Acta Orthop. Belg., 2009, **75**, 808-814

ORIGINAL STUDY

Does tendon lengthening surgery affect muscle tone in children with Cerebral Palsy ?

Maria VLACHOU, Rosemary PIERCE, Rita Miranda DAVIS, Michael SUSSMAN

From Shriners Hospitals for Children, Portland, Oregon, USA

The objective of this study was to determine if surgical lengthening of the hamstrings and gastrocnemius/Achilles complex affects muscle tone in patients with cerebral palsy. The question was if the dynamic component of muscle length changes after orthopedic surgery. A retrospective study was performed on ambulatory children with cerebral palsy who underwent either hamstring lengthening or gastrocnemius/Achilles tendon lengthening.

A total of 135 consecutive patients with an average age of 13 years were included in the study. A single random side was selected for children with bilateral surgery and the affected limb was analyzed for those undergoing unilateral surgery.

The popliteal angle measurement was performed with a quick and slow stretch, as well as the ankle dorsiflexion, and measurements were made using a goniometer.

The difference (Δml) between initial grab with fast stretch and end of range (EOR) with slow stretch was used as a measure of spasticity. The Bohannon modification of the Ashworth score was also assessed.

Postoperatively, 18° popliteal angle improvement in end-of-range and 32° improvement in quick stretch in the hamstrings group were noted, with change in slow stretch, quick stretch and Δml (comparison between quick and slow stretch) being significant at $p < .0001$.

In the triceps surae group, 14° ankle dorsiflexion improvement in end-of-range, and 18° improvement in quick stretch were noted postoperatively, with change in slow stretch, quick stretch and Δml at $p < .0001$, $p < .0001$, and $p < .0180$ respectively.

Ashworth scale was reduced by at least one grade in 89% of subjects in the hamstring group and 78% of subjects in the triceps surae group of the children with preoperative Ashworth 3 and above.

Keywords : spasticity ; cerebral palsy ; tendon lengthening.

INTRODUCTION

Patients with cerebral palsy present specific features like the loss of selective muscle control, dependence on primary reflex patterns for ambulation, abnormal muscle tone, and relative imbalance between the agonists and antagonists across joints, which with growth leads to muscle contracture and bony deformity, as well as to deficient equilibrium reactions. As spasticity is defined as an increased velocity-dependent resistance to joint motion, its degree increases with the amplitude and the velocity of stretch.

The spastic muscle tends to hold the joint about which it functions in an abnormal position, its

■ Maria Vlachou, MD, Clinical Fellow in Pediatric Orthopaedics.
■ Rosemary Pierce, PT, Physical Therapist.
■ Rita Miranda Davis, PT, Physical Therapist.
■ Michael Sussman, MD, Paediatric Orthopaedic Surgeon.
Department of Pediatric Orthopaedics, Shriners Hospitals for Children, Portland -Oregon, USA.
Correspondence : Maria Vlachou, MD, 64 Kavatha Street, Goudi 15775, Athens, Greece. E-mail : vlahma@yahoo.com

No benefits or funds were received in support of this study

excursion is reduced and consequently the muscle does not grow as rapidly as its adjacent bone, thus becoming contracted.

The effect of spasticity on the growth and development of skeletal muscle results in a muscle that has fewer fibers, shorter fiber length, and a longer tendon. This aberration results in a muscle that is weaker with a diminished excursion because of a decreased cross-section area, resulting in a decreased joint range of motion (*8*).

Opposing muscles should be in harmony to grow relative to the growth of the bones. When disharmony is present, the weaker antagonist group cannot stretch the stronger agonist group, resulting in a relative shortening of the agonist group, in relation to the growing bone (*7*). In spasticity, the antagonists have to exert greater force to stretch the muscles functioning with reduced reflex inhibition.

For normal function of a muscle group, the opposing muscles must be sufficiently long and free from spasticity. Lengthening is performed to correct the deformity (contracture), or to weaken the muscle if there is a functional deficit, even in the absence of a contracture. The goal is to harmonize the function of the joint by achieving a more normal range of motion and by decreasing the muscle strength, and so the spasticity to be reduced.

Our hypothesis was that when there is contracture due to persistent spasticity, the musculotendinous unit becomes shortened and there is excessive tension on the muscle.

