Original Clinical Article

JOURNAL OF CHILDREN'S ORTHOPAEDICS

Indications for gastrocsoleus lengthening in ambulatory children with cerebral palsy: a Delphi consensus study

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Abstract

Purpose Equinus is the most common deformity in cerebral palsy (CP) and gastrocsoleus lengthening (GSL) is the most commonly performed surgery to improve gait and function in ambulatory children with CP. Substantial variation exists in the indications for GSL and surgical technique. The purpose of this study was to review surgical anatomy and biomechanics of the gastrocsoleus and to utilize expert orthopaedic opinion through a Delphi technique to establish consensus for surgical indications for GSL in ambulatory children with CP.

Methods A 17-member panel, of Fellowship-trained paediatric orthopaedic surgeons, each with at least 9 years of clinical post-training experience in the surgical management of children with CP, was established. Consensus for the surgical indications for GSL was achieved through a standardized, iterative Delphi process.

Results Consensus was reached to support conservative Zone 1 surgery in diplegia and Zone 3 surgery (lengthening of the Achilles tendon) was contraindicated. Zone 2 or Zone 3 surgery reached general agreement as a choice in hemiplegia and under-correction was preferred to any degree of overcorrection. Agreement was reached that the optimum age for GSL surgery was 6 years to 10 years and should be avoided in children aged under 4 years. Physical examination measures with the child awake and under anaesthesia were important in decision making. Gait analysis was supported both for decision making and for assessing outcomes, in combination with patient reported outcomes (PROMS).

Conclusions The results from this study may encourage informed practice evaluation, reduce practice variability, improve clinical outcomes and point to questions for further research.

Level of Evidence: V

Cite this article: Rutz E, McCarthy J, Shore BJ, Shrader MW, Veerkamp M, Chambers H, Davids JR, Kay RM, Narayanan U, Novacheck TF, Pierz K, Rhodes J, Shilt J, Theologis T, Van Campenhout A, Dreher T, Graham K. Indications for gastrocsoleus lengthening in ambulatory children with cerebral palsy: a Delphi consensus study. *J Child Orthop* 2020;14:405-414. DOI: 10.1302/1863-2548.14.200145

Keywords: cerebral palsy; equinus; surgical indications; consensus; gastrocsoleus lengthening

Introduction

Equinus is the most common deformity in children with cerebral palsy (CP) with a prevalence of 83.3% in a recent large survey of children with bilateral spastic cerebral palsy.[1] This study reported that equinus deformity increased with age; 73% at age 3 years to 8 years and 92% after 17 years. There were two distinct groups: 40% had isolated contracture of the gastrocnemius and 60% had a combined contracture of the gastrocnemius and soleus.[1,2]

Surgical lengthening of the gastrocsoleus muscle-tendon unit (MTU) is performed as either a single-level procedure in children with hemiplegia or as part of multi-level surgery in children with diplegia.[3-5] In children with diplegia, the issue of coupling between the ankle, knee and hip levels needs to be considered, with the accepted approach being to correct all levels in one sitting.[4,5] A recent study surveyed current practice and preferences in the management of equinus in children with CP by both paediatric and general orthopaedic surgeons. The study reported discordant responses as well as knowledge practice gaps. The authors concluded that this might lead to inconsistent treatment, suboptimal outcomes and overburdening of the health care system.[6] These reports informed the design and interpretation of our study.

The background to clinical decision making in cohort studies and randomized controlled trials of surgery for equinus are rarely discussed in sufficient detail to provide data which is generalizable and practical.[6,7] The clinical heterogeneity of the ambulant CP population in terms of age, movement disorder, severity of contracture, CP subtype (unilateral/hemiplegia versus bilateral/diplegia), functional status (Gross Motor Function Classification System, GMFCS) and associated deformities serve to compound what seems at first glance to be a simple surgical problem.[7,8] In addition, more than 12 procedures have been described for the correction of equinus deformity.[9-11] Our hypothesis was that, using shared knowledge of gastrocsoleus anatomy and gait biomechanics, we could use a combination of best available evidence and expert orthopaedic surgeon opinion through a Delphi technique to establish areas of consensus for surgical indications and outcome assessment for gastrocsoleus lengthening (GSL) in ambulatory children with CP, and to identify where there is less agreement and a need for more evidence. We convened an international group of experts with clinical experience in the treatment of children with CP and the use of 3D gait analysis (3DGA), and the methodology has been described in detail in a previous report.[12] The specific goal of this study was to determine if consensus could be achieved for the indications for GSL in ambulatory children with CP as well as the assessment of surgical outcomes using the Delphi method. In posing the questions for the Delphi Consensus Process, on GSL, questions were framed using the 3-Zone Classification of gastrocsoleus surgical anatomy.[13]

Surgical anatomy of the gastrocsoleus MTU

Zone 1 is from the origin of the gastrocnemius on the distal femoral condyles to the termination of the medial gastrocnemius belly. In Zone 1 the gastrocnemius is easily separated from the underlying soleus. The Strayer Distal Gastrocnemius Recession is the most widely used Zone I procedure, although technically it is performed at the junction between Zone 1 and Zone 2.[13,14] In Zone 1 isolated lengthening of the gastrocnemius is possible (Fig. 1a). Differential lengthening of gastrocnemius and soleus is also possible, that is lengthening of the two muscles by different amounts (Figs. 1a and 1b). Zone 1 lengthening is inherently stable and resistant to overlengthening.[13]

