Gait & Posture 100 (2023) 254–260

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Foot drop after gastrocsoleus lengthening for equinus deformity in children with cerebral palsy

Nicholas Sclavos [a,b], Pam Thomason [b,c], Elyse Passmore [b,c,d], Kerr Graham [a,b,e], Erich Rutz [a,b,c,e,f,*,1]

[a] Department of Paediatrics, The University of Melbourne, Parkville, Victoria 3052, Australia
[b] Hugh Williamson Gait Analysis Laboratory, The Royal Children's Hospital, 50 Flemington Road, Parkville, Victoria 3052, Australia
[c] Murdoch Children's Research Institute, 50 Flemington Road, Parkville, Victoria 3052, Australia
[d] Department Biomedical Engineering, The University of Melbourne, Parkville, Victoria 3052, Australia
[e] Department of Orthopaedics, The Royal Children's Hospital, 50 Flemington Road, Parkville, Victoria 3052, Australia
[f] Medical Faculty, The University of Basel, Basel 4001, Switzerland

ARTICLE INFO

Keywords:
Equinus
Cerebral palsy
Foot drop
Gait
Gastrocsoleus lengthening

ABSTRACT

Background: Gastrocsoleus lengthening (GSL) is the most common surgical procedure to treat equinus deformity in ambulant children with cerebral palsy (CP). Foot drop, where the ankle remains in plantarflexion during swing phase, can persist in some children post-operatively. There is currently limited understanding of which children will demonstrate persistent foot drop after GSL.
Research question: Which children develop persistent foot drop after GSL surgery for equinus?
Methods: We conducted a retrospective cohort study on ambulant children with CP who had GSL surgery for fixed equinus deformity. The aims of the study were: to determine the frequency of persistent foot drop post-operatively and to compare outcome parameters from physical examination and three-dimensional gait analysis for children with hemiplegia or diplegia.
Results: One hundred and ten children functioning at GMFCS Levels I/II/III of 28/75/7 met the inclusion criteria for this study. There were 71 boys and mean age was 9.1 years at time of GSL surgery. The overall frequency of persistent foot drop was 25%, with a higher frequency of persistent foot drop in children with hemiplegia (42%) than children with diplegia (19%). There were significant improvements in dorsiflexor strength and in selective motor control in children with diplegia but not in children with hemiplegia. Mean (SD) pre-operative mid-swing ankle dorsiflexion for children with hemiplegia was − 14.0° (9.9°) and improved post-operatively to − 1.6° (5.5°). For children with diplegia, the pre-operative mid-swing ankle dorsiflexion was − 12.1° (12.9°) and improved post-operatively to + 4.2° (6.9°).
Significance: Foot drop is present following GSL surgery for fixed equinus deformity in a significant number of children with hemiplegia and to a lesser extent in children with diplegia, which may reflect a difference in the central nervous system lesion between these groups. New management approaches are required for this important and unsolved problem.

1. Introduction

The most common musculoskeletal deformity in ambulant children with cerebral palsy (CP) is equinus, defined as a fixed contracture of the gastrocnemius or gastrocnemius and soleus muscles [1]. Equinus gait can cause tripping, falling, and may ultimately impact participation [1,2]. Children with hemiplegia may present with unilateral equinus on their affected side [3]. Children with diplegia may present with unilateral or bilateral equinus, and bilateral equinus may be symmetrical or asymmetrical [1,2,4]. Management of fixed equinus is treated by surgical lengthening of the gastrocsoleus muscle-tendon unit (MTU), by a variety of techniques [5].

* Correspondence to: Bob Dickens Chair for Paediatric Orthopaedic Surgery, Department of Orthopaedic Surgery, The Royal Children's Hospital, Flemington Road, Parkville, Victoria, Australia.
E-mail address: erich_rutz@hotmail.com (E. Rutz).
1 Present address: The Royal Children's Hospital Melbourne, Flemington Road, Parkville, VIC 3052, Australia.

https://doi.org/10.1016/j.gaitpost.2023.01.007
Received 13 November 2022; Received in revised form 5 January 2023; Accepted 11 January 2023
Available online 13 January 2023

