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ABOUT COVER

Editorial Board Member of *World Journal of Clinical Cases*, Dr. Mukul Vij is Senior Consultant Pathologist and Lab Director at Dr Rela Institute and Medical Center in Chennai, India (since 2018). Having received his MBBS degree from King George Medical College in 2004, Dr. Vij undertook postgraduate training at Sanjay Gandhi Postgraduate Institute of Medical Sciences, receiving his Master's degree in Pathology in 2008 and his PDCC certificate in Renal Pathology in 2009. After 2 years as senior resident, he became Assistant Professor in the Department of Pathology at Christian Medical College, Vellore (2011), moving on to Global Health City as Consultant Pathologist and then Head of the Pathology Department (2013). (L-Editor: Filipodia)

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Limb length discrepancy after total knee arthroplasty: A systematic review and meta-analysis

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Abstract

BACKGROUND

Limb length discrepancy (LLD) after total knee arthroplasty (TKA) has been considered as one of the reasons for the unsatisfactory outcome. However, there is no consensus about the extent of LLD that can be considered as clinically relevant.

AIM

To evaluate the incidence of radiographic LLD and its impact on functional outcome following TKA.

METHODS

All randomized-controlled trial and observational studies on LLD in TKA, published till 22nd June 2020, were systematically searched and reviewed. The primary outcome was "limb lengthening or LLD after TKA". The secondary outcomes included "assessment of LLD in varus/valgus deformity" and "impact of LLD on the functional outcome".

RESULTS

Of 45 retrieved studies, qualitative and quantitative assessment of data was

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performed from eight studies and six studies, respectively. Five studies ($n = 1551$) reported the average limb lengthening of 5.98 mm . The LLD after TKA was ranging from $0.4 \pm 10 \text{ mm}$ to $15.3 \pm 2.88 \text{ mm}$. The incidence of postoperative radiographic LLD was reported in 44% to 83.3% of patients. There was no difference in the preoperative and postoperative LLD (MD -1.23; 95%CI: -3.72, 1.27; $P = 0.34$). Pooled data of two studies ($n = 219$) revealed significant limb lengthening in valgus deformity than varus (MD -2.69; 95%CI: -5.11, 0.27; $P = 0.03$). The pooled data of three studies ($n = 611$) showed significantly worse functional outcome in patients with LLD of $\geq 10 \text{ mm}$ compared to $< 10 \text{ mm}$ (standard MD 0.58; 95%CI: 0.06, 1.10; $P = 0.03$).

CONCLUSION

Limb lengthening after TKA is common, and it is significantly more in valgus than varus deformity. Significant LLD ($\geq 10 \text{ mm}$) is associated with suboptimal functional outcome.

Key Words: Arthroplasty; Knee; Replacement; Limb length; Joint diseases; Surgery

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Core Tip: Limb length inequality following total knee arthroplasty (TKA) is an important cause of patient dissatisfaction. This meta-analysis evaluated the limb length discrepancy (LLD) and its impact on the functional outcome following TKA. Five studies ($n = 1551$) reported the average limb lengthening of 5.98 mm . The LLD after TKA was ranging from $0.4 \pm 10 \text{ mm}$ to $15.3 \pm 2.88 \text{ mm}$. There was no difference in the preoperative and postoperative LLD (MD -1.23; 95%CI: -3.72, 1.27; $P = 0.34$). Pooled data of two studies ($n = 219$) revealed significant limb lengthening in valgus deformity than varus (MD -2.69; 95%CI: -5.11, 0.27; $P = 0.03$). The pooled data of three studies ($n = 611$) showed significantly worse functional outcome in patients with LLD of $\geq 10 \text{ mm}$ compared to $< 10 \text{ mm}$ (standard MD 0.58; 95%CI: 0.06, 1.10; $P = 0.03$). Most of the patient's limb gets lengthened after TKA; however, it affects the functional outcome when the LLD is more than equal to 10 mm .

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INTRODUCTION

Despite the advancement in technology and a better understanding of total knee arthroplasty (TKA), nearly 15%-20% of patients remain dissatisfied after surgery^[1,2]. Many studies have reported that there is a discrepancy in the patient-reported outcome, and physicians reported outcome after TKA. The clinical and functional outcomes, as reported by the physicians, are higher than the patients reported outcome^[1-3]. Although many factors may contribute to this disparity, limb length discrepancy (LLD) is one of the crucial issues, and it has not been adequately studied^[4]. Unlike total hip arthroplasty, where the limb length can be adjusted with implant modifications and surgical techniques, it is least modifiable in TKA. The principle of TKA involves minimal bone resection and ligament balancing with equal flexion-extension gap, and hence limb length alteration is unavoidable^[5]. The change in limb length is not commonly measured after TKA; nevertheless, LLD has been shown to increase the incidences of back pain, radiculopathy, gait disorders, and general dissatisfaction^[6-10].

The patient may perceive the gait modification after unilateral TKA as an unacceptable outcome. It has been proven that mechanical load and isometric torque is more on the longer limb, and it has a negative impact on the nearby joints. There may be precipitations of low back pain, hip pain because of arthritic changes and also

compensatory pelvis and spinal curvature changes^[6-10]. There are limited studies in literature till date evaluating LLD after TKA^[11-18]. While few studies reported LLD as a common occurrence after TKA^[11-14], others reported that radiographic LLD is uncommon^[15-17]. Recently, few researchers have reported radiographic LLD of ≥ 10 mm as a clinically relevant change^[16,17]. Contrary to it, the perceived LLD has been given more weightage in a few studies^[15,16]. Therefore, this systematic review and meta-analysis were conducted to evaluate the incidence of radiographic LLD and its impact on functional outcome following TKA.

MATERIALS AND METHODS

This systematic review was performed with a predefined protocol using the (Patients, Intervention, Comparison and Outcome) PICO format. The review was conducted and presented according to Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement standards (Figure 1). This systematic review was registered in PROSPERO (Regd. No. CRD42020193434).

Eligibility criteria

All randomized-controlled trials and observational studies that evaluated the limb length alteration or LLD after TKA surgeries were included for review.

Participants

Patients operated with unilateral or bilateral TKA with measurement of lower limb length in the preoperative period and postoperative period were included. The patients operated with revision knee arthroplasty, associated extra-articular deformity, previous knee surgery or lower limb bony procedures were excluded.

Intervention

All patients should have undergone TKA (either conventional Jig based surgery or navigation or robotic-assisted) with any surgical approach using either cruciate-retaining or posterior stabilized implant. The principle of TKA should be either gap balancing or measured resection technique.

