*Systematic Review*

JOURNAL OF CHILDREN'S ORTHOPAEDICS

Journal of Children's Orthopaedics
2022, Vol. 16(5) 333–346
© The Author(s) 2022
DOI: 10.1177/18632521221112496
journals.sagepub.com/home/cho

# Surgical management of pes planus in children with cerebral palsy: A systematic review

**Poppy MacInnes[1], Thomas L Lewis[2], Cora Griffin[1], Michela Martinuzzi[1], Karen L Shepherd[2], and Michail Kokkinakis[2]**

**Abstract**

**Purpose:** Pes planus (or flatfoot) is the most common deformity in children with cerebral palsy. There are several surgical interventions used to treat it: single calcaneal osteotomies, extra-articular arthrodesis, double calcaneal osteotomy, calcaneo-cuboid-cuneiform osteotomy, intra-articular arthrodesis, and arthroereisis. There is currently no evidence on optimal treatment for flatfoot in children with cerebral palsy. Our purpose is to systematically review studies reporting complications, recurrence rates, and radiological outcomes of the surgical management of flatfoot in children with cerebral palsy.

**Methods:** Five databases were searched to identify studies published from inception until July 2021, with keywords relating to flatfoot, cerebral palsy, and surgical interventions. We included prospective, retrospective, and comparative study designs in the English language. Data was extracted and tabulated in duplicate into Excel, and analysis was conducted using Python SciPy.

**Results:** In total, 1220 studies were identified of which 44 met the inclusion criteria, comprising 2234 feet in 1364 patients with a mean age of 10.3 years and mean follow-up of 55.9 months. Radiographic outcomes showed improvement with all procedures; complications and recurrence rates were too poorly reported to compare. Only 6 (14%) studies were assessed as a low risk of bias. There was substantial heterogeneity of outcome measures.

**Conclusion:** There is a lack of high-quality, comparative studies assessing the radiological outcomes, complications, and recurrence rates of surgical alternatives to treat flatfoot in children with cerebral palsy. There is currently no clear evidence on optimal surgical treatment.

**Level of evidence:** IIa based on Oxford Centre for Evidence-based Medicine.

**Keywords:** Flatfoot, pes planovalgus, pes planus, surgery, cerebral palsy, pediatrics, orthopedics

## Introduction

Pes planus (also known as flatfoot or pes planovalgus) is the most common foot deformity in children with cerebral palsy (CP).[1] The pathology develops due to the lateral displacement of the navicular, causing loss of the medial longitudinal arch, talar head uncovering, and talar prominence in the medial foot.[1] The condition can be categorized into flexible and stiff.[2] Flexible deformity involves preservation of the arch when sitting, extending the great toe or standing on tiptoes; stiff deformity involves a flat arch with limitation of motion during weight-bearing and non-weight-bearing, and is more difficult to treat.[3] Higher functioning, ambulatory patients (Gross Motor Function Classification System (GMFCS) I–III) usually present with flexible flatfoot, whereas stiff flatfoot is more common in adolescents with lower functional ability (GMFCS IV–V).[4] The deformity usually worsens during late childhood and can cause significant pain, pressure ulcers, and difficulty walking or wearing

[1]GKT School of Medical Education, King's College London, London, UK
[2]Evelina Children's Hospital, St Thomas' Hospital, London, UK

Date received: 13 April 2022; accepted: 17 June 2022

**Corresponding Author:**
Poppy MacInnes, GKT School of Medical Education, King's College London, Strand, London WC2R 2LS, UK.
Email: poppy.macinnes@gmail.com

shoes.[3,5] Surgical management is indicated when conservative measures have failed.

There are several surgical interventions used to treat pes planus but no guidelines on how to choose between them. Extra-articular arthrodesis (EAA) or single calcaneal osteotomies (SCO) are commonly used to treat children with milder, flexible deformities, and lower GMFCS levels. SCO includes calcaneal lateral column lengthening (LCL) and calcaneal slide (CS) with concomitant soft tissue procedures (peroneus brevis lengthening, tibialis posterior shortening, and talonavicular joint capsule reefing), and occasionally a medial cuneiform osteotomy. Double calcaneal osteotomy (DCO) and calcaneo-cuboid-cuneiform "triple C" osteotomies (TCO) have been used to treat moderate-to-severe deformities that would likely recur with SCO and EAA.[6] Intra-articular arthrodesis (IAA) is an invasive procedure that has been reserved for children with GMFCS IV or V and/or severe, stiff deformities.[1,5] Subtalar arthroereisis (SA) is a non-fusion procedure that has recently received renewed interest in the literature as an alternative to SCO and EAA.[2]

The purpose of this study is to systematically review the literature regarding the radiological outcomes, complications, and recurrence rates of current surgical management of flatfoot in children with CP.

## Methods

This systematic review was reported according to Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) checklist and the AMSTAR 2 critical appraisal tool.[7,8] The protocol was prospectively registered on PROSPERO CRD420201239285.[9] The authors declare no conflict of interest relevant to this work.

### Search strategy

A literature search was conducted using the online Cochrane Library, EMBASE, MEDLINE, Web of Science, and PubMed databases, using the following terms: ((cerebral palsy)) AND (((pes planus) OR (flat foot) OR (pes planovalgus)) OR ((calcaneal) OR (calcaneus) OR (calcaneum) OR (slide) OR (double) OR (heel) AND (osteotomy) OR ((fusion) OR (arthrodesis) OR ((arthroereisis) OR ((Grice Green) OR (Grice-Green) OR ((lateral column lengthening) OR (MOSCA))). No limitations were placed on gender, date, or language. All results from inception until July 31, 2021 were included (Appendix 1).

### Inclusion criteria

We included all prospective, retrospective, and comparative study designs (randomized controlled trials (RCTs), case studies, cohort studies, and case-controlled studies) reporting original/primary data on one or more of the outcomes of interest. A scoping review identified a significant lack of RCTs on this subject, thus including non-randomized studies was necessary for an all-encompassing review.

### Exclusion criteria

We excluded duplicate articles, cost-effectiveness studies, and studies not reporting on primary data (such as review articles, editorials, discussions, commentaries, letters, and conference abstracts). We excluded studies not reporting data on radiographic outcomes, complications, and recurrence rates. Studies where data for pediatric patients with CP was not readily separable from other participants and where surgery was not the primary intervention were excluded on the grounds of not being relevant to the aims of the review.

### Participants

Children with CP and symptomatic pes planus were included. Studies with a mean age of participants below 18 years of age were included. Children without CP treated for foot deformities other than pes planus were not included.

### Intervention

The intervention was operative surgical management to treat symptomatic pes planus where conservative management had failed. The specific procedures identified by a scoping review included calcaneal LCL, EAA, CS, DCO, calcaneo-cuboid-cuneiform TCO, IAA, and SA. Data on variations of these procedures and any soft tissue procedures performed in conjunction was also extracted.

LCL is a procedure originally described by Evans that equalizes both columns in the foot via an osteotomy of the calcaneus bone approximately 1.5 cm proximal to the calcaneocuboid joint; as the lateral column is shorter in flatfoot, this equalization corrects forefoot abduction and restores the medial longitudinal arch.[10] Mosca popularized the procedure by adding the soft tissue procedures of peroneus brevis lengthening, tibialis posterior shortening, and talonavicular joint reefing, and a plantar closing-wedge osteotomy of the medial cuneiform.[11]

EAA, originally used by Green and first reported by Grice in 1952, involves the extra-articular positioning of a structural autograft (either fibula or anterior tibia) between the talus and the calcaneus.[12]

CS is the medial displacement of the posterior part of the calcaneus, thus creating a compensating deformity to improve the heel valgus and normal weight-bearing.[13] DCO is a combination of LCL and CS.

TCO is a versatile procedure that allows correction at the fore-, mid- and hindfoot by three osteotomies: a CS, an opening-wedge cuboid osteotomy, and a plantar flexion closing-wedge osteotomy of the medial cuneiform.[14]

SA involves the insertion of an implant into the sinus tarsi or adjacent to it to prevent talonavicular impingement which consequently blocks and corrects excessive eversion movements of talus and calcaneus, and maintains the subtalar joint in a more neutral position.[2]

Finally, IAA is a fusion of one or all of the joints of the hind- or midfoot, usually undertaken as a triple arthrodesis involving the talonavicular, subtalar, and calcaneocuboid joints.[15]

### Comparators

There is currently no gold standard for the surgical management of flatfoot in children with CP. We included papers that surgically managed flatfoot by LCL, CS, DCO, TCO, EAA, IAA, and SA using traditional or modified techniques. Nonsurgical management of flatfoot was excluded.

