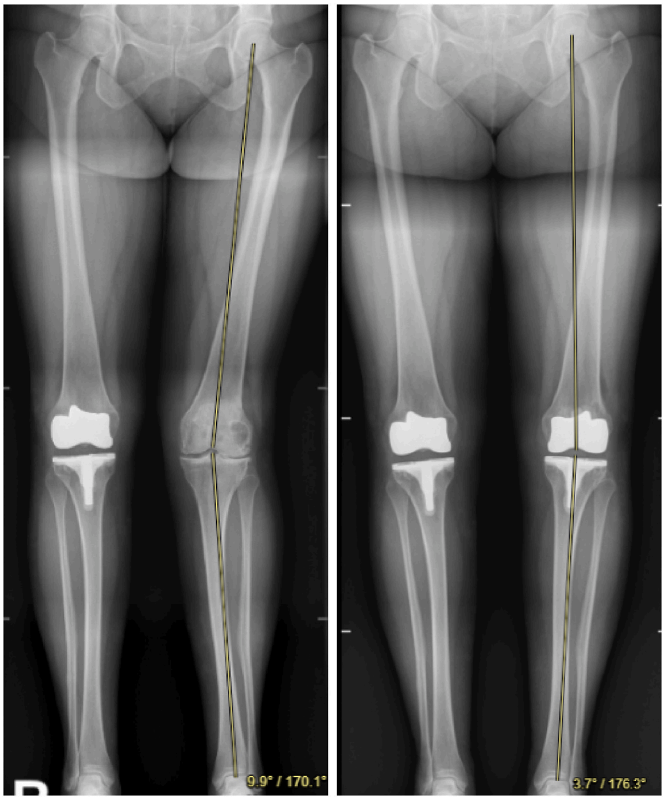

Fig. 2. Example of a case of overcorrection. The patient had a preoperative mHKA of 9.9° of valgus. The leg was overcorrected to 3.7° of varus postoperatively.

consisted of 33 patients (37 TKAs).

As a control group, patients with preoperative malalignment that was either corrected to neutral (mHKA ± 3° in the same mHKA phenotype as preoperatively) or left in slight undercorrection (mHKA >3° in the same mHKA phenotype as preoperatively) were selected. They were matched by age, gender, BMI, operation side, and presence of total hip arthroplasty (THA) or contralateral TKA. To account for dropouts, a group of 150 patients (165 TKAs) was selected. Fifty-seven patients (61 TKAs) were not available for follow-up due to various reasons. The final control group consisted of 93 patients (104 TKAs).

2.2. Surgical details

All surgical procedures were conducted by two senior surgeons. Three different implant designs were used; Journey II Bi-cruciate stabilized total knee (Smith & Nephew; Memphis, TN, USA), NexGen Legacy posterior stabilized (LPS) flex fixed bearing and Persona posterior stabilized total knee (Biomet Zimmer, Warsaw, IN, USA).

Knee exposure was achieved through a conventional medial parapatellar incision. A standard intramedullary reference system was used to align the femoral component and an extramedullary reference system was used for the tibial component. Target alignment was neutral or slight undercorrection in selected cases. Femoral rotation was determined using a measured resection technique. All components were cemented. A selective patella resurfacing strategy was adopted. All patients followed a standardized postoperative rehabilitation protocol: bed rest on day of surgery, continuous passive motion starting on day one, ambulation with crutches on day two and ascending/descending stairs on day three.

2.3. Radiological assessment

All patients underwent standardized, weight-bearing, full-leg radiographs preoperatively and at six weeks postoperatively. Full-leg radiographs were taken following hospital protocols with patients standing barefoot with the patellae oriented forward as proposed by Paley.[12]

Alignment was determined based on full-leg radiographs according to criteria defined by Cooke et al..[13] The mHKA angle was calculated as the angle between the mechanical femoral axis and the mechanical tibial axis.

