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Are percutaneous epiphysiodesis and Phemister technique effective in the treatment of leg-length discrepancy? A systematic review

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Epiphysiodesis is considered the preferred treatment for children predicted to have leg length discrepancies (LLDs) 2–5 cm at maturity. The aim of this study was to systematically review the existing literature on the effectiveness of permanent epiphysiodesis for LLD treatment, and secondarily to address the reported complications of permanent epiphysiodesis techniques. This systematic review was performed according to PRISMA guidelines. We searched MEDLINE (PubMed), Embase, Cochrane Library, Web of Science and Scopus for studies on skeletally immature patients with LLD treated with permanent epiphysiodesis. The extracted outcome categories were effectiveness of epiphysiodesis (LLD measurements pre/post-operatively, successful/unsuccessful), physeal fusion/arrest, and complications that were graded on severity. Forty-nine studies (3051 patients) were included, 1550 underwent Phemister/modified Phemister epiphysiodesis and 1501 percutaneous epiphysiodesis (PE). Total successful permanent epiphysiodesis surgeries (16 studies) were 73.7% (516/700). Only 13 out of 23 studies had a mean final LLD of less than 1.5 cm. In total, 17.5% (513/2936) of complications were reported. 57 angular deformities were reported (1.9%). Phemister technique had higher percentage of complications (39%) than PE (19.1%) in total, but when failure to achieve adequate reduction in LLD was not included, complication rates for both were close to 14%. However, severe complications were 10.2% for Phemister group and 5.1% for PE. The high complication rates and the relative low success rate call for optimization of the timing and the applied techniques when treating LLD with permanent epiphysiodesis. Phemister technique was found to have higher percentage of severe complications than PE. Registration: PROSPERO (CRD42023435177). ***J Pediatr Orthop B*** **33: 543–551**

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Introduction

Leg length discrepancy (LLD) or anisomelia refers to the condition where the length of the paired lower extremity limbs is visibly unequal, and the prevalence of LLD greater than 2 cm is 1/1000 [1]. The causes of LLD are numerous, including congenital and developmental causes, trauma, infection, or idiopathic [2]. While minor differences in limb length may not significantly impact daily activities, individuals with a LLD of 2 cm or more may experience several adverse effects [3]. These can include feelings of imbalance, low-back pain, altered biomechanics affecting the lumbar spine, increased risk of hip and knee osteoarthritis, and an abnormal gait [4–7].

The management of LLD in children aims to achieve equal leg lengths and restore normal lower limb alignment. Several treatment modalities have been utilized, including shoe lifts, orthotics, and surgical interventions. Epiphysiodesis, the process of closing the growth plate, is considered the preferred treatment for children who are predicted to have leg length discrepancies (LLDs) ranging from 2 to 5 cm at maturity [2]. This treatment option is applicable when the growth plates (physes) are still open and there is enough remaining growth potential. There are two primary types of epiphysiodesis: permanent and temporary. Temporary epiphysiodesis is a reversible procedure where the growth plate is temporarily slowed down to manage LLD [8]. Permanent epiphysiodesis refers to an irreversible intervention, where the growth plate is closed permanently, and the goal is to achieve leg-length equality while minimizing the risk of

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complications associated with more invasive surgical procedures, such as limb lengthening [9]. Most used techniques for permanent epiphysiodesis are percutaneous epiphysiodesis (PE) with drills/curettes and Phemister/modified Phemister technique [10,11].

Campens *et al*. in a retrospective series over a 21-year period found no statistically significant difference between PE and Phemister technique concerning their efficacy in correction of LLD, while complication rates were also comparable [12]. Burger *et al*. reported on results using the PE for idiopathic LLD and found a mean correction of 13 mm (LLD 21 mm pre-operative and 8 mm post-operative) [13]. Although a great number of studies reporting the use of permanent epiphysiodesis have been published, there is currently no systematic review that summarizes the outcomes from the existing literature on the topic. Permanent epiphysiodesis was in the present study, defined as techniques that involved a destruction of a substantial part of the growth plate with the intent of bony fusion.

The aim of this study was to systematically review the existing literature on the effectiveness of permanent epiphysiodesis for the treatment of LLD in the pediatric population. The secondary aim was to address the reported complications of PE and Phemister surgical procedures.

