




Lateral column lengthening versus subtalar arthroereisis for paediatric flatfeet: a systematic review

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Abstract

Purpose This systematic review aimed to compare radiographic correction, clinical outcomes, complications, and re-operations between lateral column lengthening (LCL) and arthroereisis (AR) for treating symptomatic flatfoot in children.

Methods We conducted a comprehensive search on MEDLINE, EMBASE, and Cochrane Library databases. Literature search, data extraction, and quality assessment were conducted by two independent reviewers. The outcomes analyzed included radiographic parameters, clinical scores, satisfaction, complications, and re-operations.

Results Twenty-one and 13 studies were included in the LCL and AR groups, respectively. The change in anteroposterior talo-first metatarsal angle was greater in the LCL (9.5° to 21.7°) than in the AR group (10.6° to 12.8°). The change in calcaneal pitch was greater in the LCL (2.1° to 26.53°) than in the AR group (−1.3° to 3.23°). Improvements in the American Orthopedic Foot and Ankle Society (AOFAS) ankle–hindfoot score were greater in the LCL (27.7 to 39.1) than in the AR group (17 to 22). The percentage of satisfaction was similar between the LCL (68% to 89%) and AR (78.5% to 96.4%) groups. The complication rate was higher in the LCL (0% to 86.9%) than in the AR group (3.5% to 45%). The most common complications were calcaneocuboid subluxation and persistent pain in the LCL and AR groups, respectively. The re-operation rate was similar between the LCL (0% to 27.3%) and AR (0% to 36.4%) groups.

Conclusions The LCL group has achieved more radiographic corrections and more improvements in the AOFAS score than the AR group. Complications were more common in the LCL group than in the AR group, and the re-operation rates were similar between the two groups.

Keywords Flatfoot · Subtalar arthroereisis · Lateral column lengthening · Calcaneal lengthening · Children · Systematic review

Introduction

Flatfoot deformity is a common reason for referral of children to an orthopaedic surgeon, with a prevalence of 15–45% in children [1]. Most children with flatfoot deformity will undergo spontaneous correction or become asymptomatic [2, 3]. Most symptoms if present resolve with conservative treatment

[4]. Surgery is indicated if pain is persistent despite conservative treatment. Multiple surgical options to treat symptomatic flatfoot have been described [5].

Evans [6] first introduced the concept of lateral column lengthening (LCL) in 1975, and Mosca [7] had modified and further popularized it. LCL has been reported to produce good results, and it has become the mainstay of surgical options to treat symptomatic flexible flatfoot deformity. However, disadvantages, such as insufficient corrections, overcorrections, loss of correction due to inadequate graft size, graft migration, or malposition, have been reported [8, 9].

Subtalar arthroereisis (AR), which is performed by placing an implant within the sinus tarsi to restrict excessive subtalar eversion, is also a common surgical procedure to treat symptomatic flexible flatfoot deformities. This procedure became popular because it is minimally invasive and allows early weight-bearing capacity and a relatively rapid return to play and sports [10]. However, outcomes of the procedure have

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been poorly studied, and the indications of the procedure have not been established because of insufficient evidence [1]. The complication rate has been reported to be up to 40%, and common complications include overcorrection and undercorrection, inflammatory synovitis, sinus tarsi pain, cortical erosion, talar avascular necrosis, and calcaneus fractures [11–13].

Although both LCL and AR are popular surgical options to treat symptomatic flexible flatfoot deformity, high-quality evidence-based studies, such as level 1 or 2 studies, that compare these two procedures are lacking. We could find only one study, a prospective comparative study [4], directly comparing the two procedures, and it showed no difference in the outcomes.

The present study aimed to perform a systematic review to compare radiographic correction, clinical scores, patient satisfaction, complications, and reoperations between LCL and AR as treatment for symptomatic flatfoot in children.

Materials and methods

Data and literature sources

Multiple comprehensive databases, including PubMed/MEDLINE, EMBASE, and Cochrane Library databases, were searched to identify studies that pertain to LCL and AR as treatment for paediatric flatfoot deformity. This study was based on the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines [14]. The following keywords and MeSH terms were included in our searches: flatfoot, planovalgus, calcaneal lengthening osteotomy, LCL, AR, pediatric, and child. After the initial electronic search, additional manual searches were conducted using the bibliographies of all selected full-text articles.

Study selection

Two authors independently decided the inclusion of all studies in accordance with the selection criteria. For study selection, the titles and abstracts of the identified studies were screened first, and then the selected studies were scanned by full text. Studies were eligible for inclusion if they met the following criteria: (1) levels I to IV clinical studies of pediatric flatfoot; (2) either LCL or AR; (3) studies including clinical and/or radiological outcome; (4) English language. The exclusion criteria were as follows: (1) studies including adult flatfoot; (2) nonclinical (e.g., cadaver or biomechanical) studies; (3) studies not reporting clinical or radiological outcomes; (4) LCL combined with medial displacement calcaneal osteotomy or triple arthrodesis; (5) LCL combined with AR; (6) review or meta-analysis articles, case reports, technique articles, and letters to the editor; and (7) non-English language.

Literature search

Database searches yielded 410 articles. After removing duplicate entries, 267 articles were identified, of which 61 were potentially eligible based on their title and abstract. After we assessed the eligibility based on the full manuscript, 28 articles were excluded. Finally, 33 studies were included in our systematic review (Fig. 1), including 1, 1, 8, and 23 level I, II, III, and IV studies, respectively (Tables 1 and 2). Among comparative studies, only one level II study [4] directly compared the LCL group with the AR group.

