Original Clinical Article

JOURNAL OF CHILDREN'S ORTHOPAEDICS

Journal of Children's Orthopaedics
2022, Vol. 16(1) 65–74

DOI: 10.1177/18632521221087529
journals.sagepub.com/home/cho

Anterior distal femoral hemiepiphysiodesis in children with cerebral palsy: Establishing surgical indications and techniques using the modified Delphi method and literature review

Benjamin J Shore[1], James McCarthy[2], M Wade Shrader[3], H Kerr Graham[4], Matthew Veerkamp[2], Erich Rutz[4], Henry Chambers[5], Jon R Davids[6], Unni Narayanan[7], Tom F Novacheck[8], Kristan Pierz[9], Thomas Dreher[10], Jason Rhodes[11], Jeffery Shilt[12], Tim Theologis[13], Anja Van Campenhout[14], and Robert M Kay[15]

Abstract

Purpose: The purpose of this study was to develop consensus for the surgical indications of anterior distal femur hemiepiphysiodesis in children with cerebral palsy using expert surgeon opinion through a modified Delphi technique.

Methods: The panel used a 5-level Likert-type scale to record agreement or disagreement with 27 statements regarding anterior distal femur hemiepiphysiodesis. Consensus was defined as at least 80% of responses being in the highest or lowest 2 of the Likert-type ratings. General agreement was defined as 60%–79% falling into the highest or lowest 2 ratings.

Results: For anterior distal femur hemiepiphysiodesis, 27 statements were surveyed: consensus or general agreement among the panelists was achieved for 22 of 27 statements (22/27, 82%) and 5 statements had no agreement (5/27, 18%). There was general consensus that anterior distal femur hemiepiphysiodesis is indicated for ambulatory children with cerebral palsy, with at least 2 years growth remaining, and smaller (<30 degrees) knee flexion contractures and for minimally ambulatory children to aid in standing/transfers. Consensus was achieved regarding the importance of close radiographic follow-up after screw insertion to identify or prevent secondary deformity. There was general agreement that percutaneous screws are preferred over anterior plates due to the pain and irritation associated with plates. Finally, it was agreed that anterior distal femur hemiepiphysiodesis was not indicated in the absence of a knee flexion contracture.

Conclusion: Anterior distal femur hemiepiphysiodesis can be used to treat fixed knee flexion contractures in the setting of crouch gait, but other associated lever arm dysfunctions must be addressed by single-event multilevel surgery.

Level of evidence: V

Keywords: Cerebral palsy, knee flexion contracture, surgical indications, consensus, anterior distal femur hemiepiphysiodesis, guided growth, treatment

[1]Boston Children's Hospital, Boston, MA, USA
[2]Cincinnati Children's Hospital Medical Center, Cincinnati, OH, USA
[3]Nemours/Alfred I. duPont Hospital for Children, Wilmington, DE, USA
[4]The Royal Children's Hospital Melbourne, Melbourne, VIC, Australia
[5]Rady Children's Hospital, San Diego, CA, USA
[6]Shriners Hospitals for Children—Northern California, Sacramento, CA, USA
[7]The Hospital for Sick Children, Toronto, ON, Canada
[8]Gillette Children's Specialty Healthcare, Saint Paul, MN, USA
[9]Connecticut Children's Hospital, Hartford, CT, USA
[10]Universitäts-Kinderspital, Zurich, Switzerland
[11]Children's Hospital Colorado, Aurora, CO, USA
[12]Texas Children's Hospital, Houston, TX, USA
[13]Oxford University Hospitals, Oxford, UK
[14]UZ Leuven, Leuven, Belgium
[15]Children's Hospital Los Angeles, Los Angeles, CA, USA

Date received: 5 July 2021; accepted: 26 February 2022

Corresponding Author:
Benjamin J. Shore, Boston Children's Hospital, Boston, MA 02115, USA.
Email: Benjamin.Shore@childrens.harvard.edu

Introduction

Cerebral palsy (CP) is the most common cause of physical disability in children[1] and improving the physical function of ambulatory children with CP positively impacts both their quality of life and that of their caregivers.[2,3] While the diagnosis of CP was first introduced in 1862,[4,5] tremendous variation remains surrounding the optimal selection and timing of surgical interventions to maximize function. Consensus methodology, including indications for surgery and interpretation of gait analysis, has been successfully used to develop guidelines for the management of other orthopedic conditions in children with CP.[6,7]

Knee problems, specifically fixed knee deformity/contracture and crouch gait are often present in children with CP.[8–11] The natural history of gait patterns and knee deformity in children with CP demonstrates increasing knee flexion deformity and contracture as children age, which negatively affects their gait kinematics.[10,12] Fixed knee flexion deformity (FKFD) can develop from spasticity or contracture of the hamstrings, weak knee extensors, anterior pelvic tilt, and various combinations of torsional deformities of the long bones in the lower limbs, including medial femoral torsion, lateral tibial torsion, and pes valgus. These deformities are sometimes referred to as lever arm deformities and the ensuing crouch gait a consequence of "lever arm disease." The final common pathway is often an associated contracture of the hamstring muscles and/or posterior capsule of the knee which can be accompanied by patella alta.[13]

