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SYSTEMATIC REVIEW

The efficacy of split tibial tendon transfers on functional gait outcomes for children and youth with cerebral palsy and spastic equinovarus foot deformities

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Aims
To systematically review the efficacy of split tendon transfer surgery on gait-related outcomes for children and adolescents with cerebral palsy (CP) and spastic equinovarus foot deformity.

Methods
Five databases (CENTRAL, CINAHL, PubMed, Embase, Web of Science) were systematically screened for studies investigating split tibialis anterior or split tibialis posterior tendon transfer for spastic equinovarus foot deformity, with gait-related outcomes (published pre-September 2022). Study quality and evidence were assessed using the Methodological Index for Non-Randomized Studies, the Risk of Bias In Non-Randomized Studies of Interventions, and the Grading of Recommendations Assessment, Development and Evaluation.

Results
Overall, 17 studies (566 feet) were included: 13 studies used clinical grading criteria to report a postoperative 'success' of 87% (75% to 100%), 14 reported on orthotic use with 88% reduced postoperative use, and one study reported on ankle kinematics improvements. Ten studies reported post-surgical complications at a rate of 11/390 feet (2.8%), but 84 feet (14.8%) had recurrent varus (68 feet, 12%) or occurrence of valgus (16 feet, 2.8%). Only one study included a patient-reported outcome measure (pain).

Conclusion
Split tendon transfers are an effective treatment for children and youth with CP and spastic equinovarus foot deformities. Clinical data presented can be used for future study designs; a more standardized functional and patient-focused approach to evaluating outcomes of surgical intervention of gait may be warranted.

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Introduction
Spastic equinovarus (EQV) foot deformities are a common foot deformity in CP.[1] These foot deformities and biomechanical changes are not present at birth, but evolve in individuals with spastic CP as they grow.[1] Overactivity of either the tibialis anterior (TA) or the tibialis posterior (TP) muscles, or both, can overpower the peroneal muscles and will contribute to the forefoot and midfoot being pulled into varus and supination (overactive TA), and the hindfoot into varus (overactive TP). This leads to increased weightbearing on the lateral aspect of the foot, with reduced foot contact surface area and base of support, thus creating instability during gait.[2] The underlying TA and TP muscle overactivity is often accompanied by a shortening of the calf muscles, which pulls the ankle joint into an equinus/plantar flexed position.[3] Combined equinus and varus further reduce foot contact during gait phases, hindering foot clearance during swing phase and increasing the likelihood of falls, and difficulty with orthotic fitting and shoe wear.[4-6]

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Table I. An outline of descriptions of the clinical criteria determined by Kling et al,[5] Green et al,[4] and Hoffer et al.[10]

Grade	Kling et al's[5] criteria (established 1985)	Green et al's[4] criteria (established 1983)	Hoffer et al's[10] criteria (established 1974)
Excellent	■ Walk with: – Plantigrade foot – Without fixed or postural deformity in a regular shoe ■ Normal callosities ■ No requirement of bracing/orthotics ■ Patients and parents were pleased with results	■ Walk with: – Plantigrade foot – Without fixed or postural deformity – Excellent heel toe gait ■ No requirement of bracing/orthotics ■ Good strength of the tibialis anterior muscle ■ Able to actively dorsiflex the foot at rest	■ Walk with: – Plantigrade foot – Total foot contact on the ground ■ No requirement of bracing/orthotics ■ Proper shoe wear
Good	■ Walk with: – less than 5° of varus, or – less than 5° of valgus, or – equinus posture of the hind part of the foot ■ Wore regular shoes without abnormal shoe-wear ■ No requirement of bracing/orthotics during gait, however requires night bracing ■ Had normal callosities ■ Patients and parents were satisfied with results	■ Walk with: – Plantigrade foot – Without fixed or postural deformity – Exaggeration of flexion of the hip and knee – Floor contact made by the entire sole of the foot ■ No requirement of bracing/orthotics during gait but required night bracing ■ Tibialis anterior muscle could dorsiflex foot to neutral position	■ Walk with: – Mild varus, valgus, or equinus deformity – Small foot contact ■ No requirement of bracing/orthotics during gait but required night bracing
Poor	Feet: ■ Have recurrent equinovarus deformity, or ■ Overcorrected into a valgus, or ■ Overcorrected to calcaneovalgus deformity ■ Requires orthotics during gait and night ■ Unable to wear normal shoe wear ■ Patients and parents were unsatisfied with results	Feet: ■ Persistence of recurrence of the varus deformity of the hind part of the foot	Feet: ■ Have overcorrection, under-correction, or equinus > 5° ■ Requires orthotics during gait and night

Excellent and good results are rated successful according to Kling et al[5] and Green et al[4] whereas those whose feet had recurrent equinovarus or varus deformity, overcorrection, under-correction, or equinus greater than 5°, and orthotics were required during gait, were considered poor/failed results and subsequently required further surgery.

Split anterior tibialis tendon transfer (SPLATT) and split posterior tibialis tendon transfer (SPOTT) are common tendon transfer surgical procedures used to correct muscle imbalance in spastic EQV in CP. These procedures work by altering the muscle-tendon-bone attachments to balance actions of the foot inverter and evertor muscles and, in doing so, acting to restore foot stability. When the varus is mostly present within the forefoot during swing phase (with high TA activity), a SPLATT to the lateral side of the foot (either the peroneus tertius (PT),[7,8] peroneus brevis (PB),[7-9] or the cuboid bone)[10-14] is indicated, aiming to neutralize the opposing varus force while enhancing dorsiflexion.[4,9] By contrast, when the impairment is more within the stance phase of gait with the hindfoot in varus and equinus (and an overactive TP), a SPOTT to the peroneus brevis (or the lateral cuneiform) on the lateral side of the foot is indicated.[15] This is considered preferable to TP lengthening, to minimize altering the capacity of the muscle to produce power through range, an undesired product of lengthening.[4,5,13] To a large degree, the actions of TA and TP muscle activity will overlap due to the phenomenon of segmental linkage, and for this reason both gait analysis and electromyographic assessments provide valuable adjuncts for operative planning.[16-18] Preoperative clinical assessments also aid in determining if concomitant soft-tissue procedures are needed, such as lengthening of the Achilles tendon, or Gastrocnemius or TP.[19]

Not all patients with EQV should be managed with the same approach, with seminal work by Chang et al[19] highlighting that the type of CP and preoperative ambulatory status play an important factor in the success of split tendon transfers. Historically, studies reported findings with grouped cohorts featuring multiple surgical interventions, thus compromising the conclusions of isolated split tendon transfer surgery.[20–23] As such, the impact on gait and functional outcomes is difficult to distinguish. The age at operation has also varied between studies; early conservative management of foot deformities means that the first operation for equinovarus can be in adolescence, or when the individual is skeletally mature. The aim of this systematic review was to evaluate the literature to determine the moderate- to long-term efficacy of isolated SPLATT/SPOTT surgery for children and youth with CP and spastic EQV, with a focus on gait-related outcomes. The United Nations definition of youth was applied, with an age of 15 to 24 years.[24]