Data extraction

Data extraction was conducted by two independent reviewers using a predefined data extraction form. Any discrepancies were arbitrated by consensus with a third reviewer. The included studies were divided into the LCL and AR groups. The LCL or AR cohort data were extracted from the comparative studies. Finally, 21 and 13 studies were included in the LCL and AR groups, respectively (Tables 1 and 2). Information

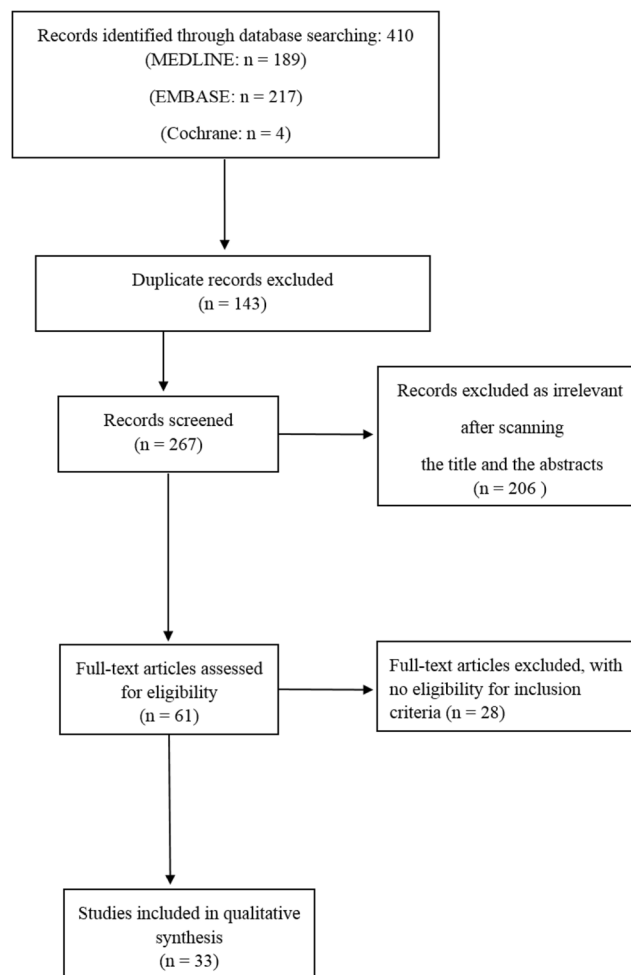


Fig. 1 Flowchart of the literature screening

Table 1 Study list and demographic data in the LCL group

Study	LOE	Diagnosis	Feet/patients, <i>n</i>	Sex: M/F, <i>n</i>	Mean age, years (SD and/or range)	Mean follow-up, months (SD and/or range)	Outcomes
Martinkevich et al. [15]*	I	Including NMD	HATCP graft, 6/6 Autograft, 5/5	HATCP graft, 1/5 Autograft, 2/3	HATCP graft, 12.3 (9.9 to 14.2) Autograft, 10.8 (8.2 to 13.7)	6	Radiographic data Ox-AFQ scores Complications Reoperations
Westberry et al. [16]	IV	Excluding NMD	21/17	9/8	13.3 ± 2.9 (6.5 to 18.2)	13.2 ± 6 (4 to 36) [†] 28.8 ± 13.2 (8 to 54) [‡]	Radiographic data Pedobarographic data Complications Reoperations
Moraleda et al. [8]	III	Excluding NMD	33/21	NR	11.6 ± 2.5	63.6 ± 48	Radiographic data ACFAS score Complications Reoperations
Viegas et al. [17]	IV	Excluding NMD	34/17	9/8	12.1 (8 to 18)	24.9 (8 to 48)	Radiographic data AOFAS score Complications Reoperations
Rhodes et al. [18]	III	Including only CP	Allograft, 34/20 Xenograft, 29/16	11/9 9/7	9.3	39.4 (25 to 53) 35.1 (21 to 49)	Radiographic data Complications Reoperations
Marengo et al. [19]	IV	Including NMD	38/27	19/8	13.3 ± 2.2 (7.8 to 17)	23.1 (6 to 48)	Radiographic data AOFAS score Satisfaction Complications Reoperations
Kim et al. [20]	III	Including NMD	28/18	10/8	10.4 (5.0 to 16.0)	35.7 (24 to 73)	Radiographic data Satisfaction Complications Reoperations
Noritake et al. [21]	IV	Including only CP	27/16	10/6	10.8 (5.8 to 14.5)	38.4 (24 to 60)	Complications Reoperations Radiographic data Satisfaction
Oeffinger et al. [22]	IV	Including NMD	13/8	NR	13.6 ± 3.8	9.7 ± 4.5	Radiographic data
Luo et al. [23]	III	Including only CP	30/20	14/6	11.9	30 (12 to 72)	Radiographic data Satisfaction Reoperations
Lee et al. [24]	III	Including NMD	304/176	186/118, feet	11.3 ± 3.4 (5.4 to 20)	19.2 ± 20.4 (7 to 99)	Radiographic data Complications Reoperations
Ahn et al. [24]	IV	Excluding NMD	44/24	13/11	9.7 (8 to 13)	25 (12 to 159)	Radiographic data Complications Reoperations
Kadhim et al. [25]	IV	Including only CP	15/15	7/8	11 ± 3.2 (4.7 to 18.3)	130.8 ± 32.4 (75 to 184)	Radiographic data Complications

Table 1 (continued)

