Adductor release and chemodenervation in children with cerebral palsy: a pilot study in 16 children

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Received: 30 October 2007 / Accepted: 29 April 2008 / Published online: 7 June 2008
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Abstract

Purpose A pilot study with short-term outcomes of a combined surgical and medical intervention for management of generalized lower limb spasticity, hip displacement and contractures of adductors in children with bilateral spastic cerebral palsy.

Methods A prospective cohort study of 16 children (9 boys and 7 girls) aged 2–6 years with bilateral spastic cerebral palsy was performed. At entry, 5 were classified as level III and 11 as level IV, according to the Gross Motor Function Classification System (GMFCS). The intervention consisted of surgical lengthening of adductor longus and gracilis combined with the phenolization of the anterior branch of the obturator nerve, using 1 ml of 6% phenol, applied under direct vision at the time of lengthening of adductor longus. The hamstring and calf muscles were each injected with Botulinum neurotoxin A at a dose of 4 U/kg/muscle. Serial clinical (hip, knee, ankle joint range of motion), radiographic (migration percentage) and functional data—taken from a functional mobility scale (FMS) or GMFCS—were collected at 3, 6, 12 and 24 months post-operatively.

Results There was a significant increase in hip abduction, knee extension (popliteal angle) and ankle dorsiflexion, maintained for 24 months; mean hip migration percentage decreased from 29 to 21% ($P < 0.001$). Using a validated mobility scale, significant improvements were noted in gross motor function. There were no complications related to the intervention.

Conclusions The combined surgical–medical intervention resulted in a reduction of spastic hip subluxation and improvements in gross motor function, as determined by the FMS. The combined intervention is, thus, useful as a temporizing measure, before definitive decisions are made considering such interventions as dorsal rhizotomy, intrathecal baclofen and single-event, multilevel surgery.

Keywords Adductor release · Phenolization of obturator nerve · Hip migration percentage

Introduction

Cerebral palsy (CP) is a neuromusculoskeletal disorder caused by a static brain lesion and characterized by progressive musculoskeletal pathology [1]. Children with spastic CP frequently develop progressive contractures, bony deformities and joint instability. Spasticity of hip adductors and flexors results in fixed contractures, muscle imbalance and progressive hip displacement [2, 3]. Without intervention, this process may end in hip dislocation, the consequences of which may be pain, gait deterioration, difficulty in seating and problems with perineal hygiene [4, 5]. Thus, these children often require intervention for spasticity and hip displacement before their gross motor prognosis is clear and before invasive spasticity management with an intrathecal baclofen pump [6, 7], selective

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dorsal rhizotomy [8, 9] or multilevel orthopaedic surgery [1, 10] for fixed deformities can be considered. We designed a novel intervention for these children consisting of a combination of soft tissue surgery and regional spasticity management. The aim was to arrest hip displacement, reduce spasticity temporarily and provide a platform for continued progress in gross motor function.

Patients and methods

This was a prospective pilot study of 16 children (9 boys and 7 girls), aged 2–6 years, with bilateral spastic CP who presented to a tertiary referral centre with hip dysplasia and lower limb spasticity. A written informed consent was obtained from all the parents. Institutional Review Board approval was obtained for the study of hip displacement in children with CP, and these patients were in that cohort. No sources of external funding or financial support were needed. The recruitment of patients and recording of results was carried out between 2002 and 2005. Specific inclusion criteria were:

- Age 2–6 years
- Level III or IV, according to the Gross Motor Function Classification System (GMFCS) [11]
- Hip migration percentage (MP) between 25 and 45% [3]
- Hip abduction-in-flexion between 10 and 40°
- Popliteal angle less than 50°
- Ankle dorsiflexion less than 0

Exclusion criteria were:

- Outside age range
- Other GMFCS levels—I, II or V
- Hip MP less than 25% or more than 45%
- Fixed flexion deformity at hip more than 15°
- Fixed flexion deformity at knee more than 15°
- Fixed Equinus more than 25°
- No consent
- Pseudobulbar palsy, a history of aspiration or frequent respiratory infections