### Outcomes

Primary outcomes were radiographic angles, complications, and recurrence rates. The radiographic angles included were most commonly used to assess flatfoot: anterior–posterior talocalcaneal (AP TC), anterior–posterior talo-first metatarsal (AP T1MT), and talonavicular coverage (TNC) angles; and lateral talocalcaneal (Lat. TC), lateral talo-first metatarsal (Lat. T1MT), calcaneal-first metatarsal (C1MT), and calcaneal pitch (CP).[2] Gait analysis and clinical outcomes were not assessed, as gait analysis is infrequently reported in studies and there is no current standardized tool for assessing clinical outcomes for each surgical procedure.

### Data extraction

Study selection was performed in duplicate (P.M., C.G., and P.M., M.M.), and data extraction was performed in duplicate (P.M., C.G., and P.M., M.M.). Discrepancies over the inclusion of any study or data extraction were resolved by consensus or arbitration by senior authors (T.L.L. and M.K.).

For every article, the following data was extracted based on a scoping literature review:

> Article demographic details (number of authors, title, year published, level of evidence (1–5), funding sources). Patient demographic details (number of patients, number of feet operated on, gender of patients, mean age, and age range of patients; GMFCS level of disability; mean follow-up (months/years) and range of follow-up).

> Surgery details: type of surgery, indication for surgery, and concurrent procedures.

> Radiographic outcomes: AP TC, AP T1MT, and TNC angles; and Lat. TC, Lat. T1MT, C1MT, and calcaneal pitch.

> Complications and recurrence rates

Gait analysis and pedobarographic outcomes were not tabulated or synthesized due to the heterogeneity of the reporting between the studies.

### Assessment of methodological quality

The level of evidence and methodological quality of included studies was assessed using the MINORS criteria.[16] A MINORS score of 16/16 or 24/24 was deemed high quality (and low risk of bias), 10–15/16 or 15–23/24 was deemed moderate quality (and moderate risk of bias), and a score of $<10/16$ or $<15$ was deemed low quality (and at high risk of bias) based on previous studies that used these scores. The articles were independently assessed by three authors (P.M., C.G., and M.M.) with a senior author settling any disagreement (T.L.L.). P.M. recorded sources of funding for individual studies included in the review.

### Statistical analysis

Where data was provided, weighted means of radiographic outcomes and recurrence rates of the surgical procedures were calculated. An independent *t*-test was used to compare the weighted means. All data analysis was conducted using Python SciPy.[17] Radiographic results were considered statistically significant when reported to have a *p*-value of less than 0.05.

## Results

### Literature search

The initial search yielded 1220 articles for review after duplicates were removed as shown in Figure 1. Review of titles and abstracts identified 80 articles for full-text screening, of which 44 met the inclusion criteria. The main reasons for excluding articles at this stage were “no reporting of outcomes” ($n=11$, 31%) and “no separation of outcomes for patients with CP to patients with different etiology for pes planus (PP)” ($n=20$, 56%).

### Study and patient characteristics

The search identified 10 comparative studies (23%): 8 of these were retrospective comparative studies (18%) and 1 was a prospective, randomized design (2%). Of the remaining studies, 7 were prospective case series (16%) and 27 were retrospective case series (63%). The study characteristics and outcomes of the papers included can be seen in Table 1 and summarized in Table 2.

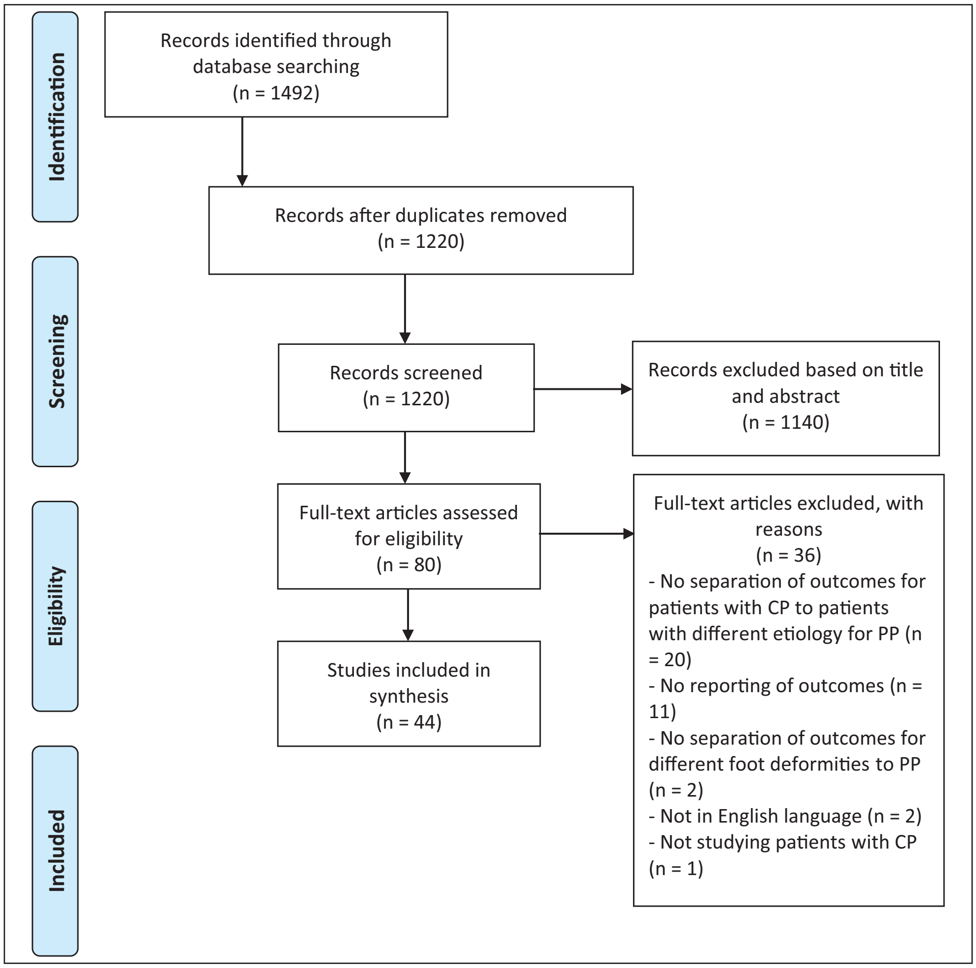


**Figure 1.** A prisma flow diagram for the systematic review detailing the database searches, the number of abstracts screened and the full texts reviewed. CP = cerebral palsy; PP = pes planus.

The studies included 2234 feet in 1364 patients with a mean age of 10.3 years (ranging from 3 to 30 years) and a mean follow-up of 55.9 months (ranging from 4.3 to 217.2 months). Studies included patients with a GMFCS level of I–V, with both stiff and flexible flatfoot deformities. There was a significant focus on ambulatory patients with GMFCS level I–III and a flexible flatfoot deformity ($n$ = 33, 75%).

## Outcomes

A majority of the papers (75%, $n$ = 33) reported on pre- and post-operative radiographic deformity correction outcomes. All of these papers clearly stated that the radiographs were weight-bearing. Overall, the radiographic angles showed significant improvement within normal range with the exception of the Lat. T1MT angle in LCL and the AP TC angle in IAA (Table 3).

The clinical outcomes were measured differently in all papers (Table 1). Similarly, of the 11 studies (25%) that reported on gait analysis, kinematics, and pedobarography, the heterogeneity of the measurements meant that a comparison of the data between studies was not possible.[19,32,38,39,46,47,49,50,55,59,60]

Given the heterogeneity in outcome measures between the studies and their general poor quality, it was not possible to synthesize a meta-analysis. A formal narrative synthesis of the results is provided following the Synthesis Without Meta-analysis (SWiM) reporting guidelines.[62]

## Complications and recurrence

Data regarding complication and recurrence rates was poorly reported (Table 4). There was no clear correlation between complication rates and GMFCS level or the severity of the deformity. Recurrence rates were highest in relation to LCL and CS, and lowest in relation to DCO, TCO, and SA (Table 5).