The surgical management of fixed knee flexion contracture and crouch gait has traditionally involved a distal femoral extension osteotomy (DFEO)[14] in isolation or in concert with a patellar tendon advancement (PTA)[15] procedure to help address quadriceps lag and patella alta. Recently, anterior distal femoral hemiepiphysiodesis (ADFH), or guided growth, has been described as an alternative to DFEOs in patients with FKFD and open physes.[13,16–18] This novel intervention is only designed to address the FKFD and not the additional lever arm dysfunction associated with crouch gait; however, from these recent studies, no firm conclusions can be drawn regarding timing, degree of deformity, or functional level indication. Therefore, the purpose of this study was to use a modified Delphi method and build on our previous work[6,7] to establish areas of consensus for surgical indications for ADFH for the management of knee flexion contracture in the setting of crouch gait in children with CP.

Research design and methods

We used a modified Delphi consensus methodology[19,20] to identify surgical indications (including timing, degree of deformity, functional level, and associated indicated procedures) for children undergoing ADFH for the management of knee flexion contracture in the setting of crouch gait in children with CP. The research design for the group has been described previously (Table 1).[6,7] Institutional review board approval for the study and from each participating member was obtained. The modified Delphi methodology is a well-established technique to determine appropriateness criteria in medicine and surgery and to develop consensus.

We convened a 16-member panel of fellowship-trained pediatric orthopedic surgeons who had expertise in computerized gait analysis (CGA) and surgery for children with CP, as previously reported.[6,7] Each member of the panel had a mean of over 20 years of experience (range = 10–41 years) in the orthopedic care of children with CP, for a combined total of over 300 years of experience, and a mean of 19.8 years (range = 7–31 years) of experience using CGA in children with CP. All members participated.

The panel agreed to and created a structured series of statements which could be assessed using a 5-point Likert-type scale regarding surgical indications for ADFH for knee flexion contracture and crouch gait surgery in children with CP (Table 2). The five rounds of statements and feedback were supplemented with face-to-face meetings of the expert panel as described previously,[7] and subsequently by video teleconferences due to the ongoing COVID-19 pandemic. For each round of statements, an electronic survey was created in Redcap (Vanderbilt University, Nashville, TN, USA, Version 9.1.0) and sent to all panel members.

Consensus for agreement occurred when at least 80% of experts selected one of the highest two responses on the 5-point Likert-type scale (strongly agree or agree). Consensus for disagreement occurred when at least 80% of the panel selected one of the lowest two responses (strongly disagree or disagree). General agreement occurred when 60%–79% chose one of the highest two responses, and general disagreement if 60%–79% chose one of the lowest two responses. There was "no consensus" if fewer than 60% of the panel responses were in either the highest or lowest 2 categories for a given statement. Opportunity for comments was provided for all statements.

Results

The panel reviewed a total of 27 statements regarding the surgical indications for ADFH. Consensus was achieved for nine statements (agreement), general agreement for eight statements, general disagreement for five statements, and no consensus for five questions (Table 3).

Regarding timing of surgical intervention, the panel reached consensus that ADFH can be performed in children with at least 2 years of growth remaining, but there was general disagreement that 1 year of remaining growth was sufficient to perform ADFH. The panel agreed that ADFH was primarily indicated for ambulatory children with CP (Gross Motor Function Classification System

Table 1. Framework for support (if applicable to the patients).

1. The clinical problem we are addressing (or preventing), and the benefit that this will translate into for the patient (intended outcome).
2. Features of the clinical history/symptoms that will point to the clinical problem above, including Gross Motor Function Classification System and age.
3. The physical examination finding(s) that support the decision:
   a. Observed gait deviation.
   b. Static (on table) exam.
4. The imaging findings (where applicable) to support the decision.
5. The video and/or three-dimensional gait analysis findings (where applicable) that support (or suggest avoiding) the procedure.
6. The intraoperative examination under anesthesia that supports (or suggests avoiding) the procedure.
7. Important outcome measures.

Table 2. Statement for consensus regarding anterior distal femur hemiepiphysiodesis.

General characteristics:
1. Crouch gait on observation gait assessment is one indication for anterior distal femoral hemiepiphysiodesis (ADFH) (guided growth).
2. ADFH is indicated in ambulatory patients (GMFCS I–III).
3. ADFH is indicated in non-ambulatory patients (GMFCS IV and V).
4. ADFH is not indicated in non-ambulatory patients with CP.
5. ADFH can be indicated in non-ambulatory patients with GMFCS IV CP in an effort to help with standing and transfers.

Indications:
6. Anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH) is indicated for small KFCs <10 degrees.
7. Anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH) is indicated for KFCs 10–20 degrees.
8. Anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH) is indicated for KFCs 20–30 degrees.
9. Anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH) is indicated for large KFCs >30 degrees.
10. There is no indication for an anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH) unless the patient has a KFC at the time of surgery.
11. ADFH (guided growth) is only indicated if the patient has a KFC regardless of other indications.
12. ADFH can be performed if the patient has at least 1 year of growth remaining (by whatever measure of skeletal maturity you use).
13. ADFH can be performed if the patient has at least 2 years of growth remaining (by whatever measure of skeletal maturity you use).
14. Recurrent knee flexion contracture after distal femoral extension osteotomy may be an indication for anterior distal femoral hemiepiphysiodesis.
15. Anterior distal femoral hemiepiphysiodesis is rarely indicated in children <10 years old.