Zone 2 is from the termination of the medial gastrocnemius belly, to the termination of the most distal soleus fibres. In Zone 2, the two layers are fused together to form the 'conjoined tendon' of the gastrocnemius aponeurosis and soleus fascia.[13,15] In Zone 2 the gastrocnemius and soleus are lengthened by an equal amount[15] (Fig. 1c, modified Vulpius). Zone 3 is the Achilles tendon. It extends from the distal soleus fibres to the insertion of the tendon on the tuberosity on the calcaneum. In cadaver testing, lengthening in Zone 3 is not selective (both muscles are lengthened by the same amount) and it is not stable, with the highest potential for inadvertent overlengthening.[13] (Fig. 1d, White slide tendo-Achilles lengthening illustrated)

Biomechanics of the gastrocsoleus MTU

The gastrocsoleus contributes more to the total body support moment than the quadriceps or hip extensors, as described by Winter and colleagues[16] (Fig. 2). Equinus is the most commonly encountered deformity in CP and lengthening of the gastrocsoleus muscle complex is the most commonly performed procedure. Since the gastrocsoleus contributes most to the total body support moment, overlengthening and calcaneus/crouch is a pervasive problem in diplegia/bilateral CP (Figs. 2 and 3). [7,9,10] Overlengthening and overcorrection at the knee and hip levels are infrequent at the knee and unknown at the hip. Recurvatum may be seen at the knee after hamstring lengthening but recurrent knee flexion/crouch is more common.[8,9,10] Following intramuscular lengthening of psoas at the hip, excessive hip extension is unknown but residual incomplete extension/excessive hip flexion is common. Delp and colleagues showed that a lengthening in a 2:1 ratio was optimal for the correction of deformity and preservation of soleal strength for push-off for moment generation.[17]