## Quality of studies included

The quality of the studies included was assessed according to the MINORS criteria (Figures 2 and 3). In total, 38

**Table 1.** Table of included studies.

| Study | Study design (Oxford level of evidence) | Procedure type | No. of patients (M: F) | No. of feet | Mean age in years (range) | GMFCS or level of disability | Outcomes used | Mean follow-up period in months (range) | MINORS score (quality) |
|---|---|---|---|---|---|---|---|---|---|
| Aboelenein et al.[18] | Prospective case series (4) | Calcaneal LCL | 15 (5:10) | 22 | 11.5 (8.3–14.5) | II–III | AP T1MT, AP TC, Lat T1MT, Lat TC, CP, and Dogan's scale | 31 (26–44) | 12 (good) |
| Abu-Faraj et al.[19] | Retrospective case series (4) | EAA | 12 (8:4) | 17 | 13.1 ± 2.6 | Ambulatory | 3D gait analysis and plantar pressure measurements | 12 | 8 (poor) |
| Adams et al.[20] | Retrospective comparative study (3) | Calcaneal LCL | 42 (19:23) | 61 | 9 (6.3–13.9) | Not stated | Lat. TC, AP and Lat. T1MT, Lat. TNC, CP, Lawrence and Kellgren criteria for OA. | 70 (41–102) | 16 (poor) |
| Ahmed et al.[21] | Prospective, randomized, comparative study (2) | Calcaneal LCL, SA | 35 | 57 | 9 | I–III | AP TNC; AP and Lat T1MT, AP and Lat. TC, CP; talar declination angle<br>Yoo et al. clinical score, patient satisfaction, orthosis, shoes | 15.6 (12–22) | 18 (poor) |
| Alman et al.[22] | Retrospective case series (4) | EAA | 29 | 53 | | Ambulatory | AP and Lat. TC, AP TNC<br>Clinical and radiographic assessment of ankle and subtalar alignment, braces, skin calluses | 106.8 | 10 (poor) |
| Aly et al.[23] | Prospective case series (4) | DCO | 16 (9:7) | 24 | 10.74 (6–16) | I–III | AP and Lat. CP, TC, T1MT<br>Talar head uncoverage (%)<br>Clinical heel valgus | 33.5 (24–48) | 10 (poor) |
| Andreacchio et al.[24] | Retrospective case series (4) | Calcaneal LCL | 15 | 23 | 9.1 (6.2–17.8) | Ambulatory | Lat. T1MT, Lat., AP TNC<br>Cosmesis, walking distance, walking support, pain | 49.2 (27.6–61.2) | 10 (poor) |
| Bhan and Malhotra[25] | Retrospective case series (4) | EAA | 10 | 16 | 6.2 (4–11) | Not stated | Lat. TC, heel valgus alignment<br>Mobility, pain | 43.2 (24–72) | 10 (poor) |
| Barrasso et al.[26] | Retrospective case series (4) | EAA | 26 (17:9) | 40 | 10.5 (3.5–14.9) | Ambulatory and non-ambulatory | Lat. TC Clinical evaluation of ambulatory status, physical examination | 30 (16–53) | 10 (poor) |
| Bourelle et al.[27] | Retrospective case series (4) | EAA | 17 (9:8) | 26 | 5.4 (3.8–8.6) | Ambulatory | AP and Lat. TC, Lat. talar declination,<br>Heel valgus alignment<br>Pain, walking assessment, type of shoe, footprint analysis, callus formation, physical examination | 243 (207–276.6) | 10 (poor) |
| Cho et al.[28] | Retrospective case series (4) | Calcaneal LCL | 44 (27:17) | 77 | 10.5 | I–IV | Lat TC, AP and Lat. T1MT, CP | 61.2 | 12 (good) |
| Costici et al.[29] | Retrospective case series (4) | IAA | 103 (64:39) | 175 | 14.7 (12–20) | I–IV | AP TC, AP TNC, Costa Bertani angle<br>Visual analogue scale for pain, GMFCS scale. | 62.4 (12–112) | 10 (poor) |
| de Moraes Barros Fucs et al.[30] | Retrospective case series (4) | IAA | 21 (13:8) | 35 | 16 (8–29) | II–IV | Inclination of the calcaneus angle, Lat. TC<br>Pain, walking assessment, need of braces, type of shoe, physical examination | 58 (30–90) | 7 (poor) |
| Elbarbary et al.[31] | Prospective case series (4) | SA | 23 (16:7) | 46 | 8.6 (6–12) | I–III | Lat-TCA, heel valgus alignment, OxFAQ-C (physical, school and play, emotional, shape of foot, shoe wear, walking ability) | 36.7 (24–40) | 12 (good) |
| El-Hilaly et al.[32] | Prospective case series (4) | TCO | 12 (7:5) | 18 | 9.7 (5.1–15.3) | I–IV | Lat. TC, Lat. T1MT, TNC, CP, dorsoplantar T1MT<br>Pedobarography | 4.25 (2.5–6.5) | 11 (poor) |
| Engström et al.[33] | Prospective case series (4) | EAA | 16 | 27 | 6 (3–12) | Not stated | Subtalar stability, corrected valgus hindfoot, gait improvement, radiographic analysis of union | 39.6 (12–96) | 7 (poor) |
| Ettl et al.[34] | Retrospective case series (4) | Calcaneal LCL | 19 (12:7) | 28 | 8.6 (4–18) | Ambulatory and non-ambulatory | Lat. T1MT, Lat. Horizontal angle, CP<br>Mosca's clinical criteria<br>AOFAS ankle-hindfoot scale | 51.6 (12–103.2) | 10 (poor) |
| Güven et al.[35] | Retrospective case series (4) | EAA | 11 (5:6) | 15 | 10.7 (6–15) | I–IV | AP and Lat. TC, AP and Lat. T1MT, CP<br>Walking, pain, skin calluses, orthoses, shoes, and survey | 24 (9–39) | 9 (poor) |
| Huang et al.[36] | Retrospective comparative study (3) | Calcaneal LCL ± medial column stabilization via talonavicular arthrodesis | 21 (8:13) | 37 | 11 (4.9–16) | II–III | AP. TNC<br>Mosca's radiographic and clinical criteria, Yoo et al. criteria | 29.4 (13–63.6) | 17 (poor) |
| Jeray et al.[37] | Retrospective case series (4) | EAA | 28 (18:10) | 52 | 7.4 (5–12) | Not stated | Lat. TC<br>Survey | 41 (27–78) | 10 (poor) |
| Kadhim et al.[38] | Retrospective comparative series (3) | IAA, Calcaneal LCL | 78 (43:35) | 138 | 11.9 (4.7–18.3) | I–IV | Lat. TC, Lat. T1MT, CP<br>Gait and kinematic analysis; pedobarography | 60 (12–184.8) | 15 (poor) |
| Kadhim et al.[39] | Retrospective comparative study (3) | IAA, Calcaneal LCL | 24 | 43 | 11 (4.7–18.3) | I–IV | Lat TC, Lat. T1MT, CP<br>Gait and kinematic analysis, pedobarography | 130.8 (75.6–184.8) | 15 (poor) |
| Kubo et al.[40] | Retrospective case series (4) | SA | 11 | 19 | 9.2 (5–13) | II–III | AP and Lat. TC, AP and Lat. T1MT, CP, lateral relative overlap of Os navicular and Os cuboideum | 35.2 (7–100) | 10 (poor) |

(Continued)

