Original Clinical Article

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Anterior distal femoral hemiepiphysiodesis with and without patellar tendon shortening for fixed knee flexion contractures in children with cerebral palsy

Susan A. Rethlefsen[1]
Alison M. Hanson[1]
Tishya A. L. Wren[1,2]
Oussama Abousamra[1,2]
Robert M. Kay[1,2]

Abstract

Purpose: Surgery is often required for fixed knee flexion contractures in patients with neuromuscular conditions. Anterior distal femoral hemiepiphysiodesis (ADFH) is an alternative to distal femoral extension osteotomy (DFEO) in skeletally immature patients. ADFH is typically not accompanied by patellar tendon shortening surgery (PTS). Our purpose was to compare ADFH alone versus ADFH with PTS for treatment of fixed knee flexion contractures and crouched gait in children with cerebral palsy (CP).

Methods: Retrospective review of pre- and postoperative gait analysis data for children with CP who underwent ADFH alone, or ADFH with PTS. Data were analysed using linear mixed models to control for covariates.

Results: In total, 25 participants (42 limbs) were included, 17 male and eight female, mean age at surgery 12.9 (SD 1.9) years. Both groups experienced significant improvement in popliteal angle, knee extension range of motion (ROM) and knee extension in stance phase. Greater improvement was seen for all variables in the ADFH/PTS group, mainly due to greater popliteal angle and knee flexion during gait preoperatively in that group ($p \leq 0.02$) rather than the procedure performed ($p \geq 0.19$). There was no difference between groups postoperatively. Rate of contracture resolution was 0.5° to 1.0° per month, faster in larger contractures ($p = 0.02$).

Conclusions: ADFH with and without PTS is effective in improving knee extension in skeletally immature patients with CP, correcting contractures at a rate of 0.5° to 1.0° per month. Combined ADFH and PTS surgery may be preferable in patients with larger contractures of up to 30° to 35°.

Level of evidence: III

[1] Children's Orthopaedic Center, Children's Hospital Los Angeles, 4650 Sunset Boulevard MS#69, Los Angeles, CA 90027, USA
[2] Keck School of Medicine, University of Southern California, 1975 Zonal Ave., Los Angeles, CA 90033, USA

Correspondence should be sent to Susan Rethlefsen, Children's Orthopaedic Center, Children's Hospital Los Angeles, 4650 Sunset Blvd., MS 69, Los Angeles, CA 90027, USA.
E-mail: srethlefsen@chla.usc.edu

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Keywords: anterior hemiepiphysiodesis; crouch; knee flexion contracture; gait; cerebral palsy

Introduction

Fixed knee flexion deformities (FKFD) are often present in children with cerebral palsy (CP).[1–3] The natural history of CP shows increasing knee flexion deformity and contracture as children age, which affects their gait kinematics and function.[1–5] The cause is often multi-factorial due to contractures of the hamstrings, inadequate knee extensor strength and eventual contracture of the posterior capsule of the knee joint.[6] Initial care is usually conservative management including physical therapy, bracing, serial casting and spasticity treatment. Failure of these therapy modalities occurs more frequently in children with fixed knee deformities compared to those with dynamic deformities.[7]

Surgical management is often required when conservative treatment for FKFD fails to improve knee range of motion (ROM).[8] Traditional surgical treatment for correction of fixed angular knee deformities has been distal femoral extension osteotomy (DFEO).[9] Patellar tendon shortening (PTS) is usually added to the surgery for patients who have quadriceps lag,[10] which is typically accompanied by patella alta on radiography. Previous authors have shown that the results of surgery for crouch gait and FKFD in patients with CP are better following combined surgery with DFEO and PTS than when either DFEO or PTS surgery is performed in isolation.[9]

Recently, anterior distal femoral hemiepiphysiodesis (ADFH), or guided growth, has been used as an alternative to DFEOs in patients with FKFD and open physes.[4,5,11–13] ADFH is typically not accompanied by PTS surgery. There has been little research done on the outcomes of ADFH with or without PTS for treatment of flexed knee gait in patients with CP.