Study	LOE	Diagnosis	Feet/patients, <i>n</i>	Sex: M/F, <i>n</i>	Mean age, years (SD and/or range)	Mean follow-up, months (SD and/or range)	Outcomes
Dogan et al. [26]	III	Including NMD	25/13	8/5	10.8 (5.5 to 14.6)	23 (13 to 75)	Pedobarographic data Complications Reoperations Ankle range of motion Radiographic data Satisfaction Complications
Ertl et al. [27]	IV	Including only CP	28/19	12/7	8.6 (4 to 18)	51.6 (12–103)	Radiographic data AOFAS score Satisfaction Complications Reoperations
Adams et al. [28]	III	Including only CP	61/42	19/23	9 (6.3 to 13.9)	70 (41 to 102)	Radiographic data Complications
Kwak et al. [29]	IV	Including NMD	118/79	44/35	9.3 (3 to 17)	15.4 (13 to 21)	Radiographic data Complications Reoperations
Yoo et al. [30]	IV	Including only CP	92/56	NR	9.2 (4.0 to 17.2)	62.4 (24 to 93)	Radiographic data Satisfaction Complications Reoperations
Danko et al. [31]	IV	Including NMD	130/96	NR	11.3 (5.3 to 20.1)	30 (7 to 93)	Radiographic data Complications
Andreacchio et al. [5]	IV	Including only CP	23/15	NR	8.2 (6.2–17.8)	49.2 (27 to 61)	Radiographic data Satisfaction Complications Reoperations
Chong et al. [4] [§]	II	Excluding NMD	LCL group, 11/8	NR	12.8 (8 to 17)	12.7, OxAFQ-C assess 12.9, radiographic assess	Radiographic data OxAFQ-C Kinematics Complications Reoperations

LOE, level of evidence; NMD, neuromuscular disease; HATCP, hydroxyapatite–tricalcium phosphate; CP, cerebral palsy; OxAFQ-C, Oxford Ankle Foot Questionnaire for Children; NR, not reported; ACFAS, American College of Foot and Ankle Surgeons score; AOFAS, American Orthopaedic Foot and Ankle Society ankle–hindfoot score; LCL, lateral column lengthening

*This study compared the structural durability of HATCP to that of autologous iliac crest bone graft in calcaneal lengthening osteotomy

[†] Motion laboratory evaluation (including plain radiography and dynamic pedobarography)

[‡] Clinical evaluation (including physical examination and patient-/parent-reported outcomes)

[§] This study is a level II study prospectively comparing the LCL group with the AR group

Table 2 Study list and demographic data in the AR group

Study	LOE	Diagnosis	Feet/patients, <i>n</i>	Sex: M/F, <i>n</i>	Mean age, years (SD and/or range)	Mean follow-up, months (SD and/or range)	Outcomes
Martinelli et al. [10]	IV	Excluding NMD	98/49	30/19	10.7 (7 to 14)	58.8 (24 to 69.6)	CHQ-CF87, CHQ-PF50 OxAFQ-C Satisfaction Complications Reoperations
Jay et al. [32]	IV	Excluding NMD	34/20	13/7	10.6 (4 to 17)	18.4 (6 to 34)	AOFAS score Reoperations
Scharer et al. [33]	IV	NR	68/39	24/15	12 (6 to 16)	24 (6 to 61)	Radiographic data Complications Reoperations
Cao et al. [34]	IV	NR	27/20	12/8	12.1 (7 to 16)	28.1 (23 to 60)	Radiographic data AOFAS score, VAS Satisfaction Complications Reoperations
Smith et al. [35]	IV	NR	40/20	NR	2 to 10	23.5 (4 to 48)	Radiographic data Complications Reoperations
Wen et al. [36]	III	Including only CP	20/12	8/4	7.8 (5 to 12)	28.3 ± 7.9 (20 to 48)	Radiographic data AOFAS score Complications Reoperations
Molayem et al. [37]	IV	Including only CP	14/8	3/5	11.7 (9.9 to 13.6)	72 (33 to 111)	Satisfaction
Viladot et al. [38]	IV	NR	234/234	143/91	5 to 15	12 to 180	Radiographic data Clinical improvement Pedobarographic data Complications Reoperations
Black et al. [39]	IV	NR	22/15	6/9	5 to 14	35 (11 to 54)	Radiographic data Clinical improvement Pedobarographic data Complications Reoperations
Vedantam et al. [40]	IV	Including only NMD	140/78	44/34	7.7 (2.1 to 14.9)	54	Radiographic data Satisfaction Complications Reoperations
Carranza-Bencano et al. [41]	IV	NR	77/43	24/19	6 to 15	72 to 168	Radiographic data Satisfaction Complications

Table 2 (continued)

Study	LOE	Diagnosis	Feet/patients, <i>n</i>	Sex: M/F, <i>n</i>	Mean age, years (SD and/or range)	Mean follow-up, months (SD and/or range)	Outcomes
Crawford et al. [42]	IV	Including only NMD	31/20	NR	2 to 10.8	49.2 (24 to 84)	Reoperations Radiographic data Satisfaction Complications Reoperations
Chong et al. [4]*	II	Excluding NMD	AR group: 13/7	NR	12.8 (8 to 17)	12.7, OxAFQ-C assess 12.9, radiographic assess	Radiographic data OxAFQ-C Kinematics Pedobarographic data Complications Reoperations

LOE, level of evidence; NMD, neuromuscular disease; CP, cerebral palsy; OxAFQ-C, Oxford Ankle Foot Questionnaire for Children; NR, not reported; AOFAS, American Orthopaedic Foot and Ankle Society ankle–hindfoot score; CHQ-CF, Child Health Questionnaire–Child Form; CHQ-PF, Child Health Questionnaire–Parent Form; VAS, visual analogue scale; AR, arthroereisis