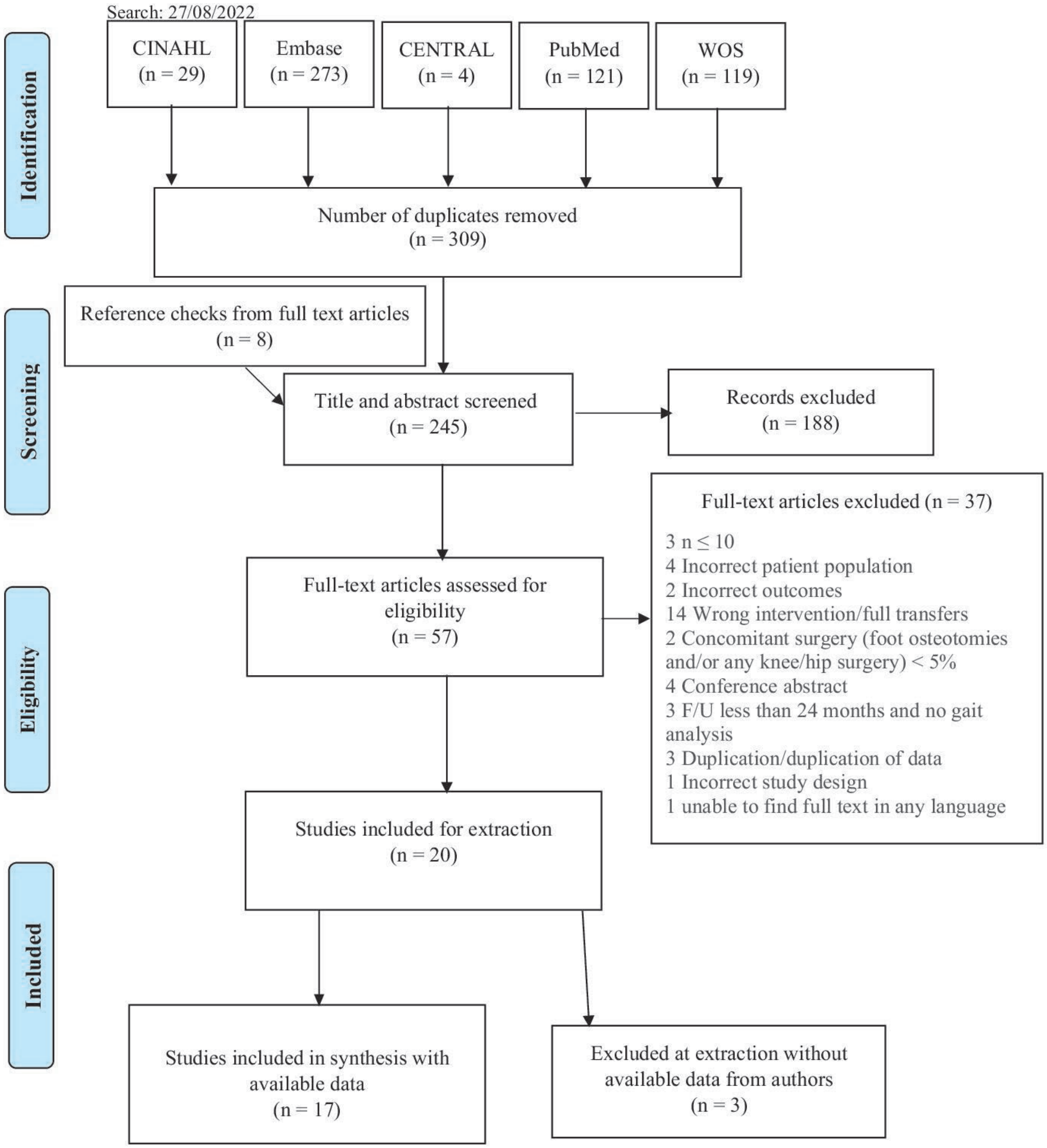

Fig. 1

PRISMA search strategy for the present systematic review. F/U, follow-up.

Methods

The protocol (PROSPERO registration CRD42021276809) followed the steps and guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[25]

Search strategy. Five electronic databases were comprehensively searched (by JHO) on 27 August 2022: the Cochrane Central Register of Controlled Trials (CENTRAL, the Cochrane library), CINAHL, Embase - OVID, PubMed, and Web of Science with search strategies comprising Medical Subject Headings (MESH)/keywords relating to CP, equinovarus, and split anterior/posterior tibialis tendon transfer (Supplementary 1). References of included studies were hand-searched for additional articles meeting the criteria.

Study eligibility. Two authors (JHO, SAW) used Covidence software (Australia) to independently review titles and abstracts, with records meeting the inclusion criteria progressing to full-text screening. Discrepancies between authors were resolved though discussion and through consultation with a third author (SS). Records unavailable in English were translated using Google Translate.

Table II. Study and participant characteristics of all 17 studies included in the systematic review, organized chronologically.

Study	Study design	Total patients, n; F:M	Mean age, yrs (range)*	CP type	Total feet, n†	Deformity pre-index reported, n‡
Green et al, 1983[4]	CS	16; NR	6.2 (4.5 to 10)	H13, Q3	16	14 EQV flexible, 2 fixed hindfoot varus deformity
Kling et al, 1985[5]	CS	31; 19:12	8.0 (3.5 to 18)	H19, D5, Q7	37	37 EQV/flexible
Hoffer et al, 1985[10]	CS	21; NR	NR (5 to 26)	NR	27	6 EQV flexible, 21 EQV with 'some' fixed deformity
Barnes and Herring, 1991[11]	CS	12; NR	7.8 (12 to 15)	H9, D1, M2	12	9 varus/flexible, 3 fixed
Synder et al, 1993[38]	CS	21; 13:8	12.9 (4.8 to 21)	H8, D4, Q4, M1	21	20 EQV, 1 fixed hindfoot varus deformity
Saji et al, 1993[29]	CS	18; 10:8	8.2 (4 to 14.5)	H10, D7, Q1	23	10 hindfoot and forefoot varus without equinus, 13 hindfoot and forefoot varus with equinus, 14 fixed, and the remaining (n = 9) flexible
Mulier et al, 1995[37]	CS	12; NR	5.5 (4 to 9)§	H10, D2	14	14 EQV/flexible
O'Byrne et al, 1997[39]	CS	16; 10:6	10.1 (5.6 to 12.7)	H7, D9	16	16 EQV/flexible
Scott and Scarborough, 2006[17]	CS	25; NR	10.8 (5 to 17)	H25	25	8 EQV, 17 hindfoot varus, all flexible
Vlachou and Dimitriadis, 2010[13]	RCS	48; 33:12¶	12.4 (9 to 18)	H32, D12, Q4	52	34 EQV mid- and forefoot, 18 Equinus hindfoot varus/ all flexible
Ahmed et al, 2011[12]	CS	20; 12:8	8.0 (6 to 10)	H15, D4, Q1	25	25 EQV/flexible
Limpaphayom et al, 2015[14]	RCS	22; 6:16	7.35 (4.24 to 13.02)	H6, D16	32	32 EQV/ flexible
Aleksić et al, 2020[15]	RCS	124; 38:86	11.0 (IQR 6.00 to 14.25)	H65, D38, Q15, P22, T6	146	146 EQV/flexible
Lullo et al, 2020[7]	RCS	37; 18:19	8.8 (3.3)	NR	37	37 varus/3 feet plantarflexion contractures (passive dorsiflexion < 0°), 34 forefeet and hindfeet could be everted passively to at least 0°
Sarikaya et al, 2020[8]	RCS	26; 14:12	8.1 (5 to 14)	NR	26	26 EQV/flexible
Wong et al, 2021[9]	RCS	52; 25:27	9.7 (6.1 to 14.11)	H52	52	52 EQV/combined flexible and fixed
Dussa et al, 2021[36]	RCS	5; 2:3	14.4 (7.0 to 21.0)	H4, D1	5	5 EQV flexible varus foot deformity

*Mean age at index surgery.
†Feet in the study which meet the review's inclusion criteria.
‡Fixed is defined as not passively correctable to neutral, while flexible is defined as passively correctable to neutral.
§Mulier et al do not account for the average age for the specific subgroup cohort which fit the inclusion criteria.
¶Vlachou et al do not account for sex in 3 patients who underwent joint SPLATT and SPOTT.
CP, cerebral palsy; CS, case series; D, diplegia; EQV, equinovarus; H, hemiplegia; IQR, interquartile range; NR, not reported; P, paraplegia; Q, quadriplegia; RCS, retrospective case series; T, tetraplegia.