Outcome measures

The primary outcome measure was assessment of limb lengthening/LLD after TKA. The secondary outcome measures included assessment of LLD in varus/valgus deformities and unilateral/bilateral TKA. The other measures were assessment of perceived LLD and the impact of LLD on functional outcome.

Definitions of outcome measures: Limb lengthening refers to increase in limb length compared to its preoperative state measured either by clinical method or radiographic method. LLD is the difference in the length of the affected limb (operated with TKA) compared to the contralateral limb (either operated with TKA or a non-operated limb). If the operated knee was lengthened, a plus sign (+) was assigned, and if it was shortened, a minus (-) sign was allotted before the parameter. Perceived LLD indicates the perception of an individual about the limb length variation.

Literature search strategy

A literature search was performed by two authors (SKT, BBP) to identify all studies related to limb length variation/discrepancy following TKA. The electronic databases of PubMed/Medline, Embase, CINAHL and the Cochrane Central Register of Controlled Trials were searched using the keywords "limb length", "limb-lengthening", "LLD", "TKA" and "total knee replacement". The last search was performed on 22nd June 2020. The search was restricted to the English language. The title and abstract of retrieved articles were assessed for possible inclusion in the review. The bibliographic lists of the relevant articles and reviews were also searched for further potentially eligible. We resolved any discrepancies in study selection by a discussion between the authors. A third independent author (PV) was consulted in the event of disagreement (Figure 1).

Data collection

Data extraction was done using a data extraction form, and two authors (SSP, PV) independently extracted data from eligible studies (author, year of publication, study design, intervention, follow up, outcome). Any disagreement was resolved through

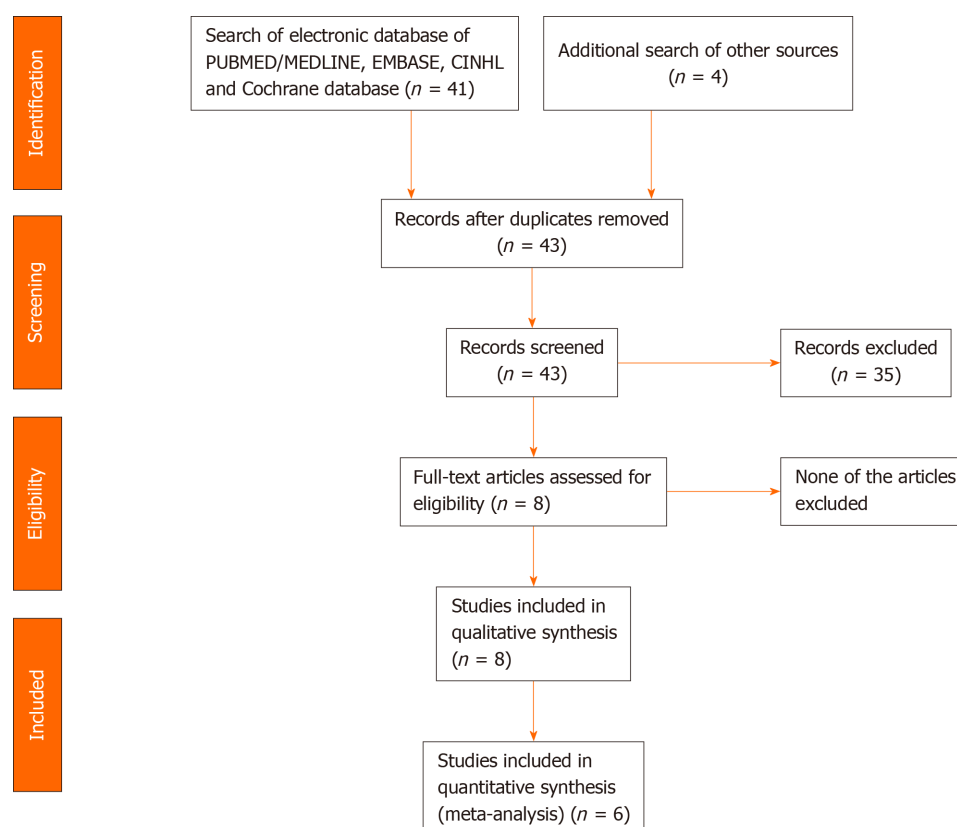


Figure 1 PRISMA Flow Diagram showing methods of study recruitment.

the discussion with a third author (SKT).

Methodological quality and risk of bias assessment

The methodological quality and risk of bias of the included articles were assessed independently by two authors (SKT, BBP) using the Newcastle–Ottawa scale (NOS)^[19] (Table 1). The NOS uses a star system with a maximum of nine stars to evaluate a study in three domains (8 items): The selection of the study groups, the comparability of the groups, and the ascertainment of the outcome of interest. Each item was allocated one star for low risk and no star for high risk. Studies that received a score of nine stars were considered as low risk of bias, seven or eight stars as moderate risk, and six or less as high risk of bias. Disagreements were resolved by discussion between the two reviewers. If no agreement could be reached, the opinion of a third author (TG) was sought.

Data synthesis

Data were analyzed using Review Manager (RevMan) V.5.1^[20]. Data were pooled and expressed as mean difference (MD) with 95%CI in case of continuous data. The odds ratio (OR) with 95%CI was calculated in categorical data. All the analyses were performed by Generic Inverse Variance method using random-effects weighting, where the log RRs (relative risk) for cohort studies or log ORs for case-control studies were weighted by the inverse of the variance to obtain a pooled RR estimate^[21]. A $P < 0.05$ was considered statistically significant. Inter-study heterogeneity was assessed by Cochrane's Q ($\chi^2 P < 0.10$) and quantified by I^2 . I^2 greater than 25% was considered as low heterogeneity, 50% as moderate, and $> 75\%$ as high heterogeneity. In order to address the high degree of heterogeneity, a random MD was calculated^[22,23].