**Table 1.** (Continued)

| Study | Study design (Oxford level of evidence) | Procedure type | No. of patients (M: F) | No. of feet | Mean age in years (range) | GMFCS or level of disability | Outcomes used | Mean follow-up period in months (range) | MINORS score (quality) |
|---|---|---|---|---|---|---|---|---|---|
| Leidinger et al.[41] | Retrospective case series (4) | EAA | 35 (20:15) | 51 | 7.8 (3.9–14.4) | Ambulatory | Lat. TC, CP<br>Heel valgus alignment, patient satisfaction, GMFCS level | 271.2 (192–387.6) | 10 (poor) |
| Luo et al.[42] | Retrospective case series (4) | Calcaneal LCL | 20 (14:6) | 30 | 11.9 | II–IV | AP and Lat. T1MT, CP, AP and Lat. TC, AP TNC, Lat. talo-horizontal angle<br>Foot pain, callosity, tolerance to a foot orthosis | 30 (12–72) | 10 (poor) |
| Mazis et al.[43] | Retrospective case series (4) | EAA | 11 (7:4) | 16 | 9.7 (6.4–12.3) | Not stated | AP and Lat. TC, AP and Lat. T1MT, TNC, CP, naviculocuboid overlap | 43.2 (24–99.6) | 9 (poor) |
| Molayem et al.[44] | Retrospective case series (4) | SA | 15 (7:8) | 27 | 12.1 (9.3–14.5) | Ambulatory | AP and Lat. TC<br>Pain, loss of function | 61.2 (26.4–111.6) | 10 (poor) |
| Muir et al.[45] | Retrospective case series (4) | IAA | 5 (3:2) | 9 | 14 (11–17) | IV–V | Radiographic outcomes not specified<br>Mobility, shoes, and braces | 60 (52–69) | 8 (poor) |
| Nahm et al.[46] | Retrospective comparative study (3) | Calcaneal LCL and either medial cuneiform dorsal opening-wedge osteotomy or medial cuneiform plantar flexion closing-wedge osteotomy | 24 (14:10) | 42 | 9.7 ± 3.4 | I–III | CP, AP and Lat. T1MT, multi-segment foot modeling (MSFM) gait analysis, physical examination | 14.4 (9.6–42) | 16 (poor) |
| Narang et al.[47] | Prospective case series (4) | Calcaneal LCL | 10 | 17 | 8–18 (11.13) | I–II | AP TC, AP TN, Lat. CP, C5MT, Lat. T1MT<br>Heel valgus alignment and heel rise tests, video gait analysis | 12 | 12 (good) |
| Noritake et al.[48] | Retrospective case series (4) | Calcaneal LCL | 16 (10:6) | 27 | 10.8 (5.8–14.5) | Ambulatory | AP TN, AP and Lat-T1MT, Lat. CP, Lat talo-horizontal angle<br>Mosca's clinical criteria | 38.4 (24–60) | 9 (poor) |
| Park et al.[49] | Retrospective comparative study (3) | EAA, Calcaneal LCL | 47 (27:20) | 81 | 8.1 (5.5–16.7) | II | AP and Lat. T1MT, AP and Lat. TC. CP<br>Pedobarography | 39 (26–61) | 16 (poor) |
| Rethlefsen et al.[50] | Retrospective comparative study (3) | CS, Calcaneal LCL | 72 (41:31) | 119 | 11.1 | I–III | Gait kinematics and kinetics<br>Modified Yoo system for change in standing foot position<br>Modified Clavien–Dindo system for complications | 38.4 | 14 (poor) |
| Rhodes et al.[51] | Retrospective comparative study (3) | Calcaneal LCL | 36 | 63 | 9.3 (4–18) | I–V | Lat. TC, AP and Lat. T1MT, AP TNC, CP<br>Worth et al. radiographic xenograft incorporation grade | 37.25 (21.2–53.7) | 16 (poor) |
| Senaran et al.[52] | Retrospective case series (4) | IAA | 138 (73:65) | 253 | 12.7 (5–20) | I–V | Radiographic reporting on fusion and hardware<br>Mobility, shoes, heel valgus alignment, skin calluses, pain | 57.6 (24–132) | 9 (poor) |
| Shore et al.[53] | Retrospective case series (4) | EAA | 46 (28:18) | 92 | 12.9 (7.8–18.4) | II–IV | Lat. TC, Lat T1MT, navicular cuboid overlap,<br>Mobility scale | 55 (30–90) | 10 (poor) |
| Sung et al.[54] | Retrospective case series (4) | Calcaneal LCL | 75 (51:24) | 75 | 11 (5–30) | Not stated | AP T1MT, CP, TC, Lat. T1MT | 37.2 (12–101) | 12 (good) |
| Turriago et al.[55] | Retrospective case series (4) | IAA | 32 (16:16) | 59 | 13.9 (9–20) | Ambulatory | Lat and AP TC, Lat and AP T1MT, Gait analysis, satisfaction questionnaire | 40 (18.3–66.7) | 7 (poor) |
| Vlachou et al.[56] | Retrospective case series (4) | EAA | 5 (2:3) | 6 | 10.6 (9–14) | Ambulatory | Lat. TC, TNC<br>physical examination; symptomatic feet | 96 (24–180) | 9 (poor) |
| Vlachou and Dimitriadis[57] | Retrospective case series (4) | EAA | 9 (3:6) | 12 | 11.7 (9–14) | Ambulatory | Lat. TC, Lat. TNC, evidence of fusion<br>Appearance of the feet, heel valgus alignment, local symptoms | 93.6 (48–180) | 9 (poor) |
| Wen et al.[58] | Retrospective comparative study (3) | EAA, SA | 26 (17:9) | 44 | 8.5 (5–15) | I–II | AP TC, Lat. T1MT<br>AOFAS-AH | 30.1 (20–60) | 16 (poor) |
| Yoo et al.[59] | Retrospective case series (4) | Calcaneal LCL | 56 | 92 | 9.2 (4–17.2) | Ambulatory | Lat. TC, Lat. T1MT, Lat. CP<br>Gait analysis,<br>heel valgus alignment | 62.4 (24–93.6) | 9 (poor) |
| Yoon et al.[60] | Retrospective case series (4) | EAA | 30 (21:9) | 50 | 9 (5–18) | Ambulatory | AP and Lat. T1MT, AP and Lat. TCA, CP, Lat. C1MT<br>Kinematic analysis | 37 (26–49) | 9 (poor) |
| Zeifang et al.[61] | Prospective case series (4) | Calcaneal LCL | 32 (22:10) | 46 | 11 (4–22) | Ambulatory | Lat. TC, Lat. T1MT, Lat. CP, AP T1MT, Costa Bertani angle Modified Phillips clinical score | 66 (36–108) | 12 (good) |

AP TC: anterior–posterior talocalcaneal; AP T1MT: anterior–posterior talo-first metatarsal; Lat. T1MT: lateral talo-first metatarsal; Lat. TC: lateral talocalcaneal; CP: cerebral palsy; TNC: talonavicular coverage; MSFM: multi-segment foot modeling; C1MT: calcaneal-first metatarsal; GMFCS: Gross Motor Function Classification System; OA: osteoarthritis; AOFAS: American Orthopaedic Foot and Ankle Society; AOFAS-AH: American Orthopaedic Foot and Ankle Society Ankle-Hindfoot scoring system; OxFAQ-C: Oxford Ankle Foot Questionnaire for Children.

**Table 2.** Summart of included studies.

| | Calcaneal LCL | CS | EAA | DCO | TCO | IAA | SA |
|---|---|---|---|---|---|---|---|
| No. of studies | 17 | 1 | 16 | 1 | 1 | 7 | 5 |
| Sample size (no. of feet) | 784 | 119 | 539 | 24 | 18 | 634 | 140 |
| GMFCS (I–V) | I–V | I–III | I–IV | I–III | I–IV | I–V | I–III |
| No. of comparative studies | 6 | 1 | 2 | 0 | 0 | 2 | 2 |

LCL: lateral column lengthening; CS: calcaneal slide; EAA: extra-articular arthrodesis; DCO: double calcaneal osteotomy; TCO: triple calcaneal osteotomy; IAA: intra-articular arthrodesis; SA: subtalar arthroereisis; GMFCS: Gross Motor Function Classification System.

**Table 3.** Radiographic outcomes summarised using the weighted mean for each procedure.

| | AP TC | Lat. TC | AP T1MT | Lat. T1MT | CP | AP TC | Lat. TC | AP T1MT | Lat. T1MT | CP |
|---|---|---|---|---|---|---|---|---|---|---|
| IAA | 42.9 | 48.2 | 25.7 | 22.2 | 12 | 33.9 | 31.6 | 5.3 | 8.7 | 12.8 |
| LCL | 30 | 42.6 | 23.2 | 27.5 | 3.7 | 20.9 | 36.2 | 6 | 11 | 10.6 |
| EAA | 38.6 | 45.9 | 28.5 | 29.5 | 11 | 25.9 | 33.3 | 7.9 | 10 | 12 |
| SA | 34.4 | 47.2 | 26.5 | 26.5 | 5.2 | 27.5 | 31 | 5.11 | 5.5 | 9.8 |

AP TC: anterior–posterior talocalcaneal angle (normal range 15°–27°); Lat. TC: lateral talocalcaneal angle (normal range 25°–45°); AP T1MT: anterior–posterior talo-first metatarsal angle (normal range 3°–11°); Lat. T1MT: lateral talo-first metatarsal angle (normal range 2°–10°); CP: calcaneal pitch (13°–23°); IAA: intra-articular arthrodesis; LCL: lateral column lengthening; EAA: extra-articular arthrodesis; SA: subtalar arthroereisis.

studies (86%) were assessed as having a high risk of bias, and 6 (14%) studies as having a low risk of bias.

## Discussion

This is the first systematic review of surgical management of pes planus in children with CP, covering 2234 operations from 44 papers. Overall, we found that substantial deformity correction was achieved by each surgical intervention. Based on the evidence, however, it is not possible to show that one intervention is superior to others.

There is a significant lack of studies on CS, DCO, TCO, IAA, and SA (Table 2). Most of the patients included in the studies in this review had flexible deformity with lower GMFCS levels; there is limited data to allow a proper assessment of treatment for moderate–severe flatfoot deformities. Ideally, studies would separate management of stiff flatfoot in GMFCS levels IV and V from flexible flatfoot in GMFCS levels I–III as it constitutes a different deformity. Many of the papers used levels I–IV or I–V, or described the patients as "ambulant" or "non-ambulant" making it difficult to undertake subgroup analysis as the data was not always clearly separated.

The radiographic outcomes show significant improvement is achievable by all surgical interventions. Severe deformity in patients with higher GMFCS levels is difficult to treat even with an invasive procedure such as IAA, and achieving long-term correction with LCL, EAA, CS, or SA is unlikely unless there is concomitant joint fusion.[34,36,50] Four of the papers offered useful parameters for when a modified or more invasive procedure than LCL or EAA should be used to treat pes planus to avoid recurrence, but these papers were limited by the bias in the studies.[24,50,54,59] Some studies combined techniques, such as Nahm et al.,[46] which are valid surgical options and would merit further research.