Inclusion criteria were: 1) participants with a diagnosis of CP and spastic equinovarus foot deformity, age range from three to 24 years at time of surgery, irrespective of functional ability level; 2) randomized control trials (RCT), quasi-RCT, case series, retrospective or prospective cohort studies, case-control and case studies with > ten participants; 3) intervention included split tibial tendon transfers; 4) reported follow-up period > 24 months (mean) and/or used instrumented gait analysis with a mean follow-up > 12 months; and 5) at least one outcome measure of interest. These outcome measures included: clinical grading criteria such as Green et al,[4] Kling et al,[5] and Hoffer et al[10] (Table I), variables of gait from 3D gait analysis, gait speed, distance, endurance, gross motor function or mobility, clinical examinations/ classifications including ankle and subtalar range of motion (ROM), radiological measurements and angles, reported complications, rate of equinovarus recurrence and revision surgery, need for orthotics, and patient-reported outcomes (e.g. pain).

Studies were excluded if < ten participants with CP and EQV (n = 3),[26–28] or if the participants had idiopathic congenital talipes equinovarus; concomitant surgical procedures (including foot osteotomies and/or any knee/hip surgery), or previous tibial tendon transfers or lower limb bone/neurosurgical interventions. We made efforts to contact corresponding authors to obtain data from studies where data for subgroups of participants meeting the review eligibility criteria were not presented. Studies were subsequently excluded if we were unable to obtain a response/data from the corresponding authors,

Table III. Details on surgical intervention, post-surgical conditions (i.e. rehabilitation, the use of casting or bracing etc), and the follow-up assessment. Included outcome measures are categorized by ICF domains Body structure and Function (B), Activity (A), and Participation (P).

Study	Soft-tissue release at index	Surgical approach	Casting, protocols/ rehabilitation	Mean follow-up (range)	Complications/ revisions/ recurrence	Outcome tools/ measures	ICF domain/s
Green et al, 1983[4]	15 feet sliding heel-cord lengthening, 1 foot calcaneus osteotomy*	SPOTT to PB	4/52 long cast with knee extension and foot neutral then BK for walking for 4/52. If the patient can actively DF to neutral then no brace or splint required.	Minimum 2 yrs	**Complications**: NR **Recurrences/ revisions:** 1 (6.3%) closing wedge osteotomy a year later	Clinical examination,† gait observation via video analysis, EMG, pressure switches, Green criteria	B
Kling et al, 1985[5]	Heel cord lengthening" was reported in "most cases". Where this was not done at index it was required a year later. Preoperatively, 6 feet had heel cord lengthening 2/6 also had TP lengthening.	SPOTT to PB	6/52 long cast with knee slight flexion and foot in neural position - BK for 2/52. PT as soon as comfortable - WB encouraged	8 yrs (4 to 14)	**Complications:** Total 4 (13%) (1 (2.7%) necrosis, 1 (2.7%) wound infection, 2 (5.4%) pressure sores) **Recurrences:** 3 (8.15%) varus **Revision:** Total 3 (8.15%) (1 (2.7%) heel cord lengthening (8 yrs old), 1 (2.7%) triple arthrodesis (10 yrs old), 1 (2.7%) lengthening of TP (12 yrs old))	Clinical examination, gait observation, Kling criteria, radiographs, photos. WB AP radiographs of foot, ankle, and calcaneus	B
Hoffer et al, 1985[10]	13 feet had TAL, 8 feet had TP lengthening	SPLATT to the cuboid	6/52 BK for WB then AFO for 6/52	Minimum 10 yrs	**Complications:** None (0%) **Recurrences**: 1 (3.7%) varus **Revision:** 1 (3.7%) calcaneal osteotomy	Clinical examination, gait observation, PROM, EMG, foot contact studies/foot switch, functional ambulatory ability, orthotic need	B
Barnes et al, 1991[11]	6 feet had lengthening, 2 feet had plantar fasciotomy	SPLATT - cuboid with intramuscular lengthening TP	6/52 BK brace with WB - no AFO required after in management	5.5 yrs (2.25 to 8.75)	**Complications:** None (0%) **Recurrences:** 3 (25%) varus (aged 8, 14, and 11 yrs). **Revisions:** Total 2 (16.6%) 1 (8.3%) triple arthrodesis, 1 (8.3%) TP transfer	Clinical examination, gait observation via video analysis, Kling criteria	B
Synder et al, 1993[38]	All had TAL	SPOTT to PB	6/52 long cast - AFO 6/12	3.4 yrs (2.5 to 6.3)	**Complications:** None (0%) **Recurrences:** 3 (14.2%) varus **Revision:** 1 (4.8) requiring a Dwyer osteotomy	Clinical examination, gait observation, WB roentgenograms, Kling criteria	B
Saji et al, 1993[29]	13 feet had release of TA, 1 foot had an osteotomy*	SPOTT to lateral cuneiform via interosseous membrane	6/52 BK with heel in slight valgus and foot plantigrade. WB at 3/52 postop - short leg caliper with posterior strap for 6/12 to 1 yr postop	8.4 yrs (4 to 14.5)	**Complications**: NR **Recurrence**: 1 (4.3%) in the varus group due to valgus deformity **Revision:** 1 (4.3%) tenotomy 4 yrs later	Clinical examination, gait observation via video analysis/ photography, AP/ lateral radiography in standing, Kling criteria, EMG	B

Continued

Table III. Continued

Study	Soft-tissue release at index	Surgical approach	Casting, protocols/ rehabilitation	Mean follow-up (range)	Complications/ revisions/ recurrence	Outcome tools/ measures	ICF domain/s
Mulier et al, 1995[37]	All had subcutaneous sliding heel cord lengthening (preop 8 patients had heel cord lengthening)	SPOTT to PB via interosseous membrane	3/52 long cast with knee in extension and foot neutral position then 3/52 BK for walking	37 mths§ (35 to 37)	**Complications:** NR **Recurrence**: 2 (14.2%) varus hemiplegia group (5 yrs/11 yrs) **Revision**: 2 (14.2%) Due to technical error and they went on to have 1 (7.1%) triple arthrodesis and 1 (7.1%) Dwyer osteotomy	Clinical examination, Kling criteria and Green criteria combined, gait observation, radiographs, and photos	B
O'Byrne et al, 1997[39]	13 feet had tendocalcaneus lengthening	SPOTT to Peroneus brevis	6/52 BK in neutral foot position	1 yr (NR)	**Complications:** NR **Recurrences/ revisions**: None (0%)	Clinical examination, gait observation, Green criteria, 3DGA (kinematic analysis of ROM ankle stance phase, and max DF during swing phase)	B
Scott et al, 2006[17]	18 feet had TAL lengthening	SPOTT-NR	6/52 BK/WB - AFO 6/12	4.8 yrs (NR)	**Complications:** NR **Recurrences/ revisions:** n = 3 (12%) varus (mean age 12.9 yrs)	Clinical examination, 3DGA (kinematic analysis of equinus in stance and drop foot in swing), EMG, Kling criteria	B
Vlachou et al, 2010[13]	Group I: 11 feet had plantar soft-tissue release, 8 had transcutaneous flexor tenotomies, and 5 had a Jones procedure. Group II: 23 feet transcutaneous flexor tenotomies, *f*= 18 achilles cord lengthenings, *f* = 15 plantar soft-tissue releases, *f* = 5 Jones, 2 feet extension tendons transfer to the metatarsals	Gr I: SPLATT - cuboid gr I (11 feet forefoot and midfoot inversion) Gr II: SPOTT - PB (38 feet hindfoot varus) Three patients had combined SPLATT and SPOTT	4/52 long cast with knee extended/foot neutral at 4/52 WB as tolerated - 2/52 BK. If patient able to DF to neutral then no brace is required	7.8 yrs (4 to 14)	**Complications:** NR **Recurrences** 4 (7.7%) varus recurrences **Revision:** 4 (7.7%) calcaneum fusion 16 to 18 months post-index	Clinical examination, Kling criteria, Hoffer criteria, AP/lateral WB radiographs	B
Ahmed et al, 2011[12]	25 feet had percutaneous lengthening tendocalcaneous, 14 feet had plantar fascia release	SPLATT to cuboid (forefoot varus and EQV);‡ SPOTT-IM-Lateral cuneiform (hindfoot varus and EQV)	6/52 long cast POP ankle neutral - 3/52, touch down WB - AFO 6/12	3.5 yrs (2 to 4)	**Complications**: Not reported **Recurrences:** 4 (16%) with marked TA shortening, 2 (8.0%) varus, 2 (8.0%) equinus **Revision:** 4 (16%) calcaneum fusion 18 mths post-index operation	Clinical examination, ROM, Kling criteria	B
Limpaphayom et al, 2015[14]	All had lengthening of TA, PT, FDL, FHL	SPLATT - cuboid	12/52 BK/WB	5.5 yrs§ (1.1 to 16)	**Complications:** None (0%) **Recurrences:** 4 (12.5%) varus **Revision**: 4 (12.5%)	Clinical examination, Kling criteria,n GMFCS	B, A