When the tendon is lengthened, the muscle belly recoils because of the elastic properties of the musculotendinous unit, it relaxes and assumes a shorter resting length. The muscle is then under less tension and the spasticity is reduced. As the contracture is being reduced, the joint range of motion increases. The question is if the dynamic component of muscle length changes after lengthening surgery.

MATERIALS AND METHODS

An institutional review board number was applied for and received. A retrospective study was performed on a consecutive sample of 135 ambulatory children with cerebral palsy. The first group (103 patients) underwent hamstrings lengthening and the second group (32 patients) underwent gastrocnemius/Achilles tendon lengthening with preoperative and one year postoperative measurement of passive range of motion (ROM) and muscle spasticity. The age of the patients ranged from 3 to 20 years with a mean age of 13 ± 4 years.

All data were obtained at the time of routine pre and postoperative evaluation in the Motion Analysis Laboratory. The consecutive cases were selected with the exclusion criteria of having previous hamstring or triceps surae lengthening surgery and selective dorsal rhizotomy.

The children had the following diagnoses : spastic diplegia (n = 90), spastic hemiplegia (n = 27), spastic quadriplegia (n = 14), spastic triplegia (n = 3), and spastic monoplegia (n = 1).

Subjects in the hamstring group underwent lengthening of medial and lateral hamstrings, including lengthening above the musculotendinous junction, intramuscular or fractional lengthening of semimembranosus, semitendinosus, biceps femoris, and release of the gracilis. Subjects in the gastrocnemius/Achilles group underwent Achilles tendon lengthening or Vulpius (transverse division of the aponeurotic tendon of the gastrocnemius and soleus just below the middle of the leg, leaving the underlying muscle fibers intact).

A single random side was selected for children with bilateral surgery and the affected limb was analyzed for those undergoing unilateral surgery. The popliteal angle test was performed with a quick and slow stretch and measured with a goniometer. Positive values showed the angle in degrees between the measured angle and full knee extension with the hip at 90°. At the ankle, testing was done with the patient supine with the hip and knee in full extension as the foot was dorsiflexed. For analysis, comparison between quick and slow stretch was labeled Δml as a measure of dynamic muscle length which may indicate the level of spasticity. For data analysis, paired t-tests were performed with significance level set at p = 0.05. The Bohannon modification of the Ashworth score was also assessed as follows : 1. normal : no increase in tone, 2. mild : slight increase, catch in limb movement, 3. moderate : marked increase through most of the ROM, 4. severe : considerable increase, passive movement difficult (*3*). The evaluating authors were the same in all cases and they were familiar with the preoperative and postoperative status of the patients.

RESULTS

In the hamstrings group, an improvement of 18° popliteal angle in the end of range and 32° in the

Table I. — Popliteal angle improvement in end-of-range (EOR) and in quick stretch postoperatively. Improvement of the Δml (comparison between quick and slow stretch) postoperatively

	Preop mean (SD)	Postop mean (SD)	Difference mean (SD)	p
Popliteal angle grab	86° (13°)	54° (18°)	-32° (17°)	< .0001
Popliteal angle EOR (end of range)	52° (14°)	34° (14°)	-18° (16°)	< .0001
Delta ML (comparison between quick and slow stretch)	34° (14°)	21° (12°)	13° (17°)	< .0001

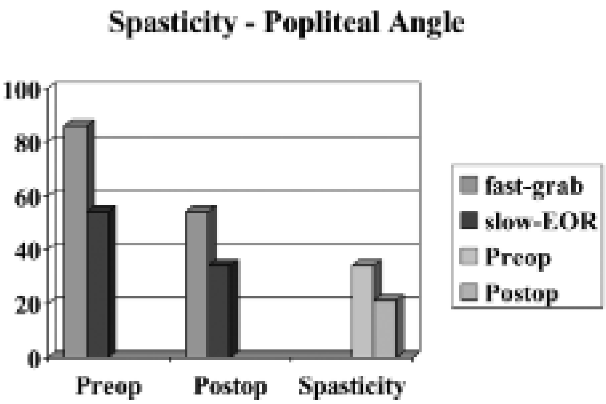

Fig. 1. — Popliteal angle results. All changes were significant at p < .0001.

quick stretch were noted postoperatively, with change in slow stretch, quick stretch and Δml (comparison between quick and slow stretch) being significant at p < .0001 (table I, fig 1).

In the triceps surae group, 14° ankle dorsiflexion improvement in the end of range, and 18° improvement in the quick stretch were noted postoperatively, with change in slow stretch, quick stretch and Δml at p < .0001, p < .0001, and p < .0180 respectively (table II, fig 2).