*This study is a level II study prospectively comparing the LCL group with the AR group

extracted from each study included authors, publication date, number of patients, underlying diagnosis, age, sex, follow-up period, radiographic measurements, clinical scores, complications, and re-operations. Various radiographic parameters were used for evaluating radiographic correction in the included studies; hence, radiographic parameters were selected if they were reported in more than two studies in each group. The following six radiographic parameters were analyzed: anteroposterior talo-first metatarsal, lateral talo-first metatarsal, calcaneal pitch, anteroposterior talocalcaneal, lateral talocalcaneal, and talar declination angles. Satisfaction with surgery was assessed in the included studies based on the Mosca clinical criteria [7], a scoring system described by Yoo et al. [30], patients' report, or authors' own criteria. The percentage of cases with satisfactory outcome was calculated. Six kinds of clinical scores were used in ten studies. The American Orthopedic Foot and Ankle Society (AOFAS) ankle–hindfoot score [43] and the Oxford Ankle Foot Questionnaire for Children (OxAFQ) scores [44] were used in more than two studies in each group, whereas other scores were used only once in one study regardless of the groups. Complications included calcaneocuboid subluxation, implant migration, nonunion, delayed union, infection, wound problem, persistent pain, overcorrection and undercorrection, recurrence of planovalgus deformity, nerve injury, hardware prominence, graft failure, and iliac bone graft donor site problem. Re-operation was defined as any surgery performed after the index surgery.

Assessment of methodological quality

The Methodological Index for Nonrandomized Studies (MINORS) scale quantified the quality of the literature [45]. The global ideal MINORS scores for non-comparative and comparative studies are 16 and 24, respectively. Two independent reviewers scored each study, and any discrepancy between the reviewers was resolved by consensus with a third reviewer. The mean MINORS score and levels of evidence in both groups are presented in Table 3, and the quality of included studies was similar between the LCL and AR groups.

Statistical analysis

Most of the included studies were nonrandomized case series without a control group, and some studies were comparative studies. Therefore, a meta-analysis was considered inappropriate because the included studies had considerable heterogeneity. Thus, a qualitative synthesis without quantitative comparison between the LCL and AR groups was performed.

Table 3 Methodological Index for Nonrandomized Studies (MINORS) scale and level of evidence of included studies

	LCL group	AR group
Number of studies	21	13
Mean MINORS score (range)	12.8 (10–20)	11.7 (6–18)
Level of evidence (number of studies)		
I	1	0
II	1	1
III	7	1
IV	12	11

LCL, lateral column lengthening; AR, arthroereisis

Results

Study demographics

Demographic data are presented in Table 1. In the LCL group, eight studies included patients with and without underlying neuromuscular diseases, five studies excluded patients with neuromuscular diseases, and eight studies included only a patient with cerebral palsy. In the AR group, three studies excluded patients with neuromuscular diseases, two studies included only patients with cerebral palsy, two studies included only patients with neuromuscular diseases, and six studies did not report underlying diagnoses.

We analyzed 1144 and 818 feet in 729 and 565 patients in the LCL and AR groups, respectively. The mean age ranged from 8.6 to 13.6 years and from 7.7 to 12.1 years in all included studies of the LCL group and in eight studies of the AR group, respectively. The remaining five studies in the AR group reported the age range (2–15 years) without the mean age. The mean follow-up period ranged from six months to 10.9 years in all included studies of the LCL group and 18.4 months to six years in 11 studies of the AR group. The remaining two studies of the AR group reported the range of the follow-up period (1–15 years) without the mean follow-up period.

Surgical procedures

In the LCL group, intra-calcaneal lengthening was performed in 17 studies [8, 15–24, 26–30, 46], and intra-calcaneal lengthening or calcaneocuboid distraction arthrodesis was conducted in four studies [4, 5, 25, 31]. The modified Evans osteotomy technique [6] was used for intra-calcaneal lengthening in most of the included studies. Bone graft was performed in 20 studies, and one study [26] did not state whether bone graft was performed.

Only autograft and allograft were used in six [19–23, 27] and seven studies [4, 5, 16, 17, 24, 25, 28], respectively. Autograft or allograft, allograft or xenograft, and autograft or hydroxyapatite–tricalcium phosphate graft were used in five studies [8, 29–31, 46], one study [18], and one study [15], respectively. The graft was not fixed in five studies [4, 15–17, 19, 24], fixed in all patients in eight studies [20–22, 25, 27, 29, 30, 46], and fixed in some patients in seven studies [4, 5, 8, 18, 23, 28, 31]. One study [26] did not describe about graft fixation.

The devices for AR in the AR group were categorized as titanium, bioresorbable, stainless steel, silicone, polyethylene, or staple implants, which were used in five studies [4, 10, 33, 34, 36], one study [32], one study [37], four studies [35, 38, 39, 41], one study [40], and one study [42], respectively. Other simultaneous procedures were performed in most studies of both groups, except for one study [4, 15] in each group, and one study [28] in the LCL group did not describe about the simultaneous procedures. Additional procedures are presented in Table 4. The most common additional procedures were Achilles tendon lengthening or gastrocnemius recession; the next most common procedures were peroneus brevis or longus tendon lengthening which were performed in both groups.

Radiographic outcomes

Six radiographic parameters were analyzed, and the range of mean values is summarized in Table 5. All radiographic parameters improved after surgery in most of the included studies in both groups. However, one study [5] in the LCL group reported that the mean lateral talocalcaneal angle increased from 19° pre-operatively to 24° at follow-up, and four (25%) of the 16 feet had poor results because of recurrence of planovalgus foot deformity. In one study [4] in the AR group, the mean calcaneal pitch decreased from 13° pre-operatively to 11.7° at follow-up.

The LCL group had more improvements in the anteroposterior talo-first metatarsal angle. The change in the anteroposterior talo-first metatarsal angle ranged from 9.5° to 21.7° and from 10.6° to 12.8° in the LCL and AR groups, respectively. The change in the anteroposterior talo-first metatarsal angle in the LCL group was > 15° in 9 [17, 19, 21, 22, 24, 26, 28, 30, 46] of 16 included studies. The LCL group also had more improvements in the calcaneal pitch. The change in the calcaneal pitch ranged from 2.1° to 26.53° and from –1.3° to 3.23° in the LCL and AR groups, respectively. As previously mentioned, one study [4] in the AR group reported that the calcaneal pitch decreased post-operatively.