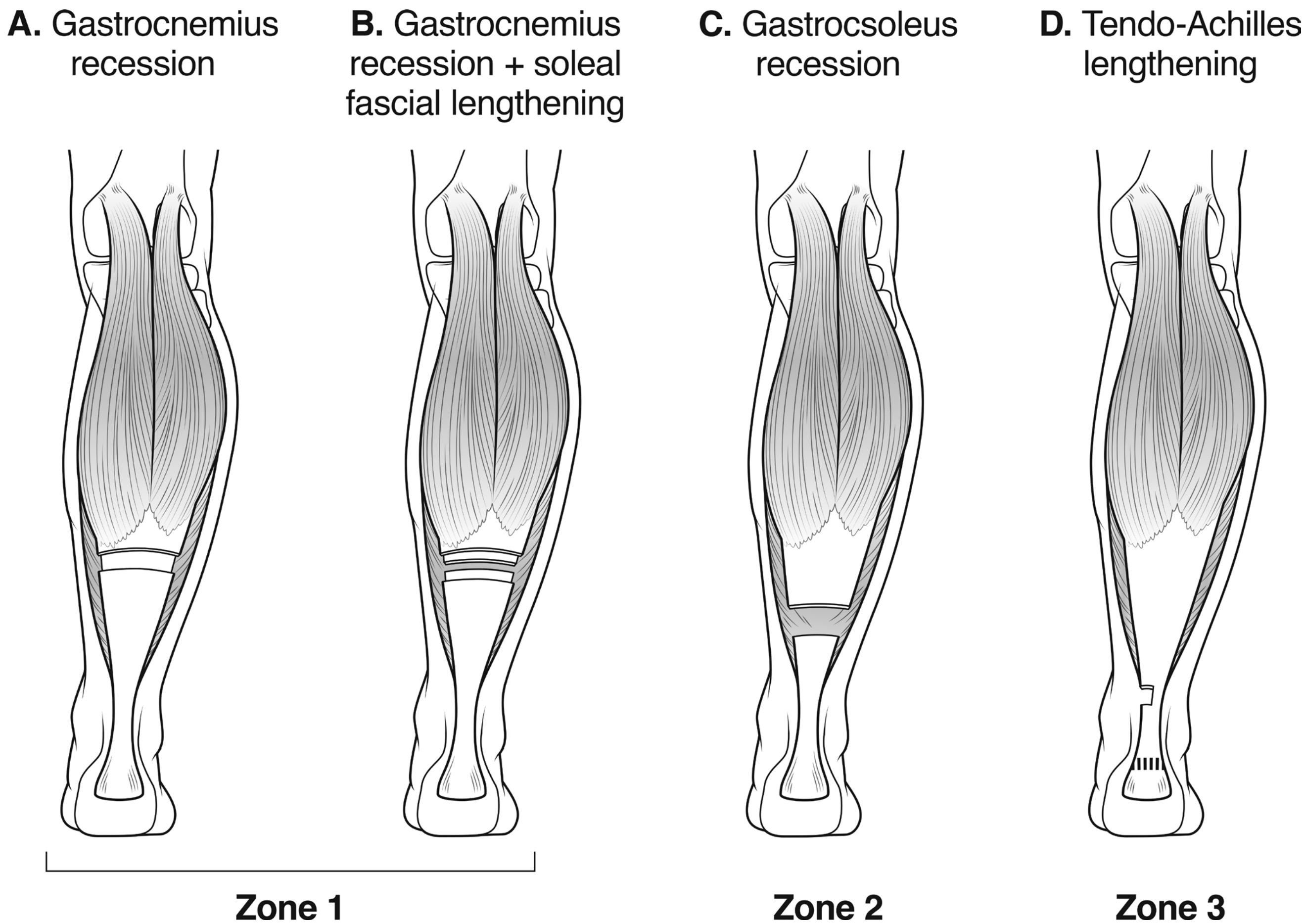

Fig. 1 Surgical anatomy of the gastrocsoleus muscle-tendon unit. Zone 1 extends from the origin of the gastrocnemius to the termination of the muscle fibres of the medial bely. There is a surgical plane between the two muscles, which can be used to recess the gastrocnemius alone or to lengthen the two muscles by different amounts. The Strayer distal gastrocnemius recession is illustrated in **(a)** and the Strayer plus SFL is illustrated in **(b)**. Zone 2 is the conjoined tendon of the gastrocnemius aponeurosis and the soleal fascia. The modified Vulpius gastrocsoleus recession (GSR) is illustrated in **(c)**. Zone 3 is the Achilles' tendon. The White slide TAL is illustrated in **(d)**, two transverse partial tenotomies with the anterior fibres cut distally (dotted line) and medial fibres cut proximally. For more detail see reference 13.

That is to say, ideally it is necessary to lengthen the gastrocnemius component by twice as much as the soleus component. In cadaver studies, Firth and colleagues demonstrated the only technique that could deliver a 2:1 lengthening ratio was the Strayer Distal Gastrocnemius Recession combined with soleal fascial lengthening (SFL, Fig. 1b).[13] The soleus is exquisitely sensitive to weakness during lengthening.[9,10,17] This is critical in choosing the most conservative, muscle strength preserving procedure for equinus surgery in children with diplegia. Even though, from a technical point of view, Strayer plus SFL lengthens both muscles, it is not equivalent to Zone 2 lengthening (Figs.1b and 1c). The Strayer plus SFL lengthens in the biomechanically desirable 2:1 ratio. The modified Vulpius lengthens both muscle components by an equal amount (Fig. 1c). This may result in overlengthening and weakening of soleus, calcaneus ankle and crouch gait.[7,9,10]

Research design and methods

We used consensus methodology (Delphi) to identify indications for GSL in ambulatory children with CP. The Delphi methodology is well established to develop appropriateness criteria.[12,18,19,20] Institutional review board approval for the study and from each participating member was obtained. We assembled a 17-member panel of paediatric orthopaedic surgeons with fellowship training, experience in gait analysis and surgery for children with CP, as previously described.[12] On average, the experts had a mean of over 20 years of experience (nine years to 40 years) with the orthopaedic treatment of children with CP, for a combined total of over 300 years of experience. All panel members also had expertise with the use of motion analysis for the assessment of gait disorders in children with CP, with a mean of 18.81 years (range