Operative technique

The child was placed supine on the operating table after the induction of mask anesthesia. The hamstring and calf muscles were injected with Botulinum Toxin A (BoNT-A) at a dose of 4 U/kg body weight, to a total dose of 16 U/kg. The Allergan preparation of BoNT-A, “Botox®” was used at a standard dilution of 100 U, reconstituted in 4 ml of preservative-free, normal saline, immediately prior to injection. The muscles were injected with 1 ml of reconstituted neurotoxin at each of four sites. We used an

insulated 27-gauge Teflon-coated insulated needle (Allergan) both to stimulate the muscle and to deliver the toxin. The needle was first inserted manually into the target muscle using a combination of anatomic landmarks, palpation of muscle bellies where possible, and movement of the distal joints to passively stretch target muscles to confirm needle placement. When the position of the needle was considered satisfactory, and after aspiration was performed to ensure it had not entered a blood vessel, it was attached to a portable battery-powered stimulator (Stimlocator, Braun, Australia). A reference electrode was then placed over the approximate position of the musculotendinous junction of the target muscle. Electrical stimulation was initiated in a train of four (TO4) fashion, and at an intensity sufficient to produce a focal and clearly visible contraction of the muscle. The required stimulating current intensity varied according to the size of the muscle and was usually 5–8 mA for larger muscles (e.g., gastrocnemius and medial hamstrings) [12]. Following the injections of BoNT-A, the perineum was isolated and the legs were draped free, to allow intra-operative assessment of the range of hip abduction.

The adductor region was explored via a 2.0-cm skin incision, parallel to the groin crease and 1 cm distal. The interval between adductor longus and brevis was identified, and the adductor longus was retracted to reveal the anterior branch of the obturator nerve. The nerve is variable in position and in its gross anatomy with between one and four main divisions, in the intermuscular interval. The delicate epimysial fascia was separated and retracted prior to phenolization of the nerve. A 6% solution of aqueous phenol was used—drawn up from a fresh ampule—immediately prior to use. With the adductor longus retracted, 1–2 ml of the 6% phenol solution was dripped from a syringe and mixing needle, directly on to the nerve. The epineurium usually changes slightly in colour from translucent to more opalescent, as the protein is denatured by the phenol.

After allowing 2–3 min for the phenol to work, the adductor longus and gracilis muscles were mobilized close to their bony origin and the tendons separated by means of electrocautery. Both hips were abducted (in flexion) until 70–80° of abduction was achieved at both hips. It is important that the passive range of hip abduction is symmetric and adequate. The psoas muscle was not released. Following hemostasis, the incision was closed in layers. We prefer to retract the intact adductor longus to visualize the anterior branch of the obturator nerve, rather than dividing the muscle first. Muscle division distorts the local anatomy and bleeding may dilute the phenol.

After the drapes were removed, the lower limbs were immobilized in plaster cylinders with the knees extended and the hips abducted 30–40° each, to a total of 60–80°.

The child was returned to the ward and was treated with a narcotic infusion, supplemented with diazepam for muscle spasms. The child was discharged when pain and muscle spasms were controlled with oral paracetamol and diazepam and with the child tolerating oral fluids and a light diet. After discharge, the children continue with physiotherapy and three specific positions are encouraged—long-sitting, prone lying and standing. These provide an effective stretch to the hamstrings, hip flexors and calf muscles, respectively.

The plaster casts were removed after 3 weeks and replaced with an abduction brace, which was used at night only (12 of 24 h) for 6 months. Our center provides funding for increased physiotherapy for the child during the first 6 months after intervention. This is useful to optimize functional gains during the period of maximum spasticity reduction, following chemodenervation.