RESULTS

Searches of electronic database identified 45 studies, of which eight studies were eligible for review (Figure 1). Four studies were retrospective cohorts, and four were prospective studies. Six studies followed the PICO format and recruited osteoarthritis (OA) knee patients with predefined inclusion and exclusion criteria. They evaluated

Table 1 Methodological quality assessment of eligible studies using Newcastle–Ottawa scale

Ref.	Selection				Comparability	Outcome				
	Representativeness of exposed cohort	Selection of nonexposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Adjust for the most important risk factors	Adjust for other risk factors	Assessment of outcome	Follow-up length	Loss to follow-up rate	Total quality score
	Postoperative limb length	Preoperative limb length	TKA	Limb lengthening/LLD	Age, sex, BMI	Varus/valgus deformity, KL grade <i>etc.</i>	Limb length change	Any postoperative period	< 20%	
Vaidya <i>et al</i> ^[11] , 2010	+	+	+	+	-	-	+	+	+	7 (moderate risk)
Lang <i>et al</i> ^[12] , 2012	+	+	+	+	+	+	+	+	+	9 (low risk)
Chang <i>et al</i> ^[13] , 2013	+	+	+	+	+	+	+	+	+	9 (low risk)
Tipton <i>et al</i> ^[14] , 2015	+	+	+	+	+	+	+	+	+	9 (low risk)
Kim <i>et al</i> ^[4] , 2015	+	+	+	-	+	+	-	+	+	7 (moderate risk)
Goldstein <i>et al</i> ^[15] , 2016	+	+	+	+	+	+	-	+	+	8 (moderate risk)
Chinnappa <i>et al</i> ^[16] , 2017	+	+	+	+	+	+	+	+	+	9 (low risk)
Hinarejos <i>et al</i> ^[17] , 2020	+	+	+	+	+	+	+	+	+	9 (low risk)

TKA: Total knee arthroplasty; LLD: Limb length discrepancy; BMI: Body mass index.

the limb lengthening/LLD or collected the data after the intervention (TKA). One study collected the data in a reverse way. They divided the patients into two LLD groups (> 15 mm *vs* ≤ 15 mm) and compared the parameters between them. Another study was totally focussed on perceived LLD (Table 2). The assessment of bias using the NOS scale revealed moderate bias in three studies and low bias in the other five studies (Table 1).

Limb lengthening after TKA

Five studies ($n = 1551$ knees) provided numeric data about the extent of limb length increase in the postoperative period of TKA^[12-14,16,17]. Overall, the limb was lengthened after TKA, and the average value of lengthening was 5.98 mm. There was a clinically relevant lengthening of ≥ 10 mm in 8.26% to 83.33% of patients after TKA (Figure 2).

Table 2 Details of the patients, intervention and follow up duration as mentioned in the studies

Ref.	Inclusion/exclusion criteria	No of knees (UL, BL)	Study design	Age in years \pm SD (range)	Sex (M:F)	BMI (Kg/m ²)	Intervention (TKA)	Follow up
Vaidya <i>et al</i> ^[11] , 2010 (level IV)	BL OA knee with varus deformity, operated for unilateral or bilateral TKA with minimum 6 mo follow up (<i>n</i> = 54 pts)	30 UL	Cohort retrospective	64 (48-80)	7:23	-	Mid-vastus approach; PFC sigma RP-F Highflex (56), PFC Sigma RP (26), IB II Zimmer (2); Patella replaced	Minimum 6 mo
		30 BL (six pts underwent stage wise TKA, included in both groups)	Cohort retrospective	65.8 (54-83)	6:24	-		Minimum 6 mo
Lang <i>et al</i> ^[12] , 2012 (level III)	BL OA knee (both varus and valgus) without significant extraarticular deformity (<i>n</i> = 102 pts)	102 (54 UL, 47 BL)	Cohort retrospective	70.3 \pm 9.9	35:67	30.0 \pm 6.4	Medial parapatellar approach, principles of flexion/extension gap balancing 85 CR and 17 PS	6 wk
Chang <i>et al</i> ^[13] , 2013 (level III)	Inclusion: TKA for primary OA knee with one year follow up. Exclusion: Pts with previous surgery on the ipsilateral limb, spine surgery, neurological disorders, cancer, death due to diseases unrelated to TKA, periprosthetic infection, or another condition capable of affecting the result of this study, such as depression, dementia, or problems of the contralateral knee were excluded (<i>n</i> = 466 pts)	761 knees (171 UL, 295 BL, 466 patients)	Cohort Retrospective study (prospectively collected data)	67.9 \pm 5.9 (49-84)	26:440	27.1 \pm 3.4	Medial parapatellar approach, patella replaced	1 yr
Tipton <i>et al</i> ^[14] , 2015 (level III)	Inclusion: Primary TKA with availability of both preoperative and postoperative standing full-length radiographs for measurement. Exclusion: Patients with gross bony deformities or poor quality radiographs were excluded (<i>n</i> = 137)	137 UL	Cross sectional Prospective study	68 \pm 10	40:82	30 \pm 5.0	Medial parapatellar approach, minimal bone resection with thinnest poly-insert	Postoperative setting
Kim <i>et al</i> ^[4] , 2015 ¹ (level IV)	Inclusion: Primary computer-assisted TKA in OA knee with varus deformity. Exclusion: Varus > 20°, hip pathology, osteotomy in the affected limb, severe bony defects, severe osteoporosis, flexion contracture > 30°, BMI > 30 kg/m ² , and spine deformity with pelvic tilt	148 (\leq 15 mm LLD in 81 knees, 55 pts; > 15 mm LLD in 67 knees, 52 pts)	Cohort retrospective	\leq 15 mm: 69.1 \pm 6.7; > 15 mm: 70.1 \pm 8.4	15:133	\leq 15 mm: 26.3 \pm 3.2; > 15 mm: 27.1 \pm 3.6	Mid-vastus approach, Orthopilot navigation system. PS implant. No patella resurfacing	Minimum 2 yr
Goldstein <i>et al</i> ^[15] , 2016 (level III)	Inclusion: Primary TKA for unilateral osteoarthritis between 18-90 yr of age. Exclusion: Pts with allergy or intolerance to the study materials, previous surgeries on the ipsilateral or contralateral joints or limbs likely to affect the outcome, substance abuse or dependence within the past 6 mo (<i>n</i> = 71)	71 UL	Cross sectional prospective study	65 \pm 8.4 (47-89)	27:44	35.1 \pm 9.9 (20.2-74.8)	Medial parapatellar or midvastus approach	1 yr
Chinnappa <i>et al</i> ^[16] , 2017 (level II)	Inclusion: Primary unilateral TKA without extraarticular deformity (<i>n</i> = 91). Exclusion: Patients with known leg length inequality due to other causes (radiographic leg lengthening post THA > 5 mm and longstanding leg length inequality > 5 yr requiring orthotics) were excluded.	91 UL	Cohort. Prospective study	70.2 \pm 8.9 (50-89)	34:57	29.4 \pm 5.0 (17.5-48.6)	Medial parapatellar approach, aim to restore neutral HKA axis. PS implant. Bone resection using Jig or computer navigation	Radiographic measurement on second postoperative day, functional outcome at 6 mo
Hinarejos <i>et al</i> ^[17] , 2020 (level II)	Inclusion: Unilateral primary TKA. Exclusion: Pts with previous fractures of the lower limbs, patients with surgeries or diseases affecting any of the hips or ankles, preoperative or postoperative flexion contracture > 5°, poor quality radiographs, patients without postoperative KSS evaluation (<i>n</i> = 460)	460 UL	Cohort. Prospective study	71 \pm 8.4	128:332	31.3 \pm 4.9	Medial parapatellar approach; intramedullary guide for femur and extramedullary jig for tibia, minimal bone resection with thinnest insert. CR in 30.4%, PS in 69.6%. Patella replaced	At 6 mo, radiographic evaluation; at 1 yr, functional evaluation

¹The study by Kim *et al*^[4], 2015 divided the study group into LLD ≤ 15 mm *vs* > 15 mm and then compared.