Our study has highlighted the need for a standardized method of measuring clinical outcomes. Four of the studies on LCL used either Mosca or Yoo's clinical criteria, the latter of which was adopted by Ahmed et al.,[21] to assess the results of SA.[11,21,34,36,48] These criteria could be combined in future and validated to compare different procedures, but could be adapted to incorporate activity levels to assess function. There was a notable lack of patient-reported outcomes in the studies which are essential to assess the effect of treatment on the patient's quality of life. For example, relief of pain post-procedure is an important treatment outcome that could not be assessed in our review because it was either not measured at all or not in a consistent way. Standardized methods of measuring gait analysis, kinematics, and pedobarography are also needed given a general consensus in the included studies on the limited ability of radiographic outcomes to fully reflect the clinical picture.[19,32,38,39,46,47,49,50,55,59,60]

The poor reporting of complications could be improved by the use of clearer definitions, for example, avoiding the interchangeable use of terms such as "non-union" and "pseudoarthrosis," or "under-correction" and "recurrence." The high recurrence rates seen in LCL and CS procedures compared to other procedures reflect the high risk of bias in the studies rather than the actual difference in recurrence rates, and other procedures reported significant complications such as hardware complications for SA. Any conclusions on the comparison between treatments in

**Table 4.** Complications and recurrence rates.

| Procedure | Study/modification to procedure | No. of feet | GMFCS/ ambulatory (A)/ non-ambulatory (NA) | Complications (%) | Recurrence rate (%) |
|---|---|---|---|---|---|
| Calcaneal LCL | Aboelenein et al.[18]<br>Minor modification to Mosca, PBL, PLL, ATL | 22 | II–III | – Infection 4.5<br>– Under-correction 9 | – |
| | Adams et al.[20]<br>– Group 1: Pin stabilization ATL, GR (PS)<br>– Group 2: No stabilization ATL, GR (NS) | 61 | – | – Subluxation 86 (PS)<br>– Subluxation 91 (NS)<br>– Osteoarthritis 6 (NS) | – |
| | Ahmed et al.[21]<br>Evans, ATL, GR | 29 | I–III | – Pain 13.8<br>– Infection 6.9<br>– Under-correction 14 | 0 |
| | Andreacchio et al.[24]<br>Mosca PBL, PLL, GR, ATL | 23 | A | – Non-union 13 | 25 |
| | Cho et al.[28]<br>Minor modification to Mosca, PBL, ATL, GR | 77 | I–IV | – Subluxation 6.5<br>– Degenerative arthrosis 2.6 | – |
| | Ettl et al.[34]<br>ATL, PBL TATT, PLL, open reduction of talonavicular joint | 28 | A and NA | – Infection 4 | 25 |
| | Huang et al.[36]<br>– Group 1: CL, ATL, GR<br>– Group 2: CL, medial column stabilization via talonavicular arthrodesis, ATL, GR | 37<br>19<br>18 | II–III | – Staple penetration into talonavicular joint 31.6 (Group 1); 11.1 (Group 2) | 36.8 (Group 1); 16.7 (Group 2) |
| | Kadhim et al.[38]<br>GR, ATL, TATT | 63 | I–IV | – | – |
| | Kadhim et al.[39]<br>GR, ATL, TATT | 15 | I–IV | – Under-correction 20<br>– Hardware prominence requiring removal of hardware 47<br>– Pain 53 | – |
| | Luo et al.[42]<br>Mosca, ATL, GR | 30 | II–IV | – Under-correction 43 | 0 |
| | Nahm et al.[46]<br>Mosca, GR, ATL | 24 | I–III | – | – |
| | Narang et al.[47]<br>Mosca, PBL, PLR | 17 | I–II | – Paraesthesia sural nerve 5.9 | 5.88 |
| | Noritake et al.[48]<br>Mosca, PBL | 27 | I–II | – Over-correction 4<br>– Under-correction 22<br>– Difficulty wearing brace 4 | 18.5 |
| | Park et al.[49]<br>Mosca, GR, ATL PBL | 37 | II | – | – |
| | Rethlefsen et al.[50]<br>PBL | 46 | I–III | – Over-correction 13<br>– Transient neuropraxia due to concomitant hamstring lengthening $<23$ | 64 |
| | Rhodes et al.[51]<br>– Group 1: Bovine xenograft (X) GR, ATL<br>– Group 2: Allograft (A) GR, ATL | 63 | I–V | – Pressure ulcer 24 (A)<br>– Delayed union 2 (X)<br>– Non-union 1 (X)<br>– Revision surgery 2 (X) | 15 (A)<br>13 (X) |
| | Sung et al.[54]<br>Minor modification of Evans, PBL, ATL GR | 75 | – | – Under-correction 28–40 | – |
| | Yoo et al.[59]<br>Minor modification to Mosca, ATL, GR, PBL, PLR | 92 | A | – Subluxation 3.3<br>– Over-correction 7.6 | 4.3 |
| | Zeifang et al.[61]<br>Evans, GR, PBL, RMC | 46 | A | – Hematoma 23<br>– Loss of correction 21<br>– Over-correction 9<br>– Subluxation 21<br>– Osteoarthritis 2 | 15.2 |
| CS | Rethlefsen et al.[50]<br>RMC or TNF | 73 | I–III | – Over-correction 4<br>– Prolonged pain $<23$<br>– Plantar hypersensitivity $<23$ | 29 |

*(Continued)*

**Table 4.** (Continued)

| Procedure | Study/modification to procedure | No. of feet | GMFCS/ ambulatory (A)/ non-ambulatory (NA) | Complications (%) | Recurrence rate (%) |
|---|---|---|---|---|---|
| DCO | Aly et al.[23]<br>Mosca and medial slide; GR, PBL, TPA | 24 | I–III | – Under-correction 12.5<br>– Heel ulcer 6.25<br>– Chronic heel pain 6.25 | 0 |
| TCO | El-Hilaly et al.[32]<br>PBL, GR, talonavicular reduction with capsular and tibialis posterior plication | 18 | I–IV | – | - |
| SA | Ahmed et al.[21]<br>ATL, GR | 28 | I–III | – Pain 25<br>– Under-correction 7 | 0 |
| | Elbarbary et al.[31]<br>ATL, PBL, PLL, multilevel release | 46 | I–III | – Infection and removal of hardware 2.2 | 0 |
| | Kubo et al.[40]<br>ATL, GR | 19 | II–III | 0 | 0 |
| | Molayem et al.[44]<br>– Group 1: Intra-sinus tarsi (IST) ATL<br>– Group 2: Extra-sinus tarsi (EST) ATL | 27 | A | – Implant dislocation 21 (IST)<br>– Implant fracture 15 (EST)<br>– Implant dislocation 23 (EST) | 0 |
| | Wen et al.[58]<br>ATL | 20 | I–II | Pain 5 | 0 |
| EAA | Abu-Faraj et al.[19] | 17 | A | – | – |
| | Alman et al.[22]<br>Modification of Grice | 53 | A | – Skin irritation 20.7<br>– Migration of smooth fixation wire 3.4<br>– Over-correction 13.7<br>– Revision surgery 3.4<br>– Tibial fracture at graft harvest site 3.4<br>– Ankle valgus 10.3 | 3.8 |
| | Barrasso et al.[26]<br>Dennyson-Fulford | 40 | A and NA | – Heel ulcer 2.5<br>– Pseudoarthrosis (asymptomatic) 5 | 0 |
| | Bhan and Malhotra[25]<br>Dennyson-Fulford, fibular dowel and screw ATL, PBT, Steindler's plantar release | 16 | A | – Infection 6.3<br>– Hardware problems 31.2 | 0 |
| | Bourelle et al.[27]<br>Chigot and Sananes modification of Grice ATL | 26 | A | – Infection 3.8<br>– Over-corrected 19.2<br>– Pain 26.6<br>– Graft resorption 27 | 0 |
| | Engström et al.[33]<br>ATL | 27 | – | – Non-union 33<br>– Under-corrected 7 | 22 |
| | Güven et al.[35]<br>Modification of Grice using subperiosteal fibular graft, GR | 15 | I–IV | 0 | 0 |
| | Jeray et al.[37] | 52 | – | – Non-union 12 | 3.8 |
| | Leidinger et al.[41]<br>ATL PTL | 51 | A | – Graft slippage 1.96<br>– Revision surgery 1.96<br>– Under-correction 9.8<br>– Over-correction 7.84<br>– Shin bone fracture 3.92 | 3.92 |