Furthermore, the pre- and postoperative lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA) were measured to assess component alignment in the coronal plane. The LDFA was defined as the lateral angle between the mechanical femoral axis and the joint line of the most distal aspects of the medial and lateral femoral condyles. The MPTA was defined as the medial angle between the mechanical tibial axis and the joint line of the proximal tibia. Neutral MPTA was defined as MPTA = 90° ± 2°, varus as MPTA <88° and valgus as MPTA >92°. For the LDFA, neutral was defined as LDFA = 90° ± 2°, valgus as LDFA <88° and varus as LDFA >92°.

The arithmetic HKA (aHKA) and the joint line obliquity (JLO) were calculated based on the MPTA and LDFA, as proposed by MacDessi et al. Neutral aHKA was defined as aHKA = 0° ± 2°, varus as aHKA < -2° and valgus as aHKA >2°. Neutral JLO was defined as JLO = 180 ± 3°, apex distal as JLO <177° and apex proximal as JLO >183°. Based on aHKA and JLO phenotypes, patients were classified into Coronal Plane Alignment of the knee (CPAK) phenotypes.[14] A change of knee phenotype was identified when the aHKA, JLO or CPAK classification after TKA differed from the preoperative classification.

The radiographic measurements were carried out by an independent observer, within a range of accuracy of 0.1°, using a Picture Archiving and Communication System (PACS) digital radiographic software.

2.4. Clinical outcomes

Patients' function and satisfaction were evaluated using disease-specific patient reported outcome measurements (PROMs): the 2011 Knee Society Knee Scoring System (2011 KSS) and Knee Injury and Osteoarthritis Outcome Score (KOOS). Both scores were translated to Dutch and validated.[15,16]

The 2011 KSS was designed to quantify patient pain, satisfaction, expectations, and physical activities after TKA. The physician-derived objective knee score was not analyzed further in this study because there is a poor correlation between physician-based scores and patient-derived scores.[17]

The KOOS is a purely patient-reported, knee specific, functional outcome questionnaire. It has five subcategories: symptoms, pain, Activities of Daily Living (ADL), sports and Quality of Life (QoL).[18]

Patients were invited for clinical and radiological review. Questionnaires were completed during this visit. When patients were unable to attend physically, a questionnaire was sent by mail. Patients were examined by an independent observer.

2.5. Statistical analysis

Based on previous literature a minimal clinically important difference (MCID) of 8–10 for the KOOS subcategories and 10 for the KSS score was deemed necessary.[18,19] A pre-hoc power analysis was performed to address the primary research question. To achieve appropriate power (beta level = 0.80) to detect a 10-point difference in both PROMs, a minimum of 60 patients in each group was required. A p-value of 0.05 was used to determine significance.

A comparison of baseline demographics across groups was conducted using Chi-square or Fisher's Exact tests for categorical variables, and One-way ANOVA or Kruskall-Wallis tests for continuous variables. Clinical outcomes across groups were compared using a regression model, adjusting for age, gender, BMI, implant design, comorbidities, and the presence of THA and contralateral TKA.

The association between radiological measures and clinical outcomes was assessed through regression analyses, with clinical outcomes as the dependent variables and radiological measures as the independent variables. Both linear and quadratic associations were evaluated. All models were further adjusted for age, gender, BMI, implant design, comorbidities, and the presence of THA or contralateral TKA. Statistical tests were two-sided, with a 5 % significance level. All analyses were performed using SAS software (SAS Institute Inc., Cary, NC, USA).

3. Results

3.1. Demographic data

The total sample size counted 141 TKAs, 37 in the overcorrection group and 104 in the control group. The mean follow-up was 68 ± 11 months.

Demographics were similar among both groups, except for gender distribution. The overcorrection group had a significantly higher female ratio compared to the control group (67.7% vs 44.2%, $p = 0.0148$). Demographic data is presented in Table 1.

3.2. Overcorrection of the mechanical HKA

The overcorrection group scored significantly better in the total KSS score and the subscores satisfaction and physical activities in comparison to the control group. The overcorrection group also scored significantly better in all KOOS subcategories and in the total KOOS score (*p*-values are presented in Table 2).

Next, the control group was divided into a neutral and an undercorrection group and compared to the overcorrection group. This revealed a similar trend. The overcorrection group scored significantly better in the total KSS score and the subscores symptoms, satisfaction, and physical activities. KOOS pain, ADL, sport, and the total KOOS score were also significantly better in the overcorrection group. There were no significant differences between the undercorrection group and the neutral group (Table 2).