Methods

This systematic review was performed according to Preferred Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [14] and registered with PROSPERO (CRD42023435177). Due to the nature of this study being literature-based, ethical approval was not necessary.

Information sources and search strategy

Eligible studies were identified through a predefined search strategy of electronic databases. We searched MEDLINE (PubMed), Embase, Cochrane Library, Web of Science and Scopus (last search date 25 November 2022). The search was carried out using combinations of the terms 'epiphysiodesis', 'limb length discrepancy', 'leg length discrepancy' and 'physiodesis'. Additionally, the terms 'tension band plating', 'guided growth' and 'eight plate' were added in the search strategy to also identify the studies that included both permanent and temporary epiphysiodesis technique. Search strategy is presented in Table S1, Supplemental digital content 1, *http://links.lww.com/JPOB/A98*. To prevent the inclusion of duplicate or overlapping samples, a thorough comparison of all studies was conducted. If overlap was found, the study with the highest number of events was chosen for inclusion. There were no restrictions on publication dates or language. Additionally, to ensure comprehensive coverage of the literature, we conducted a thorough search of the reference lists of included studies, relevant reviews identified through our systematic search, and the personal files of the authors.

Eligibility criteria

Inclusion criteria were as follows: (1) skeletally immature pediatric population, defined as growth being complete at age 14 years for girls and age 16 years for boys (2) LLD that was treated surgically (3) surgical techniques in which there is a surgical destruction of the growth, including Phemister and the modified Phemister technique, PE with drills/curette, or any other percutaneous technique that was mentioned as permanent epiphysiodesis.

Exclusion criteria were (1) non-operative treatment of LLD, or leg lengthening surgical treatment (2) epiphysiodesis for tall stature (3) hemiepiphysiodesis and angular deformity correction (4) temporary epiphysiodesis, including PE using transphyseal screws.

Considering the studies design, randomized controlled trials, controlled (non-randomized) clinical trials, prospective and retrospective cohort studies, case-control or nested case-control studies, analytical cross-sectional studies and case series were eligible for inclusion. Only human studies were included. We excluded case reports (defined as articles that describe and interpret one to three individual cases), experimental animal studies, letters, editorials, reviews, and commentaries.

Intervention - surgical techniques information

The Phemister technique entails removing a rectangular block of cortical bone, measuring 1 cm, which includes the outermost portion of the growth plate as well as the surrounding metaphyseal and epiphyseal bone from both the medial and lateral sides of the growth plate. The growth plate is then scraped out (curetted), and the bone blocks are reinserted after undergoing a 180-degree rotation. This results in the formation of a bone bridge that circumvents the growth plate [10].

In PE, the medial and lateral thirds of the growth plate are thoroughly scraped out (curetted) or a drill is passed several times through the physis, causing significant damage that effectively hinders any further growth [11].

Selection process

The eligibility criteria were used to screen all studies identified through the search strategy. The literature search was independently conducted by two authors (MT and JFJ), and any disagreements were resolved through discussion to reach a consensus. In instances where a consensus couldn't be reached, a third author provided guidance.

Data collection process

The study characteristics of each included study were assessed according to a predefined data extraction form

included in the Cochrane Handbook for Systematic Reviews. The following information was extracted from each study independently by two reviewers: study details (first author, country and year of publication), type of study, type of epiphysiodesis, study duration, inclusion/exclusion criteria, assessment pre-operatively (skeletal maturity definition, timing of epiphysiodesis, predicted length at maturity), surgery details (technique information, post-operative protocol), sample size, mean age, sex, LLD etiology, side and bone where the epiphysiodesis was performed, effectiveness of epiphysiodesis (LLD measurements pre/post-operatively, successful/unsuccessful), physeal fusion/arrest, follow-up duration, complications. Complications were categorized based on the classification system developed by Black *et al.* [15] (Table 1). All complications were identified by MT and assessed for severity. A second reviewer (SK) then evaluated and graded the complications based on their severity. In cases of disagreement between the reviewers, a consensus discussion was held to resolve the differences.

Because the studies included in the analysis varied significantly, it was not feasible to conduct a meta-analysis. Instead, a systematic review was performed, presenting a pooled analysis and a narrative synthesis of the results.