Continued

Table III. Continued

Study	Soft-tissue release at index	Surgical approach	Casting, protocols/ rehabilitation	Mean follow-up (range)	Complications/ revisions/ recurrence	Outcome tools/ measures	ICF domain/s
Akeksic et al, 2020[40]	73 feet had Hokes procedure, 25 feet had strayerst, 1 foot had Achilles elongation, 1 foot had Achilles elongation, 6 feet had Z-plasty, 1 had tenotomy of FD muscle, 5 feet had the Hoke TAL and elongation of FD muscle, 2 feet had elongation of FD muscle	SPOTT 41 feet: to PB (modified group) and remaining part of TP tendon lengthened, standard (green techniques) SPOTT to PB 105 feet	6/52 BK/WB cast, rehab protocol mentioned but no details	8.0 yrs (IQR 6 to 11)	**Complications:** None (0%) **Recurrence:** 29 (19.8%), 26 (17.8%) in standard intervention group, 3 (2.0%) modified group. **Revision:** 19 (13.0%). Triple arthrodesis in 16 (15.2%) feet in the standard group, 3 (7.3%) in the modified group.	Clinical examination, gait observation, Kling criteria, GMFCS	B, A
Lullo et al, 2020[7]	16 feet had Gastrocnemius recession, 10 feet had TAL, 18 feet had PTTL, 15 feet had SPOTT Pre-index 2 feet had osteotomies*	SPLATT- PB/tertius	6/52 BK/WB as tolerated then part time bracing (at least 6 to 8 hrs a day) 6/12 postoperatively	4.4 yrs (4.0)	**Complications:** 1 (2.7%) cast sore **Recurrence:** 11 (29.7%) (8 (21.6%) varus (average age 5.1 yrs and 3.2 years post-intervention)) n = 3 (8.1%) valgus, (average age 11.4 yrs and 3.7 yrs post intervention) **Revisions:** 9 (24.3%) (7 varus (18.9%), 2 (5.4%) valgus)	Medical records, clinical examination, 3DGA (Vicon-kinematic analysis DF during swing phase), PROM, Modified clavien-Dindo complication rating scale, postoperative recurrences	B
Sarikayai et al, 2020[8]	10 feet had Gastroc tenotomy, 3 feet had gastrocnemius tenotomy and plantar fasciotomy, 2 feet had achilloplasty, 2 feet had achilloplasty and plantar fasciotomy, 1 foot had a plantar fasciotomy, 1foot had Flexor carpi ulnaris tenotomy	SPLATT to peroneus tertius and 2 feet SPLATT to cuboid	6/52 BK in neutral position	28.8 mths§ (24 to 42)	**Complications:** 1 (4%) wound detachment **Recurrence/ revisions:** none (0%)	Kling criteria, GMFCS, clinical examination, gait observation, medical records	B, A

Continued

Table III. Continued

Study	Soft-tissue release at index	Surgical approach	Casting, protocols/ rehabilitation	Mean follow-up (range)	Complications/ revisions/ recurrence	Outcome tools/ measures	ICF domain/s
Wong et al, 2021[9]	All had IML-TP and SPLATT-PB. 14 feet had B toxin to gastrocnemius, 5 feet had strayers, 2 feet had strayers with solealfascial lengthening, 31 feet had a modified vulpius gastrocsoleus recession, and 11 had white slide lengthening of the AT	SPLATT-PB	Hinged AFO for 12 mths. Hinge closed in 44 patients to protect calf lengthening surgery for 3 to 6 mths	7 yrs (3.3 to 10.2)	**Complications:** 5 (9.6%) (3 (5.8%) cast sores, 2 (3.8%) pain/spasm) **Recurrence:** 12 (23.1%) (3 (5.7%) recurrent varus, 2 due to persistent varus (10.3 yrs, 14.8 yrs, 16 yrs), 9 (17.3%) valgus) **Revisions:** 12¶ (23.1%) (3 (5.7%) SMO, 2 (3.8%) Evans, 3 (5.7%) vulpius, 2 (3.8%) SPLATT tenotomy, 2 (3.8%) CCFx)	Clinical examination, gait observation via video analysis, AP/ lateral radiographs in WB, Likert pain scale, Likert shoe wear, medical records	B
Dussa et al, 2021[36]	3 feet had the Baumann procedure	SPLATT-cuboid, SPOTT-PB, all feet were combined, SPLATT/SPOTT		21.4 mths (13 to 37)	**Complications**: None (0%) **Recurrences:** 3 (60%) valgus **Revision:** 1 (20%)	Clinical examination, AP/ lateral radiological analysis, kinematic gait analysis	B

Complications = early postoperative complications.
No previous operations reported if not stated above.
*< 5 % bony surgery previous/at index.
†Clinical examination involved: observed gait pattern - foot alignment and balance and muscle control, active range of motion, passive range of motion, observation of any callus formation, or wear and tear on shoes.
‡Does not subgroup number of SPLATT and SPOTT in study.
§Specific subgroup data not available.
¶Study reported a delay in the older patients accessing surgery relayed to delayed referral to the service with prolonged cycles of injections of Botulinum Toxin A.
AFO, ankle foot orthosis; AP, anterior-posterior; AT, Achilles tendon; BK, below-knee cast (short leg cast); CCFx, calcaneocuboid shortening fusion plus medial deep plantar release; DF, dorsiflexion; 3DGA, 3D gait analysis; EMG, electromyography; EQV, equinovarus; f, number of feet; FDL, flexor digitorum longus; FHL, flexor hallucis longus; GMFCS, Gross Motor Function Classification Scale; ICF, International Classification of Functioning Disability and Health ; IML-TP, intramuscular tibialis posterior lengthening; IQR, interquartile range; NR, not reported; NWB, non-weightbearing; PB, peroneus brevis; POP, plaster of paris; PT, posterior tibialis; PTTL, posterior tibial tendon lengthening; PWB, partial weightbearing; ROM, range of motion; SMO, supramalleolar osteotomy of tibia; SPLATT, split anterior tibialis tendon transfer; SPOTT, split posterior tibialis tendon transfer; TA, tendo-Achilles; TAL, tendo-Achilles lengthening; TP, tibialis posterior; WB, weightbearing.

however they were included if these data were less than 5% of their overall cohort.[4,7,29]

Data extraction and reporting. Data were extracted using a purpose-developed extraction form, including available information on study and participant characteristics, variables related to the intervention and rehabilitation, and the reported outcome measures, which were categorized by their corresponding domain (JHO, SAW) within the International Classification of Functioning Disability and Health (ICF).[30] Data were tabulated to facilitate synthesis and interpretation of the results. Calculated averages for clinical graded criteria, need for orthotics, complications, recurrences, and revisions were recorded to provide an overall synthesis of results. Due to confounding variables of age, Gross Motor Function Classification Scale (GMFCS), and topography in addition to heterogeneity between reported outcomes, we were unable to complete subgroup analysis and meta-regression.

Data from studies only presenting preoperative information are not included within the synthesis of data, nor are outcomes of walking distance, endurance, anatomical, and foot switch measures due to heterogeneous methods, measurements, and infrequent/lack of reporting. The intention of the review to also evaluate outcomes of gross motor function/mobility measures was not possible, as these measures were not included within the studies included for review.