Planning for gastrocsoleus lengthening (GSL) and other procedures can be optimised by a full biomechanical assessment, including three-dimensional gait analysis (3DGA) [1,6,7]. It has been established that GSL improves kinematic parameters in the stance phase of gait, in short- and long-term studies, in children with hemiplegia and diplegia [6–8]. In contrast, there is less understanding of the effects of GSL surgery on the swing phase of gait [9,10]. Gastrocsoleus lengthening corrects fixed contracture in the calf muscles, but it does not always improve the function of the dorsiflexor muscles [6–10]. Some children present with persistent ankle plantarflexion during swing phase (foot drop) after GSL surgery [9,10]. This may be due to weakness of the tibialis anterior muscle and impairments of selective motor control (SMC), as a negative feature of the upper motor neuron (UMN) syndrome of CP [11]. Impaired SMC refers to the reduced ability to isolate the activation of muscles in a selected pattern in response to the requirements of a voluntary posture or movement [11].

There are several consequences of persistent foot drop after GSL and current management strategies are limited [9–11]. Persistent foot drop can cause catching of the toes, tripping, and falling, and may also impair the functional and cosmetic outcomes of GSL surgery [11]. Children with persistent foot drop may be reliant on an ankle-foot orthosis (AFO). Many teenagers prefer not to wear AFOs, despite having symptomatic foot drop, and wearing an AFO may be associated with poor body image, anxiety and bullying at school [11]. Persistent foot drop after GSL is a major, unsolved problem for young people with CP [9–13].

The prevalence and predictors of foot drop after GSL have not been extensively reported in the literature. Previous studies investigating the effect of GSL on swing phase have limitations. Sample sizes were too small to permit robust statistical comparison between children with hemiplegia and children with diplegia [14]. It is recognised that these subgroups may respond differently to GSL, as children with hemiplegia often demonstrate more severe equinus and require more extensive GSL [1]. To our knowledge there has been no previous investigation of between group differences in swing phase outcomes in children with hemiplegia and diplegia, after GSL. The aim of our study was to assess the frequency of foot drop after surgery for equinus and to compare physical examination and kinematic outcomes between children with hemiplegia and diplegia.

2. Materials and methods

This was a retrospective cohort study of ambulant children with CP who underwent GSL for equinus deformity at the Royal Children's Hospital, Melbourne. Pre- and post-operative comparisons were investigated to study the effect of GSL on physical examination measures, gait kinematics, and to determine the frequency of persistent foot drop after GSL surgery in our group of children with CP.

Inclusion criteria:

- GSL surgery for equinus deformity, between January 2004 and December 2020
- A diagnosis of spastic CP with registration on the State-wide CP Register
- Gross Motor Function Classification System (GMFCS) Levels I-III
- Age 4–14 years, at the time of surgery
- Pre-operative 3DGA within 12 months prior to surgery
- Post-operative 3DGA between 12 and 24 months after surgery

Children were excluded if they had previous GSL surgery, selective dorsal rhizotomy or required the use of a K walker pre-operatively. Children who required a K walker had marked variability in their kinematic data and were therefore excluded. All other children who were GMFCS III, and who completed 3DGA using walking sticks or Canadian crutches, had good quality data and were therefore included. Following data review and selection, data from children with hemiplegia and diplegia were grouped for statistical analysis. The protocol for this study was reviewed and approved by the Royal Children's Hospital Melbourne Human Research Ethics Committee (HREC Reference Number: 65442).

2.1. Surgery for equinus

The indications for GSL were equinus during stance phase > 2 standard deviations (SD) below the range for typically developing children (TDC) and the presence of a fixed contracture limiting dorsiflexion to less than neutral, during pre-operative examination under anaesthesia [1,7]. Techniques for GSL were classified by a three-zone classification system, based on the anatomy of the gastrocsoleus MTU [1,5]. Decision-making regarding the appropriate surgical zone was based on the principle to use the most conservative GSL procedure required to achieve between plantigrade and 5° of dorsiflexion, intra-operatively, with the knee extended, in children with diplegia [1]. In children with hemiplegia the intraoperative target was 10 degrees of dorsiflexion, with the knee extended. (11) Zone 1 surgery is the most conservative and Zone 3 surgery the most aggressive [1,5]. The choice of GSL surgery was in keeping with the recommendations of a recent Delphi consensus statement [1].

Zone 1 procedures included the Strayer procedure, sometimes with soleal fascial lengthening. Zone 2 procedures included the modified Vulpius procedure [15]. Zone 3 procedures were lengthening of the Tendo Achillis [16]. In children with diplegia, GSL was usually a component of multi-level surgery [1,7,15,17–19].