OA: Osteoarthritis; UL: Unilateral; BL: Bilateral; M: Male; F: Female; BMI: Body mass index; LLD: Limb length discrepancy; CR: Cruciate retaining; PS: Posterior stabilized; KSS: Knee society score; TKA: Total knee arthroplasty; HKA: Hip–knee–ankle angle.

LLD after TKA

Five studies mentioned about LLD after TKA^[11-13,16,17]. The LLD after TKA was ranging from 0.4 ± 10 mm to 15.3 ± 2.88 mm. The incidence of radiographic LLD after TKA was reported in 44% to 83.3% of patients. One study considered ≥ 10 mm as a relevant radiographic LLD and reported only 11% incidence of postoperative radiographic LLD taking 10 mm as the cut-off point^[16]. One study considered > 15 mm as clinically relevant and observed 45% of patients with significant postoperative LLD^[4] (Tables 3 and 4).

Three studies ($n = 1017$) mentioned the preoperative LLD^[13,16,17]. The value of preoperative LLD was ranging from -3 ± 8 mm to 6 ± 5 mm. Pooled analysis of these studies revealed no significant difference in preoperative and postoperative LLD (MD -1.23 ; 95%CI: $-3.72, 1.27$; $P = 0.34$). There was significant heterogeneity among these studies ($I^2 = 95\%$, $P < 0.00001$) and hence random mean values were assessed (Figure 3).

Perceived LLD

Three studies mentioned about perceived LLD^[11,15,16]. The incidence of perceived LLD in the preoperative period varies from 16% to 25%. Postoperative perceived LLD varies between 10% and 26.66%. However, the perception of postoperative LLD improved over time, and one study reported complete resolution of perception after an average duration of 8.5 wk^[15].

Factors affecting limb lengthening/LLD after TKA

Age/sex: Five studies assessed the impact of age on limb length variation or LLD^[4,12,15,16,17]. There was no significant association between LLD and age. Three studies evaluating the association of gender on radiographic LLD did not find a significant association^[15-17]. One study reported a significant association between perceived LLD and female gender^[16].

Body mass index: Seven studies evaluated the association between body mass index (BMI) and LLD^[4,12-17]. Six studies did not find any association between BMI and LLD/limb length variation^[4,12,14-17]. One study reported increased limb length with smaller BMI^[13].

OA grade: Two studies reported the grade of OA^[12,14]. One study reported the LLD of 3.9 ± 11.5 mm in patients with contralateral knee OA of Kellgren and Lawrence (KL) grade 3, 4 compared to 2 ± 5 mm in contralateral KL grade 1 and 2^[12]. Another study also reported -2.00 ± 8.87 mm limb lengthening in the ipsilateral knees with

Table 3 Limb lengthening/limb length discrepancy after total knee arthroplasty surgery

Ref.	Deformity (degree)			Pre-op LLD (mm)	Postop LLD (mm)	% of patients with limb lengthening/LLD	Limb lengthening (mm)	% of patients with perceived postop LLD	Factor affecting radiographic LLD/remarks
	Preop (°)	Postop (°)	Change in alignment (°)						
Vaidya <i>et al</i> ^[11] , 2010	-	-		-	15.3 ± 2.88	83.3 (≥ 10 mm in all)		8 (26.7)	LLD is more common after unilateral TKA than bilateral. LLD of ≥ 2 cm is perceived by patient after unilateral TKA. LLD affects the functional outcome after UL TKA in BL OA knee with varus deformity
	-	-		-	5 ± 2.01	46.66 (≥ 10 mm in all)		0	
Lang <i>et al</i> ^[12] , 2012	2.5	1	1.5	-	2 (95%CI: 0.5-3.5)	83.3%	6.3 ± 6.85 (range -11-24)	-	Limb lengthening is frequent after TKA and is almost similar to that of nonoperative limb. Limb lengthening had no relationship with age ($P = 0.864$), sex ($P = 0.514$), BMI ($P = 0.548$), or constraint type ($P = 0.849$), contralateral OA knee severity. LLD in bilateral TKA is minimal but it is significantly different in unilateral TKA
Chang <i>et al</i> ^[13] , 2013	11.9 ± 5.5° (37° to -9°)	1.5 ± 2.7 (11° to -6°)	10.4	6 ± 5	5 ± 4	43.9% limb lengthening by ≥ 10 mm, 3.4% limb shortening of ≥ 10 mm	9 ± 1.1	-	Greater LL increase was correlated with a greater preoperative HKA angle and smaller BMI. Preoperative flexion contracture, postoperative flexion contracture and postoperative HKA have no correlation to LL. Limb length, height, and weight increased, BMI remained unchanged, and LLD decreased 1 year after TKA. The bilateral group had a greater height increase and lower rate of LLD
Tipton <i>et al</i> ^[14] , 2015	4.16	2.76	1.40	-	-	59.1%	4.28 ± 1.11, 59% reported increase in limb length by 4.38 mm		There was no correlation BMI with limb length. Limb lengthening after TKA does not frequently occur to a statistically significant extent, regardless of preoperative joint state
Goldstein <i>et al</i> ^[15] , 2016	-	-	-	-	-	-	-	10%	Perceived LLD is common in patients undergoing TKA and it decreases after surgery. About 10% of patients perceive a LLD after surgery and it usually resolves with time. Age, BMI, Preoperative and postoperative mechanical axis and preoperative perceived LLD has no correlation with postoperative perceived LLD
Chinnappa <i>et al</i> ^[16] , 2017	-3.1	0.8	3.9	-3.0 ± 8.0	0.4 ± 10	77% (≥ 10 mm in 11%)	3.5 ± 8.4 (77% lengthened: Mean 6.7 ± 4.9 mm; 23% shortened: Mean -7.4 ± 8.5)	14%	Radiographic LLD is uncommon after TKA. It has no correlation with age, sex, BMI, polyethylene insert thickness, pre-operative FFD, post-operative FFD, contralateral knee OA, or arthroplasty, severity of pre-operative angular deformity or degree of angular correction. Post-operative radiographic LLD is associated with increased preoperative LLD ($P < 0.001$). Perceived post-operative LLD was associated with female gender ($P = 0.02$), decreased satisfaction (18% vs 84%, $P < 0.001$) and poorer functional score
Hinarejos <i>et al</i> ^[17] , 2020	5.5 ± 7.7	3.7 ± 3.8	1.8	-1.1 ± 6.4	0.8 ± 6.1	60% (≥ 10 mm in 8.26%)	1.9 ± 8.84		Increased LLD has no correlation with age, gender, BMI, HKA angles or with preoperative knee function. However HKA angle changes correlate with LLD. Significant LLD is not frequent after TKA, but the functional results of the surgery can be suboptimal when it is present