3D movement analysis:
16. Excessive knee flexion in stance on 3D motion analysis is one indication for anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH).
17. ADFH (guided growth) is indicated in patients with excessive knee flexion in stance on 3D motion analysis.

Technique:
18. I prefer the use of plates for anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH).
19. I prefer the use of screws for anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH).
20. Plate/screw constructs often cause more pain than screws only constructs following anterior distal femoral hemiepiphysiodesis.
21. In a patient with a KFC undergoing ADFH, I will perform a PTA/PTS if indicated at the same time.
22. In a patient with a KFC undergoing ADFH, I will wait to perform a PTA/PTS until the KFC is corrected.
23. A PTA/PTS can be performed at the time of ADFH if there is an extension lag.
24. A PTA/PTS can be performed at the time of ADFH even if there is not an extension lag.
25. A PTA/PTS should not be performed at the time of ADFH.

Outcome questions:
26. Anterior distal femoral hemiepiphysiodesis (guided growth) (ADFH) is less effective for large KFCs >30 degrees unless supplemented with additional treatments.
27. After any form of ADFH/guided growth ongoing clinical/radiological follow-up, to skeletal maturity, is essential to monitor correction and to detect unintended coronal plane deformities.

ADFH: anterior distal femoral hemiepiphysiodesis; GMFCS: Gross Motor Function Classification System; CP: cerebral palsy; KFC: knee flexion contracture; PTA: patellar tendon advancement; PTS: patella tendon shortening.

(GMFCS) I–III), but also felt that the procedure was indicated for GMFCS IV children to help improve knee extension for standing and transfers.

The panel reached consensus that the optimal knee flexion contracture as a surgical indication for ADFH is 10–20 degrees. The panel could not reach consensus if

Table 3. Results of consensus for anterior distal femoral hemiepiphysiodesis (ADFH) statements.

Statement	Consensus for statement (% agree)	General agreement for statement (% agree)	No consensus (% agree, % neutral, % disagree)	General disagreement against statement (% disagree)
1. ADFH is indicated in ambulatory patients (GMFCS I–III).	X (94%)			
2. ADFH is not indicated in non-ambulatory patients with CP.				X (69%)
3. ADFH is indicated in non-ambulatory patients (GMFCS IV and V).		X (60%)		
4. ADFH can be indicated in non-ambulatory patients with GMFCS IV CP in an effort to help with standing and transfers.	X (100%)			
5. ADFH can be performed if the patient has at least 2 years of growth remaining (by whatever measure of skeletal maturity you use).	X (94%)			
6. ADFH can be performed if the patient has at least 1 year of growth remaining (by whatever measure of skeletal maturity you use).				X (60%)
7. ADFH is rarely indicated in children <10 years old.			X (56%, 13%, 31%)	
8. ADFH (guided growth) is indicated for small KFCs <10 degrees.			X (56%, 25%, 19%)	
9. ADFH distal (guided growth) is indicated for KFCs 10–20 degrees.	X (94%)			
10. ADFH (guided growth) is indicated for KFCs 20–30 degrees.			X (50%, 25%, 25%)	
11. ADFH (guided growth) is indicated for large KFCs >30 degrees.				X (60%)
12. ADFH (guided growth) (ADFH) is less effective for large KFCs >30 degrees unless supplemented with additional treatments.	X (94%)			
13. ADFH (Guided growth) is only indicated if the patient has a KFC regardless of other indications.		X (63%)		
14. There is no indication for an ADFH (guided growth) unless the patient has a KFC at the time of surgery.	X (88%)			
15. After any form of ADFH/guided growth, ongoing clinical/radiological follow-up, to skeletal maturity is essential, to monitor correction and to detect unintended coronal plane deformities.	X (100%)			
16. Crouch gait on observation gait assessment is one indication for ADFH (guided growth).		X (63%)		
17. Recurrent knee flexion contracture after distal femoral extension osteotomy may be an indication for ADFH.	X (81%)			
18. Excessive knee flexion in stance on 3D motion analysis is one indication for ADFH (guided growth).		X (69%)		
19. ADFH (guided growth) is indicated in patients with excessive knee flexion in stance on 3D motion analysis general agreement.		X (69%)		
20. A PTA/PTS can be performed at the time of ADFH if there is an extension lag.	X (81%)			
21. A PTA/PTS should not be performed at the time of ADFH.				X (63%)
22. A PTA/PTS can be performed at the time of ADFH even if there is not an extension lag.			X (19%, 38%, 43%)	
23. In a patient with a KFC undergoing ADFH, I will wait to perform a PTA/PTS until the KFC is corrected.		X (69%)		
24. In a patient with KFC undergoing ADFH, I will perform a PTA/PTS if indicated at the same time.			X (13%, 38%, 50%)	
25. I prefer the use of plates for ADFH (guided growth).				X (60%)
26. I prefer the use of screws for ADFH (guided growth).		X (60%)		
27. Plate/screw constructs often cause more pain than screws only constructs following anterior distal femoral hemiepiphysiodesis.		X (75%)		

ADFH: anterior distal femoral hemiepiphysiodesis; GMFCS: Gross Motor Function Classification System; CP: cerebral palsy; KFC: knee flexion contracture; PTA: patellar tendon advancement; PTS: patella tendon shortening.