2.2. Three-dimensional gait analysis and outcome measures

Pre- and post-operative 3DGA was conducted by experienced physiotherapists and biomedical engineers using standardised protocols, to obtain both physical examination measures and to collect kinematic and kinetic data. The reliability of the physical examination measures has previously been reported [20]. The physical examination measures included in this study were passive range of motion of the ankle and knee, dorsiflexor strength and SMC of the ankle. Ankle dorsiflexor strength was assessed using the five-point Medical Research Council scale [21]. In this study, grades of 3 + and 4 + were included for children who were between Grade 3 and 4, and Grade 4 and 5, respectively. Selective motor control of ankle dorsiflexion was assessed via the five-point SMC scale, described by Boyd & Graham [21].

Three-dimensional gait analysis was conducted according to the standardised protocols described by Baker [22]. This involved the application of reflective markers on the lower limbs of the child, according to the Plug-in-Gait marker-set (Vicon Motion systems), with additional markers on the thigh and shank to enhance segment tracking [23,24]. Following the placement of markers, a static standing calibration trial was performed, followed by the child walking barefoot at a self-selected speed. A minimum of five walks were recorded. Children walked with or without the use of mobility aids, depending on their individual walking ability. Marker trajectories were captured at 100 Hz and filtered using a Woltring filter (MSE=15) using Vicon Nexus [25]. Lower limb joint kinematics were calculated according to Plug-in-Gait in Vicon Nexus (Vicon, Oxford Metrics, UK). A single representative stride for each limb was selected, as previously described [26].

Included kinematic measures:

- Maximum and minimum ankle dorsiflexion in stance phase
- Ankle range at initial contact
- Ankle range at terminal stance
- Maximum and minimum ankle dorsiflexion in the middle-third of swing phase

The definition of foot drop used in this study is: a maximum ankle dorsiflexion in mid-swing that is greater than two SD below the mean of typically developing children (TDC) which was > 2.2° of plantarflexion in our cohort [9].

This study included gait measures derived from kinematic data, the Gait Profile Score (GPS) and Gait Variable Scores (GVS) [27]. The GPS and GVS are measured in degrees and a higher value represents greater deviation from the gait of TDC. This study included the sagittal ankle GVS, the GPS for each operated limb and the global GPS for both lower limbs.

2.3. Statistical analysis

Statistical tests were completed using STATA Statistical Software, release 10 (StataCorp, College Station, TX, USA). Parametric and non-parametric statistical tests were utilised to compare pre- and post-operative outcomes, both within and between the groups of children with hemiplegia and diplegia. Within each topographical group, paired sample t-tests were used to evaluate change between pre- and post-operative measures, for continuous variables. The Wilcoxon signed-rank test was used for categorical variables. Independent sample t-tests and Mann-Whitney tests were used to compare children with hemiplegia and diplegia, and to compare those children who demonstrated persistent foot drop and those that did not.

3. Results

3.1. Demographics

One hundred and ten children met the inclusion criteria: 36 children with hemiplegia and 74 children with diplegia. There were 71 males and 39 females. Mean age at surgery was 9.4 years (SD 2.0, range 4.6 – 13.5 years). Mean age of children with hemiplegia was 9.8 years (SD 2.0, range 6.0 – 13.5 years) and children with diplegia was 9.2 years (SD 1.9, range 4.6 – 13.4 years). There were 28, 75 and 7 children functioning at a GMFCS Level I, II and III, respectively. Complete demographics are summarised in Table 1.

3.2. Surgical procedures

The 36 children with hemiplegia had GSL on their affected side (36 limbs). Of those children with diplegia, 33 had unilateral GSL and 41 bilateral GSL (115 limbs). In total, 151 limbs underwent GSL. Further details regarding the type and frequency of the different GSL procedures are listed in Table 1.

Table 1
Demographics of children, timing, and frequency of gastrocsoleus lengthening surgery.