Quality assessment. Two reviewers (JHO, SAW) independently assessed quality using the Methodological Index for Non-Randomized Studies (MINORS),[31] risk of bias using Risk of bias In Non-Randomized Studies of Interventions (ROBINS-I),[32] and quality of evidence using GRADE[33] for clinical criteria outcomes. Any disagreements were resolved through discussion. A third reviewer (NSS) resolved any further discrepancies (full scoring provided in the Supplementary Material).

Table IV. Clinical scoring outcomes (number of feet meeting criteria and % of overall feet included in the study) and subgroup comparison analysis post-split tendon transfer of the 13 studies using such criteria.

Study	Total feet	Excellent, n (%)	Good, n (%)	Successful, n (%)†	Poor, n (%)‡
	Kling criteria				
Kling et al, 1985[5]	37	30 (81)	4 (11)	34 (92)	3 (8)
Barnes et al, 1991[11]	12	9 (75)	0 (0)	9 (75)	3 (25)
Synder et al, 1993[38]	18	12 (67)	3 (17)	15 (83)	3 (17)
Saji et al, 1993[29]					
EQV group	13	12 (92)	1 (8)	13 (100)	0 (0)
Varus group	10	2 (20)	7 (70)	9 (90)	1 (10)
Mulier et al, 1995[37]					
Hemi gr	12	4 (33)	6 (50)	10 (83)	2 (16)
Diplegic gr	2	0 (0)	2 (100)	2 (100)	0 (0)
Scott et al, 2006[17]					
EQV group	8	8 (100)	0 (0)	8 (100)	0 (0)
Varus group	17	9 (53)	5 (29)	14 (82)	3 (18)
Vlachou et al, 2010[13]					
SPLATT Gr I*	11	8 (73)	3 (27)	11 (100)	0 (0)
SPOTT Gr II	38	20 (53)	14 (37)	34 (90)	4 (10)
SPLATT and SPOTT*	3	2 (67)	1 (33)	3 (100)	0 (0)
Ahmed et al, 2011[12]	25	14 (56)	7 (28)	21 (84)	4 (16)
Limpaphayom et al, 2015[14]	32	23 (72)	5 (15.5)	28 (87.5)	4 (12.5)
Sarikayai et al, 2020[8]	26	21 (81)	5 (19)	26 (100)	0 (0)
Akeksic et al, 2020[40]					
Standard gr	105	45 (43)	34 (32)	79 (75)	26 (25)
Modified gr	41	25 (70)	13 (32)	38 (93)	3 (7)
	Green criteria				
Green et al, 1983[4]	16	11 (69)	4 (25)	15 (94)	1 (6)
O'Byrne et al, 1997[39]	16	13 (81)	3 (19)	16 (100)	0 (0)
Total	442	298 (66)	116 (26)	385 (87)	57 (13)

*Hoffer criteria converted to Kling.
†Successful outcomes equal total of excellent and good, able to walk with a plantar grade foot < 5° varus, valgus, or equinus, normal shoe wear, no prescribed orthotics during gait, and patients and carers are satisfied.
‡Poor outcomes were classified as failed outcomes with recurrent varus/equinus or development of valgus/calcaneovalgus.
EQV, equinovarus.

Results

Search results and study quality. The original search yielded 546 records, of which 309 duplicates were removed, 245 underwent screening of title and abstract, 57 going through full-text review, and 20 subsequently included for review (Figure 1). Seven publications required additional data/information to confirm eligibility and for reporting,[7,9,14,19,34–36] from which four were received,[7,9,14,36] and three were subsequently excluded (data unavailable from authors),[19,34,35] resulting in a total of 17 studies included for data extraction. Of these 17 studies, authors of nine studies reported or supplied subgroup data for the subgroups of participants with CP meeting our inclusion criteria.[7,9,13–15,17,29,36,37] Two studies had participants undergoing our target surgical intervention as part of multilevel soft-tissue surgery.[7,14]

Scores on the MINORS ranged from 6 to 12 (Supplementary Table ii). The majority of studies (11/17) were graded as moderate-risk according to the ROBINS-I assessment, mostly owing to retrospective analyses, non-blinded assessors, and use of subjective clinical measures (Supplementary Table iii). The GRADE summary of evidence (Supplementary Tables iv to vi) illustrates varied certainty of evidence between very low (measures of ambulation), to low (clinical grading criteria, orthotics use), to moderate certainty (maximum dorsiflex during swing, radiological measures, foot kinematics, spatiotemporal parameters, pain (Likert scale), difficulty in shoe wear (Likert scale), early complications, and recurrences). The GRADE quality of evidence for split tibial tendon transfers restoring a functional plantigrade foot for children and youth with CP and EQV deformity (Supplementary Table iv) was moderately confident in the estimated effect: the true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different. By contrast, low quality of evidence was determined in relation to gait functional outcomes (Supplementary Table v), largely due to the serious concerns of risk of bias due to subjective, unblinded measures and lack of quantitative objective measures in the majority of studies. Equally, there were serious concerns overall in the imprecision due to the small effect sizes in the studies

Table V. Collated pre- and postoperative data.

	Orthotic use			Ambulation/Gross motor status		
Study	**Preop, n**	**Postop, n**	**Improved, n (%)**	**Preop**	**Postop**	**Change**
Green et al, 1983[4]	16	0	16 (100)			
Kling et al, 1985[5]	36	4	32 (89)	28 mobile unaided	1 required crutches	
Hoffer et al, 1985[10]	27*	1	26 (96)	19 community walkers, 2 non-ambulators	Improvements in the 2 non-ambulatory	
Barnes et al, 1991[11]	2	0	2 (100)	12/12 community walkers, 1 with crutches	No change	
Synder et al, 1993[38]	21	3	18 (86)	18 ambulant, 1 able to stand, 2 wheelchair-bound	18 ambulant, 1 crutches household-ambulant, 2 non-ambulant improved DF and able to wear regular shoes	
Mulier et al, 1995[37]	13	2	11 (85)			
Scott et al, 2006[17]	25*	0	25 (100)			
Vlachou et al, 2010[13]	48*	4	44 (92)			
Ahmed et al, 2011[12]	25*	4	21 (84)			
Limpaphayom et al, 2015[14]	32*	4	28 (88)	GMFCS I = 3, II = 16, III = 3	GMFCS I = 18, II = 3, III = 1	15 improved to I, 2 improved to II
Sarikayai et al, 2020[8]	26	0	26 (100)	GMFCS II = 17, III = 3, IV = 6	GMFCS, II = 21, III = 4, IV = 1	4 improved to II, 4 improved to III/1 to II
Akeksic et al, 2020[40]	146*	29	117 (80)			
Wong et al, 2021[9]	52	6	46 (88)	Pain = 2.8 (SD 1.2)† Shoe wear = 4.1 (SD 1.2)†	Pain = 1.6 (SD 0.9) Shoe wear = 1.6 (SD 0.9)	Data indicate reduced pain and improved shoe wear‡
O'Byrne et al, 1997[39]	16	0	16 (100)			
Total change in orthotic use			428 (88)			

*Assumed all required orthotics preoperatively, however not clearly reported.
†Likert scale (0 to 9) where 0 indicates no pain or no difficulties with shoe-wear or brace-wear, and 9 indicates either severe pain or being unable to use a brace or regular shoes.
‡No formal statistics available for subgroup data.
DF, dorsiflexion; GMFCS, Gross Motor Function Classifications Scale; PF, plantar flexion; SD, standard deviation.

which did highlight quantitative measures. As such, our confidence in this effect estimate is limited: the true effect may be substantially different. The overall quality of the evidence for split tendon transfers reducing pain postoperatively was moderate (Supplementary Table vi). This was reflected within the GRADE domains, with no serious concerns of risk of bias, inconsistency, indirectness, or publication bias. However, due to the low estimate of effect,[9] imprecision was rated as a serious concern.