Table 4 Additional procedures performed in the LCL and AR groups

Additional procedures	LCL group	AR group
Achilles lengthening or gastrocnemius recession	17 [4, 5, 8, 17–27, 29, 30, 46] (19.0 to 100%)	9 [10, 32, 33, 35–37, 40–42] (9.6 to 100%)
Peroneus brevis ± longus lengthening	11 [5, 8, 19–22, 24, 26, 27, 30, 46] (15.4 to 100%)	3 [36, 40, 42] (6.4 to 57.1%)
Hamstring lengthening	2 [25, 27] (3.6 to 86.7%)	2 [40, 42] (6.4 to 10.7%)
Flexor hallucis longus lengthening	1 [23] (20%)	1 [42] (3.2%)
Extensor digitorum longus lengthening	1 [23] (10%)	
Hip muscle release		2 [40, 42] (5.7 to 12.9%)
Medial column plantar flexion osteotomy	3 [8, 16, 17] (4.8 to 18.2%)	
Rotational deformity correction	2 [16, 25] (9.5 to 33.3%)	1 [40] (5%)
Open reduction and varus osteotomy of the hip		1 [40] (2.1%)
Medial supportive procedures*	4 [8, 17, 20, 27] (51.5 to 64.3%)	4 [33–35, 40] (5.9 to 40.7%)
Hallux valgus correction	1 [25] (26.7%)	
Tibialis anterior tendon transfer	2 [17, 27] (35.7 to 100%)	
Triceps surae transfer		1 [40] (17.1%)
Tibialis posterior tendon transfer		1 [40] (10.7%)
Peroneal transfer	1 [4] (18.1%)	
Rectus transfer	2 [25, 27] (7.1 to 26.7%)	

Values are expressed as the number of studies reported with the percentage range of each procedure (in parentheses)

*Medial supportive procedures: capsular imbrication of the talonavicular joint, Kidner procedure

Clinical outcomes

The AOFAS score and satisfaction are shown in Table 6. Eight and six studies in the LCL and AR groups, respectively, reported satisfaction with outcome. The percentage of satisfaction ranged from 68 to 89% and from 78.5 to 96.4% in the LCL and AR groups, respectively. Three and three studies in the LCL and AR groups reported AOFAS score, respectively.

Improvements of the mean AOFAS score ranged from 27.7 to 39.1 and from 17 to 22 in the LCL and AR groups, respectively.

Three studies reported OxAFAQ scores. First, the only available prospective comparative study [4] reported that both the LCL and AR groups showed improvements in their OxAFAQ scores, but only the AR group achieved statistical significance. Two patients in the LCL group did not fill out

Table 5 Radiological outcome

Radiographic parameters (range of mean value)	Anteroposterior talo-first metatarsal angle	Lateral talo-first metatarsal angle	Calcaneal pitch	Anteroposterior talocalcaneal angle	Lateral talocalcaneal angle	Talar declination angle
Lateral column lengthening						
Number of studies reported	16*	18†	17‡	6§	12¶	7**
Preoperative	15.9 to 30.6	0 to 33.7	−0.8 to 14.4	27.9 to 41.9	19 to 53	25 to 48.5
Postoperative	−0.41 to 11.5	1 to 20.7	11.3 to 31.0	16.9 to 27.3	22 to 50.8	16.2 to 34.7
Change	9.5 to 21.7	3 to 26.44	2.1 to 26.53	7.3 to 16	−5 to 14.8	3.4 to 24.6
Arthroereisis						
Number of studies reported	2	3	3	4	5	3
Preoperative	18.9 to 19.1	19.6 to 31	9.4 to 13.0	29.3 to 35	39 to 52.9	39 to 44.8
Postoperative	6.3 to 8.3	0 to 19.1	11.5 to 11.7	19.0 to 21.6	31.6 to 43.8	26.9 to 30
Change	10.6 to 12.8	11.9 to 20	−1.3 to 3.23	7.6 to 16	4.25 to 18	7.7 to 17.9

*Reference number of studies reported parameter: lateral column lengthening [4, 8, 16–23, 26, 28–31, 46]; arthroereisis [4, 34]

†Reference number of studies reported parameter: lateral column lengthening [4, 5, 8, 16–24, 26–28, 30, 31, 46]; arthroereisis [4, 34, 36]

‡Reference number of studies reported parameter: lateral column lengthening [4, 8, 16–23, 26–31, 46]; arthroereisis [4, 34, 35]

§Reference number of studies reported parameter: lateral column lengthening [8, 17, 23, 26, 29, 30]; arthroereisis [33, 35, 36, 38]

¶Reference number of studies reported parameter: lateral column lengthening [4, 5, 8, 16–18, 23, 26, 28, 30, 31, 46]; arthroereisis [4, 33, 35, 40, 42]

**Reference number of studies reported parameter: lateral column lengthening [19, 21–23, 26, 27, 31]; arthroereisis [34, 35, 40]

Table 6 Satisfaction and AOFAS score

	Lateral column lengthening	Arthroereisis
Satisfaction		
Number of studies reported	8*	6*
Satisfactory	68 to 89%	78.5 to 96.4%
AOFAS score (range of mean value)		
Number of studies reported	3 [†]	3 [†]
Pre-operative	49.9 to 68.59	61 to 71.1
Post-operative	68.5 to 96.35	67.7 to 88.1
Change	27.7 to 39.1	17 to 22

AOFAS, American Orthopaedic Foot and Ankle Society ankle–hindfoot score

*Reference number of studies reported satisfaction: lateral column lengthening [5, 19–21, 23, 26, 27, 30]; arthroereisis [10, 34, 37, 40–42]

[†]Reference number of studies reported AOFAS score: lateral column lengthening [17, 19, 27]; arthroereisis [32, 34, 36]

preoperative Oxford questionnaires, which may be why the LCL group was unable to achieve statistical significance. The pre- and post-operative OxAFQ scores were not compared between the two groups. Second, Martinkevich et al. [15] compared structural hydroxyapatite–tricalcium phosphate graft to autologous iliac crest bone graft in calcaneal lengthening osteotomy. In this study, both groups showed comparable changes towards higher OxAFQ scores (improvement) in the physical function and footwear item at 6-month follow-up. Finally, one study [47] in the AR group noted a significant

improvement in the mean OxAFQ scores in the “Emotional” and “Footwear” items for the children scale and in the “School and Play” and “Footwear” items for the parent scale.