Quality assessment

Two reviewers worked independently to evaluate the quality assessment of included studies. To resolve cases in which the two reviewers' decisions differed, a third reviewer evaluated the text and decided upon its inclusion or otherwise. The methodological quality of studies was assessed by using Methodological Index for Non-Randomized Studies (MINORS) for non-randomized studies [16]. The items are scored 0 (not reported), 1 (reported but inadequate) or 2 (reported and adequate). The global ideal score is 16 for non-comparative studies and 24 for comparative studies. Supplementary material presents the MINORS criteria, giving explanation for each of them.

Table 1 Complication classification according to Black *et al.* [15]

Category	Definition	Examples
I	Minimal intervention required; treatment goal still achieved	Infection treated by antibiotics, effusion/edema, hematoma/haemarthrosis, knee pain, reduced knee range of motion, wound dehiscence/healing, skin burn/skin blistering, peroneal nerve neuropathy
II	Substantial change in treatment plan; treatment goal still achieved	Further surgical intervention/reoperation, infection treated by debridement or revision, wound dehiscence/healing if additional surgery is required, skin burn/skin blistering if additional surgery is required
IIIA	Failure to achieve treatment goal; no new pathology or permanent sequelae	Fracture, failure of growth plate arrest, failure to achieve adequate reduction in LLD, additional surgeries needed for LLD treatment
IIIB	Failure to achieve treatment goal and/or new pathology or permanent sequelae developed	Overcorrection, angular deformity, genu recurvatum, asymmetrical closure of the growth plate with progressive malalignment, exostosis, neurapraxia

Results

Data search results

The initial literature search conducted using the aforementioned databases yielded a total of 1469 articles. After removing duplicates and applying eligibility criteria to the titles and abstracts, 63 articles were deemed suitable for full-text review. The full-text articles underwent screening, applying the inclusion and exclusion criteria. Out of the screened articles, 14 were excluded (Table S2, Supplemental digital content 2, *http://links.lww.com/JPOB/A99*), resulting in 49 relevant studies that were included in the present systematic review [12,13,17–63]. There were 24 studies including only PE technique, eight only Phemister technique, eight PE and Phemister, six PE and temporary epiphysiodesis techniques, and three Phemister and temporary epiphysiodesis techniques. For the last two type of studies, only information about the permanent technique was extracted and presented in this systematic review. The literature selection process adhered to the PRISMA guidelines and is visually represented in Fig. 1.

Quality assessment of included studies

For non-comparative studies, the mean MINORS score was 7.8 (n = 37, ranging from 4 to 11, with an ideal score of 16). Comparative studies, on the other hand, achieved a mean MINORS score of 12.5 (n = 12, ranging from 7 to 17, with an ideal score of 24). A full overview of the scores per study is shown in Table S4, Supplemental digital content 3, *http://links.lww.com/JPOB/A100*.