The purpose of this study was to compare ADFH alone *versus* combined ADFH with PTS for treatment of fixed knee flexion contractures and crouched gait in children with CP. We hypothesized that there would be larger and faster correction with combined ADFH and PTS.

Methods

Participants

Institutional review board approval was obtained before study initiation with a waiver of informed consent to access existing medical records. Records were retrospectively reviewed for all children with CP and fixed knee flexion contractures who underwent ADFH with or without PTS at our centre, with pre- and postoperative gait analysis testing performed. In total, 25 participants (42 limbs) were included, 17 male and eight female. Mean age at surgery was 12.9 years (SD1.9; range 8.6 years to 16.1 years). All participants were ambulatory with or without assistive devices. Gross Motor Functional Classification System (GMFCS)[14] distribution of patients with CP was one at GMFCS level I, nine at level II, nine at level III and six at level IV. Surgeries for knee flexion deformities included ADFH alone in 15 subjects (25 limbs), and ADFH with PTS in ten subjects (17 limbs).

Pre- and postoperative computerized gait analysis was performed for all subjects. Postoperative gait analysis was done at the time of full correction prior to hardware removal in cases of skeletal immaturity, and at full correction or plateau in correction for skeletally mature subjects. This included measurements of knee flexion contracture (maximum knee extension obtained passively in supine with the hip extended), and hamstring ROM (popliteal angle, or the maximum knee extension obtained in supine with the hip flexed to 90 degrees and the opposite hip extended). 3D joint motion data were collected using a Vicon motion capture system (Vicon Motion Systems Ltd, Oxford, UK). In total, 15 to 19 retro-reflective markers were placed on the subject's lower body according to the Plug-In-Gait Model and kinematic data were collected at 120 Hz. Subjects walked along a 15-metre walkway at a self-selected speed, using assistive devices as necessary. For each patient, five to ten trials were recorded, and the data of at least three representative strides from different trials were averaged. The maximum knee extension achieved in stance phase during barefoot gait was extracted and recorded for analysis. The Gait Deviation Index (GDI), a summary measure of gait quality, was calculated from the kinematic data and used for analysis.[15] Only sides that underwent ADFH with or without PTS were included (bilateral in 18 subjects, unilateral in eight subjects).

Indications and surgical techniques

Anterior distal femoral hemiepiphysiodesis

ADFH is typically indicated in children with CP who have significant crouch, fixed knee flexion contractures > 10 degrees, and open distal femoral physes. Most candidates