*(Continued)*

**Table 4.** (Continued)

| Procedure | Study/modification to procedure | No. of feet | GMFCS/ ambulatory (A)/ non-ambulatory (NA) | Complications (%) | Recurrence rate (%) |
|---|---|---|---|---|---|
| | Mazis et al.[43]<br>Chigot and Sananes modification of Grice ATL | 16 | – | – Non-union 18.8<br>– Graft absorption 18.8 | 12.5 |
| | Park et al.[49]<br>Modified Dennyson-Fulford, GR, ATL PBL | 44 | II | – | – |
| | Shore et al.[53]<br>Modified Dennyson-Fulford (dowel allograft) | 92 | II–IV | – Stable fibrous union 2.2 | 0 |
| | Vlachou et al.[56]<br>Batchelor-Grice | 6 | A | 0 | 0 |
| | Vlachou and Dimitriadis[57]<br>Batchelor-Grice ATL | 12 | A | 0 | 0 |
| | Wen et al.[58]<br>Dennyson-Fulford, GR, ATL | 22 | I–II | – Pain 4.5<br>– Screw fracture 4.5 | 0 |
| | Yoon et al.[60]<br>Modified Dennyson-Fulford ATL GR PBL | 50 | A | – Heel sore 6<br>– Necrosis of incision wound 4 | 0 |
| IAA | Costici et al.[29]<br>Double arthrodesis<br>Talonavicular + calcaneocuboid joint, GR | 175 | I–IV | – Infection 2.3<br>– Delayed union 3.4<br>– Hardware breakage 2.9<br>– Revision surgery 4.6<br>– Persistent pain 4 | – |
| | de Moraes Barros Fucs et al.[30] | 35 | II–IV | – Non-union 50<br>– Pseudoarthrosis 37<br>– Pain 4.8<br>– Revision surgery 38.1 | – |
| | Kadhim et al.[38]<br>Allograft and screw fixation, GR, ATL | 75 | I–IV | – | – |
| | Kadhim et al.[39]<br>Allograft and screw fixation, GR, ATL | 28 | I–IV | – Under-correction 29<br>– Hardware prominence requiring hardware removal 25<br>– Pain 11 | – |
| | Muir et al.[45]<br>ATL | 9 | IV–V | – Non-union 11 | – |
| | Senaran et al.[52]<br>ATL GR | 253 | I–V | – Infection 0.3<br>– Skin hypersensitivity 2.4<br>– Non-union 2<br>– Screw removal for irritation of tendons 2<br>– Pseudoarthrosis 0.8 | 2 |
| | Turriago et al.[55] | 59 | A | – Pseudoarthrosis 12<br>– Under-correction 3.4<br>– Over-correction 1.7<br>– Revision surgery 12<br>– Pain 8.5 | 0 |

LCL: lateral column lengthening; DCO: double calcaneal osteotomy; TCO: triple calcaneal osteotomy; SA: subtalar arthroereisis; IST: intra-sinus tarsi; EST: extra-sinus tarsi; EAA: extra-articular arthrodesis; IAA: intra-articular arthrodesis ; PBL: peroneus brevis tendon lengthening; PLL: peroneus longus tendon lengthening; ATL: Achilles tendon lengthening; GR: gastrocnemius recession; PS: pin stabilisation; NS: nonstabilised; TATT: tibialis anterior tendon transfer; PLR: peroneus longus release; RMC: reefing medial capsule; NF: talonavicular joint fusion; TPA: tibialis posterior tendon advancement; PBT: peroneus brevis transfer; PTL: peroneal tendon lengthening.

**Table 5.** Weighted mean of recurrence rates for each procedure where data was provided.

| LCL | CS | DCO | TCO | SA | EAA | IAA |
|---|---|---|---|---|---|---|
| 18% | 29% | 0% | 0% | 0% | 2.9% | 1.6% |

LCL: lateral column lengthening; CS: calcaneal slide; DCO: double calcaneal osteotomy; TCO: triple calcaneal osteotomy; SA: subtalar arthroereisis; EAA: extra-articular arthrodesis; IAA: intra-articular arthrodesis.

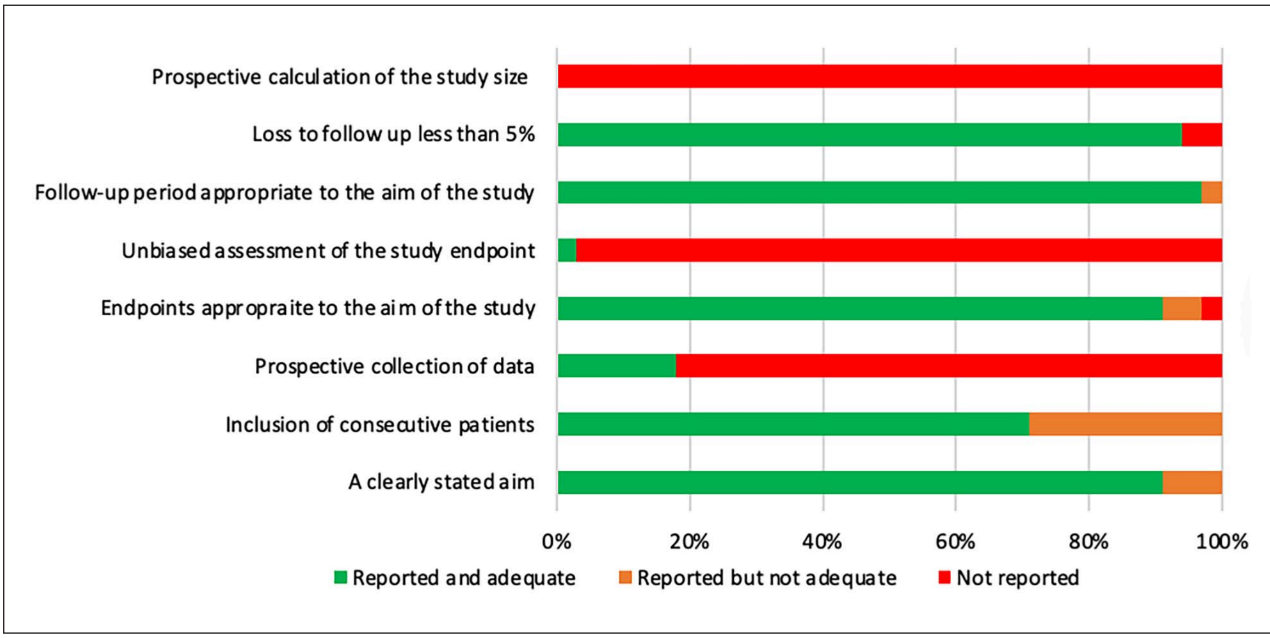


**Figure 2.** Bar chart demonstrating how non-comparative studies scored on MINORS.

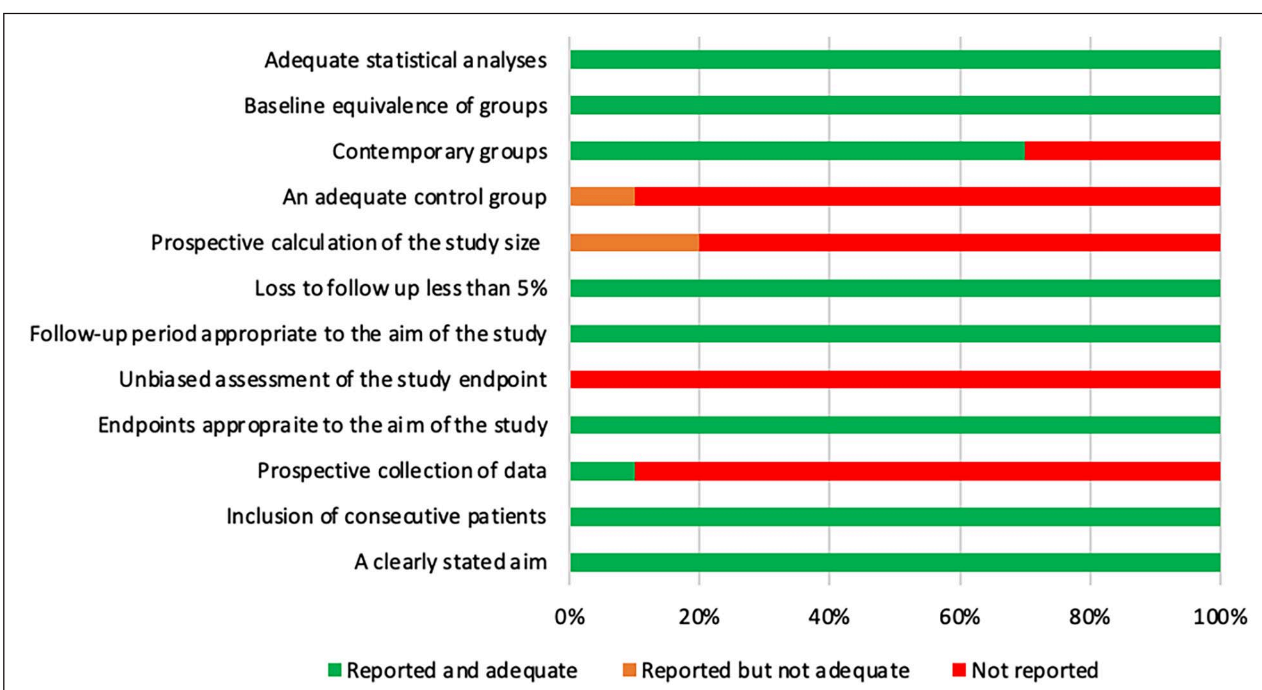


**Figure 3.** Bar chart demonstrating how comparative studies scored on MINORS.

regard to recurrence rates and complications would be misleading given the small size of the studies, short follow-up and reporting bias which may have hidden recurrence rates and complications.