Range of motion was recorded every 3 months for 12 months, and yearly thereafter, using a plastic goniometer and standardized protocols previously described [13]. Hip development was monitored by measuring MP as described by Reimers: a vertical line is drawn from the lateral edge of the acetabulum perpendicular to a horizontal line connecting both triradiate cartilages to the pelvis. The measurements were performed every 12 months on an anteroposterior radiograph of the pelvis with the patient supine, with both femora in neutral abduction–adduction relative to the pelvis and the patella facing anteriorly. The portion of the femoral head lateral to the Perkins line was measured and was expressed as a percentage of the entire horizontal width of the femoral head. Repeatability of this method of radiologic measurement has already been described [14]. Every 12 months, the child attended the motion analysis laboratory for a standardized physical examination by a physiotherapist, a video recording of standing and walking and grading of gross motor function according to both the GMFCS and the FMS [15]. The FMS uses three distances (5, 50, 500 m), which represent typical distances walked by children at home, in school and in the community. A unique feature of FMS is the ability to distinguish between different assistive devices used by children in these different settings.

Fig. 1 Graphical representation of the range of abduction at intervention and 3, 6, 12, and 24 months following surgery

Statistical methods

The statistical software used was Stata 7. Pre- and post-operative values were compared using paired *t* tests for MP, and change in ordinal variables with time was performed using the Wilcoxon signed rank test, for FMS and GMFCS, with significance levels set as $P < 0.01$. The changes with time in hip abduction, popliteal angle and ankle dorsiflexion were examined using linear regression models fitted with generalized estimating equations using an exchangeable working correlation structure to allow for non-independence of legs from the same subject and the repeated measurement of legs at five time points.

Results

Results from 24 months after surgery are presented. Mean hip abduction was limited to 32.5° before intervention, increased dramatically at the 3-month follow-up and gradually decreased over the next 19 months (Fig. 1) (Table 1). The improvements in popliteal angle and ankle dorsiflexion were both clinically and statistically significant at 3, 6, 9 and 12 months post-intervention but had relapsed at 24 months (Figs. 2, 3) (Table 1). At the time of entry to the study, 5 children were GMFCS level III and 11 were level IV. A non-significant improvement in GMFCS levels was found after intervention (Table 2). There were

Table 1 Joint range of motion (hip abduction, popliteal angle and ankle dorsiflexion) before and after intervention. Data for left and right sides are combined (16 patients, 32 lower limbs). All values expressed are mean $\pm$ SD in degrees

Time (months)	0	3	6	12	24
Hip abduction	32.5 (9.2)	74.1 (7.2)*	65.1 (7.7)*	56.8 (12.7)	53.7 (8.2)
Popliteal angle	70.8 (8.4)	41.4 (10.2)*	49.8 (9.6)	58.5 (8.3)	68.6 (6.6)
Ankle dorsiflexion	−10.6 (8.3)	+4.1 (7.4)*	−0.8 (4.4)*	−3.1 (2.2)	−3.9 (4.3)

− ankle dorsiflexion = equinus deformity, + ankle dorsiflexion = dorsiflexion

* = Significant change by paired ‘*t*’ test compared with time zero ($P < 0.01$)

Fig. 2 Graphical representation of popliteal angle at intervention and 3, 6, 12, and 24 months following intervention

Fig. 3 Graphical representation of ankle dorsiflexion (with knee extended) at intervention and 3, 6, 12, and 24 months following intervention

Table 2 Pre-intervention and post-intervention (at 24 months) Gross Motor Function Classification System (GMFCS) values

No. of children	Pre-GMFCS	Post-intervention GMFCS			Total
		II	III	IV	
5	III	0 (0%)	5 (100%)	0 (0%)	5 (100%)
11	IV	1 (9%)	4 (36%)	6 (55%)	11 (100%)

GMFCS gross motor function classification system

no changes on the 500 subscale, but clinically and statistically significant improvements were found on the 5 and 50 subscales (Tables 3, 4).

The mean hip MP decreased from 29.0% pre-intervention to 20.9% post-intervention. Three hips in two children required additional intervention during the period of follow-up. One child was managed by repeat release of the hip adductors and flexors and the other by bilateral femoral varus derotation osteotomies, for recurrent hip subluxation and internal rotation gait.