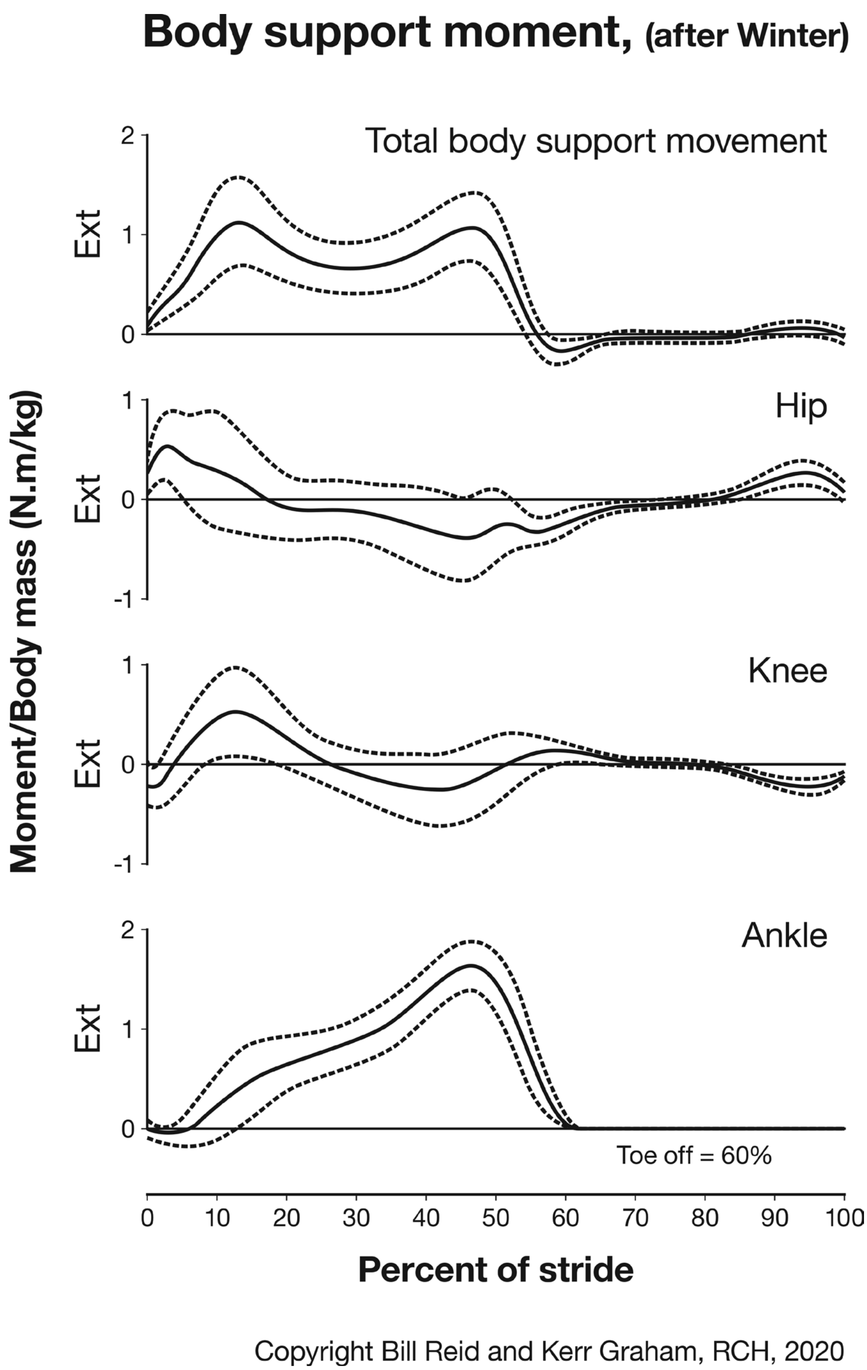

Fig. 2 The body support moment, drawn after Winter[16]. The body support moment, which maintains upright posture during stance phase, is the sum of the moments from the gastrocsoleus, quadriceps and hip extensors. The gastrocsoleus contributes most to the body support moment.

6 years to 30 years). No members withdrew. Our expert panel then created and agreed to a structured format for categorizing the indications for GSL. This format consisted of five categories including the clinical problem/history and symptoms on presentation, physical examination including observational gait analysis, imaging findings, 3D motion analysis data, intraoperative exam under anaesthesia (EUA) and important outcome measures.[9-11,21] The three rounds of questions and feedback, face-to-face meetings of the expert panel and distilling of responses have been described in a previous publication.[12] In the current COVID-19 era, face-to-face meetings of the authors have been replaced by email and Zoom conferencing. The expert panel created and agreed to a

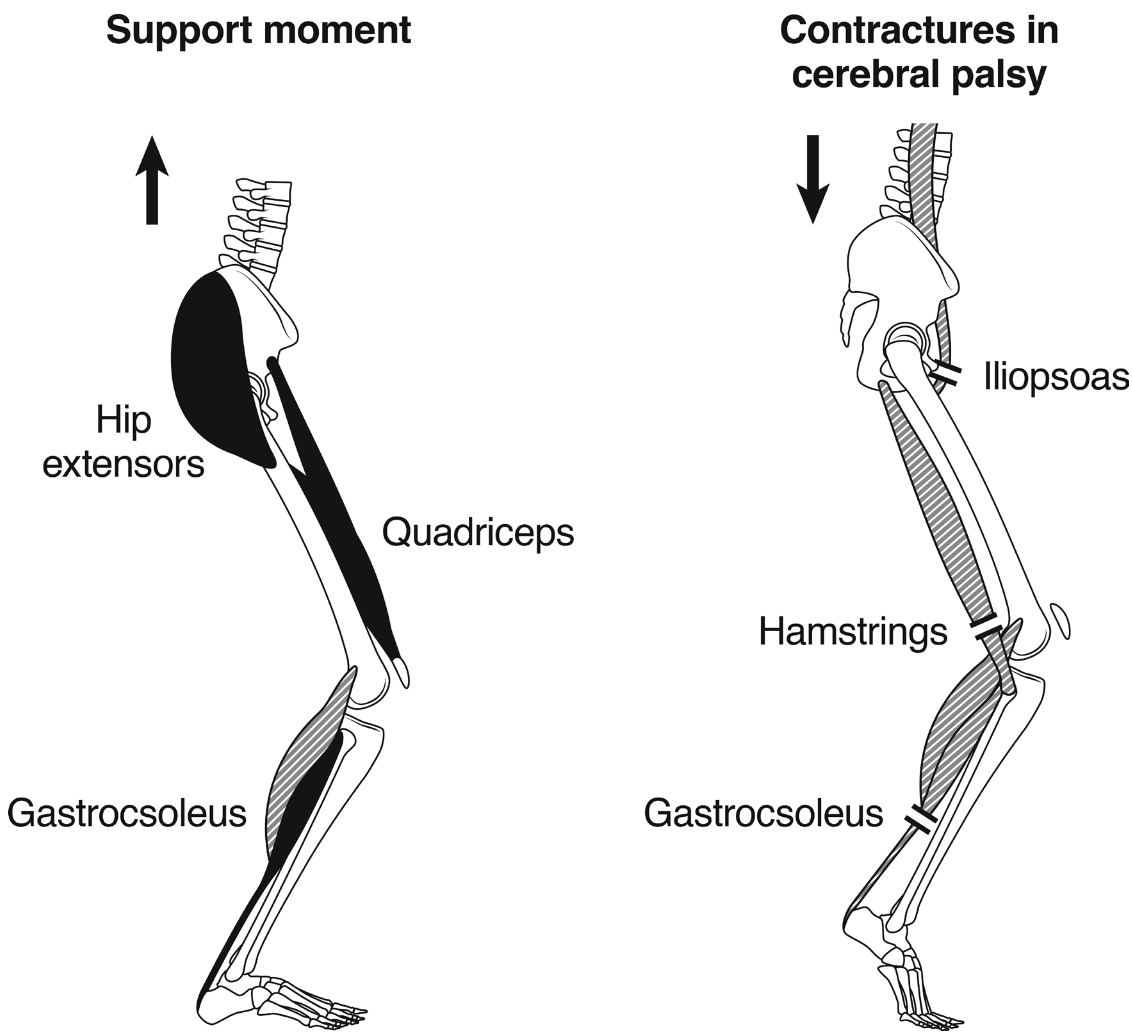

Fig. 3 The sagittal plane motors for the lower limb. Of the three muscle groups that contribute to the body support moment, only the gastrocsoleus is commonly lengthened.