ADFH was indicated for a knee flexion contracture <10 degrees or >20 degrees, and generally disagreed that ADFH was indicated for a knee flexion contracture >30 degrees. The panel reached consensus that ADFH was indicated for the treatment of recurrent knee flexion contracture after DFEO. General agreement was reached regarding excessive knee flexion in stance on three-dimensional (3D) motion analysis as an indication for ADFH. The panel reached consensus that ADFH was only indicated in the setting of a knee flexion contracture and was not indicated for crouch gait without the presence of a knee flexion contracture.

Adjunctive procedures such as patella tendon shortening (PTS) or patella tendon advancement (PTA) were considered in concert with ADFH. The panel reached consensus that PTA or PTS could be performed concurrently with ADFH in the presence of an extensor lag. In the absence of an extensor lag, the group was unable to reach consensus on the indications for PTA or PTS. The panel also acknowledged that ADFH is designed to address fixed knee flexion contractures and does not address the concomitant lever arm dysfunction associated with crouch gait. Finally, regarding implant of choice, the panel preferred screws versus plates for ADFH as it was generally agreed that plates cause more pain than screws.

Discussion

The management of knee flexion contractures in children with CP is a critical component of their care and has evolved considerably over the last quarter century. First-generation techniques involved isolated soft tissue lengthening of the distal hamstrings, which was associated with weakness and anterior pelvic tilt, and second-generation techniques involved acute bony correction (extension osteotomy) with increasing surgical complexity; hybrid techniques which harness the power of guided growth have gained popularity more recently.[21] Anterior distal femur hemiepiphysiodesis has been proven to be a safe and effective treatment for knee flexion deformity in children with neuromuscular disease and remaining growth potential.[17] One of the advantages of ADFH is that the procedure is minimally invasive and allows for immediate weight bearing, thus limiting hospitalization, morbidity, and rehabilitation compared to second-generation techniques. Unlike for patients being considered for DFEO surgery, considerations such as a child's cognition, body habitus, adjacent torsional deformities, socioeconomic milieu, and access to therapy are less critical with ADFH due to the limited morbidity and immediate weight bearing and range of motion allowed post-operatively. In fact, panel members often perform ADFH in patients in whom DFEO is contraindicated due to limited cognition and/or rehabilitation potential. Despite these obvious advantages, the timing and indications for guided growth in the management of knee flexion contracture in children with CP are unclear. In this article, we present consensus guidelines regarding the surgical indications for ADFH for the management of knee flexion contracture in children with CP developed through a modified Delphi technique with the participation of international neuromuscular pediatric orthopedic experts.

A handful of surgical approaches has been described to achieve ADFH, including anterior tension-band plating, staples, and antegrade or retrograde percutaneous screws. While each technique has demonstrated efficacy associated with correction of knee flexion deformity, a superior technique has not been identified. Outcomes of antegrade and retrograde percutaneous screw insertion have been described.[17,22] McClure et al.[21] showed an unacceptably high rate (56%) of hardware migration with retrograde screws, which led them to abandon that technique. Although tension-band plating is quite common for coronal correction, bilateral parapatellar arthrotomies for tension-band plating or stapling for FKFD has been reported to create pain and stiffness.[17] Furthermore, the location of these implants can be problematic for patients who function at GMFCS IV, who may prefer to crawl on their knees as a means of household mobility, resulting in increased pain and/or wound healing problems. In this study, there was general agreement among the panel that percutaneous antegrade transphyseal screws were the preferred method to achieve ADFH, because of less pain compared to anterior plates. However, there are only a few comparative studies and no clinical trials to support this assertion.

The goal of ADFH is to enhance knee extension after surgery and present an alternative to DFEO. Children undergoing DFEO for the correction of crouch gait are often functioning at GMFCS II or III, and looking to improve knee extension during gait.[15] However, due to the morbidity and prolonged rehabilitation associated with DFEO and PTA/PTS, this procedure has rarely been indicated for those patients exclusively looking to improve standing and transfers. In this study, the panel reached consensus that ADFH was indicated for ambulant children (GMFCS I–III) with knee flexion contractures to improve knee flexion in midstance (Figure 1). In addition, there was general agreement that due to the minimal morbidity and rehabilitation associated with ADFH, this procedure was also indicated for children functioning at GMFCS IV looking to improve knee extension to help with standing and transfers. Previous authors have reached similar conclusions regarding the utility of ADFH, demonstrating the ability to correct knee flexion deformity while allowing for immediate weight bearing and limited morbidity.[16,23]

The optimal timing of when to perform guided growth and the degree of fixed knee flexion correction is somewhat elusive in the literature. The recorded rate of knee flexion contracture correction associated with ADFH has been reported to vary between 0.5 and 1.5 degrees/month without significant differences noted between implant