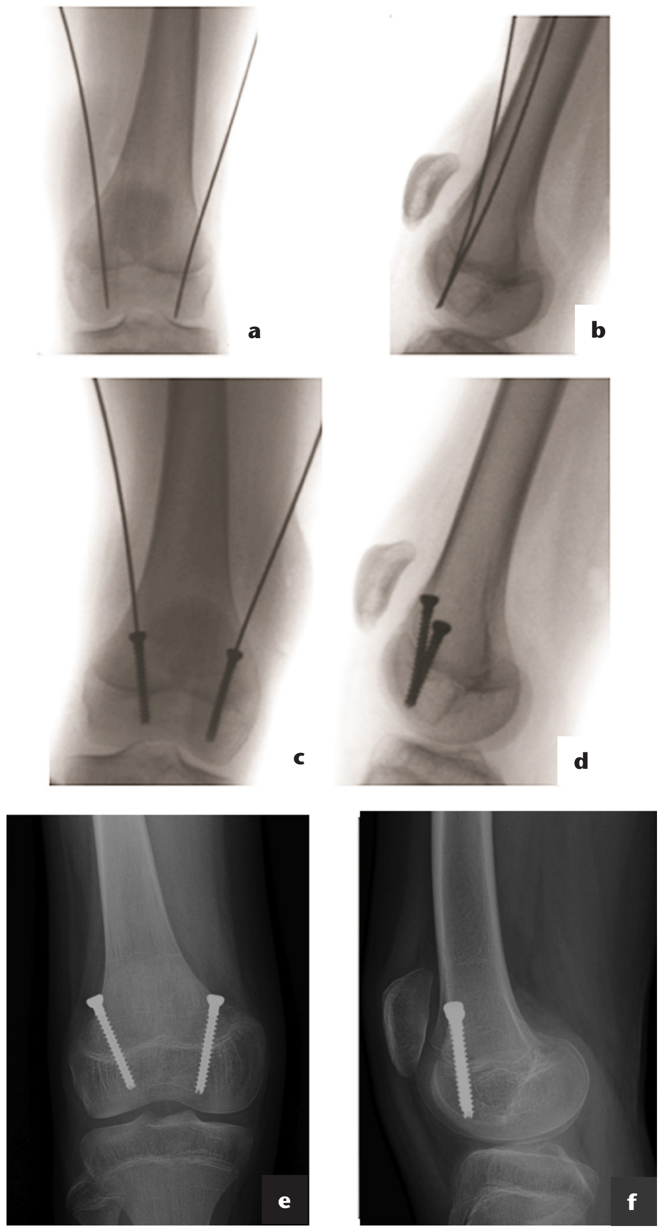

Fig. 1 **(a and b)** Site and direction of lateral and medial guide wire insertion in anterior 1/3 of the physis; **(c and d)** screw insertion/placement using guide wire; **(e and f)** final screw alignment.

for ADFH are peri-adolescent. ADFH is performed percutaneously, and the specific technique has been described in detail elsewhere.[12,13] Two 4.5 mm cannulated transphyseal screws were placed (using guide wires) across the anterior third of the distal femoral physis. Guide wire and screw position were verified using fluoroscopy. A screw length was chosen that was 3 mm to 4 mm longer than the measured depth to facilitate later hardware removal (Fig. 1). Screw removal was not routinely performed. Screws were subsequently removed if painful, or if full correction was achieved prior to skeletal maturity.

Patellar tendon shortening

The decision to perform PTS was made on a case by case basis, depending on the surgeon's clinical judgement of the patient's potential to benefit from ADFH alone, and the surgeon's assessment of the presence of knee extensor lag and/or patellar tendon laxity. Quadriceps lag is present if active knee extension in a sitting position is less than passive knee extension ROM tested in the same position. If the patient lacks the cognitive ability to perform this task, the patellar tendon is palpated with the knee in a flexed position and determined to be lax if it is pliable in this position.

An anterior longitudinal incision was used for PTS. The knee extensor mechanism was exposed, and transverse drill holes were made in the central third of the patella and posterior to the tibial tubercle. FiberTape (2 mm wide) (Arthrex, Inc., Naples, Florida, USA) was passed through the drill holes and the patella was advanced distally. Size 2-0 or 2 FiberWire (depending on patient and patellar tendon size) was used to imbricate the redundant patella tendon with three to four figure-8 sutures (Fig. 2).

After ADFH +/- PTS, patients were allowed full activity and weight bearing as tolerated immediately postoperatively. They typically wore knee immobilizers 16 hours per day for two to three weeks, and overnight thereafter for three months. If PTS was done, knee flexion activities were discouraged for the first month postoperatively.

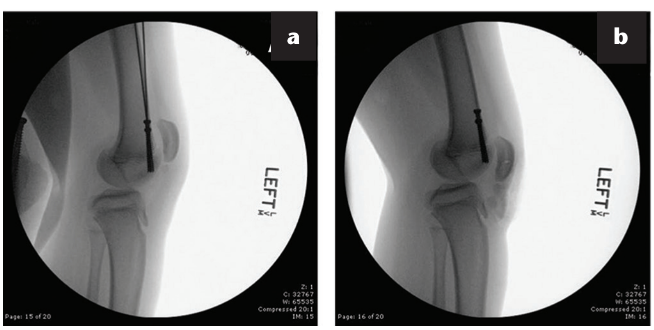

Fig. 2 (a) Patellar position prior to shortening; **(b)** patellar position after shortening and patellar tendon imbrication.