structured format for categorizing the indications. Based on the literature review and submitted indications we then used this structure to create open-ended questions regarding the surgical indications for GSL. These questions were then collated by category and a well-structured anonymous electronic survey was created in Redcap (Vanderbilt University, Nashville, Tennessee, Version 9.1.0) to formally rate the level of evidence supporting each indication using a Likert 5-point scale.[18-20] This survey was sent to all experts. This process was repeated for three rounds. Consensus for an indicated criterion was awarded when at least 80% of experts agreed to the top two Likert scales (strong indication or indication) or to contraindication for procedure if at least 80% of experts agreed to the bottom two Likert scales (not indicated or strongly not indicated). Opportunity for comments were provided for all questions. General agreement was awarded for questions with at least 60%, but less than 80% of experts agreed to the top two Likert scales, or general disagreement for questions with at least 60%, but less than 80% of experts agreed to the bottom two Likert scales. The focus of the current study was on children with CP with spasticity because spasticity is present in 80% to 90% of ambulant children with CP in most population-based studies.[8,10,11] Some of the principles underlying GSL for ambulant children with spasticity may apply to children with dystonia or mixed movement disorders but, in general, outcomes are less predictable and greater caution is required.[8,9,10]

Results

A total of 63 questions were surveyed (53 indications questions and ten outcome questions) with Likert scales. A total of 34 questions achieved consensus and an

Table 1 Age, CP subtype, ambulatory status and preferred surgical zone for GSL.

	Consensus: > 80%	General Agreement: 60% to 79%	No Consensus < 60%
< 4 years	-	-	Zone 1, 2, 3
4 years to 6 years	-	Zone 2	Zone 1, 3
6 years to 10 years	-	Zone 1, 2	Zone 3
> 10 years	-	Zone 1, 2	Zone 3
Hemiplegia	Zone 2	Zone 3, 1	-
Diplegia	Zone 1, 2 (*Zone 3: contraindicated*)	-	-
Ambulatory	Zone 2	Zone 1	Zone 3
Non-ambulatory	-	Zone 2, 3	Zone 1

Ambulatory: GMFCS I-III, Non-ambulatory: GMFCS IV and V
Hemiplegia = unilateral CP, Diplegia = bilateral CP

Table 2 Gait analysis, physical examination awake and examination under anaesthetic (EUA). Ankle dorsiflexion measures indicating surgery for equinus.

	Consensus: 80%	General Agreement: 79% to 60%	No Consensus: < 60%
(Awake) DFKExt	–15°, –30°	< 0°	-
(Awake) DFKFx	–15°, –30°		0°
(EUA) DFKExt	< 0°	-	
(EUA) DFKFx	< 0°	-	-
(EUA) DFKFx + Ext	<0°	-	-
Gait observation	Mid-foot breach/limited heel contact Equinus on kinematics		
Gait analysis		Exaggerated PFKE Couple Absence of 2nd Rocker	Absence of 1st Rocker Alteration of ankle power generation Abnormal gastroc EMG

DFKExt, Ankle Dorsiflexion, Knee Extended; DFKFx, Ankle Dorsiflexion, Knee Flexed; DFKFx + Ext, Ankle Dorsiflexion, Knee Flexed and Extended; EMG, Electromyographic; PFKE, Plantarflexion, Knee Extension

Table 3 GSL outcome parameters: clinical (including GOAL®), gait analysis and physical Examination, ankle Range of Motion (ROM).

Consensus: > 80%	General Agreement: 60% to 79%	No Consensus: < 60%
Improved ankle kinematics	-	-
Improved ankle kinetics	-	
Improved GDI	Normalization PFKE couple index	-
-	Improved GPS	-
-	Improved ankle GVS	
Better brace tolerance	Decreased AFO use	-
Improved stability stance	-	-
Less tripping	-	-
	Improved GOAL® scores Satisfaction with cosmesis	-
Dorsiflexion to neutral	-	Dorsiflexion > 10 past neutral

AFO: Ankle Foot Orthosis ; GDI, Gait Deviation Index; GOAL®, Gait Outcomes Assessment List; GPS, Gait Profile Score; GVS, Gait Variable Score, PFKE, Plantarflexion, Knee Extension
Note. Not shown in the table was that the group achieved consensus, that intraoperative dorsiflexion > 20° was *not* a GOAL for surgery for equinus in ambulant children with cerebral palsy. Also, not shown was that there was general agreement that under-correction was preferred to overcorrection outcome measures.

additional nine general agreement. A narrative summary of the Delphi process is found in Appendix 1 and the main results are summarized in Tables 1 to 3.