Limb length measurement: Vaidya *et al*^[11], 2010-clinical method of measurement using measuring tape was used for limb length measurement in supine position; remaining. OA: Osteoarthritis; BMI: Body mass index; LLD: Limb length discrepancy; TKA: Total knee arthroplasty; HKA: Hip – knee – ankle angle.

preoperative KL grade 1, 2 and 0.594 ± 1.11 mm in KL grade 3 and 4^[14] (Table 4).

Preoperative deformity: Two studies ($n = 239$) evaluated the limb length alteration in varus ($n = 153$) and valgus ($n = 101$) deformity (Figure 4A and B)^[12,14]. The average increase in limb-length in valgus deformity (mean 7.06; 95%CI: 4.29, 9.84) was significantly higher than varus deformity (mean 4.42 mm; 95%CI: 3.02, 5.82) (Figure 4A-C). However, there was a high degree of heterogeneity among the studies ($I^2 = 90\%$). One study reported limb length increase of 4.7 mm for every 10-degree correction of varus deformity and 6.2 mm for every 10-degree correction of the valgus deformity^[12] (Table 4).

Unilateral vs bilateral: Three studies ($n = 617$) compared the LLD in unilateral TKA and bilateral TKA^[11-13]. All these studies reported a higher LLD following unilateral TKA ($n = 255$) than bilateral ($n = 372$). The pooled data of three studies comparing unilateral TKA and bilateral TKA noted no significant difference in LLD (MD 4.5 mm, 95%CI: 11.4, 2.40; $P = 0.20$). However, there was a high degree of heterogeneity among the studies ($I^2 = 99\%$, $P < 0.001$) (Figure 4D).

Correlation of radiographic parameters with perceived LLD: One study evaluated the correlation of radiological LLD to perceived LLD^[16]. Clinically relevant LLD of ≥ 10 mm was noted only in 11% of patients, whereas perceived LLD was observed in 21% of patients^[16]. Another study did not find any correlation of change in mechanical axis to perceived LLD^[15].

Effect of LLD on the functional outcome

Four studies reported the effect of LLD on functional outcome^[4,11,16,17] (Table 5). The study by Kim *et al*^[4] categorized their patients into > 15 mm *vs* ≤ 15 mm^[4]. They reported a significantly inferior outcome in patients with LLD of > 15 mm. The data of the remaining three studies ($n = 611$) were pooled to look for the functional outcome in patients with LLD of < 10 mm ($n = 453$) *vs* ≥ 10 mm ($n = 158$). The functional outcome [Knee society score (KSS) function] was significantly worse in patients with LLD of ≥ 10 mm (standard MD 0.58; 95%CI: 0.06, 1.10; $P = 0.03$). There was moderate heterogeneity among the studies ($I^2 = 68\%$, $P = 0.05$) (Figure 5).

DISCUSSION

The main finding of this review is that limb lengthening after TKA is common with an average lengthening of 5.98 mm. The limb lengthening after TKA is significantly more in the valgus knee compared to varus knee. Assessment of pooled data regarding the impact of LLD on function revealed worse functional outcome with LLD of ≥ 10 mm. Thus LLD of ≥ 10 mm may be considered as one of the causes of dissatisfaction or poor outcome after TKA.

There is a wide variation in reporting of limb length measurement after TKA. The incidence of LLD/ limb length variations in the published studies varies between 44% and 83% of patients^[11-17]. This wide variation could be because of different inclusion criteria of the patients and different methods of measurement. Vaidya *et al*^[11] measured the limb length using measuring tape^[11], and other studies evaluated the radiographic limb length. The radiographic limb length measurement is more precise and seems to be a better method^[12-17]. The radiographic method of limb length measurement as proposed by Lang *et al*^[12] has been widely used and recommended for uniformity in limb length assessment^[12]. Hinarejos and his associates proposed that the presence of flexion contracture can affect the limb length^[17]. Ohmori *et al*^[24] performed a simulation study and reported the importance of “flexion contracture” and “HKA angle correction” on limb length alteration following TKA^[24]. Immediate postoperative evaluation (2 d to 6 wk) for radiographic LLD can affect the limb length because of flexion attitude of the limb. Hence, the timing of limb length measurement has an impact on LLD, and the ideal time should be after six weeks when most of the residual deformities are corrected, and pain is minimal^[16].

There are multiple factors that affect LLD after TKA^[11,18]. Age and gender were not found to be associated with radiographic LLD in many studies^[12-17]. It is difficult to comment on the impact of BMI on LLD, as few studies have omitted morbid obese patients in their series^[4]. Chang *et al*^[13] reported the association between greater LLD with smaller BMI in their series of 466 patients at one-year follow-up^[13]. All studies reported a greater increase in limb length following valgus deformity than varus^[12,14].

Table 4 Factors affecting limb length variation/limb length discrepancy in total knee arthroplasty