There were no surgical complications, specifically no groin hematomas or wound infections. Pain was easily controlled and children were discharged after a mean of

Table 3 Pre-intervention and post-intervention Functional Mobility Scale (FMS) scores for 50 m

Pre-FMS 50 score	Post-intervention FMS 50 score			Total
	1	2	3	
1	3	6	0	9
2	0	5	2	7

Wilcoxon signed-rank test, *P* value = 0.005

FMS 50 Functional Mobility Scale for 50 m

Table 4 Pre-intervention and post-intervention Functional Mobility Scale (FMS) scores for 5 m

Pre-FMS 5 score	Post-intervention FMS 5 score		Total
	2	3	
1	7	1	8
2	4	3	7
3	0	1	1

Wilcoxon signed-rank test, *P* value = 0.001

FMS 5 Functional Mobility Scale for 5 m

48 h in hospital (range 1–4 days). There were no complications relating to the administration of phenol or Botox.

Discussion

Gross motor function increases rapidly in younger children with CP, and about 90% is gained by 5 years of age [16]. It can be difficult to choose appropriate management in younger children who are changing rapidly as they grow and develop. Ideally, intervention should be effective, safe and minimally invasive, and not preclude other options when the child is older.

The intervention was specifically designed for children functioning at GMFCS levels III and IV, typically ambulant with assistive devices for short distances but dependent on wheelchairs for community ambulation. It is not applicable to children at GMFCS levels I and II, who ambulate independently. Such children do not have clinically significant hip displacement and rarely require adductor surgery [17]. It is also not applicable to children at GMFCS level V, with the most severe involvement, who lack head control and who have no independent mobility. In such children, spastic hip displacement is very common and often resistant to intervention; thus, they are more efficiently managed by more aggressive surgical interventions.

The intervention described is effective in reversing or at least stabilizing hip displacement, with no child requiring further hip intervention for 2 years. It is effective at the level of impairment, with improvements in joint range of motion (hip adduction, knee extension and ankle

dorsiflexion) for 12–24 months. Finally, the reduction in muscle hypertonia, combined with introduction of orthotics and a physiotherapy program, promotes gains in gross motor function, greater than would be expected by natural history. GMFCS levels have been reported to be stable over time in children with CP, but a small number of children in this study moved up one level during the first year after intervention. Without a control group, it is impossible to know whether this improvement is greater than would be anticipated from natural history. The FMS was designed to be responsive to changes in functional mobility after intervention [15]. Clinically and statistically significant gains were found on the FMS 5 and FMS 50 subscales but not on the FMS 500 scale. Again, the lack of a control group precludes a firm conclusion as to whether the functional improvement was in excess of natural history.

The duration of effect in the components of this combined intervention are of interest. Muscle-tendon lengthening is considered to be a permanent intervention, although it is accepted that recurrent contracture may be common [18]. This is more likely when the conditions that caused the contracture (spastic hip adductors and reduced activity) persist after intervention. Surgical neurectomy is not recommended in children with ambulatory potential because this may result in excessive, permanent weakness of the hip adductors and abduction contracture [19]. In a study of gait analysis after phenol neurolysis of the obturator nerve, a significant increase in the width of the base of support was shown [20]. The effect of phenol on peripheral nerves depends on concentration, dose and the method of administration [21, 22]. It is best used for pure motor nerves and is not recommended for mixed nerves because of the incidence of disabling sensory dysesthesias [23]. Use of 6% phenol by open method of phenolization allowed us to use a small dose, applied accurately to the target nerve and to avoid the potential complications of phenol-induced damage to surrounding soft tissues. Phenol denatures protein resulting in non-selective neurolytic injury to axons of all sizes, effectively blocking transmission of nerve impulses to the target muscles. When phenol is dripped onto a nerve, the axons in the center of the nerve sheath are less affected and blocks are rarely complete. Muscle strength is more often preserved than stretch reflexes [24]. Since phenol has local anesthetic properties, there is an immediate reduction in muscle tone. The longer-term effect caused by protein denaturation develops several days later when Wallerian degeneration is initiated. Regeneration occurs slowly, and the time course depends on the length and depth of the nerve segment that has undergone this degeneration. Recovery of nerve has been reported to take around 1–10 months [25, 26]. Increased hip abduction without development of abduction contractures was maintained even at 2 years post-surgery. We think that there is a permanent reduction in adductor spasticity, but how

much is related to the muscle release and how much to the phenol is impossible to judge. This may contribute to long-term beneficial effects on muscle over activity.