Finally, the overcorrection group was further divided into mild (2°≤ mHKA <3° opposite to the preoperative mHKA phenotype, N = 18) and severe overcorrection (mHKA ≥3° opposite to the preoperative mHKA phenotype, N = 19). There was no significant difference in KOOS or KSS scores between the mild and severe overcorrection groups.

There was no linear association between PROMs and postoperative mHKA. After adding a quadratic component, a statistically significant association between KSS symptoms and postoperative mHKA was found ($R^2 = 0.07; p = 0.0419$), with the worst outcome between neutral and 1° of varus.

Table 1
Patient characteristics.

	Overcorrection (n = 37)	Control (n = 104)	*p* value
Age (yrs)	73.2 ± 9.7	73.8 ± 8.4	*n.s.*
Gender F/M (%/%)	67.6/32.4	44.2/55.8	*0.0148*
BMI (kg/m^2)	29.9 ± 4.6	29.1 ± 5.2	*n.s.*
Operated side L/R (%/%)	56.8/43.2	45.2/54.8	*n.s.*
Follow-up (mo)	66.5 ± 13.8	68.2 ± 10.4	*n.s.*
Preop mHKA (°)[a]	6.2 ± 2.4	7 ± 2.9	*n.s.*
Preop valgus/varus (%/%)	46/54.1	30.8/69.2	*n.s.*
Prosthesis design (%)			*n.s.*
LPS Flex	8.1	*9.6*	
Persona	48.7	51.9	
Journey II	43.2	38.5	

Values are expressed as mean ± SD. Level of significance: $p < 0.05$. *n.s.* not significant.

[a] Preoperative mHKA is presented as an absolute value, independent of valgus/varus.

3.3. Preoperative valgus mHKA phenotype

For patients with preoperative valgus mHKA phenotype, the overcorrection group demonstrated higher KSS physical activities and total KSS scores. The overcorrection group also scored significantly better in the KOOS symptoms subcategory (*p*-values are presented in Table 3a).

Subsequent subdivision of the control group into a neutral and an undercorrection group revealed a similar trend of comparable to better scores in the overcorrection group, which reached a statistically significant difference for the KSS physical activities subscore ($p = 0.0317$). There were no significant differences between the undercorrection group and the neutral group (Table 3a).

3.4. Preoperative varus mHKA phenotype

For patients with preoperative varus mHKA phenotype, the overcorrection group showed significantly higher KOOS sport scores ($p = 0.028$).

Subsequent subdivision of the control group into a neutral and undercorrection group resulted in a similar outcome among groups (Table 3b).

3.5. CPAK classification

A change in aHKA phenotype was found in 87 cases. In ninety-one cases a change in JLO phenotype was observed. A changed CPAK phenotype was observed in 122 cases. PROMs between patients with and without a restored knee phenotype after TKA, as per aHKA, JLO or CPAK, were not significantly different (Fig. 3).

Postoperative aHKA or JLO did not demonstrate any statistically significant linear or quadratic association with PROMs.

3.6. Component alignment

Clinical outcome scores between neutral, valgus and varus component alignment after TKA were found to be not statistically different.

Postoperative MPTA or LDFA did not demonstrate any statistically significant linear or quadratic association with PROMs.

4. Discussion

The impact of malalignment on function and patient satisfaction is controversial. We tried to assess the impact of limb overcorrection on patient satisfaction and functional outcome. The main finding of the current study is that patients with accidental limb overcorrection following TKA did not do worse than the control group at a mean of 68 months after surgery. On the contrary, they had even higher patient satisfaction and better clinical outcome scores, which contradicted our hypothesis. One possible explanation for this finding might be that, as long as other intraoperative variables such as ligament balancing, implant fixation and rotation are well managed, overcorrection seems to be well tolerated.