Characteristic	Number
Sex: male / female	71 / 39
Topography: hemiplegia / diplegia	36 / 74
GMFCS Level: I / II / III	
Total cohort	28 / 75 / 7
Hemiplegia	16 / 20 / 0
Diplegia	12 / 55 / 7
Age: mean (SD), range in years	
Pre-op 3DGA for total cohort	8.9 (1.9), 4.5 – 13.4
Surgery for total cohort	9.4 (2.0), 4.6 – 13.5
Hemiplegia	9.8 (2.0), 6.0 – 13.5
Diplegia	9.2 (1.9), 4.6 – 13.4
Post-op 3DGA for total cohort	10.5 (2.0), 6.6 – 15.0
Time interval: mean (SD), range in years	
Pre-op 3DGA to surgery	0.5 (0.3), 0.0 – 1.1
Surgery to post-op 3DGA	1.1 (0.3), 0.9 – 2.1
Surgery: hemiplegia / diplegia / total	
Number of operated limbs	36 / 115 / 151
Zone 1 Strayer	7 / 66 / 73
Zone 1 Strayer plus SFL	6 / 25 / 31
Zone 2 Modified Vulpius	20 / 20 / 40
Zone 3 Percutaneous TAL (Hoke)	3 / 0 / 3
Zone 3 Open TAL (White slide)	0 / 4 / 4

GMFCS = Gross Motor Function Classification System, SD = standard deviation, Pre-op = pre-operative, 3DGA = three-dimensional gait analysis, Post-op = post-operative, SFL = Soleal fascia lengthening, TAL = Tendo Achillis lengthening

Eighteen children underwent isolated GSL. Ninety-two children had multi-level surgery. Mean number of procedures per child was 4.2. The surgical indications followed previously published guidelines [1,7]. The total number of surgeries, other than GSL, by anatomical level (hip, knee, ankle/foot) and the type of surgery (bony or soft tissue procedure) are shown in supplementary material (Table S1).

3.3. Physical examination

Ankle dorsiflexor strength measures were possible for most of the cohort (hemiplegia n = 29/36; diplegia n = 107/115). Post-operatively, 41% (12/29) of children with hemiplegia demonstrated unchanged ankle dorsiflexor strength, 31% (9/29) had increased strength and 28% (8/29) had decreased strength. The strength changes in children with hemiplegia were not significant ($p = 0.786$). In children with diplegia, 35% (37/107) had unchanged strength, 46% (49/107) had increased strength and 20% (21/107) had decreased strength. Children with diplegia demonstrated a statistically significant increase in ankle dorsiflexor strength. ($p < 0.001$).

In children with hemiplegia, 50% (18/36) had unchanged SMC, 36% (13/36) had improved SMC and 14% (5/36) had worsened SMC. Changes in this group were not statistically significant ($p = 0.071$). In children with diplegia, 49% (56/115) demonstrated unchanged SMC, 43% (49/115) had improved SMC and 9% (10/115) had worsened SMC. The improvement in SMC was statistically significant ($p < 0.001$).

There were no pre-operative between group differences in ankle dorsiflexor strength ($p = 0.161$) or SMC ($p = 0.317$) when children with hemiplegia were compared to children with diplegia. Post-operatively, there were statistically significant between group differences. Children with diplegia had increased ankle dorsiflexor strength ($p = 0.020$) and improved SMC ($p = 0.026$) after GSL.

3.4. Gait kinematics

Pre- and post-operative kinematic measures, and reference data of TDC, are reported in Table 2. Pre- and post-operative ankle and knee kinematic traces are shown in Fig. 1. Complete kinematics are included in supplementary material (Figs. S1 and S2). Children with hemiplegia and diplegia demonstrated significant improvement in all stance and swing phase measures ($p < 0.001$). Mean pre-operative (SD) mid-swing ankle dorsiflexion in children with hemiplegia was -14.0° (9.9°) compared to post-operative mean (SD) of -1.6° (5.5°). The mean difference (95% confidence interval (CI)) from pre- to post-operative was 12.4° (9.0–15.7°, $p < 0.001$). The corresponding figures for children with diplegia were -12.1° (12.9°) preoperatively and 4.2° (6.9°) postoperatively. The mean difference (95% CI) from pre- to post-operative in this group was 16.3° (14.1–18.5°, $p < 0.001$).

Between group differences in ankle kinematic measures are found in Table 3. The between group difference in pre-operative maximum ankle dorsiflexion in mid-swing ($p = 0.419$) was not significant. Post-operatively, children with diplegia had greater maximum ankle dorsiflexion in mid-swing than those with hemiplegia. The post-operative between group difference (95% CI) was 5.8° (3.3–8.3°, $p < 0.001$). Children with diplegia demonstrated a greater pre- to post-operative change than those with hemiplegia. The mean difference (95% CI) in pre- to post-operative change between the two groups was 3.9° (-0.4 to 8.2°). This was not statistically significant ($p = 0.074$).