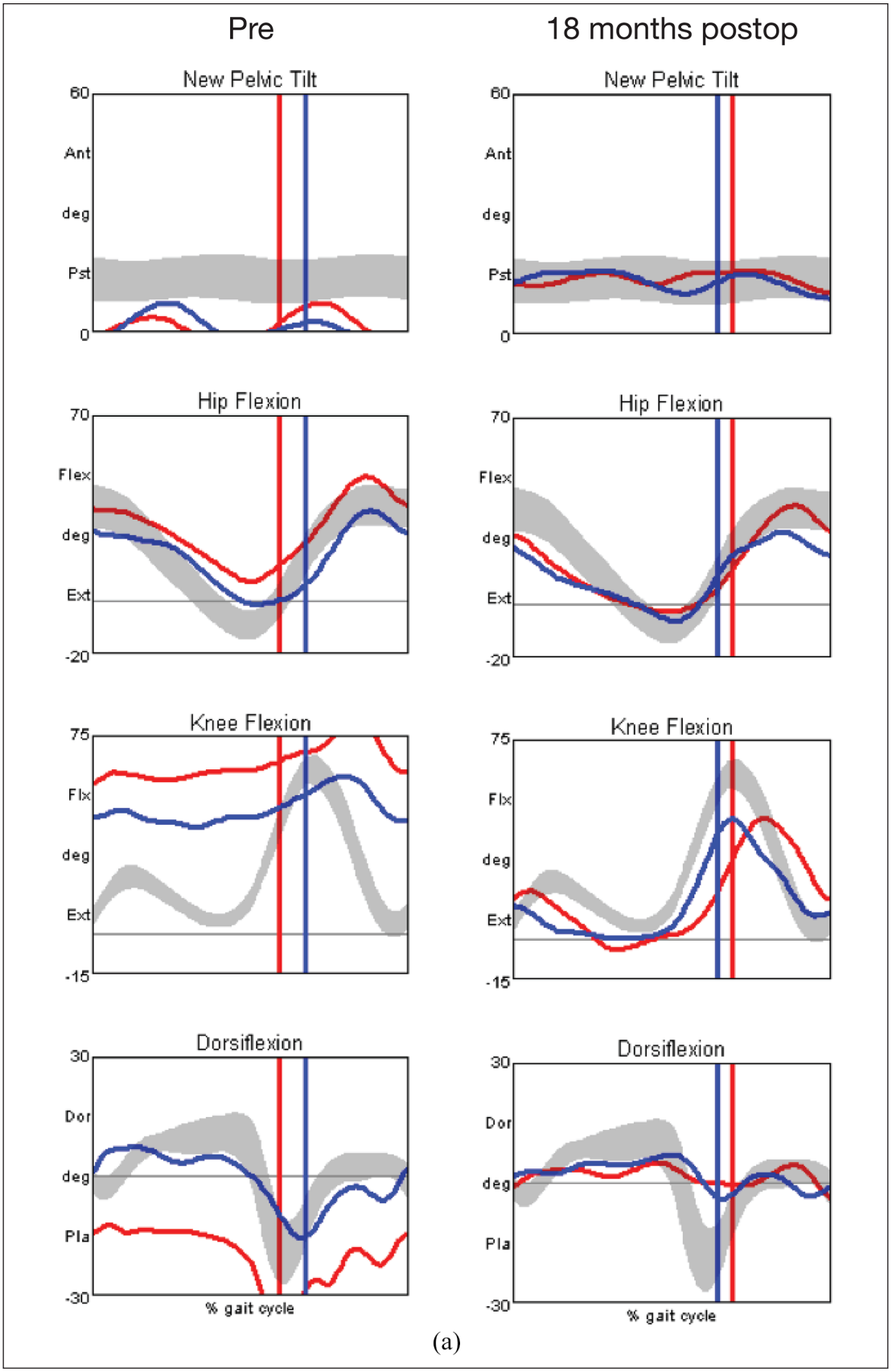

Figure 1. *(Continued)*

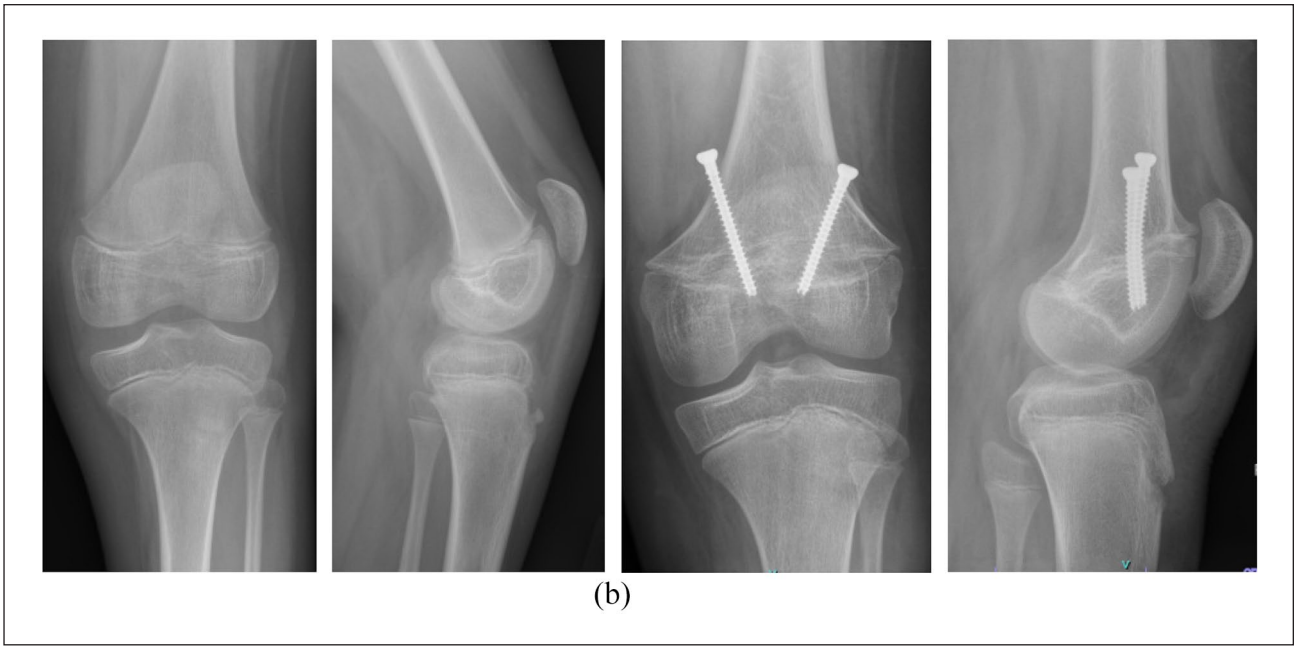

Figure 1. (a) Pre-operative (left) and post-operative (right) sagittal kinematics of a 10-year-old boy with severe crouch gait, GMFCS level II at the time of surgery, and FMS 5,5,1. He has severe crouch gait, marked lower limb weakness and asymmetric knee flexion contractures: 17 degrees on the left side (red lines) and 3 degrees on the right side (blue lines). He was considered a poor candidate for DFEO/PTA because of weakness and poor balance. He had bilateral SEMLS which included bilateral transfer of semitendinosus to the adductor tubercle, medial hamstring lengthening, and combined ADFH with screws for the left knee. At 12 months after SEMLS and rehabilitation, stance phase knee kinematics have improved as have ankle, hip, and pelvis kinematics. Gait Profile Score improved from 16.8 to 11.9 degrees. FMS improved from 5,5,1 to 5,5,5, meaning he regained independent ambulation in the community. ADFH can be incorporated into SEMLS to address knee flexion deformity or used as a stand along intervention when appropriate. (b) Pre- and post-operative radiographs of the left knee demonstrate the expected physeal changes seen with anterior tethering of the distal femoral physis prior to screw removal and bending of the screws illustrating the strength of distal femoral physis.

types.[16,17] Rethlefsen et al.[16] have reported that greater rates of knee flexion contracture correction have been observed in scenarios where the starting knee flexion contracture is greater. Currently, no guidelines exist within the literature to indicate when ADFH is indicated in terms or age or degree of knee flexion contracture. The panel agreed (consensus) that a minimum of 2 years of growth remaining must be present to consider ADFH for knee flexion contracture correction in children with CP. There was no agreement regarding the indication for ADFH in children under 10 years of age and general disagreement that ADFH was indicated if there was less than 2 years of growth remaining.