Ref.	Type of deformity									
	Varus					Valgus				
	No of knees	Preop varus (°)	Postop varus (°)	Change in angle	Average lengthening	No of knees	Preop varus (°)	Postop varus (°)	Change in angle	Average lengthening
Lang <i>et al</i> ^[12] , 2012	66	8.7 ± 4.6	2.1± 2.5	-6.6	5.2 ± 5.8 (S)	36	-8.9 ± 5.9	-1.1 ± 3.3	-7.8	8.4 ± 8.2 (S)
Tipton <i>et al</i> ^[14] , 2015	87	9.34 ± 4.66	4.86 ± 3.03	-4.99 (4.77)	3.77 ± 11.1 (S)	45	-6.67 ± 5.79	-0.468 ± 3.57	-6.08 ± 5.72	5.56 ± 11.3 (S)
	Severity of deformity									
	-10 to 10 degree		< -10 (valgus)		> 10 (varus)					
	No of knees	Limb length change	No of knees	Limb length change	No of knees	Limb length change				
Lang <i>et al</i> ^[12] , 2012	65	4.7 ± 6.4 (S)	12	12 ± 8.6 (S)	25	7.9 ± 5.2 (S)				
Tipton <i>et al</i> ^[14] , 2015	93	1.64 ± 10.3 (NS)	9	15.1 ± 10 (NS)	35	8.51 ± 10.7 (NS)				
	Unilateral or bilateral TKA									
	Unilateral TKA		Bilateral TKA							
	No of knees	LLD	No of knees	LLD						
Vaidya <i>et al</i> ^[11] , 2010	30	15.3 ± 2.88	30	5 ± 2.01 (S)						
Lang <i>et al</i> ^[12] , 2012	54	3.0 (95%CI: 0.5-5.4, NS)	47	0.9 (95%CI: -0.9-2.7, NS)						
Chang <i>et al</i> ^[13] , 2013	171	6 ± 4	295	5 ± 4 (S)						
	Severity of OA in contralateral nonoperative limb/ipsilateral limb in preoperative period									
	KL 1, 2			LLD (mm)		No of knees in KL 3, 4			LLD (mm)	
Lang <i>et al</i> ^[12] , 2012	Contralateral knee OA status (<i>n</i> = 26)			2 ± 5		Contralateral limb status (<i>n</i> = 28)			3.9 ± 11.5 (NS)	
Tipton <i>et al</i> ^[14] , 2015	Ipsilateral preop knee OA status			-2.00 ± 8.87 (only limb lengthening)		Ipsilateral preop knee OA status			0.594 ± 1.11 (NS)	

S: Significant $P < 0.05$, NS: Non-significant $P > 0.05$; OA: Osteoarthritis; LLD: Limb length discrepancy; TKA: Total knee arthroplasty.

The pooled analysis of two studies reporting the limb length variation following TKA observed limb lengthening of 7.06 mm in valgus deformity *vs* 4.42 in varus deformity ($P < 0.05$)^[12,14]. The LLD (MD -2.69 mm; 95%CI: -5.11, -0.27) was significantly less in varus knee compared to the valgus knee. While all three studies demonstrated a smaller LLD in bilateral TKA compared to unilateral TKA, the assessment of pooled data did not show a statistically significant difference in LLD between unilateral and bilateral cases^[11-13].

Recently, the perceived postoperative LLD or the awareness of LLD among patients is getting more acceptances among the researchers^[15]. It has no association with radiographic LLD^[16]. Studies have shown no association between mechanical HKA angles and perceived LLD^[15]. Goldstein *et al*^[15] observed 25% preoperative LLD and only 10% in the postoperative period. Of 18 patients (25%) with preoperative LLD in their series, only one had persistent LLD in the postoperative period. They concluded that most of the preoperative LLD gets settled with surgery. In patients with persistent or newly developed postoperative LLD, complete resolution was noted within three months period^[15]. Chinnappa *et al*^[16] observed an increased incidence of postoperative LLD among female patients^[16].

The pooled analysis of 611 patients revealed statistically significant inferior functional outcome in patients with radiographic LLD of ≥ 10 mm^[11,16,17]. Evaluation with functional KSS in these three studies maintained the homogeneity; however, the

Table 5 Correlation of limb length discrepancy to functional outcome

Ref.	Functional score	Functional outcome	LLD vs functional outcome	Perceived LLD	Remarks
Vaidya <i>et al</i> ^[11] , 2010	Knee society clinical rating system	Mean score in UL group was 73 ± 16.79 (95%CI: 66.73-79.27 (range 45-100))	No LLD (5): Functional score 85; LLD 10 mm (5): functional score 83; LLD 20 mm (19): Functional score 68.16; LLD 30 mm (1): Functional score 55; < 10 mm (21): 82.1429 ± 9.439 ; ≥ 10 mm (39): 73.9744 ± 5.261	26.66% (8) pts perceived LLD; no LLD: Not perceived; LLD 10 mm: Not perceived; LLD 20 mm: 7 patients; LLD 30 mm: One patient	The functional outcome after UL TKA in BL OA knee with varus deformity is inferior to BL TKA
	Knee society clinical rating system	Mean score in BL group was 80.67 ± 21.2 (95%CI: 72.75-88.58, range 0-100).	No LLD (16): Functional score 81.25; LLD 10 mm (13): Functional score 80; LLD 20 mm (1): Functional score 80	No one perceived LLD	
Kim <i>et al</i> ^[4] , 2015	KSS function score		LLD > 15 mm: KSS function score 88.2 ± 7.0 ; LLD ≤ 15 mm: KSS function score 80.1 ± 14.7 (S); no difference in ROM, HSS, KSS knee score and WOMAC	Not evaluated	Patients with LLD of > 15 mm had significantly inferior outcome than LLD < 15 mm. Preop LLD has high risk of postop LLD. Patients with unilateral TKA have higher chances of postoperative LLD
Chinnappa <i>et al</i> ^[16] , 2017	WOMAC; KSS knee; KSS; function 6 mo		LLD < 10 mm: 89% pts.; LLD ≥ 10 mm: 11% pts. a: 37.1 ± 16 in ≥ 10 mm LLD vs 30.8 ± 21.2 with < 10 mm LLD (NS); b: 37 ± 20.8 in ≥ 10 mm LLD vs 29.2 ± 35.2 with < 10 mm LLD (NS); c: 29.4 ± 21.2 in ≥ 10 mm LLD vs 23.6 ± 27.7 with < 10 mm LLD (NS)	Preoperative LLD: 16% pts. Postoperative LLD: 21% pts. a: 13.1 ± 22.6 in ≥ 10 mm LLD vs 35.5 ± 18.8 with < 10 mm LLD (S); b: 16.2 ± 26.2 in ≥ 10 mm LLD vs 31.0 ± 34.1 with < 10 mm LLD (NS); c: 15.3 ± 28.9 vs 26.1 ± 27.1 (NS)	Significant radiological LLD (≥ 10 mm) after TKA is uncommon (11%) and doesn't correlate to perceived LLD. Perceived LLD is associated with decreased satisfaction and function
Hinarejos <i>et al</i> ^[17] , 2020	Function KSS	Mean preop score of 51.3 ± 13.5 improved to 80.5 ± 15.1 at 12 mo ($P < 0.0001$)	LLD < 10 mm (422, 91.7%): Functional score 82.3 (14.6). LLD ≥ 10 mm (38, 8.3%): Functional score 76.7 (14.0)	Not evaluated	Patients with LLD of > 10 mm had significantly worse outcome

S: Significant $P < 0.05$; NS: Non-significant $P > 0.05$; KSS: Knee society score; HSS: Hospital for special surgery score; WOMAC: Western Ontario and McMaster Universities scores; LLD: Limb length discrepancy; TKA: Total knee arthroplasty.

points allocated for each question were different in the study of Chinnappa *et al*^[16] 2017. Hence standard mean difference was taken into consideration. Kim *et al*^[4] also observed significant functional difference among patients with better ability in terms of stair climbing and KSS functional score in patients with radiographic LLD of ≤ 15 mm^[4]. However, they included only preoperative varus knee with 15 mm LLD as the cut-off point. Chinnappa *et al*^[16] reported no significant association between radiographic LLD (≥ 10 mm) with KOOS, KSS and WOMAC score; however, the perceived LLD showed significantly lower functional score in the domains of KOOS Pain, KOOS Activities of Daily Living, KOOS Quality of Life and WOMAC functional scores^[16]. There is decreased satisfaction among patients with perceived LLD.