Data collection

Operative notes and medical records were reviewed to record age at surgery, type of surgical procedure performed, concomitant procedures and length of follow-up. Length of follow-up was defined as time between surgery and hardware removal or postoperative gait analysis (in cases of skeletal maturity and hardware retention). Pre- and postoperative gait analysis records were reviewed, and data extracted included popliteal angle and knee extension ROM (from physical examination) and maximum knee extension in the stance phase of gait (obtained from gait kinematic data).

Statistical analysis

Demographic and preoperative variables were compared between groups using unpaired *t* tests. Variables that differed significantly between groups were included as covariates in subsequent adjusted analyses as described below. The main comparisons were performed using linear mixed models with side (left or right) as a fixed effect and a random intercept term for participant to model the potential repeated measures within participants (e.g. two sides from the same patient). Treatment group, visit (pre- or postoperative), and their interaction were included as fixed effects in initial unadjusted analysis of popliteal angle, knee extension ROM and maximum knee extension in stance, followed by analysis of pre- to postoperative change in the three outcome measures with group and side remaining as fixed effects. Adjusted analysis of pre- to postoperative change was then performed including the variables that differed significantly between groups preoperatively as covariates (preoperative variables including popliteal angle, knee extension ROM and knee extension in stance phase of gait). All statistical analyses were performed in STATA (version 12.0, StataCorp LP, College Station, Texas, USA). Statistical significance was set at $p < 0.05$.

Results

Average age at surgery was 12.9 years (sd 1.9 years) and average length of follow-up was 17.7 months (sd 7.8 months) for all subjects, with no significant differences between the ADFH and ADFH/PTS groups (Table 1). Preoperative popliteal angle, knee extension ROM and maximum knee extension in the stance phase of gait were significantly worse for the combined ADFH/PTS group (Table 1).

In most cases surgery had been done as part of single event multilevel surgery. Concomitant surgeries are detailed in Table 2.

Both groups experienced statistically significant improvement in popliteal angle, knee extension ROM

Table 1 Preoperative patient characteristics

	ADFH (N = 25 limbs)		ADFH/PTS (N = 17 limbs)		p-value*
	Average (SD)	Range	Average (SD)	Range	
Age (years)	12.6 (2.1)	8.6 to 16.1	13.2 (1.6)	10.7 to 15.9	0.48
Length of follow-up (months)	17.4 (7.1)	6.4 to 33.8	18.2 (8.8)	10.7 to 47.2	0.74
Popliteal angle (°)	51 (13)	20 to 75	62 (10)	40 to 80	0.004
Knee extension ROM (°)	–13 (5)	–25 to –5	–19 (8)	–32 to –10	0.003
Maximum knee extension in stance (°)	–31 (9)	–16 to –46	–51 (16)	–29 to –78	< 0.001

ADFH, anterior distal femoral hemiepiphysiodesis; PTS, patellar tendon shortening surgery; ROM, range of motion
*p-value based on unpaired t-test (continuous variables) or Chi-square (categorical variables)

Table 2 Concomitant procedures

Procedure	No. limbs	Indications	Techniques
Hamstring lengthening	31	Excessive knee flexion terminal swing/stance Popliteal angle > 40° Failed non-operative intervention	Open or percutaneous hamstring lengthening Medial lengthening is typical, though lateral hamstrings may be lengthened if tight after medial lengthening
Adductor lengthening	13	Excessive hip adduction during gait Hip abduction range < 40° in extension	Open or percutaneous lengthening of adductor longus +/- gracilis
Femoral derotational osteotomy	13	Excessive femoral anteversion statically Excessive internal hip rotation during gait interfering with function	Distal femoral derotational osteotomy in younger patients without hip subluxation Proximal in cases of hip subluxation, patients near skeletal maturity or the desire to avoid postoperative casting
Tibial derotational osteotomy	8	Excessive internal or external tibial torsion interfering with function	Distal tibial derotational osteotomy
Calcaneal osteotomy	16	Valgus foot that cannot be braced effectively, causes lever arm dysfunction and/or is painful and interferes with shoe and brace wear	Medial calcaneal sliding osteotomy most common Lateral column lengthening considered in GMFCS I/II with significant talar uncovering
Tendo-Achilles lengthening/Gastrocnemius recession	6	Static plantarflexion contracture Excessive plantarflexion during gait	Gastrocnemius recession (PF contracture only w/knee extended) TAL if PF contracture knee flexed and extended
Hallux valgus correction	7	Hallux valgus, painful and/or interfering with shoe wear	Fusion of the first metatarsophalangeal joint Hallux valgus reconstruction with proximal or distal metatarsal osteotomy considered in GMFCS I/II
Hardware removal	4	Pain	Dependent on hardware and location
None	8	–	–

