KINEMATIC AND KINETIC EVALUATION OF THE ANKLE AFTER INTRAMUSCULAR INJECTION OF BOTULINUM TOXIN A IN CHILDREN WITH CEREBRAL PALSY

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Intramuscular botulinum toxin A (BTA) injection has a role in the conservative management of dynamic equinus deformity in children with cerebral palsy. The effect of BTA injection of the gastrocsoleus muscle during gait was evaluated. Eight children with hemiplegia (median age 4.4 years, range 2 to 8 years) were included in this retrospective study. Assessment included kinematic and kinetic gait analysis before and after (median 57.5 days) treatment. Postinjective kinematics showed significant improvement of ankle range of motion in the stance phase of gait. Ankle kinetics demonstrated a significant decrease of pathological power generation in midstance. The ankle power quotient (APQ) was also significantly improved. Ankle power in terminal stance was improved, although not to a significant level. These results provide evidence of normalization of energy production at the ankle, which is critical for normal gait. The effect of BTA is temporary and can be successfully repeated. This allows deferring the need for surgical intervention until the child is older and recurrence rate is lower.

Keywords : botulinum toxin ; cerebral palsy ; equinus ; gait analysis ; kinematics ; kinetics.
Mots-clés : toxine botulinique ; IMOC ; équin ; analyse de la marche ; cinématique ; cinétique.

INTRODUCTION

Equinus deformity is the most common problem interfering with normal walking in children with spastic cerebral palsy (CP). It has a dynamic component, which is caused by spasticity and is more important in young children. Fixed equinus is the result of failure of longitudinal muscle growth (5). Treatment of equinus deformity has traditionally consisted of stretching the contracted tissue through serial casting, physical therapy and brace management. Persistent deformity that interferes with function is treated by surgical lengthening of the Achilles tendon or the gastrocnemius fascia, which has a risk of recurrence or overcorrection (13). In ideal circumstances, surgery is deferred until the age six to eight years, when multilevel correction is accomplished and postoperative cooperation of the child is better (7).

More recently, injections of botulinum toxin A (BTA) have been used in the conservative management of CP. Intramuscular BTA, a potent neurotoxin produced by *Clostridium botulinum*, produces a temporary dose-dependent chemical denervation resulting in reduced muscular activity (11). Early treatment (between one and six years of age) has the potential to reduce the development of fixed equinus and delay surgery (1).

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Children with spastic CP most commonly land with a foot flat or toe contact. In the sagittal plane, ankle dorsiflexion during stance phase is often limited (fig. 1). In the ankle plantar flexion moment curve a biphasic ('double bump') pattern is common, with an initial peak before midstance of greater magnitude than the peak occurring during terminal stance. The power curve at the ankle is typically triphasic. An abnormal premature burst of power generation in midstance is followed by a second peak, which is appropriately timed, yet often reduced in amplitude (2, 9). Improvement of kinematics and functional performance after BTA injection of the gastrocsoleus muscle has been shown by a number of randomized controlled studies (3, 12, 14, 15). Boyd *et al.* (2) were the first to report improvement of the typical ankle kinetics in a prospective randomized trial.

The specific aim of our study was to objectively evaluate the effect of intramuscular BTA injection at the ankle in a homogeneous group of children with hemiplegic CP.

MATERIAL AND METHODS

In the Gait Analysis Laboratory at the University Hospital Pellenberg, children with CP are followed in the course of their treatment. Within this population, we studied retrospectively a consecutive series of patients, who were treated with BTA injection for spastic equinus between February 1996 and September 1998.

Patients between the ages of two and eight years with hemiplegia were included. All were independent ambulators. Out of 13 patients, eight had full gait analysis data before treatment (median 67 days, range 125) and after treatment (median 57.5 days, range 37). Three patients were girls and five were boys, with a median age of 4.4 years (range 4.1). For demographics of the study population, see table I.