When DFEO is performed for crouch gait, it is typically combined concurrently with PTA/PTS to achieve optimal results.[14,15] The DFEO removes an anterior wedge from the distal femur and the PTA or PTS takes up the slack in the quadriceps pre-existing or induced by the DFEO.[24] Musculoskeletal modeling has demonstrated that with an acute 30 degree knee flexion correction with a DFEO between 2 and 3 cm, a PTA/PTS is necessary to balance muscles around the knee.[24] In contrast to DFEO, ADFH induces a gradual knee flexion contracture correction and the surgical indications regarding concurrent PTA/PTS are poorly described in the literature. The panel agreed that a PTA/PTS was indicated at the same time as ADFH if an extensor lag was clinically present. However, the panel was unable to reach consensus regarding whether to perform a PTA/PTS if an extensor lag was not clinically present. Rethlefsen and colleagues[16] found that in 25 patients (42 knees) undergoing ADFH, those who underwent simultaneous PTS experienced greater improvement in both knee flexion contracture and in knee extension in stance, but acknowledged that the combined ADFH/PTS patients started with a greater knee flexion contracture at baseline. Both groups had comparably good outcomes post-operatively. The authors recommended examining children for the presence of quadriceps lag or patellar laxity at time of ADFH and to consider concomitant PTA/PTS, and to consider concomitant PTA/PTS with ADFH in those children with greater magnitude of knee flexion contracture (>25 degrees).

Anterior guided growth of the distal femur is a relatively novel treatment for knee flexion deformity. Complications associated with ADFH are scarce in the literature, and hardware removal appears to be the most

common occurrence.[23] The panel agreed (consensus) on the importance of continued radiographic surveillance while implants are in place as unintended sagittal and coronal deformities can occur. The panel recommended continuous follow-up every 6 months with radiographs while the physis remains open. Iatrogenic secondary deformity is a risk when physes are open and implants are in place. Although not addressed in the modified Delphi process, consideration should be given to leaving the screws slightly proud (4 mm) which makes later hardware removal easier.