The strengths of this review are that it includes papers on multiple interventions with a large sample size and a long follow-up. The 44 studies reported on a homogeneous population with minimal loss to follow-up. The main limitation of this review is the quality of the included studies which were mostly graded as "poor" and thus had a high risk of bias. The robustness of our synthesized results is difficult to assess given that data was often missing from the studies, especially regarding complications of the procedures. Furthermore, the heterogenous complication results meant that any analysis between the procedures is difficult to undertake. The retrospective case series did not have comparator interventions, meaning a potential lack of systematic pre- and post-operative assessment, and a high risk of bias in the clinical and radiographic outcomes. *P*-values were often not provided by papers to demonstrate whether radiographic outcomes were statistically significant, and often not combined with clinical outcomes to make them useful. The prospective and comparative studies were weakened by small study sizes and short follow-up periods. Longer follow-up periods are needed to reliably assess whether there are any degenerative changes to adjacent joints that can occur after fusion. Degenerative changes after IAA were not reported in the six studies with a mean follow-up of 71.4 months, thus a longer follow-up may be needed to exclude this outcome.[29,30,38,39,45,52,55]

## Conclusion

Pes planus is the most common foot condition for children with CP; a more robust evidence base is needed to provide guidance to surgeons on the optimal intervention for patients. Our review has highlighted the need for multi-center, large-scale, prospective, comparative studies, using standardized radiographic, clinical, and pedobarographic outcomes. Future studies should focus on interventions for patients with severe, stiff deformities, and higher GMFCS levels, and how the addition of fusion to procedures affects these patients in the long term.

### Author contributions

**Poppy MacInnes:** Study conception, design, data collection, analysis, article preparation.
**Thomas L Lewis:** Study conception, design, data collection, analysis, article preparation.
**Cora Griffin:** Data collection, analysis, article preparation.
**Michela Martinuzzi:** Data collection, analysis, article preparation.
**Karen L Shepherd:** Data collection, analysis, article preparation.
**Michail Kokkinakis:** Study conception, design, data collection, article preparation.

### Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Compliance with ethical standards

The authors have no conflicts of interest to declare that are relevant to the content of this article. Ethical approval was not required.

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The open access fee was supported by Lavender Medical ltd and Ames Medical, and this funding was secured after the completion of the study.

### ORCID iDs

Poppy MacInnes https://orcid.org/0000-0003-3641-120X
Cora Griffin https://orcid.org/0000-0002-2922-162X

### References

1. Sees JP and Miller F. Overview of foot deformity management in children with cerebral palsy. *J Child Orthop* 2013; 7(5): 373–377.
2. Smith C, Zaidi R, Bhamra J, et al. Subtalar arthroereisis for the treatment of the symptomatic paediatric flexible pes planus: a systematic review. *EFORT Open Rev* 2021; 6(2): 118–129.
3. Halabchi F, Mazaheri R, Mirshahi M, et al. Pediatric flexible flatfoot; clinical aspects and algorithmic approach. *Iran J Pediatr* 2013; 23(3): 247–260.
4. Kadhim M and Miller F. Pes planovalgus deformity in children with cerebral palsy: review article. *J Pediatr Orthop B* 2014; 23(5): 400–405.
5. Carr JB 2nd, Yang S and Lather LA. Pediatric pes planus: a state-of-the-art review. *Pediatrics* 2016; 137(3): e20151230.
6. Kim JR, Shin SJ, Wang SI, et al. Comparison of lateral opening wedge calcaneal osteotomy and medial calcaneal sliding-opening wedge cuboid-closing wedge cuneiform osteotomy for correction of planovalgus foot deformity in children. *J Foot Ankle Surg* 2013; 52(2): 162–166.
7. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 2021; 372: n71.
8. Shea BJ, Reeves BC, Wells G, et al. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. *BMJ* 2017; 358: j4008.
9. MacInnes P, Lewis TL, Griffin C, et al. Surgical management of pes planus in children with cerebral palsy: a systematic review. *PROSPERO2021 CRD42021239285*, https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021239285 (2021, accessed 22 December 2021).
10. Evans D. Calcaneo-valgus deformity. *J Bone Joint Surg Br* 1975; 57(3): 270–278.

11. Mosca VS. Calcaneal lengthening for valgus deformity of the hindfoot. Results in children who had severe, symptomatic flatfoot and skewfoot. *J Bone Joint Surg Am* 1995; 77: 500–512.
12. Grice DS. An extra-articular arthrodesis of the subastragalar joint for correction of paralytic flat feet in children. *J Bone Joint Surg Am* 1952; 34A(4): 927–940.
13. Koutsogiannis E. Treatment of mobile flat foot by displacement osteotomy of the calcaneus. *J Bone Joint Surg Br* 1971; 53(1): 96–100.
14. Rathjen KE and Mubarak SJ. Calcaneal-cuboid-cuneiform osteotomy for the correction of valgus foot deformities in children. *J Pediatr Orthop* 1998; 18(6): 775–782.
15. Williams PF and Menelaus MB. Triple arthrodesis by inlay grafting—a method suitable for the undeformed or valgus foot. *J Bone Joint Surg Br* 1977; 59: 333–336.
16. Slim K, Nini E, Forestier D, et al. Methodological index for non-randomized studies (minors): development and validation of a new instrument. *ANZ J Surg* 2003; 73(9): 712–716.
17. Virtanen P, Gommers R, Oliphant TE, et al. SciPy 1.0: fundamental algorithms for scientific computing in Python. *Nat Methods* 2020; 17: 261–272.
18. Aboelenein AM, Fahmy ML, Elbarbary HM, et al. Calcaneal lengthening for the pes planovalgus foot deformity in children with cerebral palsy. *J Clin Orthop Trauma* 2020; 11(2): 245–250.
19. Abu-Faraj ZO, Harris GF and Smith PA. Surgical rehabilitation of the planovalgus foot in cerebral palsy. *IEEE Trans Neural Syst Rehabil Eng* 2001; 9(2): 202–214.
20. Adams SB Jr, Simpson AW, Pugh LI, et al. Calcaneocuboid joint subluxation after calcaneal lengthening for planovalgus foot deformity in children with cerebral palsy. *J Pediatr Orthop* 2009; 29(2): 170–174.
21. Ahmed AH, Hanna AA, Arafa AS, et al. Prospective comparison of subtalar arthroereisis with calcaneal lengthening in the management of planovalgus feet of ambulatory children with spastic cerebral palsy? *Foot Ankle Spec*. Epub ahead of print 3 December 2020. DOI: 10.1177/1938640020974886.
22. Alman BA, Craig CL and Zimbler S. Subtalar arthrodesis for stabilization of valgus hindfoot in patients with cerebral palsy. *J Pediatr Orthop* 1993; 13(5): 634–641.
23. Aly AS, Abdel Rahman AF and Mahmoud S. Double calcaneal osteotomy in treatment of flexible planovalgus foot deformity in ambulatory cerebral palsy. A case series study. *Foot Ankle Surg* 2019; 25(5): 640–645.
24. Andreacchio A, Orellana C, Miller F, et al. Lateral column lengthening as treatment for planovalgus foot deformity in ambulatory children with spastic cerebral palsy. *J Pediatr Orthop* 2000; 20: 501–505.
25. Bhan S and Malhotra R. Subtalar arthrodesis for flexible hindfoot deformities in children. *Arch Orthop Trauma Surg* 1998; 117(6-7): 312–315.
26. Barrasso JA, Wile PB and Gage JR. Extraarticular subtalar arthrodesis with internal fixation. *J Pediatr Orthop* 1984; 4(5): 555–559.
27. Bourelle S, Cottalorda J, Gautheron V, et al. Extra-articular subtalar arthrodesis. A long-term follow-up in patients with cerebral palsy. *J Bone Joint Surg Br* 2004; 86(5): 737–742.
28. Cho BC, Lee IH, Chung CY, et al. Undercorrection of planovalgus deformity after calcaneal lengthening in patients with cerebral palsy. *J Pediatr Orthop B* 2018; 27(3): 206–213.
29. Costici PF, Donati F, Russo R, et al. Double hindfoot arthrodesis technique for the treatment of severe equino-plano-valgus foot deformity in cerebral palsy: long-term results and radiological evaluation. *J Pediatr Orthop B* 2019; 28(3): 235–241.
30. de Moraes Barros, Fucs PM, Svartman C, de Assumpção RMC, et al. Surgical technique: medial column arthrodesis in rigid spastic planovalgus feet. *Clin Orthop Relat Res* 2012; 470: 1334–1343.
31. Elbarbary HM, Arafa AS, Said ABZ, et al. Clinical and radiological outcomes of subtalar arthroereisis for management of planovalgus foot in children with cerebral palsy: 3-year follow-up. *Foot Ankle Spec*. Epub ahead of print 20 December 2020. DOI: 10.1177/1938640020880911.
32. El-Hilaly R, El-Sherbini MH, Abd-Ella MM, et al. Radiological outcome of calcaneo-cuboid-cuneiform osteotomies for planovalgus feet in cerebral palsy children: relationship with pedobarography. *Foot Ankle Surg* 2019; 25(4): 462–468.
33. Engström A, Erikson V and Hjelmstedt A. The results of extra-articular subtalar arthrodesis according to the green-grice method in cerebral palsy. *Acta Orthop Scand* 1974; 45(6): 945–951.
34. Ettl V, Wollmerstedt N, Kirschner S, et al. Calcaneal lengthening for planovalgus deformity in children with cerebral palsy. *Foot Ankle Int* 2009; 30: 398–404.
35. Güven M, Tokyay A, Akman B, et al. Modified Grice-Green subtalar arthrodesis performed using a partial fibular graft yields satisfactory results in patients with cerebral palsy. *J Pediatr Orthop B* 2016; 25(2): 119–125.
36. Huang CN, Wu KW, Huang SC, et al. Medial column stabilization improves the early result of calcaneal lengthening in children with cerebral palsy. *J Pediatr Orthop B* 2013; 22(3): 233–239.
37. Jeray KJ, Rentz J and Ferguson RL. Local bone-graft technique for subtalar extraarticular arthrodesis in cerebral palsy. *J Pediatr Orthop* 1998; 18(1): 75–80.
38. Kadhim M, Holmes L Jr, Church C, et al. Pes planovalgus deformity surgical correction in ambulatory children with cerebral palsy. *J Child Orthop* 2012; 6(3): 217–227.
39. Kadhim M, Holmes L Jr and Miller F. Long-term outcome of planovalgus foot surgical correction in children with cerebral palsy. *J Foot Ankle Surg* 2013; 52(6): 697–703.
40. Kubo H, Krauspe R, Hufeland M, et al. Radiological outcome after treatment of juvenile flatfeet with subtalar arthroereisis: a matched pair analysis of 38 cases comparing neurogenic and non-neurogenic patients. *J Child Orthop* 2019; 13: 346–352.
41. Leidinger B, Heyse TJ, Fuchs-Winkelmann S, et al. Grice-Green procedure for severe hindfoot valgus in ambulatory patients with cerebral palsy. *J Foot Ankle Surg* 2011; 50(2): 190–196, http://paperpile.com/b/q99xCw/vrjI
42. Luo CA, Kao HK, Lee WC, et al. Limits of calcaneal lengthening for treating planovalgus foot deformity in children with cerebral palsy. *Foot Ankle Int* 2017; 38(8): 863–869.
43. Mazis GA, Sakellariou VI, Kanellopoulos AD, et al. Results of extra-articular subtalar arthrodesis in children with cerebral palsy. *Foot Ankle Int* 2012; 33(6): 469–474.