At each visit a comprehensive clinical examination, surface electromyography and three-dimensional video gait analysis were performed, but for the purpose of this study these results are not included. The biomechanical assessment of gait was undertaken using a six-camera VICON data capturing system (Oxford Metrics Ltd, UK) and two AMTI force plates (Advanced Medical Technology, Inc., Newton, MA). Data were processed by the VICON Clinical Manager software to kinematic and kinetic data, based on Euler angles and Newtonian

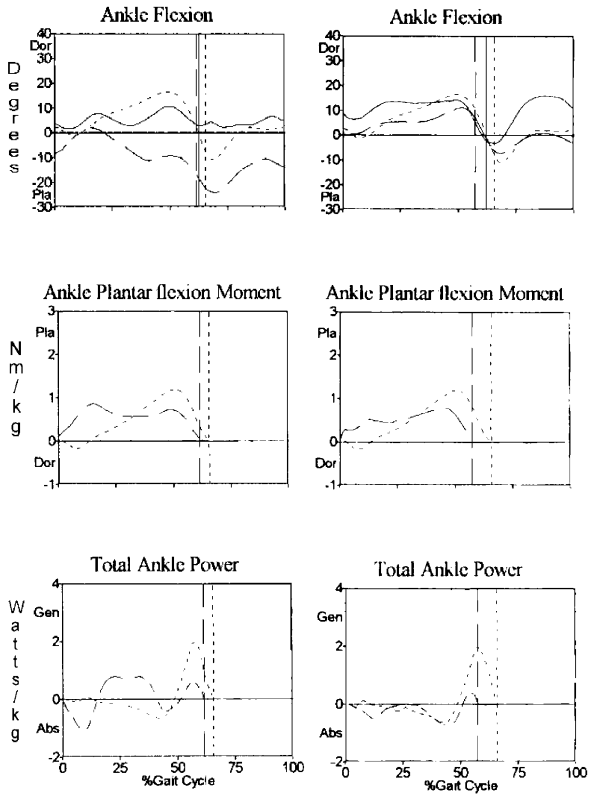

Fig. 1. — Sagittal plane ankle kinematics and kinetics in a four-year-old subject with right- sided spastic hemiplegia. Comparison before and 79 days after BTA injection of gastrocsoleus and medial hamstrings. Interrupted line, right lower limb; solid line, left lower limb; dotted line, normal. The horizontal axis represents stance and swing phase, which are separated by a vertical line at toe off.

mechanics. At least three trials were taken of each child walking at a self-selected speed, and a representative trial was chosen.

All injections were performed under light general anesthetic. The injection technique used was to four sites in the gastrocsoleus muscle as described by Cosgrove *et al.* (6). A dose of 4-8 units per kilogram of total body weight BOTOX (Allergan, CA) was administered in the gastrocsoleus muscle (table I). One patient received an additional injection of the posterior tibialis muscle, six patients of the medial hamstrings and two patients of the adductor muscles. Three patients had been injected previously, but not within the previous 11 months. No patients received repeat injections for at least nine months afterwards. Seven patients were also treated with a 2-4 week period of casting. All patients continued their routine physiotherapeutic and orthotic program. There were no injection-related complications.

Table I. — Subject demographics

Patient/sex/ age (yr)	Gait analysis		Dose (U/kg)	Simultaneously injected muscles	Cast (wk)
	Time before treatment (d)	Time after treatment (d)			
1/M/4.0	9	57	6	–	4
2/M/4.4	81	79	6	MH	4
3/F/4.3	61	42	6	MH, AD	4
4/F/3,9	4	56	6	–	0
5/F/6.7	129	58	8	TP, MH	4
6/M/7.5	73	70	8	MH	4
7/M/3.4	11	72	4	MH	2
8/M/5.3	96	57	6.5	MH, AD	4

Dose in units BOTOX (Allergan, CA) per kilogram of total bodyweight, injected in the gastrocnemius and soleus muscle ; MH, medial hamstrings ; AD, adductor muscles ; TP, posterior tibialis muscle ; duration adjuvant casting in weeks.

Kinematics were evaluated for the following parameters : (1) ankle dorsiflexion at initial contact and maximum ankle dorsiflexion in stance ; (2) knee extension at initial contact. Kinetics were evaluated for the following parameters : (1) maximum ankle plantar flexion moment before midstance and in terminal stance ; (2) maximum ankle power in midstance and in terminal stance ; (3) ankle moment quotient (AMQ), which is the ratio of the maximum ankle moment before midstance to the maximum ankle moment in terminal stance ; (4) ankle power quotient (APQ), which is the ratio of the maximum ankle power in midstance to the maximum ankle power in terminal stance. A decrease in either AMQ and/or APQ denotes improvement (2). Two temporospatial parameters, velocity and step length, were also evaluated.

Statistical analysis was by paired *t* tests (significance at $p < 0.05$).