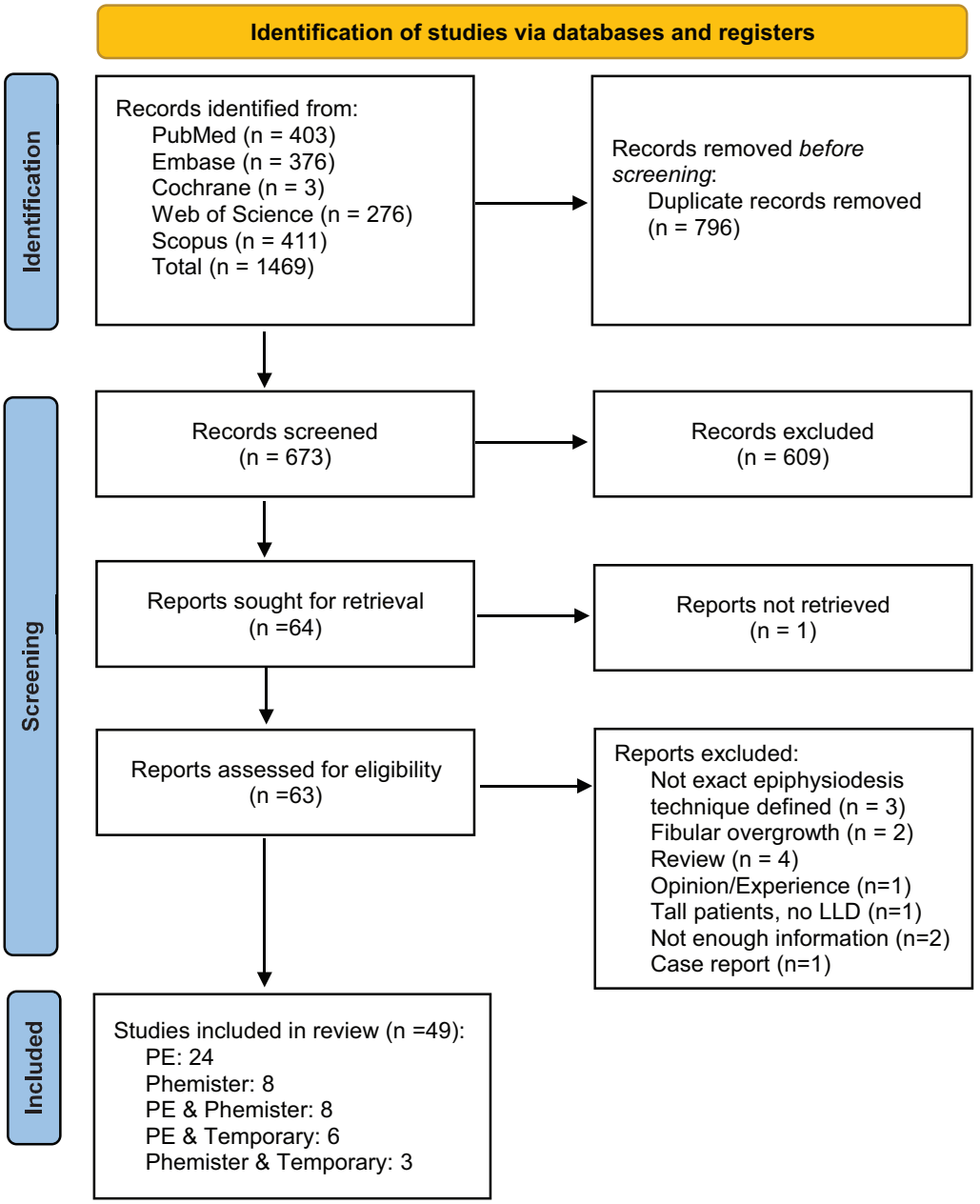
Demographic characteristic

The 49 studies included 3051 patients, from which 1550 underwent Phemister/modified Phemister epiphysiodesis and 1501 PE. Types of studies were the following: six cohort, 40 case series/retrospective review, two non-randomized comparative studies and one cost analysis study.

Eighteen studies were published between 2010–2022 [12,13,17,18,28–34,51–57], 10 studies between 2000–2009 [35–42,58,59] and 21 studies before 2000 [19–27,43–50,60–63]. The two main categories of LLD causes were congenital and idiopathic LLD. In addition, Phemister technique has been used only in four studies after 2000 (countries: two studies from the USA, two from Europe).

Nearly all studies except from five reported the pre-operative assessment method used, with the use of long-standing radiographs being the main assessment tool,

Fig. 1



PRISMA flowchart presenting the selection process for included studies, providing also reason for exclused studies.

followed by scanogram. In 27 studies (55%) patients were followed to maturity, and seven studies did not report the duration of the follow-up. Considering the methods used to predict final LLD, with the most used being Green-Anderson growth line (nine studies), Moseley straight line graph (eight studies) or one of these two (seven studies) and two Menelaus and White arithmetic model. Sixteen studies did not mention any method of prediction. Detailed presentation of each study characteristics is included in Table S3, Supplemental digital content 4, *http://links.lww.com/JPOB/A101*.