Correction to neutral limb alignment is traditionally considered an important intraoperative variable that influences postoperative outcome and implant survival.[8] But the concept of mechanical alignment and its 'one size fits all' approach, independent of the patient's natural phenotype, has been challenged in recent years.[9,14,20,21] Indeed, this study has not been able to identify an optimal alignment target for mHKA, MPTA or LDFA that is associated with improved clinical outcome. There was one statistically significant association between postoperative mHKA and the KSS subscore symptoms. However only 7 % of the variance in the KSS symptoms score was explained by the postoperative mHKA, thus this association can be regarded as very weak

Table 2
Postoperative clinical outcome scores for the whole cohort.

		Overcorrection (n = 37)	Control (n = 104)	p- value[a]	Neutral (n = 64)	Undercorrection (n = 40)	p-value[a]
Post-op mHKA (°)[b]		3.4 ± 1.5	2.4 ± 1.7		1.4 ± 0.9	4.2 ± 1	
KSS	Symptoms	22.2 ± 3.8	20.3 ± 5.7	n.s.	19.7 ± 6.1	21.3 ± 4.8	0.0373
	Satisfaction	36.5 ± 5.4	32.6 ± 7.7	0.0125	32.2 ± 7.9	33.4 ± 7.3	0.0181
	Expectations	10.5 ± 2.2	10.4 ± 2.8	n.s.	10.2 ± 2.9	10.7 ± 2.7	n.s.
	Physical activities	82 ± 15.7	73.1 ± 21.3	0.0045	73.3 ± 22.2	72.7 ± 20.1	0.0169
	Total score	151.3 ± 22.8	136.2 ± 33.7	0.0063	135.3 ± 35.6	137.7 ± 30.8	0.0169
KOOS	Symptoms	88.1 ± 9.1	81.7 ± 13.4	0.0269	81.7 ± 14.8	81.6 ± 10.9	n.s.
	Pain	92.9 ± 10.5	83.1 ± 20.5	0.0108	83.1 ± 19.5	83.2 ± 21.9	0.035
	ADL	90.7 ± 10.9	83.1 ± 20.5	0.0383	81.9 ± 22.5	84.9 ± 17.1	0.042
	Sport	62 ± 28.1	46.2 ± 30.1	0.0013	45.8 ± 31.2	46.9 ± 28.7	0.0058
	QoL	82.8 ± 17.3	72.5 ± 25	0.0342	72.4 ± 26.9	72.7 ± 21.9	n.s.
	Total score	83.3 ± 11.8	73.3 ± 18.3	0.0026	73 ± 20.1	73.9 ± 15.1	0.0094

Values are expressed as mean ± standard deviation. *n.s.* not significant.
[a] Given *p*-values in the right columns represent the results of the One-way ANOVA test between the overcorrection, neutral and undercorrection groups, adjusted for covariates.
[b] Postoperative mHKA is presented as an absolute value, regardless of valgus/varus.

Table 3A
Postoperative clinical outcome scores for the valgus cohort.

		Overcorrection (n = 17)	Control (n = 32)	p- value[a]	Neutral (n = 27)	Undercorrection (n = 5)	p- value[a]
Postop mHKA (°)[b]		−3.8 ± 1.9	1.7 ± 1.3		1.3 ± 1	3.7 ± 0.7	
KSS	Symptoms	22.6 ± 3.4	20.2 ± 5.8	n.s.	20.1 ± 5.8	20.4 ± 6.3	n.s.
	Satisfaction	36.4 ± 6.1	32.6 ± 6.6	n.s.	32.9 ± 6.3	30.8 ± 8.3	n.s.
	Expectations	10.3 ± 2	10.3 ± 2.6	n.s.	10.4 ± 2.6	10.2 ± 2.6	n.s.
	Physical activities	85.6 ± 10.7	72.1 ± 22.5	0.01	74.5 ± 20.7	59.2 ± 29.7	0.0317
	Total score	154.8 ± 18.5	135 ± 34.4	0.0425	137.8 ± 32.1	120.6 ± 46.1	n.s.
KOOS	Symptoms	91 ± 7.9	80.8 ± 11	0.0289	81.4 ± 11.6	77.9 ± 7.7	n.s.
	Pain	92.8 ± 12.7	82.7 ± 17.9	n.s.	84.2 ± 15.5	75 ± 28.9	n.s.
	ADL	91.1 ± 10.1	82.8 ± 20	n.s.	84.8 ± 18	72.4 ± 28.9	n.s.
	Sport	63.8 ± 26.8	48.9 ± 33.2	n.s.	49.6 ± 34.7	45 ± 26.7	n.s.
	QoL	86.8 ± 16.4	72.9 ± 23.9	n.s.	74.1 ± 24.1	66.3 ± 24.4	n.s.
	Total score	85.1 ± 11.6	73.6 ± 18.5	n.s.	74.8 ± 18.2	67.3 ± 21.1	n.s.