Complications

Eighteen and 11 studies in the LCL and AR groups, respectively, contributed to the analysis of the complication rate (Table 7). The complication rates ranged from 0 to 86.9% and from 3.5 to 45% in the LCL and AR groups, respectively.

Table 7 Complications

	Lateral column lengthening	Arthroereisis		
		Old-type implants	Recent-type implants	Total
Number of studies reported	18*	5*	6*	11
Overall complication rate (range of %)	0 to 86.9	3.5 to 45	3.7 to 15.4	3.5 to 45
Complications (range of %, number of studies reported)				
Calcaneocuboid subluxation	0.8 to 86.9 (7)			
Nonunion	3 to 13 (4)			
Delayed union	6.1 (1)			
Subtalar problem	3 to 4.3 (2)			
Graft donor site problem	2.6 to 3 (2)			
Recurrence	4.3 to 39.4 (2)			
Graft failure	4 to 29.3 (2)			
Hardware prominence	20 (1)			
Nerve injury	9 to 17.6 (2)			
Infection	1.6 to 20 (4)	2.6 to 3.8 (2)		2.6 to 3.8 (2)
Wound problem	3 to 66.7 (3)	7.8 (1)		7.8 (1)
Overcorrection	7.6 to 8.7 (2)	2.5 to 2.9 (2)		2.5 to 2.9 (2)
Persistent pain	40 (1)	0.7 to 36.4 (3)	1.5 to 15.4 (6)	0.7 to 36.4 (9)
Implant migration		2.6 to 19.3 (2)	3.7 (1)	2.6 to 19.3 (3)
Undercorrection		20 (1)		20 (1)

*Reference number of studies reported complications: lateral column lengthening [4, 5, 8, 15–20, 24–31, 46]; arthroereisis old-type implant [35, 38–41]; arthroereisis recent-type implant [4, 10, 32, 33, 36]

The complication rates in the LCL group were > 50% in six studies [8, 15, 19, 25, 28, 46]. The most common complication in the LCL group was calcaneocuboid subluxation, followed by nonunion. The calcaneocuboid subluxation rate ranged from 0.8 to 86.9% in seven studies [8, 19, 20, 26, 28, 29, 46] and > 50% in four [8, 19, 28, 46] of seven studies. However, calcaneocuboid subluxation did not have an effect on the clinical score and did not lead to symptoms and osteoarthritic changes in the calcaneocuboid joint [8, 20, 46]. The nonunion rate in the LCL group was noted in four studies [5, 8, 16, 18], ranging from 3 to 13%. However, the nonunion rate ranged from 3 to 4.7% after excluding Andreacchio et al.'s study [5]. The nonunion rate was 13% in Andreacchio et al.'s study [5], and LCL was performed through intra-calcaneal lengthening or calcaneocuboid distraction arthrodesis. Nonunions developed only in patients with calcaneocuboid distraction arthrodesis, and all nonunions were asymptomatic with maintenance of the surgical correction.

Persistent pain and implant migration were the most frequently reported complications in the AR group. Eight studies [4, 10, 32, 33, 35, 36, 39, 40] in the AR group reported persistent pain, ranging from 0.7 to 36.4%, whereas only one study [25] in the LCL group reported persistent foot pain. Three studies [34, 35, 41] contributed to the analysis of the implant migration rate, and the implant was used differently in each study. The migration rate was 3.7%, 19.3%, and 2.6% in the studies using Kalix II (Integra LifeSciences, Plainsboro, NJ, USA) [34], Silastic plug [35], and Viladot implant [41], respectively. The complication rate based on the implant type ranged from 3.5 to 45% and from 3.7 to 15.4% in the old-type [35, 38–41] (silicone, polyethylene, and staple implants) and recent-type implants [4, 10, 32–34, 36] (titanium, bioresorbable, and stainless steel implants), respectively. Infection, wound problem, overcorrection, and undercorrection were reported in only the old-type implants.

Re-operation

Fifteen [4, 5, 8, 15–20, 23–25, 27, 29, 30] and twelve studies [4, 10, 32–36, 38–42] in the LCL and AR groups, respectively, reported re-operations. The re-operation rates ranged from 0 to 27.3% and from 0 to 36.4% in the LCL and AR groups, respectively (Table 8). Four studies [5, 24, 29, 30] in the LCL

group reported that revision surgeries were performed for loss of correction, and one study [15] reported that revision surgeries were performed for deep infection. Hardware removals were performed in two studies [4, 25] because of hardware prominence or extrusion of the graft and staple. Implant removal in the AR group was performed in nine studies [4, 10, 33, 35, 36, 38–41] because of implant migration, persistent pain, deep infection, or overcorrection. Implant change was performed for implant migration, overcorrection, or undercorrection in four studies [33, 34, 41, 42]. The re-operation rate based on the implant type ranged from 0.9 to 36.4% and from 0 to 15.4% in the old-type [35, 38–42] and recent-type implants [4, 10, 32–34, 36], respectively.