Effectiveness of permanent epiphysiodesis

Fifteen studies reported PE effectiveness, either by reporting successful/unsuccessful surgeries (seven studies) or by reporting pre- and post-operative LLD measurements (thirteen studies). Seven studies presented in total 187/254 (73.6%) successful PE surgeries and 67/254 (26.4%) unsuccessful ones. However, the definition of good result was different for most of the studies (Table 2). Thirteen studies (446 patients) reported initial LLD (range: 2.1–4.5 cm) and final LLD (range: 0.8–3.2 cm), with all of them showing a decrease of the LLD. Eleven

Table 2 Percutaneous epiphysiodesis studies with effectiveness as main outcome (successful/unsuccessful or LLD measurements initial/final and difference)

Study	Number of patients	Main outcome measurement	Successful	Unsuccessful	LLD initial (cm)	LLD final (cm)	Difference in LLD (cm)
Percutaneous epiphysiodesis (PE)							
Elizondo 2022 [28]	46	NM	NM	NM	2.8 ± 1.1 (0.7–5.8)	1.2 ± 1.3 (–2.1 to 4.8)	1.6
Burger 2019 [13]	18	Good ≤ 1 cm	14	4	2.1 ± 0.56 (1.4–3.2)	0.8 ± 0.36 (0.1–1.3)	1.3
Ramos 2018 [30]	29	Good ≤ 1.5 cm, acceptable 1.5–2 cm	20	9	3.0 (0.82–6.7)	1.7 (–0.3 to 4.58)	1.3
Niedzielski 2016 [31]	34	Criteria of Kemnitz and Campens (good ≤ 1.5 cm)	23	11	2.8 (2.0–4.5)	1.4 (0–3.5)	1.4
Ledesma 2016 [32]	44	Good ≤ 2.5 cm	32	12	3.1 (0.5–7.4)	2.2 (0–8.0)	0.9
Inan 2009 [36]	88	good ≤ 2.5 cm	NM	NM	3.3 (0–9.2)	1.3 (0–3.5)	2.0
Inan 2008 [37]	12	NM	NM	NM	3.0 (1.8–4.5)	1.25 (0–2)	1.75
Kemnitz 2003 [41]	57	Good ≤ 1.5 cm	39	18	2.7 (1.6–4.1)	1.2 (0–3)	1.5
Lejman 1999 [43]	25	NM	NM	NM	4.3 (2–10)	1.3 (0–4)	3.0
Craviari 1998 [44]	60	very good (–0.5 < LLD < 1 cm), good (1–1.5 or –1 to –0.5 cm)	48	12	3 (1.5–6.7)	NM	-
Gabriel 1994 [46]	12 (maturity)	Good ≤ 1 cm	11	1	NM	NM	-
Timperlake 1991 [47]	50	Acceptable ≤ 2 cm	NM	NM	3.2 (2.0–6.1)	1.5 (0.2–4.0)	1.7
Ogilvie 1990 [49]	7	NM	NM	NM	4.5 (2.5–6.2)	2 (0.9–3)	2.5
Canale 1990 [50]	22	NM	NM	NM	4.1	3.2	0.9
Babu 2014 [55]	14	NM	NM	NM	3.7	1.2	2.5
Total/range	518 patients (254 patients examined for success of PE, 446 patients with LLD measurements)		187/254 (73.6%)	67/254 (26.4%)	2.1–4.5	0.8–3.2	0.9–3.0

NM, not mentioned.

Table 3 Phemister/modified Phemister studies with effectiveness as main outcome (successful/unsuccessful or LLD measurements initial/final and difference)

Study	Number of patients	Main outcome measurement	Successful	Unsuccessful	LLD initial (cm)	LLD final (cm)	Difference in LLD (cm)
Phemister/modified Phemister technique							
Makarov 2018 [17]	77	NM	NM	NM	3.7 ± 1.3	2.0 ± 1.1	1.7
Koczewski 2013 [18]	35	Criteria of Kemnitz and Campens (good ≤ 1.5 cm)	26	9	3.8 (1.4–9.0)	1.7	2.1
Eckardt 1997 [19]	40	Good ≤ 1.5 cm	22	18	3.07 ± 1.52	1.66 ± 1.06	1.4
Macnicol 1997 [20]	35	Good ≤ 1.5 cm	32	3	3.3 ± 0.9 (2.0–4.5)	0.7 ± 0.6	2.6
Dewaele 1992 [21]	83	Good ≤ 1.5 cm	47	36	Group A: 3.8 (1.4–8.8); Group B: 2.9 (1.7–8.2)	Group A: 1.9; Group B: 1.5	Group A: 1.9; Group B: 1.4
Heeg 1992 [22]	67	Good ≤ 1 cm, satisfactory 1–1.5 cm	58 (47 + 11)	9	3.2 (2.4–5.7)	1.2	2.0
Blair 1982 [23]	67	Good ≤ 1 cm without polio, good ≤ 2 cm for polio	41	26	4.4 (2.2–8.3)	1.9	2.5
TOTAL/RANGE	404 patients (327 patients examined for success of PE, 404 patients with LLD measurements)		226/327 (69.1%)	101/327 (30.9%)	2.9–4.4	0.7–2.0	1.4–2.6