There are certain limitations to this review. First of all, all the studies were of low to moderate evidence. The high level of heterogeneity among the studies reflects the deficiencies in the currently available evidence. Second, we could perform a limited meta-analysis because of the clinical and methodological heterogeneity. There were no uniformity in limb length assessment, data evaluation and functional outcome assessment. The strength of this review is that it is the first qualitative and quantitative synthesis of evidence on leg length discrepancy in TKA. This study clearly showed that there was a significant impact of LLD on functional outcome. LLD after TKA is probably an important but under-reported modifiable cause of dissatisfaction.

CONCLUSION

In conclusion, radiological limb lengthening is common after TKA, but it may not be clinically relevant as the limb length increase is usually below 10 mm. Significant limb lengthening of ≥ 10 mm after TKA is uncommon, but it is associated with suboptimal functional outcome. There is no correlation between radiographic LLD and perceived

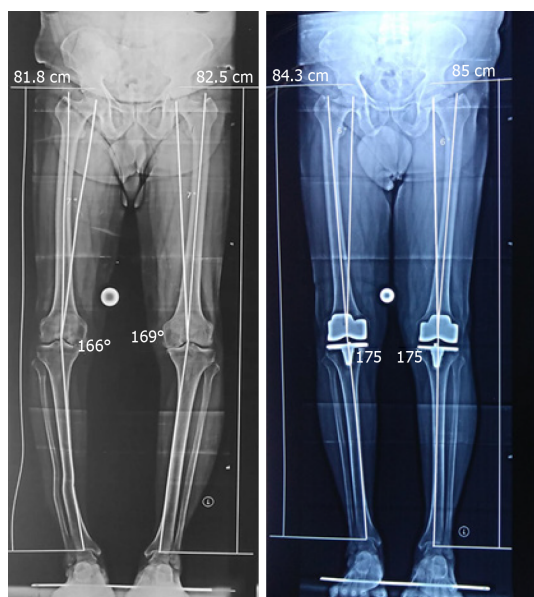


Figure 2 Preoperative and postoperative scanogram showing limb length variations in a 63-year-old male patient. Preoperative hip—knee—ankle angle (HKA) angle Rt, Lt: 166°, 169°, limb length Rt, Lt: 81.8 cms, 82.5 cms; postoperative HKA angle Rt, Lt: 175°, 178°, limb length Rt, Lt: 84.3 cms, 85 cms.

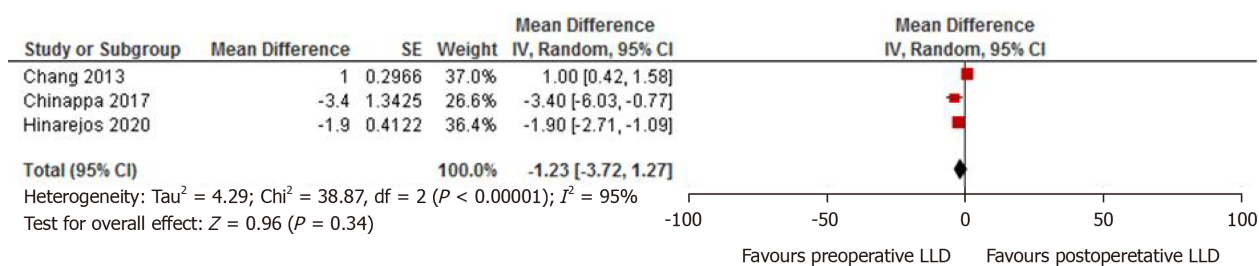


Figure 3 Forest plot showing limb length discrepancy in the preoperative period and postoperative period. LLD: Limb length discrepancy.

LLD. Patients with perceived LLD are less satisfied, and they usually have a poor functional outcome. The surgeon should be aware of such a possibility and should avoid excess limb lengthening. Probably better-designed trials on LLD in TKA can explore the deficiencies, and more research on perceived LLD can further evaluate its impact on the functional outcome.