The values are given as mean ± standard deviation. n.s. not significant.
[a] Given *p*-values in the right column represent the results of the One-way ANOVA test between the overcorrection, neutral and undercorrection groups, adjusted for covariates.
[b] Postoperative mHKA: A negative value indicates varus, a positive value indicates valgus.

Table 3B
Postoperative clinical outcome scores for the varus cohort.

		Overcorrection (n = 20)	Control (n = 72)	p- value[a]	Neutral (n = 37)	Undercorrection (n = 35)	p- value[a]
Postop mHKA (°)[b]		3.1 ± 1	−2.8 ± 1.7		−1.4 ± 0.9	−4.2 ± 1	
KSS	Symptoms	21.9 ± 4.2	20.3 ± 5.7	n.s.	19.4 ± 6.4	21.4 ± 4.6	n.s.
	Satisfaction	36.7 ± 4.8	32.6 ± 8.2	n.s.	31.6 ± 9	33.7 ± 7.2	n.s.
	Expectations	10.8 ± 2.4	10.4 ± 2.9	n.s.	10 ± 3.1	10.8 ± 2.8	n.s.
	Physical activities	79.2 ± 18.5	73.6 ± 20.9	n.s.	72.5 ± 23.4	74.8 ± 17.9	n.s.
	Total score	148.5 ± 25.8	136.7 ± 33.6	n.s.	133.5 ± 38.1	140.3 ± 27.8	n.s.
KOOS	Symptoms	85.6 ± 9.6	82.1 ± 14.4	n.s.	82 ± 17	82.2 ± 11.3	n.s.
	Pain	92.9 ± 8.7	83.3 ± 21.5	n.s.	82.4 ± 22.2	84.4 ± 21	n.s.
	ADL	90.4 ± 11.8	83.2 ± 20.9	n.s.	79.9 ± 25.3	86.6 ± 14.5	n.s.
	Sport	60.5 ± 29.8	45 ± 28.8	0.028	43 ± 28.6	47.1 ± 29.3	n.s.
	QoL	79.4 ± 17.8	72.3 ± 25.6	n.s.	71.1 ± 29.1	73.6 ± 21.7	n.s.
	Total score	81.7 ± 12.1	73.2 ± 18.3	n.s.	71.7 ± 21.5	74.8 ± 14.3	n.s.

The values are given as mean ± standard deviation. n.s. not significant.
[a] Given *p*-values in the right column represent the results of the One-way ANOVA test between the overcorrection, neutral and undercorrection groups, adjusted for covariates.
[b] Postoperative mHKA: A negative value indicates varus, a positive value indicates valgus.

and of no clinical importance.

This is consistent with the findings in the majority of existing literature on this subject. A systemic review conducted in 2016 concluded that 64 % of literature at that time demonstrated no relationship between coronal malalignment and patient-reported outcomes following TKA. They concluded that the relationship of malalignment with worse patient-reported outcomes is likely to be weak and of dubious clinical significance.[22] More recent literature investigating the impact of the mHKA on clinical outcomes did not show a relationship with worse clinical outcome in the short to medium-term[4,10,23–30] or long-term follow-up.[31–33]