The strength of this article is that a panel of experts in the field of CP pediatric orthopedic surgery has identified best practice guidelines for the application of ADFH for the correction of knee flexion deformity. Since ADFH in the management of knee flexion contracture for children with CP is relatively novel with current literature limited and not yet robust enough to support quality meta-analysis, the results from this study can help guide clinicians in the application and standardization of surgical recommendations and indications. When reviewing the results of this Delphi, it is important to recognize that ADFH is designed to treat fixed knee flexion contracture, which is often just one element of multilevel contributors to crouch gait. ADFH cannot address and treat all of the lever arm dysfunctions associated with crouch gait, and as seen in our case example (Figure 1), ADFH can be used in conjunction with other single-event multilevel surgery (SEMLS) interventions for effective management of knee flexion contractures associated with crouch gait in children with CP.

This article can now serve as the framework for future prospective study regarding the indications and application of ADFH. This consensus is especially important for children with CP, who present with a very heterogeneous and often unique combination of biomechanical, neurological, and social characteristics. 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. Despite the strengths of this study, our conclusions have limitations. We acknowledge that additional study and investigation is required to understand the long-term effects of ADFH. Furthermore, ADFH is often performed in concert with other lower extremity interventions in the setting of SEMLS. Addressing each possible surgical indication for ADFH in conjunction with SEMLS is beyond the scope of this study; however, ADFH is commonly performed simultaneously with hamstring lengthening and hamstring transfer. While previous work has identified the indications for hamstring lengthening,[7] how ADFH can be combined with hamstring lengthening and transfer has yet to be quantified. Since a meta-analysis is not feasible at this time, we believe that the Delphi consensus is the best alternative. We hope that consensus statements from an international panel can clarify surgical indications for this novel treatment for knee flexion deformity in children with CP.

This panel of international experts reached consensus regarding the following statements for anterior distal femur hemiepiphysiodesis for the treatment of knee flexion contracture in children with CP:

1. ADFH is indicated in ambulatory patients (GMFCS I–III).
2. ADFH can be indicated in non-ambulatory patients with GMFCS IV CP in an effort to help with standing and transfers.
3. ADFH can be performed if the patient has at least 2 years of growth remaining (assessed by any measure of skeletal maturity).
4. ADFH distal (guided growth) is indicated for KFCs 10–20 degrees.
5. ADFH (guided growth) (ADFH) is less effective for large KFCs >30 degrees unless supplemented with additional treatments.
6. Recurrent knee flexion contracture after DFEO may be an indication for ADFH.
7. There is no indication for an ADFH (guided growth) unless the patient has a KFC at the time of surgery.
8. After any form of ADFH/guided growth, ongoing clinical/radiological follow-up, to skeletal maturity is essential, to monitor correction and to detect unintended coronal plane deformities.
9. A PTA/PTS can be performed at the time of ADFH if there is an extension lag.

This panel of international experts with significant experience in the treatment of children with CP has gone through an iterative process to provide a practical set of surgical indications and useful information to help guide practicing pediatric orthopedic surgeons considering ADFH for guided growth and correction of fixed knee flexion contracture in children with CP.

Author contributions

B.J.S. contributed to the conception & design, drafting of the article, acquisition of the data, critical revision of the article for important intellectual content, and final approval of the article. J.M. contributed to the conception & design, drafting of the article, acquisition of the data, critical revision of the article for important intellectual content, administrative, technical, or logistic support, and final approval of the article. M.W.S. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. K.G. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article.

K.M.V. contributed to the conception & design; acquisition of the data; analysis & 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; and collection & assembly of data. E.R. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. H.C. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. J.R.D. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. U.N. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. T.F.N. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. K.P. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. T.D. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. J.R. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. J.S. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. T.T. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. A.V.C. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article. R.M.K. contributed to the conception & design, drafting of the article, critical revision of the article for important intellectual content, and final approval of the article.

Declaration of conflicting interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: J.M. 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, all outside of the scope of the submitted work. Dr J.M. has also been an unpaid consultant for OrthoPediatrics and is a board member of the Pediatric Orthopaedic Society of North America. M.W.S. is a member of the Editorial Board of the Journal of the Pediatric Orthopaedic 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. K.G. 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. H.C. has received personal fees from OrthoPediatrics Corp. and Allergan Corp., outside the scope of the submitted work. J.R.D. is a consultant and board member of OrthoPediatrics Corp., outside the scope of the submitted work. J.R. has received personal fees from OrthoPediatrics Corp., outside the scope of the submitted work and research support Smith & Nephew Corp. and is on Editorial Board of Gait & Posture. R.M.K. owns stock in Zimmer/Biomet, Medtronic, Pfizer, and Johnson & 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.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

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.