RESULTS

Kinematic data (table II) demonstrated a significant increase in ankle dorsiflexion at initial contact and maximum ankle dorsiflexion in stance (median change 6.4° and 3.9°, respectively). Knee extension at initial contact was also significantly changed toward normal (mean 8.3°). Kinetic analysis (table II) showed a significant decrease of maximum ankle plantar flexion moment before midstance ($p < 0.05$), decrease of power absorption in midstance ($p < 0.05$) and increase of maximum plantar flexion moment in terminal stance ($p < 0.05$). Maximum ankle power in terminal stance was also improved, although not to a statistically significant level. AMQ ($p < 0.05$) and APQ ($p < 0.05$) were significantly improved. No changes in velocity and step length were noted.

DISCUSSION

This study demonstrates the gait analysis results of children with hemiplegic CP, before and after treatment for dynamic equinus. After intramuscular BTA injection, a significant increase of ankle dorsiflexion during gait was noted. This kinematic improvement is similar to that previously described (3, 12, 14). Improvement of range of motion is a technical parameter and is no proof for improvement of functional performance. Energy conservation is critical for normal gait function and is estimated by kinetic gait analysis (9). Kinetic gait analysis therefore is an objective measurement of functional performance. This study shows significant improvement of ankle kinetics after BTA injection. Literature reports one study with kinetic data after BTA injection for equinus deformity (2). In 25 children with CP (15 diplegic, 10 hemiplegic), improvement of APQ three months after injection was comparable to our results. A similar change in ankle kinetics has been reported with surgical lengthening of the gastrocnemius fascia (13).

Table II. — Gait analysis changes before and after BTA treatment

	Preinjection	Postinjection	p value
Kinematic data			
Ankle angle			
Dorsiflexion at initial contact	-9.45 (15.5)	-3.05 (12.8)	0.0006
Maximum dorsiflexion in stance	7.50 (23.3)	11.4 (12.2)	0.0063
Knee angle			
Extension at initial contact	-23.75 (30.1)	-15.45 (14.2)	0.0449
Kinetic data			
Ankle plantar flexion moment			
Maximum before midstance	0.70 (0.4)	0.60 (0.7)	0.0419
Maximum in terminal stance	0.80 (0.8)	0.80 (0.7)	0.0106
Ankle moment quotient	1.15 (2.2)	0.65 (1)	0.0134
Total ankle power			
Maximum in midstance	0.60 (2.0)	0.00 (0.9)	0.0169
Maximum in terminal stance	0.75 (1.5)	0.90 (1.9)	0.3585
Ankle power quotient	0.70 (3.7)	0.15 (1.0)	0.0311
Temporospatial parameters			
Velocity	0.96 (0.8)	0.96 (0.8)	0.4962
Step length	0.38 (0.3)	0.43 (0.2)	0.2889

Median and range of angles in degrees, moments in Newton-meter per kilogram of bodyweight, powers in watts per kilogram of bodyweight, velocity in meters per second and step length in meters. Paired t-test for significance of difference.

In cerebral palsy gait, the first ankle plantar flexion moment 'bump' in each gait cycle is caused by a gastrocsoleus muscle stretch reflex, induced by landing on the forefoot (9). Tone reduction after intramuscular BTA injection allows more adequate prepositioning of the foot, reducing this pathologic plantar flexion moment and absorption of power. The second moment 'bump' creates generation of power for push-off. It appeared increased after treatment, although intramuscular BTA causes temporary paresis. A possible explanation for this paradoxical increase of plantar flexion moment may be improvement of ankle dorsiflexion, which provides a better biomechanical position of the gastrocsoleus muscle relative to the ankle (2).

Improved prepositioning reduces energy absorption at the ankle. Because adequate prepositioning depends on both ankle and knee kinematics, we measured knee extension at initial contact, which showed a significant increase after treatment. The reason for this improvement is not only because the gastrocsoleus is a two-joint muscle, but also five children received BTA injection in the medial hamstrings. BTA injection may be more profitably used in combination with injections at other levels (4).

Corry *et al.* (3) compared serial casting to BTA injection for dynamic equinus in CP in a randomized prospective trial (12 children, 21 limbs). They found that significant improvement of ankle kinematics was maintained at 12 weeks, whereas the cast group relapsed. Boyd *et al.* (2) compared kinetic results after BTA injection between the non-cast and plus-cast subgroups (nonrandomized). After 12 weeks, improvement of APQ was similar in both subgroups. In our series of eight children, seven were treated with adjuvant casting. The role of adjunctive treatments such as orthoses and casting together with BTA needs to be further evaluated.