44. Molayem I, Persiani P, Marcovici LL, et al. Complications following correction of the planovalgus foot in cerebral palsy by arthroereisis. *Acta Orthop Belg* 2009; 75(3): 374–379.
45. Muir D, Angliss RD, Nattrass GR, et al. Tibiotalocalcaneal arthrodesis for severe calcaneovalgus deformity in cerebral palsy. *J Pediatr Orthop* 2005; 25(5): 651–656.
46. Nahm NJ, Sohrweide SS, Wervey RA, et al. Surgical treatment of pes planovalgus in ambulatory children with cerebral palsy: static and dynamic changes as characterized by multi-segment foot modeling, physical examination and radiographs. *Gait Posture* 2020; 76: 168–174.
47. Narang A, Sud A and Chouhan D. Calcaneal lengthening osteotomy in spastic planovalgus feet. *J Clin Orthop Trauma* 2021; 13: 30–39.
48. Noritake K, Yoshihashi Y and Miyata T. Calcaneal lengthening for planovalgus foot deformity in children with spastic cerebral palsy. *J Pediatr Orthop B* 2005; 14(4): 274–279.
49. Park KB, Park HW, Lee KS, et al. Changes in dynamic foot pressure after surgical treatment of valgus deformity of the hindfoot in cerebral palsy. *J Bone Joint Surg Am* 2008; 90(8): 1712–1721.
50. Rethlefsen SA, Hanson AM, Wren TAL, et al. Calcaneal sliding osteotomy versus calcaneal lengthening osteotomy for valgus foot deformity correction in children with cerebral palsy. *J Pediatr Orthop* 2021; 41: e433–e438.
51. Rhodes J, Mansour A, Frickman A, et al. Comparison of allograft and bovine xenograft in calcaneal lengthening osteotomy for flatfoot deformity in cerebral palsy. *J Pediatr Orthop* 2017; 37(3): e202–e208.
52. Senaran H, Yilmaz G, Nagai MK, et al. Subtalar fusion in cerebral palsy patients. *J Pediatr Orthop* 2011; 31(2): 205–210.
53. Shore BJ, Smith KR, Riazi A, et al. Subtalar fusion for pes valgus in cerebral palsy: results of a modified technique in the setting of single event multilevel surgery. *J Pediatr Orthop* 2013; 33(4): 431–438.
54. Sung KH, Chung CY, Lee KM, et al. Calcaneal lengthening for planovalgus foot deformity in patients with cerebral palsy. *Clin Orthop Relat Res* 2013; 471(5): 1682–1690.
55. Turriago CA, Arbeláez MF and Becerra LC. Talonavicular joint arthrodesis for the treatment of pes planus valgus in older children and adolescents with cerebral palsy. *J Child Orthop* 2009; 3: 179–183.
56. Vlachou M, Demetriades D and Hager I. Subtalar arthrodesis with the combined Batchelor–Grice technique. *Foot Ankle Surg* 2004; 10: 79–84.
57. Vlachou M and Dimitriadis D. Progressive neuromuscular planovalgus foot deformity treated with a modified extra-articular subtalar fusion. *Foot Ankle Int* 2009; 30(7): 647–652.
58. Wen J, Liu H, Xiao S, et al. Comparison of mid-term efficacy of spastic flatfoot in ambulant children with cerebral palsy by 2 different methods. *Medicine* 2017; 96: e7044.
59. Yoo WJ, Chung CY, Choi IH, et al. Calcaneal lengthening for the planovalgus foot deformity in children with cerebral palsy. *J Pediatr Orthop* 2005; 25: 781–785.
60. Yoon HK, Park KB, Roh JY, et al. Extraarticular subtalar arthrodesis for pes planovalgus: an interim result of 50 feet in patients with spastic diplegia. *Clin Orthop Surg* 2010; 2(1): 13–21.
61. Zeifang F, Breusch SJ and Döderlein L. Evans calcaneal lengthening procedure for spastic flexible flatfoot in 32 patients (46 feet) with a followup of 3 to 9 years. *Foot Ankle Int* 2006; 27(7): 500–507.
62. Campbell M, McKenzie JE, Sowden A, et al. Synthesis without meta-analysis (SWiM) in systematic reviews: reporting guideline. *BMJ* 2020; 368: l6890.

## Appendix 1

Database: Ovid MEDLINE(R) ALL <1946 to July 31, 2021>

Search Strategy:

| | |
|---|---|
| 1 | cerebral palsy.mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] (70342) |
| 2 | (pes planus or flatfoot or pes planovalgus).mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] (2997) |
| 3 | (lateral column lengthening or MOSCA).mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] (4471) |
| 4 | ((calcaneal or calcaneum or calcaneus or slide or heel or double) and osteotomy).mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] |
| 5 | (fusion or arthrodesis).mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] (601149) |
| 6 | Arthroereisis.mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] (394) |
| 7 | (Grice Green or Grice-Green).mp. [mp=ti, ab, hw, tn, ot, dm, mf, dv, kw, fx, dq, nm, kf, ox, px, rx, ui, sy] (40) |
| 8 | 2 or 3 or 4 or 5 or 6 (607577) |
| 9 | 1 and 7 (1499) |