GMFCS, Gross Motor Functional Classification System; PF, plantarflexion; TAL, tendo-Achilles lengthening

Table 3 Within and between group comparisons of change in knee variables (degrees)

	ADFH (N = 25 limbs)				ADFH/PTS (N = 17 limbs)				Change between groups		
	Pre mean (SD)	Post mean (SD)	Change (SD)	p-value for change*	Pre mean (SD)	Post mean (SD)	Change (SD)	p-value for change*	p-value unadjusted*	p-value adjusted*,**	95% Confidence Interval adjusted**
Popliteal angle (degrees)	51 (13)	39 (13)	–12 (11)	< 0.001	62 (10)	38 (9)	–24 (12)	< 0.001	0.005	0.31	–14.1 to 4.5
Knee extension ROM (degrees)	–13 (5)	–5 (7)	8 (7)	< 0.001	–19 (8)	–4 (7)	15 (9)	< 0.001	0.03	0.19	–2.2 to 11.6
Maximum knee extension stance (degrees)	–31 (9)	–15 (18)	16 (17)	< 0.001	–51 (16)	–17 (14)	34 (19)	< 0.001	0.01	0.53	–10.7 to 21.0
GDI	68 (9)	74 (11)	6 (8)	< 0.001	59 (12)	73 (11)	13 (12)	< 0.001	0.05	0.54	–6.1 to 11.6
Rate of change in knee extension ROM (degrees/month)	0.52 (0.37)				1.02 (0.71)				0.02	0.27	-0.18 to 0.63

ADFH, anterior distal femoral hemiepiphysiodesis; GDI, Gait Deviation Index; PTS, patellar tendon shortening surgery; ROM, range of motion; PTS, patellar tendon shortening
*Linear mixed model
**Adjusted analysis controls for preoperative popliteal angle, knee extension ROM and maximum knee extension in stance

and maximum knee extension in stance during gait, as well as GDI. Unadjusted analysis showed the combined ADFH/PTS group had greater improvement in these four variables. However, after controlling for covariates that differed between groups at baseline (preoperative popliteal angle, knee extension ROM and maximum stance knee extension) in adjusted analysis, there were no differences between groups for amount of change in any of these variables. All between group differences in pre to postoperative change were due to greater magnitude of popliteal angle and flexed knee position during gait in the combined ADFH/PTS group preoperatively ($p \leq 0.02$), rather than the procedure performed ($p \geq 0.19$) (Table 3). There was no difference between groups for any of the variables postoperatively ($p > 0.52$).

Average rate of improvement in knee extension ROM was 0.5 degrees per month for the ADFH group, and 1.0 degrees per month for the combined ADFH/PTS group. Unadjusted analysis showed a significant difference between groups. However, when controlling for covariates this difference was not due to the procedure performed but to the greater preoperative knee flexion contracture in the combined ADFH/PTS group ($p = 0.02$).

Discussion

The safety and efficacy of ADFH has been established for treatment of fixed knee flexion contractures in skeletally immature children with neuromuscular conditions. Previous study at our centre found that ADFH using two transphyseal screws results in deformity correction comparable to that obtained using either a single screw or plate and screw constructs, with minimal complications and no cases of physeal arrest or overcorrection.[13] This previous study also showed markedly lower rates of postoperative pain with screws only constructs compared to those using plates and screws. Since bone overgrowth can make screw removal challenging, the senior author (RMK) now leaves the screws 3 mm to 4 mm longer than the measured depth, which has made hardware removal much easier in the vast majority of patients.