Characteristics of included studies. The 17 studies reported on 506 patients (200 females: 195 males, sex not reported in five studies)[4,10,11,17,37] and 566 feet (Table II). All 17 studies were non-randomized, seven were retrospective follow-up case series, and ten were indicated to be case series. Within the 17 studies, five drew comparison of outcomes between type of foot deformity (i.e. equinovarus vs varus),[17,29] intervention (i.e. modified SPLATT vs standard SPLATT or SPLATT vs SPOTT),[13,15] and type of CP (i.e. hemiplegia vs diplegia).[37]

Around half of the studies (n = 9/17) described participants as having 'flexible' EQV foot deformities, and seven reported some participants with fixed deformities (four studies of which were conducted prior to the year of 1993).[4,7,9–11,29,36,38] Two studies out of the 17 focused on hindfoot and forefoot varus deformities,[7,11] and three compared groups between EQV and varus foot deformities.[13,17,29] Out of the total 506 patients, 275 were classified as hemiplegic, 99 diplegic, 35 quadriplegic, two monoplegic, 22 paraplegic, and five tetraplegic. Three studies did not report CP topography (i.e. n = 68 patient topography unaccounted for).[7,8,10] All studies included in the review were aligned with treating foot muscle imbalance in spastic CP muscle tone, however the tone abnormality was not graded in severity prior to surgical intervention.

Indications for surgery were an EQV/varus gait pattern, and cohorts were often described as ambulant, with or without aids, or had the "potential to become ambulant" postoperatively. Only five studies reported participants' preoperative GMFCS level (GMFCS I, n = 49, II, n = 117, III, n = 22, IV, n = 26, V, n = 21, and n = 5 combined level I/II).[7–9,14,36] These specific levels were not reported in studies pre-dating 2011, however brief descriptions of ambulation were provided.

Surgical interventions. Participant ages at time of the index intervention ranged from 3.3 to 26 years, with a calculated mean age of nine years, however the majority

Table VI. Collated pre- and postoperative data: radiological outcomes/gait analysis. Values are presented as means and ranges.

Study	Preop	Postop	Change
O'Byrne et al, 1997[39]	Max DF = -9.1° (PF)	Max DF = 8.6 (DF)	Improved DF*
	(11.5° DF to 34.13° PF)	(3.7° DF to 16.9°DF)	Positioned closer to 'normal' mean TFPA of 15°*
	TFPA = 8°	TFPA = 18°	
Lullo et al, 2020[7]†	Max DF in swing = 2.5° (DF)	Max DF in swing = -3.5° (PF)	p = 0.18
	Mean DF in swing = -3.2° (PF)	Mean DF in swing = -8.14° (PF)	p = 0.14
	Time of max DF (% swing) = 54.6	Time of max DF (% swing) = 80.5	p = 0.22
	PROM forefoot eversion = 17.7° (SD 9.4°)	PROM forefoot eversion = 18.2° (10.4°)	p = 0.94
	PROM hindfoot eversion = 9.2° (SD 6.6°)	PROM hindfoot eversion = 8.7° (SD 6.8°)	p = 0.85
Wong et al, 2021[9]	**Radiological comparison**	**Radiological comparison**	
	TCA = 88°	TCA = 65.7°	22.3°, 95% CI 16.1° to 27.3°, p < 0.001
	LTCA = 20.3°	LTCA = 41°	20.7°, 95% CI -23.5° to -19.5°, p < 0.001
	NCO = 2.2%	NCO = 42.9%	40.7%, 95% CI -46.7% to -34.5%, p < 0.001
	TNCA = -26.8°	TNCA = 23.2°	50°, 95% CI -56.2° to -46.7°, p < 0.001
	LT first MTA = -9.8°	LT first MTA = 13.6°	23.4°, 95% CI -27° to -20.2°, p < 0.001
	APT first MTA = -20.2°	APT first MTA = 7.9°	28.1°, 95% CI -36.7° to -26.9°, p < 0.001
	MSA = 30.1°	MSA = 11.1°	19°, 95% CI 16.9° to 23.2°, p < 0.001
Dussa et al, 2021[36]	**Radiological comparison, °**	**Radiological comparison, °**	
	LTCA = 43.1 (33.5 to 54.1)	LTCA = 43.9 (28.7 to 52.8)	p = 0.51
	LT 1st MTA = 3.9 (-12.3 to 23.5)	LT 1st MTA = 8.4 (-11.2 to 24.6)	p = 0.10
	LCI = 15.2 (0.0 to 24.8)	LCI = 14.4 (2.9 to 23.7)	p = 0.47
	LTNA = 7.8 (-4.3 to 21.3)	LTNA = 6.8 (-7.5 to 18.9)	p = 0.59
	LNCA = –1.3 (-13.8 to 14.1)	LNCA = 5.1 (-10.9 to 33.9)	p = 0.13
	APTCA = 10.0 (-4.5 to 26.8)	APTCA = 13.7 (4.5 to 26.3)	p = 0.08
	APTN = -15.5 (-38.1 to 17.7)	APTN = -1.2 (-24.2 to 24.0)	p < 0.05
	APT 1st MTA = -26.4 (-50.7 to -36.5)	APT 1st MTA = -11.2 (-36.5 to 13.2)	p < 0.05
	APT 2nd MTA = -20.7 (-44.6 to 17.6)	APT 2nd MTA = -2.9 (-29.3 to 28.3)	p < 0.05
	APC 4th MTA = -21.2 (-36.8 to 1.6)	APC 4th MTA = -10.1 (-24.4 to 14.0)	p < 0.05
	Clinical assessment	**Clinical assessment**	
	Passive ankle DF = 0.4 °(-10 to -5)	Passive ankle DF = 1.9 ° (-5 to 5)	p = 0.17
	Passive ankle PF = 36.9 ° (15 to 50)	Passive ankle PF = 22.7 ° (10 to 45)	p < 0.05
	‡ Ankle DF strength = 30 (0 to 5)	Ankle DF strength = 2.7 (0 to 5)	p = 0.34
	Ankle PF strength = 2.8 (1 to 5)	Ankle PF strength = 2.5 (0 to 4)	p = 0.27
	Spatiotemporal parameters	**Spatiotemporal parameters**	
	Velocity = 34.0% (20.0 to 47.0)	Velocity = 32.8% (16.0 to 45.0)	p = 0.40
	Step length = 61.5 (34 to 79)	Step length = 60.1 (33 to 71)	p = 0.40
	Cadence = 54.5% (48 to 62)	Cadence = 54.1% (41 to 61)	p = 0.79
	Foot kinematics: hindfoot to tibia, °	**Foot kinematics: hindfoot to tibia, °**	
	Mean eversion stance = 8.1 (0.3 to 15.7)	Mean eversion stance = -4.7 (-10.9 to 8.9)	p < 0.05
	Mean eversion swing = 7.5 (-0.3 to 14.9)	Mean eversion swing = -4.7 (-12.3 to 9.3)	p < 0.05
	Flexion ROM stance = 14.2 (7.9 to 22.3)§	Flexion ROM stance = 15.9 (7.9 to 22.1)	p = 0.03
	Eversion ROM stance = 8.0 (5.3 to 12.2)¶	Eversion ROM stance = 6.8 (3.4 to 14.5)	p = 0.14
	Rotation ROM stance = 20.6 (10.2 to 40.5)	Rotation ROM stance = 20.5 (12.4 to 38.5)	p = 0.94
	Foot kinematics: midfoot to forefoot, °	**Foot kinematics: midfoot to forefoot, °**	
	Midfoot supination stance = -3.8 (-14.6 to 5.6)	Midfoot supination stance = 5.6 (-4.9 to 17.1)	p < 0.05
	Midfoot adduction stance = 17.5 (7.8 to 28.8)	Midfoot adduction stance = 8.8 (-2.4 to 25.8)	p < 0.05
	Flexion ROM stance = 9.4 (4.9 to 18.4)	Flexion ROM stance = 12.3 (4.5 to 24.5)	p = 0.03
	Supination ROM stance = 9.9 (3.0 to 13.9)	Supination ROM stance = 9.1 (6.06 to 15.1)	p = 0.38
	Adduction ROM stance = 6.1 (3.2 to 10.0)	Adduction ROM stance = 5.5 (2.6 to 8.0)	p = 0.40