There was also a difference of Δml at p < .0846 in Achilles tendon lengthenings and p < .1208 in intramuscular lengthenings (table IV).

The Ashworth scale was reduced by at least one grade in 89% of subjects in the hamstring group and 78% of subjects in the triceps surae group of the children with preoperative Ashworth 3 and above (table III, fig 3-4).

DISCUSSION

The muscle strength is the maximal force that can be produced in a single isometric contraction of unrestricted duration. This is related to the number of contractile units in parallel and therefore to both the number of sarcomeres in parallel and the cross-section areas of those sarcomeres. Architecture of the fibers also influences the muscle strength. A bipennate muscle with short fibers, that passes obliquely to the anatomic axis of the muscle, is much stronger than the unipennate, which although it is of the same size, has a smaller number of fibers, but has a greater excursion, and consequently maintains its strength over a greater range of length (*10*). The muscle's fiber length determines the muscle excursion length and therefore the active range of motion of the joint.

Muscles unlike bones do not have an obvious anatomic or histologic growth physis, although some consider the musculotendinous junction as the area of growth, calling it the "muscle growth plate" (*25*).

In spasticity the antagonists have to exert a greater force to stretch those muscles functioning with reduced reflex inhibition. The aim of surgically lengthening tendons and /or muscles is to harmonize function by achieving approximately normal joint excursion and by decreasing muscular strength so that spasticity is also reduced, and the antagonist functions better when the spastic agonist is weakened (*18,19*). In the contrary, the antagonists often exert a stronger force after lengthening of a spastic agonist in such a way that changes in activity of these muscles are noticed (*14,21*).

In spastic equinus deformity the antagonist functions more strongly after lengthening and weakening of the agonist (*17*). An increased spasticity however

Table II. — Improvement in end-of-range and in quick stretch of ankle dorsiflexion postoperatively. Improvement of the Δml (comparison between quick and slow stretch) postoperatively

	Preop mean (SD)	Postop mean (SD)	Difference mean (SD)	p value
Dorsiflexion grab	-23° (11°)	-5° (8°)	18° (13°)	< .0001
Dorsiflexion EOR (end of range)	-8° (12°)	6° (6°)	14° (13°)	< .0001
Spasticity	15° (7°)	11° (7°)	4° (9°)	< .0180

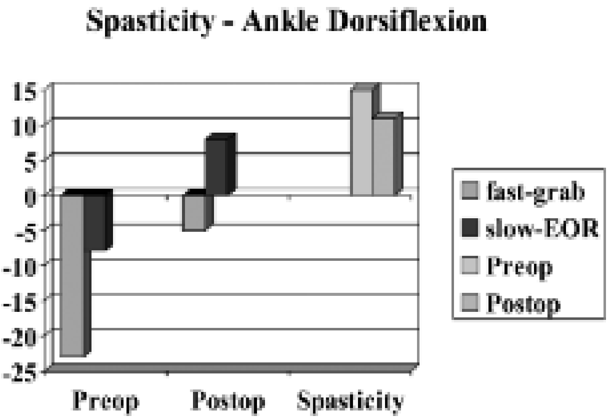

Fig. 2. — Ankle dorsiflexion results. All changes were significant at p < .0001 and p < .0180.

Table III. — Ashworth scale was reduced by at least one grade in 89% of subjects in the hamstring group and 78% of subjects in the triceps surae group of the children with preop Ashworth 3 and above

	1 normal	2 mild	3 moderate	4 severe
PREOP	4	29	49	6
POSTOP	20	60	9	0

is often observed in the rectus after lengthening of the hamstrings. Reimers (*18,19*) stated that after lengthening of the triceps surae, an immediate improvement was noted in the strength of the antagonists while considerably reduced strength of the quadriceps was noted after lengthening of the hamstrings.

It has also been reported that the strength of the quadriceps may increase significantly within a year and, since spasticity increases simultaneously, troublesome spasticity of the rectus may result (*18,19*).

The immediate biomechanical response to surgical lengthening of a musculotendinous unit is a decrease in the effective muscle force, a factor that could be problematic in children who already are weak. However the issue of whether surgical tendon lengthening produces a permanent loss of strength *in vivo* has not been resolved theoretically.