Most of the existing literature does not consider the preoperative

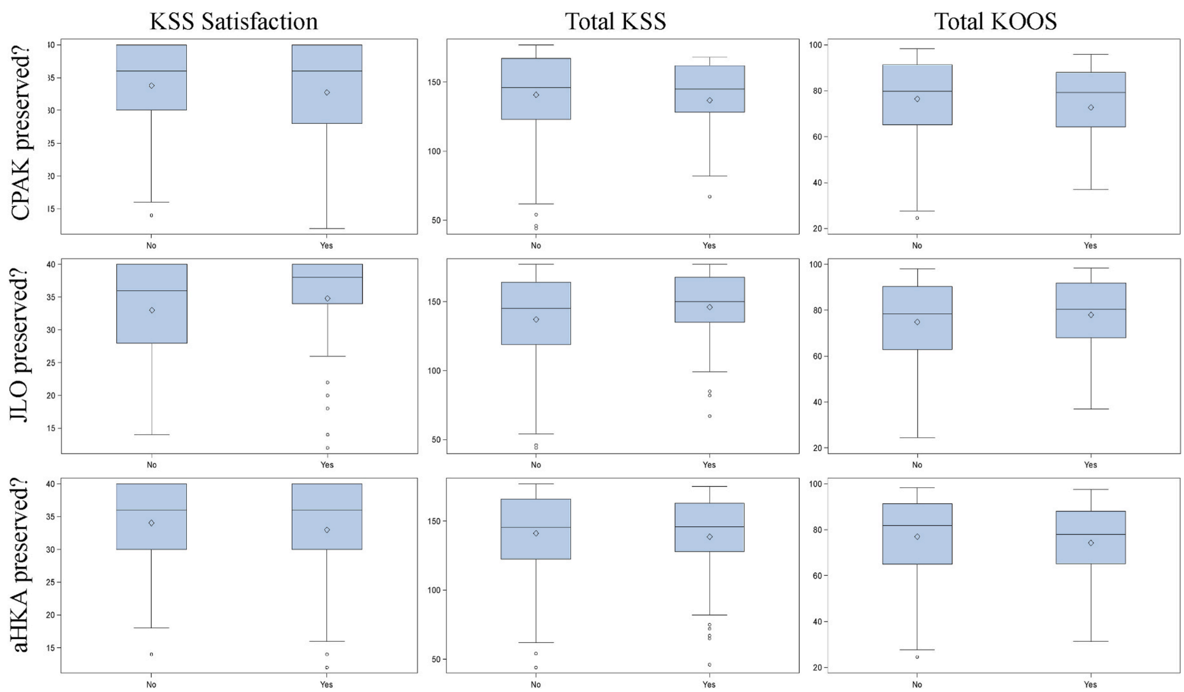

Fig. 3. Boxplots demonstrating postoperative patient satisfaction, KSS and KOOS scores for patients with and without a change in knee phenotype following TKA. No difference between groups were found.

knee phenotype or only describes malalignment as a dichotomous variable without evaluating the direction of the malalignment (undercorrection vs. overcorrection).[4,23–25,27,30–32] Slevin et al. could not find any correlation between postoperative mHKA, MPTA or LDFA and KSS scores in a prospective clinical study. However, a subsequent study by the same group, using the same radiological protocol, revealed a significant correlation between neutral limb alignment and higher KSS scores in patients with preoperative non-varus alignment. There was no correlation between KSS scores and mHKA in preoperative varus patients.[30,34] The current study tried to overcome these shortcomings by analyzing the impact of preoperative knee phenotype and a change in phenotype after TKA on patient outcome scores.

To our knowledge this is the first matched case-control study to examine the impact of accidental limb overcorrection following TKA on patient satisfaction and function.