*No formal statistics available for subgroup data.
†Swing phase gait kinematic parameters (patients without concomitant gastrocnemius recession or tendo-Achilles lengthening only n = 18).
‡Strength measured on a scale of 0 to 5.
§Hindfoot to tibia flexion ROM stance.
¶Hindfoot to tibia eversion ROM stance.
APC 4th MTA, anterior-posterior calcaneal 4th metatarsal angle; APTCA, anterior-posterior talocalcaneal angle; APTN, anterior-posterior talonavicular; APT 2nd MTA, anterior-posterior talo-2nd metatarsal angle; APT 1st MTA, anteroposterior talo-1st metatarsal angle; CI, confidence interval; DF, dorsiflexion; GMFCS, Gross Motor Function Classifications Scale; LCI, lateral calcaneal inclination; LNCA, lateral navicular cuneiform angle; LTCA, lateral talocalcaneal angle; LTNA, lateral talo navicular angle; LT 1st MTA, lateral talo-1st metatarsal angle; Max DF, maximal dorsiflexion during swing phase measured in plantar flexed position ranging from dorsiflexion to plantar flexion; MSA, metatarsal stacking angle; NCO, navicular cuboid overlap; PF, plantar flexion; PROM, passive range of motion; ROM, range of motion; SD, standard deviation; TCA, tibiocalcaneal angle; TFPA, transverse foot-placement angle; TNCA, talonavicular coverage angle.

(14 of 17 studies, 82%) were between 3.3 and 17 years. Data from one study included a patient aged 26 years who could not be removed from the group analysis.[10] Although this participant was older than this review's eligibility criteria, we elected to retain the study within the review. Eight studies (205 feet) implemented the SPLATT intervention,[7-14] of which three studies were published in 2020 or, more recently,[7-9] implementing the SPLATT to Peroneus Brevis/Peroneus Tertius approach versus the SPLATT to cuboid approach (used in studies prior to 2015). Ten studies implemented SPOTT (353 feet),[4,5,12,13,15,17,29,37–39] with the majority reporting the SPOTT to Peroneus Brevis surgical approach. Out of these studies, two reported either SPLATT or SPOTT intervention groups depended on the clinical presentation,[12,13] and one had a subgroup combining both procedures during index operation (n = 3 feet).[13] One study combined both interventions for all participants (n = 5 feet).[36] The majority of the studies reported participants as having no previous operations, however Kling et al[5] and Mulier et al[37] included data from 14 participants (out of a total of 43 participants) with soft-tissue procedures prior to index operation which were unable to be differentiated in the data. A small number (< 5%) of participants within the study by Lullo et al[7] had soft-tissue or bony procedures.

Three studies reported use of above-knee casts for at least six weeks with periods of restricted weightbearing,[5,12,36] with nine reporting the use of below-knee casts and earlier weightbearing.[7,8,10,11,14,15,17,29,39] Four studies[4,5,13,37] described a combination of above- and below-knee casts. Follow-up times varied widely from one to 16 years, with seven studies[5,9,10,13,14,29,40] reporting outcomes at a mean of five years or more, and six studies over seven years post-surgery.[5,9,10,13,29,40]

Complications, recurrences, and revisions. Ten studies reported on post-surgical complications (presence or absence of),[5,7–11,14,15,36,38] with four reporting the presence of complications. An overall reported early complications rate of 2.8% (n = 11/390 feet) was apparent: one necrosis of the skin flap, one superficial wound infection, two pressure sores over the heel,[5] four cast sores,[7,9] two pain/spasm,[9] and one described as "wound detachment."[8]

Recurrence of EQV foot deformity postoperatively was reported in all studies. The total overall (varus and equinus) foot deformity recurrences recorded were 68 out of 566 feet (12%), with ten studies reporting < three recurrences.[4,5,8,10,11,17,29,37–39] Post-surgical development of the opposite deformity – plano or equinovalgus was reported by four studies and in 16 feet (2.8%).[7,9,29,36]

Revision surgery was reported for 67 out of the 84 equinovarus or valgus postoperative occurrences. Overall, 11.8% of feet required a second surgical procedure (n = 67/566).

Outcome measures. All studies reported gait-related outcomes categorized in the ICF body structure and function domain,[30] and three reported measures at the level of activity (Table III).[8,14,40] The most commonly reported gait-related outcome measures included the use of gait analysis, gait observation, ambulation, range of motion (ROM), and clinical grading tools. Table IV outlines the results of overall clinical function at postoperative follow-up. Tables V and VI include outcomes from 16 studies which presented pre- and postoperative data including assessments at both timepoints. One study did not include pre- and postoperative data.[29]

Overall clinical function at postoperative follow-up. Studies commonly used a clinical grading tool at final follow-up such as Kling (n = 11), Green (n = 2), or Hoffers (n = 1), rating 'successes' by a combination of 'excellent' and 'good'. The mean 'success' rate was 87%, ranging between 75% to 100% (mean follow-up time 6.3 years) of which six studies had a success rate greater than 90% (Table V).[4,5,8,13,29,39] Aleksić et al[15] reported higher rates of surgical success (defined by Kling) in patients with higher levels of gross motor function prior to the surgery: GMFCS I = 100% success, II = 94.8%, III = 69.8%, IV = 9.1%, however the participant numbers in each classification level were not reported. Aleksić et al[15] also reported success rates for patients with hemiplegia (58/65 (89%)), diplegia (29/38 (76%)), and quadriplegia (2/13 (15%)).

Changes in orthotic needs and changes in shoe wear. A total of 14 studies directly reported on orthotics use, with postoperative use during gait reduced by 88% (428/485 feet). All studies reported orthotic usage improvements over 80% following surgery (i.e. no orthotics prescribed postoperatively). One study reported on patient-reported levels of difficulty in shoe-wearing which reduced postoperatively.[9]

Changes in foot alignment and passive range of motion. Preoperative and postoperative values for weightbearing radiological measures were reported in two studies.[9,36] Compared with standardized normative measures reported in the literature,[41] the preoperative radiological values of the included cohorts differ substantially. Postoperative values changed significantly in all reported radiological measures from Wong et al,[9] and in 4/5 anteroposterior radiological parameters reported by Dussa et al.[36] Passive assessments of ROM showed no significant changes in forefoot or hindfoot eversion,[7] or dorsiflexion,[36] postoperatively.

Changes in ankle motion in gait. Two studies[7,39] used instrumented gait analysis pre- and postoperatively. O'Byrne et al[39] used a single-segment foot model, with data indicating a (non-significant) postoperative change from a more plantar-flexed position to a dorsiflexed position through swing. Using a multisegmented foot model, data from Dussa et al,[36] showed statistically significant improvements in ankle eversion through gait (reductions through stance and swing), increases in hindfoot-to-tibia flexion ROM, and in supination and adduction of the midfoot-to-forefoot segment.

Pain. Only one study measured (patient reported) pain,[9] with low preoperative levels that reduced further postoperatively, however we were unable to complete a statistical analysis of the change in pain data from the provided data.

Discussion

This review evaluated the outcome of split tibial tendon transfers for spastic EQV feet in children and youth with CP. Overall, these transfers had an 87% success rate in improving outcomes related to gait, based on clinical grading tools, postoperative orthotic requirements, radiological changes, and gait studies. However, there was a 12% recurrence of EQV foot deformity and a 2.8% occurrence of the opposite valgus deformity, with > 80% of the subsequent recurrent foot deformities undergoing revision surgery. Overall, the review found that the quality of reporting of the evidence was generally poor, with low- to moderate-certainty of evidence to support a successful outcome, and it was not possible to identify factors that predicted better outcomes from surgery. Gaps in evidence were also apparent, with a lack of functional objective measures relating to activity and participation domains of the ICF, and an absence of patient-/caregiver-reported outcomes.