NM, not mentioned.

out of thirteen studies showed a mean final LLD of less than 2 cm, and nine studies with less than 1.5 cm. The range of decrease was 0.9–3.0 cm.

Considering Phemister efficiency, six out of seven studies reporting Phemister efficiency presented 226/327 (69.1%) successful Phemister surgeries and 101/327 (30.9%) unsuccessful ones, with all except one study defining good result as less than 1.5 cm final LLD (Table 3). The initial LLD (range: 2.9–4.4 cm) and final LLD (range: 0.7–2.0 cm) were reported in all seven studies and the LLD decrease ranged from 1.4 to 2.6 cm, with all the studies showing a mean final LLD of less than 2 cm, but only two studies with less than 1.5 cm.

Four studies presented the effectiveness of both techniques, with success number of surgeries 103/119 (86.6%)

Table 4 Percutaneous epiphysiodesis and Phemister/modified Phemister technique studies with effectiveness as main outcome (successful/unsuccessful or LLD measurements initial/final and difference)

Study	Number of patients	Main outcome measurement	Successful	Unsuccessful	LLD initial (cm)	LLD final (cm)	Difference in LLD (cm)
Percutaneous epiphysiodesis (PE) and Phemister/modified Phemister technique							
Campens 2010 [12]	67	Criteria of Kemnitz and Campens (good ≤ 1.5 cm)	57	10	3.2 (1.5–8.1)	1 (–0.5 to 4.6)	2.2
Grimm 1997 [60]	28	NM	NM	NM	3.8 (2.1–4.7)	2.1 (0–5)	1.7
Scott 1996 [61]	32	Based on the change in slope of growth line for the long leg on the Moseley straight line graph	Phemister: 10/12, PE: 17/20	Phemister: 2/12, PE: 3/20	NM	NM	-
Porat 1991 [63]	20	good ≤ 2 cm	19	1	CDH 3.0 ± 0.3, anisomelia 3.5 ± 1.0, infection 3.8 ± 0.8	CDH 0.7 ± 0.6, anisomelia 0.6 ± 0.08, Infection 0.5 ± 0.6	CDH 2.3, anisomelia 2.9, infection 3.3
TOTAL/ RANGE	518 patients (119 examined for success of PE and Phemister, 115 patients with LLD measurements)		103/119 (86.6%)	16/119 (13.4%)	3.0–3.8	0.5–2.1	1.7–3.3

CDH, congenital dislocation of the hip; NM, not mentioned.

and 16/119 (13.4%) unsuccessful ones (3 studies). The initial LLD (range: 3.0–3.8 cm) and final LLD (range: 0.5–2.1 cm) were reported in three studies, while the LLD decrease ranged from 1.7 to 3.3 cm (Table 4), with two out of the three studies reporting a mean final LLD of less than 1.5 cm.

Total successful permanent epiphysiodesis surgeries (16 studies) were 516 out of 700 (73.7%), while the unsuccessful ones 184 out of 700 (26.3%). In studies reporting good result ≤ 1.5 cm, success rate was the same with the total one (352/478 successful, 126/478 unsuccessful). Out of 23 studies that reported final LLD measurements after permanent epiphysiodesis, only 13 studies had a mean final LLD of less than 1.5 cm.

In 15 studies the main outcome was physeal arrest/fusion, mainly assessed by radiographs (Table S5, Supplemental digital content 5, *http://links.lww.com/JPOB/A102*). Other outcomes that were reported were LLD correction, cost- analysis, mechanical axis deviation (MAD), difference from the calculated discrepancy and mean longitudinal growth across the operated physis.