In total, 25% of operated limbs (37/151) demonstrated persistent foot drop after GSL surgery. There was a higher frequency of persistent foot drop in children with hemiplegia compared to children with diplegia: 42% vs 19%.

Pre-operative strength and SMC were compared between children who demonstrated persistent foot drop and those that did not. In children with hemiplegia, those with persistent foot drop had decreased pre-

Table 2
Ankle kinematic features pre- and post-gastrocsoleus lengthening surgery.

Kinematic feature	Hemiplegia (n = 36 limbs)			Diplegia (n = 115 limbs)			TDC
	Pre-op mean (SD)	Post-op mean (SD)	Mean diff (95% CI)	Pre-op mean (SD)	Post-op mean (SD)	Mean diff (95% CI)	Mean (SD)
Max DF stance	-1.0° (11.1°)	11.7° (5.5°)	12.7° (8.6–16.9°)*	-1.9° (13.8°)	11.9° (6.0°)	13.8° (11.1–16.4°)*	13.0° (3.9°)
Min DF stance	-18.1° (13.1°)	-9.7° (4.1°)	8.4° (4.2–12.6°)*	-27.1° (16.8°)	-6.3° (6.9°)	20.8° (17.8–23.7°)*	-9.7° (5.2°)
DF late stance	-2.4° (12.4°)	11.6° (5.8°)	13.9° (9.4–18.5°)*	-5.6° (14.9°)	11.2° (6.5°)	16.7° (14.1–19.6°)*	12.8° (4.1°)
DF initial contact	-13.5° (9.6°)	-7.6° (4.0°)	6.0° (2.7–9.3°)*	-12.0° (12.4°)	-0.9° (5.0°)	11.1° (8.9–13.2°)*	-0.2° (3.3°)
Max DF mid-swing	-14.0° (9.9°)	-1.6° (5.5°)	12.4° (9.0–15.7°)*	-12.1° (12.9°)	4.2° (6.9°)	16.3° (14.1–18.5°)*	3.3° (2.7°)
Min DF mid-swing	-19.0° (11.3°)	-6.1° (6.2°)	12.9° (9.6–16.3°)*	-20.4° (15.0°)	-1.4° (8.4°)	19.0° (16.4–21.6°)*	-3.8° (3.5°)

Pre-op = pre-operative, Post-op = post-operative, SD = standard deviation, diff = difference, CI = confidence interval, DF = dorsiflexion, Max = maximum, Min = minimum, TDC = typically developing children, * = p < 0.05