BoNT-A blocks the release of acetylcholine at the neuromuscular junction for about 3 months, before normal neuromuscular conduction is re-established [27]. The biochemical effects of BoNT-A would appear to be completely reversible, and the clinical effects last on average 6 months. There is anecdotal evidence that the magnitude and duration of BoNT-A-induced chemodenervation can be enhanced by casting immediately after the injection and the use of appropriate ankle foot orthosis [28, 29]. The response to adductor surgery combined with phenol and abduction splinting, was very marked. The muscle tone in the hip adductors was reduced and hip abduction range increased at 3 months after intervention. Some parents and therapists complained that the child was “too floppy” at this stage. However, muscle tone gradually recovered and the (excessive) range of hip abduction gradually decreased during the first year after intervention. Hip displacement (MP) either improved or did not deteriorate. At 24 months after intervention, most children maintained an improved hip abduction and none was troubled by scissoring postures.

The use of phenol for chemodenervation of the hip adductors gave us opportunity to use BoNT-A in an adequate dose in the hamstrings and calf muscles, without undue concerns regarding systemic effects. In a position paper published in 2000 [30], we recommended a maximum dose of 12 U/kg body weight. Since then, there have been reports of administration of higher doses, without significant side effects [31]. Nevertheless, the maximum safe dose has not been clearly established, and we think that combining phenol and BoNT-A chemodenervation is a logical and useful strategy. It must be remembered that not all children are at equal risk of complications following large doses of BoNT-A. Children with pseudobulbar palsy, a history of aspiration and frequent chest infections are particularly at risk [32]. Such children should not be managed using this protocol.

With regard to the knee, the combination of injection of the hamstrings with BoNT-A and post-operative casting in extension resulted in improvements in popliteal angle, which were greater in magnitude and duration than casting alone. At the ankle level, we recorded a significant improvement in ankle dorsiflexion after injection with BoNT-A. Standing in the casts provided a very effective stretch to the gastrocnemius, with the knee held in extension and the ankle dorsiflexed by body weight or passively by the parent or therapist. The introduction of ankle-foot-orthosis and improvements in weight bearing also prolonged the effects of chemodenervation with BoNT-A. Lengthening of the gastrocnemius in these patients has a very high incidence of calcaneus deformity [33]. Although

we anticipate that this will be necessary in some of the children in this study, we prefer to delay this for as long as possible. Chemodenervation of the hamstrings and gastrocnemius with phenol carries an unacceptable risk of sensory dysesthesias and, in our view, should not be considered unless BoNT-A is contraindicated [25].

A wide range of good results among different series following soft tissue releases for hip subluxation is because of differences in neurological involvement, age at surgery, MP, surgical technique and duration of post-operative follow-up. A MP of less than 30–40% was associated with successful outcomes for 75–90% of hips [34–36]. Conversely, hips with a MP of greater than 40–50% had a more uncertain outcome, with 75–77% of hips remaining subluxated or dislocated [34, 37]. In our study, children had a pre-operative MP between 25 and 45%. None of the children required further intervention for 2 years post-surgery. BoNT-A has been shown to have some benefit for management of adductor spasm and scissoring [38], but in a randomized control trial it had little or no effect on hip displacement or MP [39].

The combined intervention achieved the stated goals in all children for a minimum of 2 years. Longer term follow-up of this cohort has indicated that one child may benefit from intrathecal baclofen, one has had revision adductor surgery and three may require multilevel orthopedic surgery. Interventions in this patient population need to strike a balance between effectiveness, safety, duration, cost effectiveness and the ability to be integrated with long-term management goals. This requires an understanding of natural history, which has been greatly enhanced by the development of the GMFCS and curves describing motor function, according to age [16].

In children with CP, muscular hypertonia has reversible and fixed elements, which respond favorably to minimally invasive muscle–tendon lengthening surgery, combined with chemodenervation, to reduce spasticity. In younger children with early hip displacement, the combined intervention we have described was effective in improving restricted joint range of motion, allowing enhanced gross motor function, and in preventing or delaying hip displacement.

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