The surgeons surveyed clearly take into consideration the age of the patient, the CP subtype and ambulatory status as part of their decision-making matrix when determining the indications for and location (Zone) for surgical management of equinus gait and equinus deformity (Table 1). With respect to age, there was consensus that, in general, GSL should be avoided in children under four years, and general agreement that the best age to perform a GSL is six years to ten years.

CP subtype also had a profound effect on decision making. In children with hemiplegia/unilateral CP a more aggressive lengthening for equinus was espoused with agreement on Zone 2 and Zone 3 surgery but no agreement on Zone 1 surgery. Presumably this was considered to be insufficient for most children with hemiplegia/unilateral CP, who are more likely to have a contracture of both gastrocnemius and soleus.[1,7] In children with diplegia/bilateral CP there was consensus that Zone 1 was preferred and Zone 3 was contraindicated.

Surgeons relied heavily on physical examination and range of motion measures both awake and asleep, with

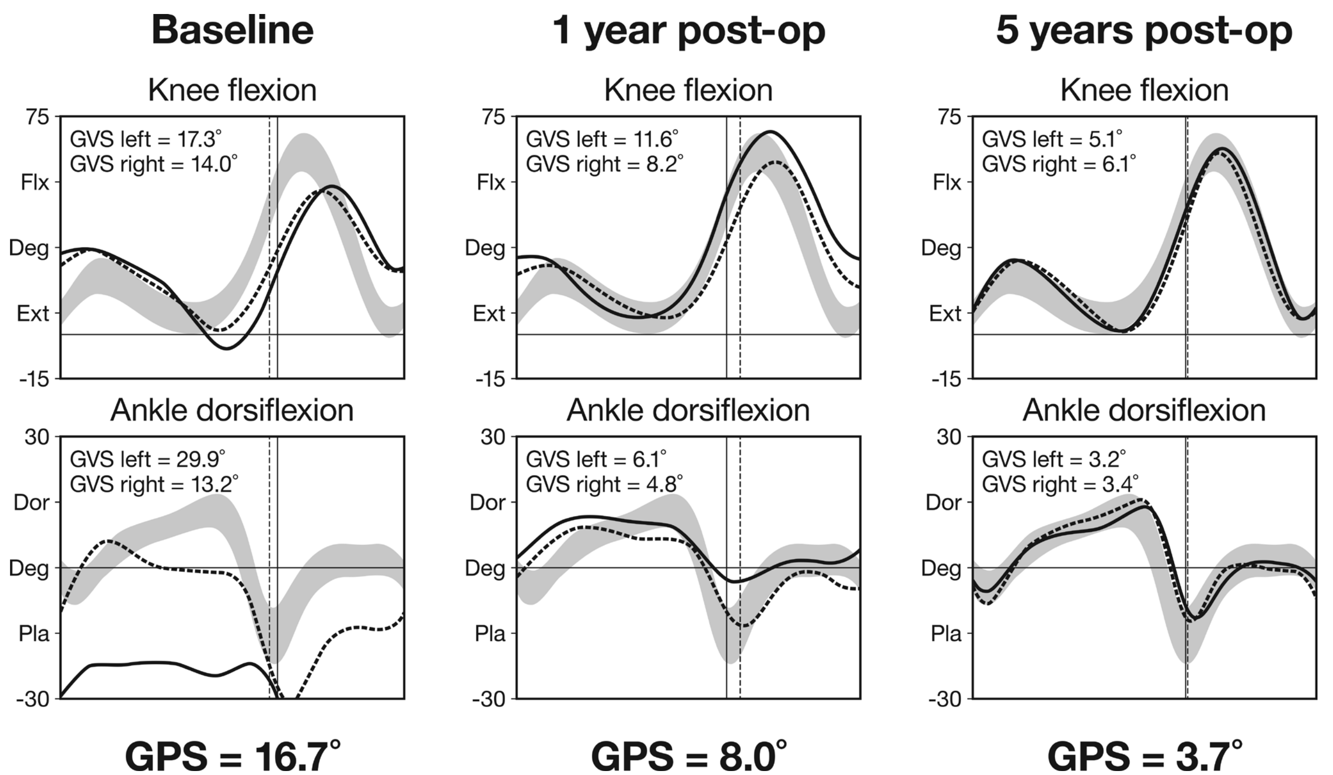

Fig. 4 Zone 1 surgery in diplegia. Sagittal ankle and knee kinematics in a ten-year-old boy with asymmetric spastic diplegia before, 12 months and five years after Single-Event Multilevel Surgery (SEMLS). On the right side (solid line) the equinus was more severe and the surgery chosen was Strayer +SFL. On the left side (dotted line) the equinus was mild, the Silverskiold test indicated a contracture of the gastrocnemius but not the soleus. A Strayer procedure was performed. Surgery at the knee level was medial hamstring lengthening and transfer of rectus femoris to the semitendinosus. The grey band indicates the laboratory normal reference range. The Gait Profile Score (GPS) and GVS values are above each kinematic trace. A decrease in GVS and GPS indicates an improvement. The minimum clinically important difference for GPS is 1.6 degrees. Stance phase dorsiflexion was improved at 12 months with further improvements at five-year follow-up with no further intervention. Note the improvement in ankle dorsiflexion in swing phase at five-year follow-up with restoration of first rocker.