When a tendon is lengthened, the muscle belly immediately recoils because of the elastic properties of the musculotendinous unit. The sarcomeres are placed "on slack", and as an adaptive response to restore optimal position of filament overlap, the number of sarcomeres in series is reduced. Loss of sarcomeres in series affects velocity of shortening rather than strength *per se*, which is more dependent on the number of sarcomeres in parallel (*9*).

Delp and Zajac (*4*) developed a computer model of the human lower extremity, to study how tendon lengthening surgery affects the force and moment generating capacity of the muscles. The results showed that the decrease in muscle force and joint moments for a given increase in tendon length is different for each muscle.

Wide variation of sensitivity was noted after muscle-tendon complex lengthening depending on parameters such as muscle fiber length, tendon length and pennation angle. A muscle with short fibers, short tendon and small pennation angle is more sensitive to changes than that with long fibers, long tendon and big pennation angle.

In general, the forces developed by the muscles that cross the ankle are more sensitive to changes in tendon length than those generated by the muscles that cross the hip. The combination of lengthening a spastic muscle while strengthening its antagonist expedites or maximizes surgical outcomes.

It is also referred that although tendon lengthenings sometimes improve posture and walking

Table IV. — Difference of Δml (comparison between quick and slow stretch) in Achilles tendon lengthenings (TAL) and intramuscular lengthening

Dorsiflexion – TAL				
	Preop mean (SD)	Postop mean (SD)	Difference mean (SD)	P
Dorsiflexion grab	-24° (13°)	-2° (7°)	22° (13°)	< .0001
Dorsiflexion EOR (end of range)	-11° (14°)	7° (7°)	19° (16°)	<. 0002
Spasticity	13° (7°)	9° (7°)	4° (9°)	< .0846
Dorsiflexion – Vulpius				
Dorsiflexion grab	-22° (9°)	-9° (7°)	14° (12°)	< .0009
Dorsiflexion EOR (end of range)	-4° (6°)	5° (6°)	9° (8°)	< .0011
Spasticity	19° (7°)	13° (7°)	5° (10°)	< .1208

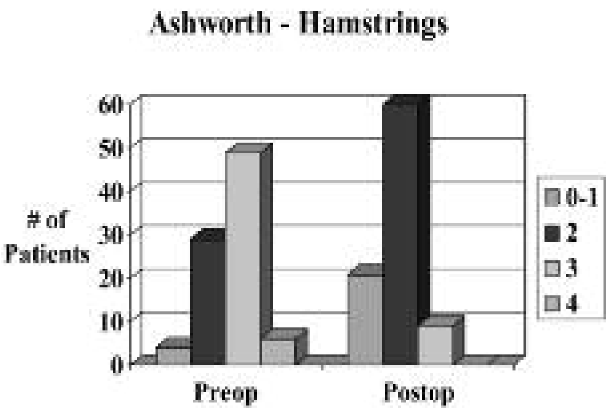

Fig. 3. — Ashworth scale results for hamstrings. The scale was reduced by at least one grade in 89% of subjects with pre-op scale 3 and above.

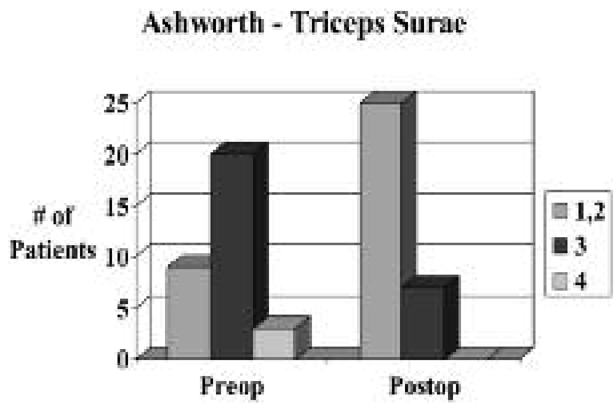

Fig. 4. — Ashworth scale results for triceps. The scale was reduced by at least one grade in 78% of subjects with pre-op scale 3 and above.

ability, they often compromise the capacity of the muscles to generate force and moments about the joints. When a tendon is lengthened, the muscle fibers may be too long or too short to develop active force and patients who cannot generate adequate muscle forces and joint moments may be left with weak or dysfunctional extremities. The forces and moments developed by the soleus and gastrocnemius change significantly with small changes in tendon length. This suggests that the Achilles tendon should be lengthened conservatively to avoid plantarflexion weakness. The observation that lengthening of the Achilles tendon may weaken the soleus more than the gastrocnemius supports those who recommend isolated gastrocnemius lengthening as a means to control plantarflexion weakness in cerebral palsy patients (*13,15*).