We have shown the results two months after a single procedure of BTA injection. The period of clinically useful relaxation is usually 12-16 weeks, but functional carryover can continue for up to six months or longer (11). Eames *et al.* (8) found a strong correlation between the magnitude and duration of response and the dynamic component of

equinus. Children with hemiplegia tended to show less good response to injection than children with diplegia, because they showed a smaller component of dynamic equinus. However, children with hemiplegia showed twice the duration for a given dynamic component, since the total dose injected was not divided between both legs. Children undergoing repeated injections showed similar correlations between response and dynamic component. Further research is required on the long-term effect of serial injections on longitudinal muscle growth and functional improvement, as well as yet unknown long-term adverse effects.

Treatment of dynamic equinus in children with CP by BTA injection results in normalization of ankle kinetics. Periodic BTA injection allows deferring the need for surgical intervention until the child is older and recurrence rate is lower.

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SAMENVATTING

A. W. ZÜRCHER, G. MOLENAERS, K. DESLOOVERE, G. FABRY. Kinematische en kinetische evaluatie op het niveau van de enkel bij de behandeling met intramusculair toegediende botuline toxine A van kinderen met infantiele encefalopathie.

Intramusculair geïnjecteerde Botulinum toxine A (BTA) speelt een rol in de conservatieve behandeling van dynamische equinus bij kinderen met infantiele encefalopathie. Het effect van injectie van BTA in de gastrocnemius- en soleusspier tijdens het lopen werd onderzocht. Acht kinderen met spastische hemiplegie (mediane leeftijd 4.4 jaar, spreiding 2-8 jaar) werden geïncludeerd in deze retrospectieve studie. Evaluatie gebeurde aan de hand van kinematische en kinetische loopbeweginganalyse voor en na (mediaan 57.5 dagen) behandeling. Kinematische resultaten na injectie lieten een significante verbetering zien van de enkelmobiliteit tijdens de standfase van de loopbeweging. Kinetische resultaten toonden een significante daling van de pathologische levering van vermogen ter hoogte van de enkel in het midden van de standfase. Ook het enkel-vermogen-quotiënt was significant verbeterd. Het enkelvermogen aan het einde van de standfase was eveneens

verbeterd, hoewel niet significant. Deze resultaten leveren het bewijs van normalisatie van de energielevering rondom het enkelgewricht, welke noodzakelijk is voor het normaal lopen. Het effect van BTA is tijdelijk en kan met succes herhaaldelijk toegediend worden. Dit geeft de mogelijkheid, om de indicatie voor chirurgisch ingrijpen uit te stellen tot het kind ouder en de kans op recidief lager is.

RÉSUMÉ

A. W. ZÜRCHER, G. MOLENAERS, K. DESLOOVERE, G. FABRY. Étude cinématique et cinétique de l'articulation de la cheville après injection intra-musculaire de toxine botulinique A chez des enfants atteints d'infirmité motrice d'origine cérébrale.

L'injection de toxine botulinique A (BTA) a une place dans le traitement conservateur de la déformation en équin dynamique chez les enfants atteints d'infirmité motrice cérébrale. Les auteurs ont étudié les effets sur la marche de l'injection de BTA dans le muscle triceps sural. Huit enfants présentant une monoplégie (âge médian : 4,4 ans ; extrêmes : 2 et 8 ans) ont été inclus dans cette étude rétrospective. L'évaluation a été basée sur une analyse cinématique et cinétique de la marche avant et après traitement (délai médian : 57,5 jours). La cinématique après injection montrait une amélioration significative de l'amplitude de mobilité de la cheville pendant la phase d'appui du pas. La cinétique de la cheville montrait une réduction significative de la génération de force pathologique au milieu de la phase d'appui. Le coefficient de puissance de la cheville était également amélioré de facon significative. La puissance de la cheville à la fin de la phase d'appui était améliorée, sans que cela n' atteigne la signification statistique. Ces résultats apportent la preuve d'une normalisation de la production d'énergie au niveau de la cheville, essentielle pour une démarche normale. L'effet de la BTA est temporaire et le traitement peut être répété avec succès. Ceci permet de différer l'indication d'un traitement chirurgical jusqu'à ce que l'enfant soit plus âgé et que les risques de récidive soient moindres.