the knee extended and the knee flexed (Silfverskiöld Test, Table 2).[1,2] In general, there was consensus that the degree of equinus on physical examination had to be greater to indicate surgery for equinus when the patient was awake than at EUA, when the patient's spasticity has been overcome (Table 2). There was no agreement that a spastic catch was an indication for surgery for equinus (i.e. a fixed contracture was a prerequisite for GSL). There was consensus agreement that a mid-foot break with limited heel contact was an indication for surgery for equinus. There was no agreement that a standing foot radiograph was helpful for decision making nor any other form of imaging. After Zone 1 surgery, if dorsiflexion has not been achieved above neutral, there was consensus that a fascial lengthening of the soleus aponeurosis should be added (SFL, Modified Strayer Procedure, Figs. 1b and Fig. 4).[9,10,13]

With respect to gait parameters, ankle equinus confirmed on 3DGA achieved consensus as an indication for equinus surgery. There was general agreement that an overactive or exaggerated plantar flexion knee extension (PF-KE) couple was an indication for surgery. There was no agreement that absence of first rocker on ankle kinematics was an indication for equinus surgery, presumably because this may occur in children with hemiplegia/unilateral CP, without an equinus contracture.[8-10] However, impairment or curtailment of second rocker had general agreement as an indication for equinus surgery. Alteration of ankle power generation, abnormal electromyographic (EMG) activity in the gastrocnemius and multi-segmental foot analysis with pedobarography did not reach the level for agreement as indications for equinus surgery.[22] Importantly, summary statistics of gait were endorsed by the panel as important outcome measures, including the Gait Deviation Index (GDI) and the Gait Profile Score (GPS, Fig. 4).[22,23]

Discussion

The panel accepted one of Mercer Rang's aphorisms that 'a little equinus is better than calcaneus' but rejected his other statement on equinus that 'there is little to choose between a gastrocsoleus recession and a lengthening of the Achilles tendon' (Tables 1,2 and 3).[11] Surgeons used the Zonal classification of the gastrocsoleus as a basis for surgical decision making, for ambulant children with CP and equinus deformity.[13] Panel members supported conservative Zone 1 and 2 surgery and preferred under-correction over full correction or overcorrection of equinus deformity, especially in diplegia/bilateral CP. Consensus was achieved for Zone 1 as the preferred Zone for surgery for equinus in diplegia. There was also consensus that Zone 3 surgery (lengthening of the Achilles tendon) was not appropriate in diplegia/bilateral CP.[7,9,10]

The expert panel was very cautious about accepting the need for GSL in younger children with CP and this caution is supported by cohort studies and systematic reviews. In a systematic review, Shore and colleagues showed that the rates of both overcorrection (calcaneus and crouch) and recurrent equinus (requiring revision surgery) are higher in younger children.[7] They also found that children with hemiplegia/unilateral CP were prone to recurrent equinus and children with diplegia/bilateral CP were prone to overcorrection, calcaneus and crouch gait.[7] Recurrent equinus is relatively easily solved by revision surgery but there is no effective salvage for overlengthening of the gastrocsoleus MTU.[9-11] This indicates the need for a good non-operative program in younger children but this was beyond the scope of the survey.[8]

The panel supported the view that children with hemiplegia/unilateral CP should not be treated in the same manner as children with diplegia/bilateral CP.[7-10] The preferred Zone in hemiplegia/unilateral CP was Zone 2 or 3 (Table 1). In hemiplegia/unilateral CP, equinus is often more severe, it usually affects both gastrocnemius and soleus and the risk of overlengthening is low.[7-10] In contrast, conservative Zone 1 surgery to the gastrocnemius was preferred in diplegia/bilateral CP; Zone 3 surgery was contraindicated because of the risk of calcaneus/crouch (Table 1) .

Gaining consensus from an international group of experts with over 300 years of combined clinical experience can provide insights and help identify areas of consensus, and also bolster clinical equipoise in support of more traditional clinical research study designs.

Our experts lean heavily on the dynamic data from 3DGA for both decision making and outcomes assessment (Table 3 and Fig. 4). This was partly due to having access to motion analysis and also experience with the evaluation and interpretation of gait data.[7-10,21] Because GSL is administered in an effort to improve dynamic ankle function, it seems that gait analysis is the only way to know whether one is making the right decision and whether the goals of surgery have been achieved.[7-10] Surgeons utilize 3DGA as part of the diagnostic matrix for decision making when considering surgical intervention in ambulant children with equinus gait and equinus deformity.[21]

It is important to note that in the Delphi process questions were dealt with in a sequential manner but surgeons use data from multiple domains simultaneously, as described in the diagnostic matrix. [21] For example, equinus identified on gait analysis on its own is not an indication for surgery for equinus correction unless there is an equinus contracture on physical examination and at EUA (Tables 1 and 2).