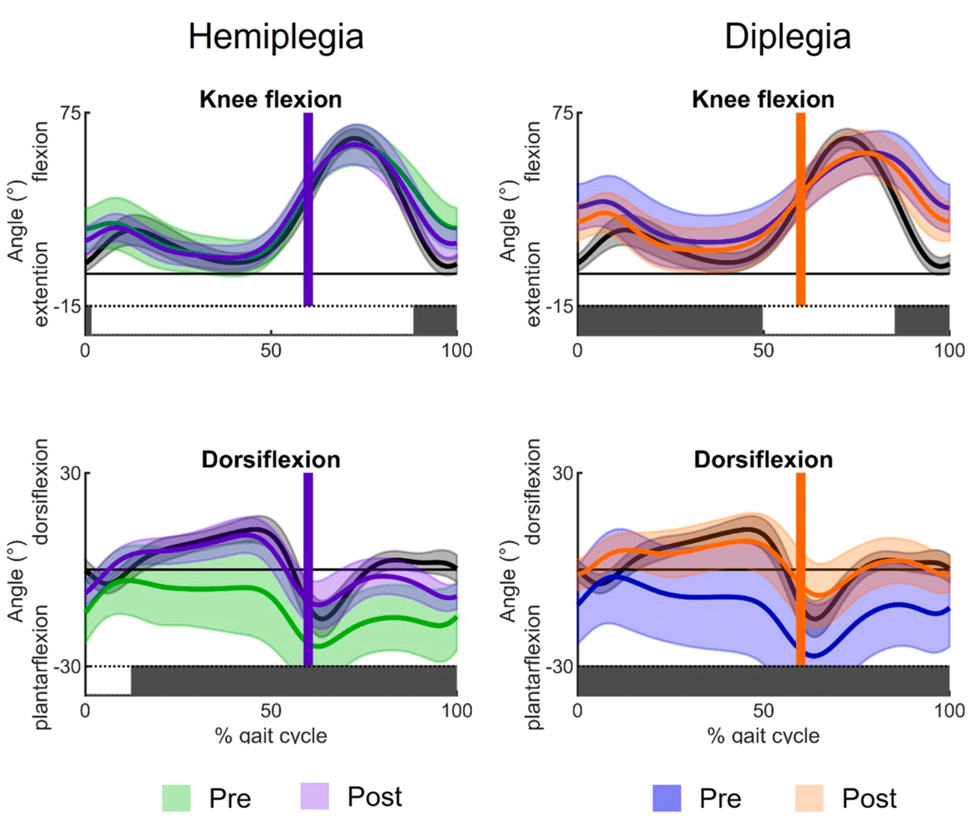

Fig. 1. Knee and ankle sagittal plane kinematics. Knee top row, ankle bottom row. Black line and grey shading represent the mean and one standard deviation (SD) of data from typically developing children. Coloured lines and shading represent the mean joint range of motion and one SD for the children with hemiplegia (left column) and children with diplegia (right column) pre- and post-gastrocsoleus lengthening surgery. Shading beneath each graph represents periods of significant difference between pre- and post-surgery kinematic curves.

operative median dorsiflexor strength (p = 0.088) and worsened SMC scores (p = 0.056), compared to those who did not have foot drop. In children with diplegia, there were no between group differences in median strength (p = 0.263) or SMC (p = 0.830) in those who did and did not demonstrate persistent foot drop.

The ankle GVS, operated limb GPS and global GPS are shown in Table 4 and Fig. 2. These demonstrated significant decrease from pre- to post-operative, in children with hemiplegia ($p < 0.001$) and diplegia ($p < 0.001$). A decrease in GVS or GPS indicates an improvement in gait towards the gait of TDC [27,28]. For both groups, the decrease in GPS exceeded the Minimal Clinically Important Difference (MCID), which is 1.6° [28]. There was no significant between group difference in pre-operative ($p = 0.177$) or post-operative ankle GVS ($p = 0.105$). The operated limb GPS and global GPS were significantly lower ($p < 0.001$) in children with hemiplegia compared to those with diplegia, both pre- and post-operatively.

4. Discussion

Foot drop in ambulant children with CP is a poorly studied and unsolved problem [9–11,14]. Hemiplegia is the most common subtype of spastic CP and according to the classification proposed by Winters, Gage and Hicks, Type I is “foot drop in the swing phase of gait” [3]. In a large population-based study of unilateral CP, Type I hemiplegia was the most common type [29]. Foot drop may therefore be the most prevalent gait impairment in ambulant children with CP [3,29]. The degree of functional impairment, and potential limitations in function and participation are variable and not yet fully described [30].

The aetiology of foot drop is poorly understood. It is usually considered to be the result of impaired SMC, as one of the negative features of the UMN syndrome [11]. Studies have identified abnormalities in tibialis anterior muscle architecture, in children with CP, including reduced muscle thickness and cross-sectional area [31]. These explain in part the weakness we recorded in the physical examination

Table 3
Between group differences for hemiplegia and diplegia in selected ankle kinematic features.

Kinematic feature	Hemiplegia vs Diplegia		
	Pre-op	Post-op	Pre- to Post-op change
	Mean diff (95% CI)	Mean diff (95% CI)	Mean diff (95% CI)
Max DF stance	0.9° (−4.1 to 5.9°)	0.2° (−2.0 to 2.4°)	1.1° (−4.2 to 6.3°)
Min DF stance	9.0° (3.0–15.0°)*	3.4° (1.0–5.8°)*	12.3° (6.6–18.1°)*
DF late stance	3.2° (−2.2 to 8.7°)	0.3° (−2.1 to 2.7°)	2.9° (−2.6 to 8.4°)
DF initial contact	-1.6° (−6.0 to 2.9°)	6.6° (4.8–8.5°)*	5.1° (0.8–9.4°)*
Max DF mid-swing	-1.9° (−6.5 to 2.7°)	5.8° (3.3–8.3°)*	3.9° (−0.4 to 8.2°)
Min DF mid-swing	1.4° (−4.0 to 6.8°)	4.7° (1.7–7.7°)*	6.1° (1.1–11.1°)*

Pre-op = pre-operative, Post-op = post-operative, diff = difference, CI = confidence interval, Max = maximum, DF = dorsiflexion, Min = minimum, * = $p < 0.05$

measures. Persistent impairments in SMC after GSL, as confirmed in this study, are probably a more important factor and worthy of further study [30]. Both ankle dorsiflexor weakness and impaired SMC pre-operatively were associated with persistent foot drop post-operatively, in children with hemiplegia. Importantly, muscle strength and SMC improved after GSL surgery in children with diplegia but not in children with hemiplegia. We interpret these findings as pointing towards fundamental differences in motor control and in the central nervous system lesion in children with hemiplegia compared to children with diplegia [11].