The most common approach to evaluating outcomes of SPLATT and SPOTT interventions was through the use of one of three clinical grading tools (the Kling,[5] the Green,[4] or the Hoffer[10]) - determining a collectively high 'success' rate for patients. These clinical grading tools capture a range of key clinical elements relevant to the goals of the intervention, relating to gait (i.e. plantigrade foot alignment, reduced orthotics need, shoewear) and foot deformity, with the Kling criteria also factoring in patient satisfaction. These findings were further supported by Wong et al,[9] who also reported that the surgery was effective in relieving symptoms of pain and difficulties with shoe-wear and brace-wear. Although easy to use, the Kling, Green, and Hoffer clinical grading tools have not been tested for reliability and ability to detect change. Different scoring systems such as the Patient-Reported Outcome Measurement Information System (PROMIS) item banks and the core outcome set for lower limb surgery in children with CP may prove to be better choices for future studies.[42,43] Given the lack of patient-reported measures, future clinical studies would also benefit from including a validated measure of pain as well as considering use of the Gait Outcome Assessment List (GOAL) (evaluating gait priorities and functional mobility for ambulant children with CP)[44] and the Oxford Ankle and Foot Questionnaire for Children (OxAFQ-C) (assessing subjective wellbeing for child patients).[45]

Many studies (n = 9/13) incorporated quantitative forms of assessments (e.g. 3DGA, weightbearing radiographs, electromyography (EMG), pressure switches) in an attempt to improve objectivity of the grading within the clinical tools.[4,5,9,13,17,29,37–39] Improvements were reported in weightbearing radiological measurements of the hindfoot, midfoot, and forefoot,[41] and some improvements in ankle kinematics noted in two studies using gait analysis.[36,39] However, there was a lack of standardized approaches for conducting (and quantifying) the gait assessments to minimize accuracy errors, and few studies provided sufficient detail regarding who graded the assessments, raising the risk of observer bias. Despite these limitations, the improved radiological findings and the changed foot (ankle joint) biomechanics supported the high rates of success recorded by the clinical grading tools. For future studies, pre- and postoperative weightbearing radiographs and dynamic measures such as EMG,[43] dynamic pedobarography,[46] and 3-DGA[47] (using multisegmented foot models) are recommended. Some studies described gross motor function either by labelling participants as 'community walkers',[10,11] or by reporting pre-/postoperative GMFCS levels.[8,14] Though it should be noted by the reader that the GMFCS is not recommended for use as an outcome measure, both studies reporting on postoperative classifications reported a tendency towards favourable changes in GMFCS levels. While suggestive of improvements in functional mobility, these approaches lack the precision needed to quantify change within the possibly wide range of abilities, and use classification systems in ways for which they were not designed. Measuring specific gait activity-related capabilities such as the Functional Mobility Scale,[48] Timed Up and Go, or the Gross Motor Function Measure (GMFM), would facilitate measures of functional gait changes.

The age of the child at the time of intervention and the severity of the foot deformity appear intertwined and careful consideration of these factors should be evaluated further. Although data were unable to be presented or subanalyzed within this review by age of receipt of the surgery, the mean age at time of the surgery was nine years (3.3 to 26). Barnes and Herring[11] reported two participants, both over the age of ten years at the time of the intervention with poor outcomes, and both of whom had fixed foot deformities preoperatively with an element of fixed varus of the hindfoot. Similarly, Scott and Scarborough[17] identified three poor ratings (out of 17 feet) in the varus comparison group, associating these outcomes with older age at time of surgery (10.5, 13.3, and 17.2 years). Previous discussions on the optimum age for intervention advise that the child is older than six years of age,[9,13] as it is thought that rapid bone growth (< 6 years) can affect the stability of the attachment over time and increase risk of recurrences.[12] It has also been suggested that there is a higher risk of subsequent valgus deformity when surgery is performed under the age of eight years.[9,19] On the other hand, studies in this review have reported varus recurrences in patients older than ten years.[9,17] Wong et al's[9] cohort reported one recurrent varus (10 years at index) and two persistent varus (15 and 16 years at index) deformities. The cohort in the Vlachou et al[13] study had an average of 12.4 years at index operation and reported four recurrent varus deformities. These reports are consistent with the literature, advocating for surgery to be implemented in the early stages of deformity prior to bone maturity and the development of 'fixed' deformities.[49,50] In addition to minimizing fixed deformities in the older years, there is widespread agreement in the studies reviewed that early (i.e. age < 6 years) surgery was a major risk factor for recurrent foot deformity. Therefore, a defined window of opportunity may be required for optimal results, and future research would be beneficial to assess this further.

Recurrence of foot deformity is an issue for discussion. For optimum results following SPLATT and SPOTT interventions, a number of authors have proposed that the patient should have 'a dynamic passively' correctable foot as a preoperative criterion.[11,38] However, foot deformity is not a binary grading, rather a gradual transition within a spectrum. Patterns of muscle spasticity, tightness, and/or dystonia can also evolve over time, which may cause recurrence, or even reversal, of deformity. Exploring possible preoperative characteristics of participants with lower success rates may aid in the planning of and screening for patient suitability, as previously indicated by Chang et al.[19] We were not able to identify features that indicated a better outcome from this review. However, previous papers have reported that children with hemiplegic CP,[13,14,40] and lower GMFCS levels, show trends towards higher success rates.[46] Nearly all the studies included some participants with tendoachilles lengthening; future studies may benefit from considering the combination of achilles lengthening and split tibialis tendon transfers. A better understanding of the causes of relapse or other foot deformity may come from pooling of multisite data, with standardized data collection prior and post-surgery.

The finding and interpretation of this review are limited by the availability of participant data (isolated to the target intervention), and the heterogeneity of reporting and selected outcome measures. Attempts made to contact authors proved particularly difficult in studies published over a decade prior (resulting in exclusion (Supplementary Table i)).[34,45,49,51,52] Details regarding preoperative levels of ambulation and the degree of varus or EQV foot deformity were at times unclear, and in some early studies the underlying assumption has been made that all participants described as having CP actually meet the current definition of CP.[5,10,38] While we have attempted to discuss outcomes in relation to their preoperative status of deformity, the transition from flexible to stiff foot is slow, gradual, and not binary. Pre- and postoperative pre/rehabilitation programmes may also impact patient outcomes, but details on these protocols were sparse (i.e. rate, period, patient adherence). Supplementary data in this domain could be beneficial, adding value to future clinical practice.

In summary, split tibial tendon transfers for the management of EQV foot deformities appear to be an effective intervention, producing and maintaining a plantigrade functional foot, eliminating the need for orthotics during gait and improving shoe wear in children and youth with CP.[7,40] Post-surgery, approximately 87% of patients were able to walk with a plantigrade balanced foot without the need for an orthosis, reducing the risks of trips and falls and thus enhancing gait function.[34] However, much of the evidence for this surgery comes from studies dating prior to 2011, with low-quality ratings and moderate risk of bias, favouring the use of Kling's observational criteria to evaluate outcomes. Nevertheless, the data presented can be used to guide prospective study designs. The recurrence of deformity and occurrence of other foot deformities necessitating revision surgery is significant, and future work needs to focus on reducing the rate of revision surgery through better patient selection and more targeted surgery.

Take home message

- Split tendon transfers are effective at restoring a functional plantigrade foot, improving gait function, and reducing the need for orthotics in about 87% of children and youth with cerebral palsy.
- 12% of patients have recurrence of varus deformity and 3% have development of the opposite deformity at mean follow-up of five years.
- About one in ten patients undergo further foot surgery, providing useful data in counselling parents about expected outcomes.
- Future standardized patient-reported and performance-related evaluation measures are warranted to assess impact on pain, function, and quality of life.

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Supplementary material

The supplementary material includes an example of the MESH search strategies, a table outlining the scoring for the MINORS for each study, the ROBINS-I outcomes, GRADE tables, and a summary of reasons for exclusion for full-text articles.

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