Complications

Two studies did not report complications [17,25], five studies reported that there were no complications [33,40,42,49,54], in two studies some complications were reported as minor without defining what those complications were [35,51].

Out of 2936 patients, 513 complications were reported in total (17.5%). 162 acute complications, 337 long-term (190 failure to achieve adequate reduction in LLD and 147 other long-term complications) and 14 not defined (Table 5). Considering angular deformities, 57 cases were reported (1.9%), with valgus being the main deformity. 1% of the patients underwent an additional surgery for LLD treatment, and failure of growth plate arrest occurred in 35 patients (1.2%) (Table 5). According to Black classification, there were 133 type I (4.5%), 24 type II (0.8%), 262 type IIIA (8.9%) and 80 type IIIB (2.7%) complications.

Phemister technique studies reported a higher percentage of complications (39%) than the PE studies (19.1%) (Table 6). When failure to achieve adequate reduction in LLD was not included as a long-term complication, the complication rates for both were close to 14% (Phemister: 14.3%; PE: 13.8%). However, severe complications were two times higher for the Phemister group (10.2%) than PE group (5.1%).

Table S6, Supplemental digital content 6, *http://links.lww.com/JPOB/A103* shows the complications for each study, while Table S7, Supplemental digital content 7, *http://links.lww.com/JPOB/A104* presents the complications according to subgroups of technique used (Phemister, PE, Phemister & PE).

Studies including both PE and Phemister technique

From eight studies including both PE and Phemister technique, only 3 reported statistical comparison between the two techniques [12,58,59]. Campens *et al.* [12] showed no significant difference both for successful results and complication rates (PE: 74% good results, 9% complication rate, Phemister: 89% good results, 6% complication rate). Surdam *et al.* [58] reported that occurrence of overall complications between the two populations was NS ($P = 0.1998$), while failure of the physis to close was also NS ($P = 0.194$). Alzahrani *et al.* [59] observed no statistically significant difference between the two groups, with no patient having failure of the growth arrest and 11% complications in both groups. Considering the remaining five studies, two studies [57,63] made no comparisons, while three studies [60–62] reported complication rate of

Table 5 Number of complications for both techniques according to Black [15]

	I	II	IIIA	IIIB	ND
Acute complications					
Infection	21	1			
Effusion/edema	40				
Hematoma/haemarthrosis	9				
Knee pain	24				
Reduced knee range of motion	16				
Fracture			5		
Wound dehiscence/healing	18				
Skin burn/skin blistering	3				
Further surgical intervention/reoperation		23			
Peroneal nerve neuropathy	2				
Long-term complications					
Failure of growth plate arrest			35		
Failure to achieve adequate reduction in LLD (according to definition of poor result)			190		
Overcorrection				14	
Angular deformity – Varus deformity				19	
Angular deformity – Valgus deformity				29	
Angular deformity (not defining what type)				9	
Genu recurvatum				1	
Asymmetrical closure of the growth plate with progressive malalignment			2		
Exostosis				4	
Neurapraxia				4	
Additional surgeries needed for LLD treatment			30		
Complications not defined (can't be categorized)					14
Total					All: 513

ND, not defined complications.

Table 6 Severity grade of complications for each type of studies/techniques

	Severity grade of complications[a]				
Factor	I	II	IIIA	IIIB	Sum
Phemister					
Number of complications	18	0	135	19	172
Complications per patient (n = 441), %	4.1	0	30.6	4.3	39
Complications per patient, % (N) without LLD poor result			5.9 (26)		14.3(63)
PE					
Number of complications	73	21	106	25	239[c]
Complications per patient (n = 1250), %	5.8	1.7	8.5	2.0	19.1
Complications per patient, % (N) without LLD poor result			3.1 (39)		13.8(172[c])
PE and Phemister					
Number of complications	42	3	21	36	102
Complications per patient (n = 1245), %	3.4	0.2	1.7	2.9	8.2
Complications per patient, % (N) without LLD poor result			1.2 (15)		7.7(96)
Total					
Number of complications	133	24	262	80	513[c]
Complications per patient (n = 2936), %[b]	4.5	0.8	8.9	2.7	17.5
Complications per patient, % (N) without LLD poor result			2.7 (80)		11.3(331[c])

[a]Black *et al.* [15].
[b]Not including the number of patients from studies that didn't mention complications.
[c]14 not defined type of complication added.

each group but without statistical analysis (complication rate respectively PE: 21%, 13%, 4%, Phemister 33%, 11%, 4,5%).