To our knowledge, this is the first study to directly compare frequency of persistent post-operative foot drop in children with hemiplegia and diplegia. Forty-two percent of children with hemiplegia and 19% of children with diplegia demonstrated foot drop after surgery for equinus. A previous study reported that 48% of the operated limbs demonstrated persistent foot drop after GSL, without stratification of children with hemiplegia and diplegia [9]. The results of the current study provide new evidence for greater frequency of persistent foot drop in children with hemiplegia.

The finding of improved dorsiflexor strength in children with diplegia is supported by the results of previous studies. Reimers [32] was the first to report that the strength of antagonist muscles improved after surgical lengthening of contracted agonists. This was demonstrated in a cohort of six children with hemiplegia and 46 children with diplegia [32]. This finding has since been confirmed by other authors [6,33]. Therefore, the results of our study are consistent with previous evidence of improved ankle dorsiflexor strength in children with diplegia after GSL [6,32,33].

We found significant improvement in SMC in children with diplegia ($p < 0.001$) but not those with hemiplegia ($p = 0.071$). There is mixed evidence in the literature regarding SMC improvement after GSL for equinus. Lofterød et al. [9] and Davids et al. [10] identified significant improvement in SMC after GSL. Galli et al. [34] and Kay et al. [35] reported no improvements in SMC. All four previous studies performed statistical analysis on a mixed cohort, including children with hemiplegia and diplegia [9,10,34,35]. To our knowledge, our study is the first

Table 4
Ankle Gait Variable Score, operated limb and global Gait Profile Score pre-surgery, post-surgery and differences between hemiplegia and diplegia.

	Hemiplegia (n = 36 limbs)			Diplegia (n = 115 limbs)			Hemiplegia vs Diplegia		
	Pre-op mean (SD)	Post-op mean (SD)	Mean diff (95% CI)	Pre-op mean (SD)	Post-op mean (SD)	Mean diff (95% CI)	Pre-op Mean diff (95% CI)	Post-op Mean diff (95% CI)	Change Mean diff (95% CI)
GVS: Ankle	15.3° (9.9°)	6.6° (2.2°)	8.7° (5.6–11.8°)*	18.3° (12.3°)	7.5° (3.1°)	10.8° (8.5–13.2°)*	3.1° (−1.4 to 7.5°)	0.9° (−0.2 to 2.0°)	2.1° (−6.7 to 2.4°)
GPS: operated limb	11.0° (4.2°)	7.6° (2.0°)	3.4° (2.0–4.8°) *	14.3° (4.8°)	9.5° (2.8°)	4.8° (3.9–5.7°) *	3.3° (1.5–5.0°) *	1.9° (0.9–2.9°) *	1.4° (−0.4 to 3.2°)
	Hemiplegia (n = 36 children)			Diplegia (n = 74 children)			Hemiplegia vs Diplegia		
GPS: Global	10.4° (3.4°)	7.9° (1.8°)	2.5° (1.4–3.6°) *	14.6° (4.3°)	9.7° (2.8°)	4.9° (3.9–5.8°) *	4.2° (2.6–5.8°) *	1.8° (0.8–2.9°) *	2.4° (0.8–3.9°) *

Pre-op = Pre-operative, SD = standard deviation, Post-op = Post-operative, diff = difference, CI = confidence interval, GVS = gait variable score, GPS = gait profile score, * = p.< 0.05