ORCID iDs

Jon R Davids https://orcid.org/0000-0002-1639-6519

Robert M Kay https://orcid.org/0000-0002-4498-6815

References

1. Colver A, Fairhurst C, Pharoah PO. Cerebral palsy. *Lancet* 2014; 383(9924): 1240–1249.
2. Mann K, Tsao E, Bjornson KF. Physical activity and walking performance: influence on quality of life in ambulatory children with cerebral palsy (CP). *J Pediatr Rehabil Med* 2016; 9(4): 279–286.
3. Raina P, O'Donnell M, Rosenbaum P, et al. The health and well-being of caregivers of children with cerebral palsy. *Pediatrics* 2005; 115(6): e626–e636.
4. Richardson JE. Little's disease, with special reference to its treatment. *Lond Hosp Gaz* 1946; 49(Suppl. 7): ii–viii.
5. Ingram TTS. A historical review of the definition and classification of the cerebral palsies. In: Stanley F, Alberman A (eds) *The epidemiology of the cerebral palsies*. London: Spastics International Medical Publications, 1984, pp. 1–11.
6. Rutz E, McCarthy J, Shore BJ, et al. Indications for gastrocsoleus lengthening in ambulatory children with cerebral palsy: a Delphi consensus study. *J Child Orthop* 2020; 14(5): 405–414.
7. McCarthy J, Wade Shrader M, Graham K, et al. Establishing surgical indications for hamstring lengthening and femoral derotational osteotomy in ambulatory children with cerebral palsy. *J Child Orthop* 2020; 14(1): 50–57.
8. Rose GE, Lightbody KA, Ferguson RG, et al. Natural history of flexed knee gait in diplegic cerebral palsy evaluated by gait analysis in children who have not had surgery. *Gait Posture* 2010; 31(3): 351–354.
9. Wren TA, Rethlefsen S, Kay RM. Prevalence of specific gait abnormalities in children with cerebral palsy: influence of

cerebral palsy subtype, age, and previous surgery. *J Pediatr Orthop* 2005; 25(1): 79–83.
10. Bell KJ, Ounpuu S, DeLuca PA, et al. Natural progression of gait in children with cerebral palsy. *J Pediatr Orthop* 2002; 22(5): 677–682.
11. Rethlefsen SA, Blumstein G, Kay RM, et al. Prevalence of specific gait abnormalities in children with cerebral palsy revisited: influence of age, prior surgery, and Gross Motor Function Classification System level. *Dev Med Child Neurol* 2017; 59(1): 79–88.
12. Gough M, Eve LC, Robinson RO, et al. Short-term outcome of multilevel surgical intervention in spastic diplegic cerebral palsy compared with the natural history. *Dev Med Child Neurol* 2004; 46(2): 91–97.
13. Al-Aubaidi Z, Lundgaard B, Pedersen NW. Anterior distal femoral hemiepiphysiodesis in the treatment of fixed knee flexion contracture in neuromuscular patients. *J Child Orthop* 2012; 6(4): 313–318.
14. Stout JL, Gage JR, Schwartz MH, et al. Distal femoral extension osteotomy and patellar tendon advancement to treat persistent crouch gait in cerebral palsy. *J Bone Joint Surg Am* 2008; 90(11): 2470–2484.
15. Novacheck TF, Stout JL, Gage JR, et al. Distal femoral extension osteotomy and patellar tendon advancement to treat persistent crouch gait in cerebral palsy. Surgical technique. *J Bone Joint Surg Am* 2009; 91(Suppl. 2): 271–286.
16. Rethlefsen SA, Hanson AM, Wren TAL, et al. Anterior distal femoral hemiepiphysiodesis with and without patellar tendon shortening for fixed knee flexion contractures in children with cerebral palsy. *J Child Orthop* 2020; 14(5): 415–420.
17. Nazareth A, Gyorfi MJ, Rethlefsen SA, et al. Comparison of plate and screw constructs versus screws only for anterior distal femoral hemiepiphysiodesis in children. *J Pediatr Orthop B* 2020; 29(1): 53–61.
18. Klatt J, Stevens PM. Guided growth for fixed knee flexion deformity. *J Pediatr Orthop* 2008; 28(6): 626–631.
19. Diamond IR, Grant RC, Feldman BM, et al. Defining consensus: a systematic review recommends methodologic criteria for reporting of Delphi studies. *J Clin Epidemiol* 2014; 67(4): 401–409.
20. Hsu C, Sandford B. The Delphi technique: making sense of consensus. *Pract Assess Res Eval* 2017; 12: 1–8.
21. Young JL, Rodda J, Selber P, et al. Management of the knee in spastic diplegia: what is the dose? *Orthop Clin North Am* 2010; 41(4): 561–577.
22. McClure PK, Alrabai HM, Herzenberg JE. Growth modulation for fixed flexion contracture of the knee: a comparison of two techniques. *J Pediatr Orthop B* 2021; 30(1): 37–42.
23. Long JT, Laron D, Garcia MC, et al. Screw anterior distal femoral hemiepiphysiodesis in children with cerebral palsy and knee flexion contractures: a retrospective case-control study. *J Pediatr Orthop* 2020; 40(9): e873–e879.
24. Lenhart RL, Smith CR, Schwartz MH, et al. The effect of distal femoral extension osteotomy on muscle lengths after surgery. *J Child Orthop* 2017; 11(6): 472–478.