Though we initially reserved ADFH for patients we thought had at least two years of growth remaining, we now recognize that important benefits can accrue to those who are more skeletally mature. In patients with knee flexion contractures, we may opt for ADFH surgery even if we think full correction may not be possible, realizing that partial correction is often a better option than accepting the full deformity or than performing a much more morbid DFEO. We do not find that obtaining bone age radiographs is helpful in these patients, given the facts that partial correction is often significantly beneficial to the patient, and that the standard deviation of bone age radiographs in adolescents is often significant (on the order of ten months). Further, our clinical experience has mirrored that of numerous previous authors that skeletal age often lags chronological age in children with CP, so the most important radiographic determinant preoperatively is an open distal femoral physis.

The current study expands on the previous one by illustrating how improvement in static knee extension ROM achieved by ADFH impacts gait. Improvements of up to 30° were seen in passive knee extension ROM, and up to 80° in dynamic knee extension in the stance phase of gait using ADFH with or without PTS as part of multilevel surgery. Rate of contracture correction ranged between 0.5° to 1.0° per month, with larger contractures correcting at a faster rate. In our patient population, correction of 50% to 60% of preoperative contracture can be expected per year with either procedure.

The current study is the first to examine the effects of PTS in combination with ADFH. Though the results confirm our hypothesis of larger and faster correction with addition of PTS, this was likely related to larger baseline contracture in this group rather than the PTS itself. Further research is needed with a larger sample to determine the specific effect of the PTS surgery on contracture correction. However, the results confirm that our selection criteria of performing combined ADFH and PTS in patients with larger contractures is reasonable. The study results show that larger contractures, such as those seen in the combined ADFH/PTS group, can be effectively corrected with the combined procedure. The addition of PTS may allow children with greater knee flexion contractures to achieve similar results to those patients with smaller knee flexion contractures.

Our practice is to perform PTS in cases of quadriceps lag or patellar tendon laxity to palpation. Patellar tendon laxity can also be determined based on patella alta measured radiographically. The Koshino Index has proven to be a more reliable measure of patella alta than the Insall-Salvati and Caton-Deschamps methods in pediatric patients with neuromuscular conditions.[16] However, its validity has not been assessed in these patients.

Our experience is that combined ADFH and PTS is successful in cases of fixed knee flexion contracture of up to 30° to 35° with patellar tendon laxity. It is not known whether or not sufficient patellar tendon tension can be achieved prior to full correction of contractures larger than this. In such cases, a staged approach may be preferable, with PTS being performed if needed after full contracture correction is achieved.

Limitations

Since this was a retrospective study of clinical patients, there was potential selection bias associated with determining which patients underwent which procedure. Patients underwent concurrent procedures that could also have contributed to improved knee extension postoperatively. The decision to perform PTS was not based on objective measures from radiographs but on clinical examination of patellar tendon laxity. The small sample size may have limited the power to detect differences between ADFH alone and the combined ADFH/PTS groups.

Conclusion

ADFH with and without PTS is effective in improving both passive and dynamic knee extension in skeletally immature patients with CP, correcting contractures at a rate of 0.5° to 1.0° per month. Combined ADFH and PTS surgery may be preferable to ADFH alone in patients with larger contractures, of up to 30° to 35°. Further research with a larger sample size is needed to determine the specific effect of PTS on contracture correction in patients treated with ADFH.

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COMPLIANCE WITH ETHICAL STANDARDS

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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.
Informed consent: Institutional review board approval was obtained before study initiation with a waiver of informed consent to access existing medical records.

ICMJE CONFLICT OF INTEREST STATEMENT

RMK owns stock in Pfizer, Johnson & Johnson, Zimmer-Biomet and Medtronic, outside the submitted work.
The other authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

SAR: Contributed to study design and coordination, Performed data collection and statistical analysis, Prepared and revised manuscript.
AMH: Contributed to study design, Performed data collection, Assisted with manuscript preparation and critical review.
TALW: Designed and directed statistical analysis, Assisted with manuscript preparation and critical review.
OU: Assisted with development of research question and aims, Assisted with manuscript preparation and critical review.
RMK: Developed research question and aims, Responsible for study design and manuscript preparation and critical review.

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