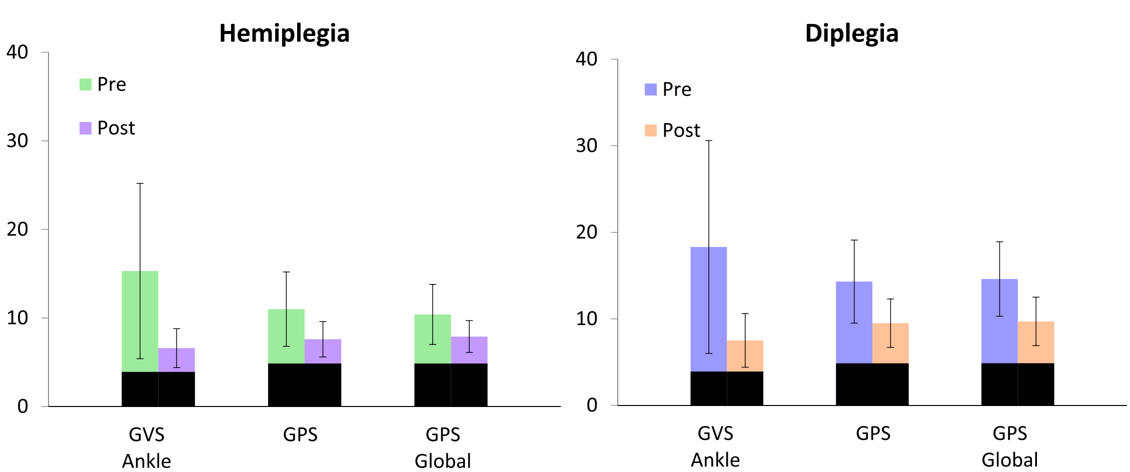

Fig. 2. Ankle Gait Variable Score (GVS), operated limb Gait Profile Score (GPS) and global GPS for children with hemiplegia (left) and diplegia (right) pre- and post-gastrocsoleus lengthening surgery. Error bars represent plus and minus one standard deviation. Black columns represent data from typically developing children.

to compare between group differences in SMC and provides evidence for greater improvement in children with diplegia.

The swing phase kinematic results support the findings of previous studies that surgery for equinus is effective in improving ankle dorsiflexion during swing phase, in both children with hemiplegia and diplegia [6,7,9,10]. Pre-operatively, there was no significant between group difference in maximum ankle dorsiflexion in mid-swing ($p = 0.419$). Post-operatively, the mean maximum ankle dorsiflexion in mid-swing in children with hemiplegia was -1.6° compared to $+4.2^{\circ}$, in children with diplegia. The post-operative between group difference was 5.8° and was statistically significant ($p < 0.001$).

There were several limitations. Our study was retrospective and short-term. Whilst we had a larger sample size, compared to previous studies, we had a disproportionately higher number of children with diplegia. This limited the power of the independent t-tests. The lack of dynamic EMG and patient reported outcome measures were further limitations [30,36].

Surgical correction of equinus deformity is a logical starting point for the management of equinus in swing phase in ambulant children with CP. Many children will have improvements in swing phase after GSL, especially children with diplegia [9,10,35]. For those with persistent drop foot, further management, and interventions, such as orthotic use, neuromuscular electrical stimulation [30], strength training or novel surgical procedures such as Tibialis Anterior Tendon Shortening [14,37] may be required to improve gait and function. Future studies are needed to evaluate the impact of persistent foot drop on gait function, and importantly activity and participation for children. The results of this study could inform the protocol for participant selection for randomised clinical trials of such interventions.

In conclusion, we found a higher frequency of persistent foot drop after gastrocsoleus lengthening in children with hemiplegia, than those with diplegia. Children with diplegia demonstrated improvement in ankle dorsiflexor strength and selective motor control after surgery. This was not observed in children with hemiplegia. This may highlight an underlying difference in the central nervous system pathology between children with hemiplegia and diplegia [11]. These results should inform future research into further management strategies for persistent foot drop after gastrocsoleus lengthening [14,30,37]. Additional areas for investigation could include a more sophisticated analysis of ankle kinematics in swing, such as waveform analysis.

Funding

Elyse Passmore is supported by a Clinician Scientist Fellowship, Murdoch Children's Research Institute.

Declarations of Interest

The authors declare no financial or personal conflict of interest with respect to this study. No external funding was received in support of this study. Kerr Graham received non-financial support from NHMRC, CP-Achieve.

Acknowledgements

The staff of the Hugh Williamson Gait Analysis Laboratory. Elyse Passmore is supported by a Clinician Scientist Fellowship, Murdoch Children's Research Institute. Kerr Graham received non-financial support from NHMRC CP-Achieve.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gaitpost.2023.01.007.

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