Subgroup analysis

The studies included in our current analysis were divided into those investigating idiopathic flatfoot and neuromuscular flatfoot in order to analyze the influence of the specific origin of flatfoot (Table 9). However, studies featuring both idiopathic and neuromuscular flatfoot could not be included in this particular subgroup analysis because patients with idiopathic flatfoot had been mixed with patients with neuromuscular flatfoot. Consequently, radiographic parameters could not be compared between LCL and AR because most studies in the AR groups rarely reported radiographic results. In the LCL group, the correction of radiographic parameters was comparable between idiopathic and neuromuscular flatfoot, even though idiopathic flatfoot had a tendency towards slightly greater correction than neuromuscular flatfoot. In both idiopathic and neuromuscular flatfoot, the complication rates were higher in the LCL group than in the AR group, and the complication rates were comparable between idiopathic and neuromuscular flatfoot in both the LCL and AR groups. However, there were limitations in this particular subgroup analysis because of the small number of studies included and due to the heterogeneity of the parameters reported.

In 21 studies incorporated into the LCL group, 13 studies included only ambulatory children, two studies included ambulatory and non-ambulatory children, and six studies did not report the ambulatory status of the patients involved. In 13 studies incorporated into the AR group, five studies included only ambulatory children and eight studies did not report the

Table 8 Re-operations

	Lateral column lengthening	Arthroereisis		
		Old-type implant	Recent-type implant	Total
No. of studies reported	15*	6*	6*	12
Overall re-operation rate (range of %)	0 to 27.3	0.9 to 36.4	0 to 15.4	0 to 36.4

*Reference number of studies reported reoperations: lateral column lengthening [4, 5, 8, 15–20, 23–25, 27, 29, 30]; arthroereisis old-type implant [35, 38–42]; arthroereisis recent-type implant [4, 10, 32–34, 36]

Table 9 Results of studies investigating radiographic parameters, complication rates and reoperation rates in idiopathic flatfoot and neuromuscular flatfoot

	LCL group		AR group	
	Idiopathic	NMD	Idiopathic	NMD
Number of studies	5*	8 [†]	3 [‡]	4 [§]
Radiographic parameters [¶]				
Anteroposterior talo-first metatarsal angle	9.5 to 21.1 (5)	6.9 to 21.7 (5)	OR	NR
Lateral talo-first metatarsal angle	9.7 to 26.4 (5)	3.9 to 20.1 (7)	OR	OR
Calcaneal pitch	2.4 to 26.5 (5)	2.1 to 11.4 (6)	OR	NR
Anteroposterior talocalcaneal angle	8.8 to 16 (2)	7.3 to 11 (2)	NR	OR
Lateral talocalcaneal angle	− 2.1 to 14.8 (5)	− 5 to 9.5 (4)	OR	7 to 18(2)
Talar declination angle	NR	3.4 to 19.2 (3)	NR	OR
Overall complication rate**	17.6 to 69.7% (5)	4 to 86.9% (6)	5.9 to 15.4% (3)	3.5 to 5% (2)
Reoperation rate**	3 to 9.1% (2)	3.2 to 26.7% (4)	6.1 to 15.4% (2)	3.2 to 5% (3)

LCL, lateral column lengthening; AR, arthroereisis; NMD, neuromuscular disease; OR, only one study reported; NR, not reported

*Reference numbers for the studies involved: [4, 8, 16, 17, 46]

[†] Reference numbers for the studies involved: [5, 18, 21, 23, 25, 27, 28, 30]

[‡] Reference numbers for the studies involved: [4, 10, 32]

[§] Reference numbers for the studies involved: [36, 37, 40, 42]

[¶] Values are expressed as range of correction angle with the number of studies reported (in parentheses)

**Values in parentheses represent the number of studies reported

ambulatory status of the patients involved. In two studies included in the LCL group, which included ambulatory and non-ambulatory children, one study [24] reported that the ambulatory status was not associated with the Goldberg score for calcaneal bone graft and does not necessarily correlate with graft failure. The other study [27] reported that there was a significant correlation between ambulatory status of the children and both clinical outcome and radiological result according to Mosca's criteria. It is well known that a non-ambulatory status is associated with poor outcomes after LCL with respect to deformity correction [9, 21].

Discussion

For the surgical treatment of paediatric flexible flatfoot deformity, LCL has been the mainstay of surgical options. AR has also gained popularity because of its advantages, such as minimal invasive procedure and an early weight-bearing capacity. Although both procedures are popular surgical options to treat pediatric flexible flatfoot deformity, studies comparing these two procedures are limited. Therefore, we performed a systematic review to compare radiographic correction, clinical outcomes, complications, and reoperations between the two procedures for pediatric flexible flatfoot deformity.

In this systematic review, six radiographic parameters, which were reported in more than two studies in each group, were analyzed to compare radiographic corrections between

both groups. The LCL group had more improvements in the anteroposterior talo-first metatarsal angle and calcaneal pitch. LCL is typically reserved for severe forefoot abduction deformity and has better correction power for midfoot transverse plane deformities than AR [4, 48]. This is supported by the result of our systematic review that the LCL group had a greater decrease in the anteroposterior talo-first metatarsal angle. Metcalfe et al. [49] reported that the calcaneal pitch among nine radiographic parameters demonstrated the least change with only small increases following AR, and Morris et al. [44] noted that AR does not change the calcaneal pitch. This is consistent with the result of our systematic review that an increase in the calcaneal pitch post-operatively in the LCL group was greater than that in the AR group. A prospective comparative study of LCL and AR for paediatric flatfoot reported that the calcaneal pitch increased significantly post-operatively only in the LCL group [4], whereas a study using AR for adult flatfoot deformity reported that the calcaneal pitch improved significantly [50].