Limb overcorrection has previously been reported in a few papers, but mostly as a subanalysis and underpowered. Some authors have reported on valgus overcorrection (mHKA $>3^\circ$ valgus, or aTFA $\geq 9^\circ$[35]), in preoperative varus knees, and found no significant difference when compared to the undercorrection or neutral groups, similar to our findings.[28,35–37] In contrast, Nishida et al. observed lower functional scores in the valgus overcorrection (mHKA $>3^\circ$ valgus) and severe varus (mHKA $>6^\circ$ varus) groups in preoperative varus knees. While Zhang et al. also found statistically significantly worse clinical outcome scores in the overcorrection (mHKA $>0^\circ$ in valgus) and severe varus groups.[38,39] Farooq et al. found in an evaluation of 1311 cases, with a mean follow-up of 2.4 years, that patients with preoperative valgus were more likely to achieve a good clinical outcome if they weren't overcorrected into varus (aTFA$<0^\circ$). Similarly, preoperative varus and neutral knees were more likely to have superior PROMs when not overcorrected into valgus (aTFA $\geq 7^\circ$).[40] However, this research was based upon short knee radiographs, which might not accurately reflect leg alignment.[41] Boyer et al. found no difference in KSS scores between the undercorrection and neutral aligned (mHKA $0^\circ \pm 4^\circ$) groups in 557 preoperative fixed valgus knees, with at least 10° of valgus preoperatively. However, the overcorrection group had worse outcomes with respect to pain, functional performance, and total KKS score.[42] The use of different definitions for overcorrection, different radiology modalities and follow-up period may be contributing factors to these contradictory findings in literature.

More recently, a more personalized alignment approach has gained popularity. It is believed that recreating the patient's native alignment phenotype can lead to more natural knee movement and soft tissue balance.[14,43] This led to our hypothesis that preserving the preoperative alignment phenotype after TKA leads to superior clinical outcomes. While some authors report favorable outcomes after more personalized alignment in TKA,[9,39,44] this was not the case in the current study. After a medium-term follow-up, reported PROMs were not significantly impacted by a change in alignment phenotype after surgery. Only patients with a preoperative axis deviation of $>3^\circ$ were included in this study, and so these results cannot be generalized. However, these findings are consistent with a recent study, which reported similar outcomes 1 year after TKA, regardless of changes in knee phenotype.[26] Sappey-Marinier et al. also found no clinically significant differences between patients with or without restored preoperative knee phenotype, as determined by CPAK classification.[45] Cherches et al. investigated the effect of changes in mHKA, MPTA and JLO after TKA and found no correlation with worse clinical outcome scores or knee flexion two years after surgery.[46]

We do acknowledge a few limitations to our study. First, because the study was retrospective, no baseline clinical scores were available. Consequently, no comparison with the preoperative status and the degree of improvement after surgery could be made. However only patients with debilitating symptoms from the knee, refractory to conservative treatment, and with radiographic evidence of end stage osteoarthritis of the knee were considered for TKA. Furthermore, baseline demographics, apart from gender distribution, were comparable between groups and all tests were adjusted for covariates. The observed difference in gender distribution, despite cohort matching, can be attributed to the matching occurring at the time of patient selection, coupled with the subsequent dropout of patients from both groups altering the gender ratio. Second, this is a radiographic study in which improper radiographic technique may lead to errors of measurement. Furthermore, it is known that changes in weight-bearing status, limb rotation, and knee flexion can significantly alter mHKA observed on full-leg radiographs.[47,48] This source of error was minimized by implementing a standardized protocol. Third, the study only focused on the coronal alignment without considering the effect of the sagittal plane, rotational alignment, and the complex interplay between all measures of alignment. Finally, the overcorrection group was underpowered, making some analyses less reliable. However, the number of patients in the overcorrection group is limited by the accidental nature of overcorrection and its rarity.

5. Conclusion

Although it is never intentional to overcorrect limb alignment during total knee surgery, the current study shows that this does not necessarily translate into worse clinical outcomes.

The present study could not identify an optimal coronal alignment that was associated with superior clinical outcomes or patient satisfaction.

The question arises whether an optimal coronal alignment exists at all, as this is only a static parameter and one of many variables that influence clinical outcome. More research with bigger sample sizes is needed to shed further light on this topic.

CRediT authorship contribution statement

Arne De Smet: Investigation, Methodology, Data curation, Writing – original draft. **Jan Truijen:** Resources, Writing – review & editing. **Luc Vanlommel:** Conceptualization, Methodology, Supervision, Resources, Writing – review & editing.

Informed consent

Informed consent was obtained from all participants included in the study.

Ethical statement

This study was performed in accordance with the ethical standards of the Declaration of Helsinki. Ethical approval was obtained from the local ethics committee, Comité Medische Ethiek, Schiepse bos 6, 3600 Genk, Belgium (ID number 20/0084U).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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