In contrast to the soleus, the force and moment developed by the iliopsoas are relatively insensitive to changes in tendon length and indicate that it can be lengthened more aggressively without so much decrease in force.

Even if we knew precisely how tendon lengthenings affect the musculoskeletal system, the functional result of these surgeries would still be unpredictable because of abnormal muscle activation patterns that are often associated with central nervous system pathology (*12,15*).

In general, potential risks associated with muscle-tendon surgery include the reduction of muscle-force generation and the development of deformities, such as calcaneal gait, crouch gait or stiff knee gait, due to overlengthening of the muscle-tendon unit or overactivity of the antagonistic muscles (*2,10,16,20-23*).

Although spasticity is difficult to be defined clinically, we can define it, as the difference between initial grab with fast stretch, and end of range (EOR) with slow stretch (*24*). According to this, we consider the reduction of quick stretch value to be a better indicator of the functional improvement than end of range, as spasticity is velocity dependent.

Reduced joint motion as a consequence of the spasticity is the most noticeable impairment. We observed significant decreases in spasticity following tendon lengthening in children with cerebral palsy with both static and dynamic components of muscle tightness being affected. Joint alignment and passive range of motion were dramatically improved after muscle-tendon surgery. Our future goal is to evaluate these patients with gait analysis to extract more thorough results about their functional outcome. The answer to the question, if cerebral palsy patients improve their walking ability and how permanent their functional outcome is after muscle-tendon surgery is controversial. Abel *et al* (*1*) concluded that improvements in walking ability and stride length were observed at 6 months after surgery and were maintained at two years after surgery, but the overall score of the GMFM (Gross Motor Function Measurement) level showed minimal change.

In the contrary, other studies showed that although joint position or joint motion were improved, walking velocity and stance time became more abnormal (*5,6,11*).

It is rather clear that the reduction of spasticity, as well as, the responsiveness of the patients to the surgical intervention are strongly related to the preoperative passive and active range of motion of the joints, the structure of the muscle (length of muscle fiber, length of tendon, pennation angle), the preoperative level of spasticity, the baseline of GMFCS (Gross Motor Function Classification System) level and the age of the patient.

Methodology and research limitations

This study aimed to document the effect of tendon lengthening surgery on muscle tone in children with cerebral palsy. The results should be interpreted with caution for the following reasons.

The cohort of the study was chosen on the basis of the described criteria. A limitation of the study is that the sample of participants has not been evaluated for their functional outcome after muscle-tendon surgery.

The study was based on clinical data concerning the dramatic improvement in passive range of motion and joint alignment following muscle-tendon surgery, as well as the significant decrease in spasticity with both the static and dynamic components of muscle tightness being affected.

An additional limitation was that the modified Ashworth score does not show a good intra-and inter-rater reliability. It is also worth mentioning that the design used was retrospective and that the data discussed were collected from the available clinical documentation ; this entails that the potential influence of other unmeasured variables must also be acknowledged.

It could also be argued that the validity and reliability of our results may have been affected by the assessors used being closely involved with the design of the study and measurement of outcomes, thus allowing for a possible experimenter bias. However, the patients were seen by two independent orthopaedic surgeons, and the range of objective and subjective outcome data used led us to conclude that there was sufficient triangulation for the results to be seen as reliable.

CONCLUSION

Significant decrease in spasticity was observed following tendon lengthening in children with cerebral palsy ; the orthopaedic surgery was found to affect both static and dynamic components of muscle tightness in these children.

REFERENCES

1. **Abel MF, Damiano DL, Pannuzio M, Bush J.** Muscle-tendon surgery in diplegic cerebral palsy : functional and

mechanical changes. *J Pediatr Orthop* 1999 ; 19 (3) : 366-375.