Ten studies [4, 8, 10, 15, 17, 19, 27, 32, 34, 36] reported clinical scores using six kinds of scores. Other scores, except the AOFAS and OxAFQ scores, were used only once in one study regardless of the groups. The AOFAS scores were reported in six studies [17, 19, 27, 32, 34, 36] (three studies in each group). In the ranges of increases of the mean AOFAS score, the minimum value in the LCL group (range, 27.76–39.1) was greater than the maximum value in the AR group (range, 17–22), which meant that the LCL group has more

improved AOFAS scores. The OxAFQ scores were reported in three studies [4, 10, 15], and both groups showed improvement in the OxAFQ scores. However, comparing the OxAFQ scores between both groups was difficult because studies reporting these scores were limited.

The complication rates in the LCL group were higher overall than those in the AR group, whereas the re-operation rates were similar in the two groups. The most common complication in the LCL group was calcaneocuboid subluxation, which was reported in seven studies [8, 19, 20, 26, 28, 29, 46]. Its incidence was > 50% in four [8, 19, 28, 46] of seven studies. The high incidence rate of calcaneocuboid subluxation might be the reason for the higher complication rate in the LCL group. Although the incidence of calcaneocuboid subluxation was high, this complication could gradually resolve over time and have little effect on the clinical outcome and symptoms [8, 20, 46]. That is why the re-operation rates were similar to the two groups, although the LCL group had a higher complication rate. The most common cause for re-operation in the LCL group was loss of correction. In the literature, the most common post-operative complications of AR were tarsal sinus pain, insufficient or excessive correction caused by inappropriate implant size, excessive intrusion or protrusion of the implants, and related synovitis [51, 52]. In this systematic review, persistent pain was the most common complication in the AR group, followed by implant migration. Residual pain after AR was the most common reason for dissatisfaction [10]. Overcorrection was an important cause of tarsal sinus pain after AR, and the solution was also implant removal [53]. In our systematic review, the highest incidence of persistent pain was 36.4% in Black et al.'s study [39], and the highest rate of implant migration was 19.3% in Smith et al.'s study [35]. Old-type implants were used in these two studies. In addition, both complication and re-operation rates in the old-type implant group were higher than those in the recent-type implant group. Therefore, the advance in AR design has improved the outcomes. The unsatisfactory or poor results in the LCL group were due to a recurrence of planovalgus deformity, overcorrection, medial foot collapse, subluxation of the calcaneocuboidal joint, and resorption of the allograft [5, 21, 25, 29, 30]. In the AR group, unsatisfactory or poor results were due to implant dislocations, implant fractures, overcorrection of hindfoot deformity, and the recurrence of deformity [34, 37, 40, 41].

Even though both LCL and AR are currently used worldwide for the treatment of symptomatic flexible flatfeet in children, the precise indications for the application of these procedures have not been established. In addition, AR is still a debated procedure because of the poor-quality evidence (level IV or V studies) reported in the current literature [54]. LCL is a more ideal procedure for flatfoot with severe forefoot abduction because forefoot abduction is better corrected with LCL than with AR [4, 48]. LCL is considered to be more applicable

for severe forefoot abduction with 40% to 50% of talonavicular uncoverage [48]. One goal of AR is to relocate the talus in an appropriate manner over the calcaneus to allow remodeling of the subtalar joint. Thus, there may not be sufficient time for the remodeling of hindfoot bones and ligaments in patients older than 12 years of age. Prior to eight years of age, many children with flatfoot may experience spontaneous correction. Therefore, AR is recommended in children between eight and 12 years of age [2]. We also prefer LCL in cases of flatfoot with severe forefoot abduction, and prefer to use AR in pre-adolescent patients with moderate forefoot abduction as an isolated or complementary surgical procedure.

This systematic review has several limitations. First, the underlying diagnosis and the inclusion criteria were heterogeneous among the included studies based on accompanying neuromuscular disease and whether or not include non-ambulatory. Hence, the heterogeneity of the underlying diagnosis and the inclusion criteria may be a potential source of bias. Second, the diversity of LCL methods, implant type for AR, and simultaneous procedures may have had an influence on the treatment outcomes. LCL methods were diverse based on lengthening site (intra-calcaneal lengthening versus calcaneocuboid joint lengthening), whether bone graft fixation was performed, methods of bone graft fixation, and kinds of bone graft. The data could not be separated by lengthening site or implant type because of the insufficient number of studies. Third, the limited number of the studies contributed to the analysis of radiographic outcomes because substantial variation was observed in the radiographic parameters reported between studies. We selected only six radiographic parameters, which were reported in more than two studies in each group, for evaluating radiographic outcome. In addition, the time frame of the final radiographic assessment varied between studies or was not clarified. Fourth, few studies reported the clinical scores, and various clinical scores were used in the included studies. Although the results of the AOFAS score in this systematic review showed that the LCL group achieved more improvement than the AR group, more studies reporting the clinical scores are necessary to strengthen this result. Finally, only one included study [4] directly compared LCL with AR. Most included studies were case series. Although nine studies [8, 15, 18, 20, 23, 24, 26, 28, 36] were comparative studies, they did not directly compare LCL with AR. Therefore, we were unable to perform a meta-analysis for statistical comparison because of the design heterogeneity of the included studies.

In conclusion, the LCL group achieved more radiographic corrections and more improvements in the AOFAS score than the AR group. Complications were more common in the LCL group than in the AR group, and the re-operation rates were similar between the two groups. Calcaneocuboid subluxation and nonunion were the major complications in the LCL group, but revision surgery was unnecessary in most of them. Loss of

correction was the main cause of revision surgery in the LCL group. Persistent pain and implant migration were the main complications in the AR group, and implant removal as a revision surgery was mainly performed for these complications.

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