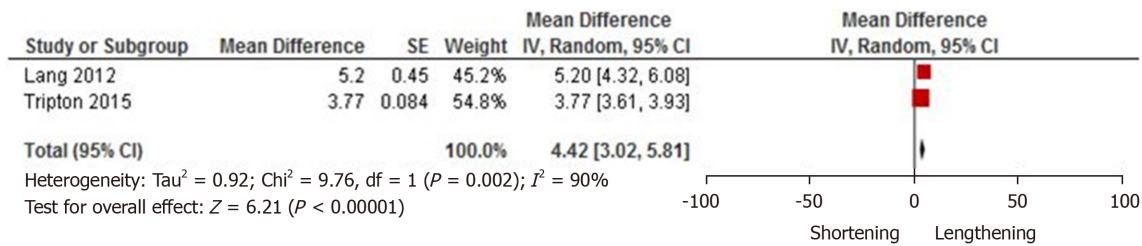
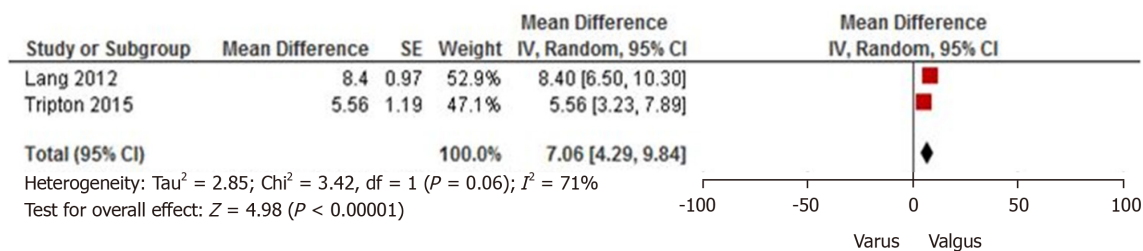
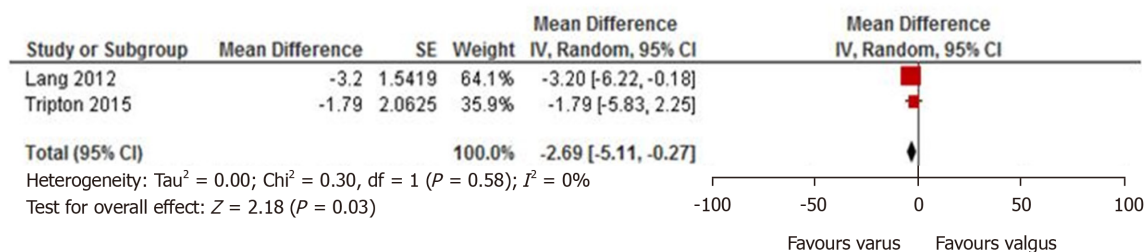
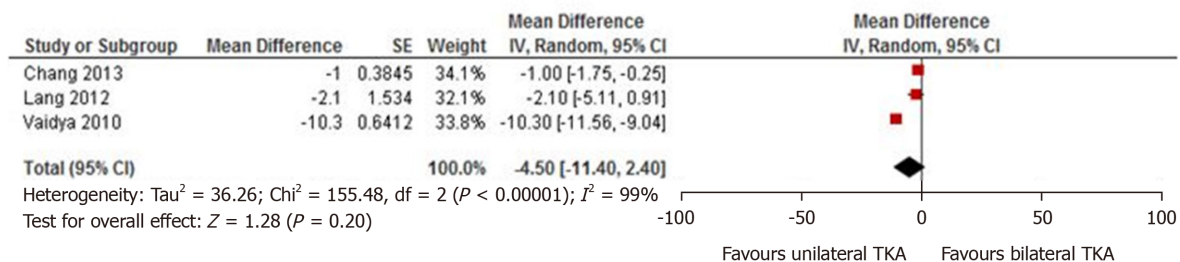
A Forest plot showing limb lengthening in varus deformity**B** Forest plot showing limb lengthening in valgus deformity**C** Forest plot showing limb lengthening in varus and valgus deformity**D** Forest plot showing LLD in unilateral and bilateral TKA

Figure 4 Forest plot showing limb lengthening/limb length discrepancy in varus deformity, valgus deformity and unilateral/ bilateral total knee arthroplasty. TKA: Total knee arthroplasty; LLD: Limb length discrepancy.

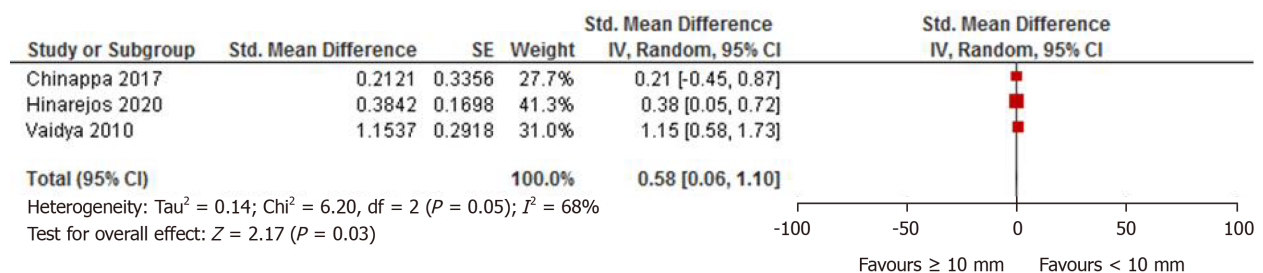


Figure 5 Forest plot showing functional outcome in patients with limb length discrepancy < 10 mm vs ≥ 10 mm.

ARTICLE HIGHLIGHTS

Research background

Limb length discrepancy (LLD) following total knee arthroplasty (TKA) has not been widely studied; however, a significant LLD has been considered as one of the important reasons for an unsatisfactory outcome.

Research motivation

There is currently no consensus about the extent of LLD that can be considered as clinically relevant following TKA. Again, few studies did not find radiographic LLD as a prognostic factor of functional outcome and stressed upon perceived LLD. Accordingly, the available studies were searched and evaluated in this systematic review and meta-analysis.

Research objectives

The objective of this systematic review was to evaluate the limb lengthening or LLD after TKA. The extent of LLD in varus and valgus deformities and in unilateral and bilateral TKA was also assessed. The impacts of radiographic and perceived LLD on the functional outcome were also evaluated.

Research methods

All randomized controlled trial and observational studies on LLD in TKA, published till 22nd June 2020, were systematically reviewed. The primary outcome was “limb lengthening or LLD after TKA”. The secondary outcomes included “assessment of LLD in varus/valgus deformity” and “impact of LLD on the functional outcome”. Data were analyzed using Review Manager (RevMan). Data were pooled and expressed as MD with 95%CI in case of continuous data. The odds ratio with 95%CI was calculated in categorical data. Inter-study heterogeneity was assessed by Cochrane's Q ($\chi^2 P < 0.10$) and quantified by I^2 . The random MD was calculated to address the high degree of heterogeneity.

Research results

Of 45 studies, qualitative and quantitative assessment of data was performed from eight studies and six studies, respectively. Five studies ($n = 1551$) reported the average limb lengthening of 5.98 mm. The LLD after TKA was ranging from 0.4 ± 10 mm to 15.3 ± 2.88 mm. The incidence of radiographic LLD after TKA was reported in 44% to 83.3% of patients. There was no difference in preoperative and postoperative LLD (MD -1.23; 95%CI: -3.72, 1.27; $P = 0.34$). Pooled data of two studies ($n = 219$) revealed significant limb lengthening in valgus deformity than varus (MD -2.69; 95%CI: -5.11, 0.27; $P = 0.03$). The pooled data of three studies ($n = 611$) showed significantly worse functional outcome in patients with LLD ≥ 10 mm compared to < 10 mm (standard MD 0.58; 95%CI: 0.06, 1.10; $P = 0.03$).

Research conclusions

Limb lengthening after TKA is common, and it is significantly more in valgus than varus deformity. Significant LLD (≥ 10 mm) is associated with suboptimal functional outcome. There is no correlation between radiological LLD and perceived LLD. Patients with perceived LLD are less satisfied, and they usually have a poor functional outcome.

Research perspectives

The arthroplasty surgeon should be aware of the possibility of LLD following TKA, and they should take appropriate measures to avoid significant lengthening. However, more research on perceived LLD can further evaluate its impact on the functional outcome.

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