2. **Bleck EE.** Special assessments and investigations. In : Bleck EE (ed). *Orthopaedic Management in Cerebral Palsy.* MacKeith Press, Philadelphia, 1987, pp 65-105.
3. **Bohannon RW, Smith MB.** Inter-rater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther* 1987 ; 67 (4) : 206-207.
4. **Delp SL, Zajac FE.** Force and moment generating capacity of lower extremity muscles before and after tendon lengthening. *Clin Orthop Relat Res* 1994 ; 284 : 247-259.
5. **Gage JR.** *Gait Analysis In Cerebral Palsy.* MacKeith Press & Cambridge University Press, New York, 1991, pp 101-203.
6. **Gage JR, Fabian D, Hicks R, Tashmkan S.** Pre- and post-operative gait analysis in patients with spastic diplegia : a preliminary report. *J Pediatr Orthop* 1984 ; 4 : 715-725.
7. **Jorgen R.** Clinically based decision making for surgery. In : Sussman MD (ed). *The Diplegic Child.* American Academy of Orthopaedic Surgeons Press, Rosemont, IL, 1992 : 151-161.
8. **Lieber R.** In : Lieber RL (ed). *Skeletal Muscle Structure and Function : Implications for Rehabilitation and Sports Medicine*. Williams and Wilkins, Baltimore, 1992, pp 231-235.
9. **Lieber RL.** Skeletal muscle adaptability ; I. Review of basic properties. *Dev Med Child Neurol* 1986 ; 28 : 390-396.
10. **Moseley CF.** Physiologic effects of soft-tissue surgery. In : Sussman MD (ed). *The Diplegic Child.* American Academy of Orthopaedic Surgeons Rosemont, IL, 1992, pp 259-269.
11. **Nene AV, Evans GA, Patrick JH.** Simultaneous multiple operations for spastic diplegia. *J Bone Joint Surg* 1993 ; 75-B : 488-494.
12. **Olney BW, Williams PF, Menelaus MB.** Treatment of spastic equinus by aponeurosis lengthening. *J Pediatr Orthop* 1988 ; 8 : 422-425.
13. **Perry J, Hoffer M.** Preoperative and postoperative dynamic electromyography as an aid in planning tendon transfers in children with cerebral palsy. *J Bone Joint Surg* 1977 ; 59-A : 531-537.
14. **Perry J, Hoffer MM, Antonelli D *et al.*** Electromyography before and after surgery for hip deformity in children with cerebral palsy. *J Bone Joint Surg* 1976 ; 58-A : 201-208.
15. **Perry J, Waters RL, Perrin T.** Electromyographic analysis of equinovarus following stroke. *Clin Orthop Relat Res* 1978 ; 131 : 47-53.
16. **Phelps WM.** Long-term results of orthopaedic surgery in cerebral palsy. *J Bone Joint Surg* 1957 ; 39-A : 53-59.
17. **Rang M, Silver R, De la Garza J.** Cerebral palsy. In : Lovell WW, Winter RB (eds). *Paediatric Orthopaedics*, vol 2, ed 5, JB Lippincott, Philadelphia, p 345.
18. **Reimers J.** Functional changes in the antagonists after lengthening the agonists in cerebral palsy. I. Triceps surae lengthening. *Clin Orthop Relat Res* 1990 ; 253 : 30-34.
19. **Reimers J.** Functional changes in the antagonists after lengthening the agonists in cerebral palsy. II. Quadriceps strength before and after distal hamstring lengthening. *Clin Orthop Relat Res* 1990 ; 253 : 35-37.
20. **Segal LS, Sienko-Thomas SE, Mazur JM, Mauterer M.** Calcaneal gait in spastic diplegia after heel cord lengthening : a study with gait analysis. *J Pediatr Orthop* 1989 ; 9 : 697-701.
21. **Sharrard WJW, Bernstein S.** Equinus deformity in cerebral palsy : A comparison between elongation of the tendo calcaneus and gastrocnemius recession. *J Bone Joint Surg* 1972 ; 54-B : 272-276.
22. **Sutherland DH, Cooper L.** The pathomechanics of progressive crouch gait in spastic diplegia. *Orthop Clin North Am* 1978 ; 9 : 143-154.
23. **Sutherland DH, Santi MS, Abel MF.** Treatment of stiff-knee gait : a comparison of proximal rectus femoris release and distal rectus femoris transfer. *J Pediatr Orthop* 1990 ; 10 : 433-441.
24. **Tardieu G, Tardieu C.** Cerebral palsy : mechanical evaluation and conservative correction of limb joint contractures. *Clin Orthop Relat Res* 1987 ; 219 : 63-69.
25. **Ziv I, Blackburn N, Rang M.** Muscle growth in normal and spastic mice. *Dev Med Child Neurol* 1984 ; 26 : 94-99.