Discussion

Permanent epiphysiodesis has been performed for more than five decades. However, in light of new treatment options for LLD such as motorized lengthening nails, the current status of the relative minor surgery of permanent epiphysiodesis is of interest. This systematic review found a 73.7% successful level of permanent epiphysiodesis surgeries, and 17.5% complication rate from pooled analysis of the existing literature. In addition, Phemister technique had higher percentage of severe complications than the PE.

Although the use of permanent epiphysiodesis led to an amount of reduction in LLD, at the end of the treatment LLD still prevailed for a total number of 184 patients out of 700. These results may be due to the timing of the surgery. Only half of the studies included information about the surgery timing and the method used to identify the correct moment for the surgery to be performed. Accurate prediction of LLD at skeletal maturity is essential to ensure the effectiveness of epiphysiodesis [64]. Some

bias might have also occurred due to different types of reporting and accessing epiphysiodesis effectiveness, while reporting physeal arrest after few months cannot lead to conclusions about the success of LLD treatment. Another possible source of bias is the follow-up period, since not all the included studies were followed up to maturity.

Considering the complications, we found in total 513 complications in total number of 2936 patients, from which 190 were failure to achieve adequate reduction in LLD (according to definition of poor result). However, even without including this as a complication, the complication rate was still high (11.3%). These findings arise concern on both the safety and effectiveness of permanent epiphysiodesis techniques.

Current available literature includes only few studies that compared Phemister and PE techniques [12,57–63]. We found that PE had 73.6% success rate, while Phemister technique 69.1% success rate. From our findings, we cannot conclude if one of the techniques are superior to the other. Phemister technique had higher percentage of complications than PE in total, but when failure to achieve adequate reduction in LLD was not included as a long-term complication, the complication rates for both were close to 14%. However, we found more severe complications reported for Phemister technique. Considering the advantages and disadvantages of these techniques, PE is a more minimal invasive and simple technique with small scar, while both techniques are irreversible and require a rehabilitation time with crutches. The complications for PE and Phemister were extracted from 1691 patients, while for the effectiveness for each technique data were extracted from 581 patients. As a result, our findings for complications rate have a stronger impact than the ones for the effectiveness due to a larger sample size.

To our best knowledge, this is the first systematic review to summarize current knowledge on effectiveness of permanent epiphysiodesis for LLD treatment. No limitations in language were addressed to limit reporting bias. The use of Black *et al*. [15] classification leads to better understanding of the complications' severity for each technique. However, this study is not without limitations. The methodological differences of the included studies mainly in study design, intervention timing, follow-up and results reporting made it difficult to perform a meta-analysis. In addition, the low quality of the included studies might indicate that results of the current study's pooled analysis can't be generalized. No studies had complications as the main outcome and most studies were retrospective studies, which might increase the risk of underreporting of complications as previously shown for other elective surgery [65]. Bias might also arise from the different percutaneous techniques (drill or curettage), lack of examination at full maturity and the different methods of initial LLD evaluation.

The low quality of the existing literature increases the need for randomized control trials to be performed on the topic to compare the two techniques, as well as it highlights the need for better reporting of the pre-operation planning since timing of the surgery is the important factor for its better results in lessening length difference.

Conclusion

Our findings support that no conclusions can be drawn about the superiority of PE or Phemister technique on successful treatment of LLD, but Phemister technique was found to have higher percentage of severe complications than PE. The low quality of the studies demonstrates the need for randomized control trials to be performed on the topic. Furthermore, this systematic review of the literature revealed a complication rate that calls for optimization of the timing and the applied techniques when treating LLD in pediatric patients with permanent epiphysiodesis.

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Ethics statement: An ethics statement is not applicable because this study is exclusively on published literature.

Conflicts of interest

There are no conflicts of interest.

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