This survey also assessed surgeons' views about which outcome measures would best capture the effectiveness of surgery for equinus. Surgeons utilize multiple parameters from instrumented gait analysis as outcome measures including ankle kinematics, ankle kinetics, and summary statistics of gait including the Gait Deviation Index (GDI) and GPS. The GDI and GPS are important for two main reasons.[22,23] The first is that isolated surgery for equinus in hemiplegia/unilateral CP may have significant effects on proximal levels as well as the contralateral limb.[3,24] In addition, surgery for equinus in diplegia/bilateral CP is frequently performed as Single-Event Multilevel Surgery (SEMLS).[4,5] The ability to examine change in each anatomical level using the decomposition of the GPS into nine Gait Variable Scores (GVS) is critically important in this context.[23] Surgeons reported that the reasons for recommending equinus surgery were to address patients' equinus-related problems with expected benefits that included improved brace tolerance, improved stability in stance and functional issues such as less tripping. Interestingly, the goal of improved appearance of gait did not achieve a level of agreement among surgeons as a reason for equinus surgery, even if this might be important to patients or their parents. There was consensus that an improvement in both Total and Domain Scores on the GOAL Questionnaire® were important outcome measures.[25] This is probably because the GOAL Questionnaire® has been shown to have validity and reliability in this patient population.[25,26] Although the GOAL Questionnaire® also reports goals that are specific to walking on tip toe and related problems, there was not a consensus among surgeons that the GOAL Questionnaire® was necessary for decision making about equinus surgery. There was consensus about its value as an important Patient Reported Outcome Measure (PROM) to measure the benefits or harms of surgical intervention for this population.

In summary, surgeons had consensus or agreement on a range of both objective (gait parameters) and subjective (outcome parameters) outcome measures, and in the comments section, there was extensive support for greater utilization of PROMS such as the GOAL.[27]

Conclusions and further directions

The surgeons surveyed in this study had a conservative approach to corrective surgery for equinus in ambulant children with CP and consider multiple factors related to the patient's age, CP subtype, ambulatory status, physical examination, examination under anaesthesia and gait parameters. The need for a different approach according to motor type (spasticity, dystonia or mixed movement disorder) was not examined and is worthy of further study. The group avoids Zone 3 in diplegia/bilateral CP because of concerns of overlengthening and crouch gait. Proximal surgery, on the gastrocnemius (Baumann or Strayer Procedures) are preferred for children with diplegia/bilateral CP. The majority of children with hemiplegia/unilateral CP can be managed by Zone 2 lengthening of the conjoined gastrocsoleus aponeurosis. With optimum non-operative care in early childhood, Zone 3 surgery is rarely required. The surgeons are cautious about the age of index surgery and try to avoid surgery in younger children when the risks of both overcorrection and recurrent equinus are high. Methods for non-operative management of equinus in younger children were beyond the scope of this study. Ankle dorsiflexion in swing phase was shown to improve after surgery for equinus in children with diplegia/bilateral CP (Fig. 4).[28,29] However, in hemiplegia/unilateral CP, drop foot in swing phase usually persists and may require long-term use of an ankle foot orthosis. More recently, two studies have provided preliminary evidence for improvement in swing phase kinematics by surgical shortening of the tibialis anterior tendon at the time of surgery for equinus.[30,31]

Received 25 June 2020; accepted after revision 24 July 2020

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

OA LICENCE TEXT

ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent: No patients or clinical subjects, informed consent was not required.

ICMJE CONFLICT OF INTEREST STATEMENT

JM has received research support in royalties and as a consultant for Nuvasive, has received consulting fees from Synthes, and has received royalties from Wolters-Kluwer-Health-Lippincott Williams & Wilkins, has been an unpaid consultant for OrthoPediatrics and is a board member of the Pediatric Orthopaedic Society of North America, all outside of the scope of the submitted work.

MWS is a member of the Editorial Board of *the Journal of the Pediatric Orthopedic Society of North America*, is a member of the National Advisory Board (NIH) on Medical Rehabilitation Research, and the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD), all outside the scope of the submitted work.

HC has received personal fees from OrthoPediatrics Corp. and Allergan Corp., outside the scope of the submitted work.

JRD is a consultant and board member of OrthoPediatrics Corp., outside the scope of the submitted work.

RMK owns stock in Zimmer/Biomet, Medtronic, and Johnson and Johnson, is on the Editorial Board of the *Journal of Pediatric Orthopaedics* and his son works for Intrinsic Therapeutics, outside the scope of the submitted work.

JR has received personal fees from OrthoPediatrics Corp., outside the scope of the submitted work.

KG has received research support from NHMRC-CRE CP-Achieve and is on the Surgeon's Advisory Board of OrthoPediatrics Corp.

The other authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

ER: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

JM: Conception and design; Acquisition of the data; Analysis and interpretation of the data; Drafting of the article; Critical revision of the article for important intellectual content; Final approval of the article; Obtaining of funding; Administrative, technical, or logistic support; Collection and assembly of data)

BJS: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

MWS: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article, Obtaining of funding)

MV: Conception and design; Acquisition of the data; Analysis and interpretation of the data; Drafting of the article; Critical revision of the article for important intellectual content; Final approval of the article; Statistical expertise; Obtaining of funding; Administrative, technical, or logistic support; Collection and assembly of data)

HC: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

JRD: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

RMK: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

UN: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

TFN: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

KP: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

JR: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

JS: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

TT: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)

AVC: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)
TD: Conception and design, Drafting of the article, Critical revision of the article for important intellectual content, Final approval of the article)
KG: Conception and design, Drafting of the article, Cadaver dissections and Biomechanical studies. Critical revision of the article for important intellectual content, Final approval of the article)

SUPPLEMENTAL MATERIAL

Supplemental material is available for this paper at https://online.boneandjoint.org.uk/doi/suppl/10.1302/1863-2548.14.200145

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