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Effects of minimally invasive surgery and functional physiotherapy on motor function of children with cerebral palsy: A non-randomised controlled trial

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ABSTRACT

Purpose: This non-randomised controlled trial investigated whether a combined programme of functional physiotherapy and minimally invasive orthopaedic surgery improves the level and degree of capacity and performance of gross motor function in children with spastic cerebral palsy (CP).

Methods: Fifty-two children with spastic CP aged 5–7 years, Gross Motor Function Classification System (GMFCS) levels II-IV, were allocated to two equal groups: experimental group (selective percutaneous myofascial lengthening [SPML] procedure and 9-month functional strengthening physiotherapy programme) and control (standard physiotherapy) groups. At baseline and at the end of the 9-month intervention, the capacity and performance of gross motor function were assessed with the Gross Motor Function Measure (GMFM) D and E subcategories and Functional Mobility Scale (FMS), respectively. The level of gross motor function was measured with the GMFCS.

Results: There was a statistically significant difference in the post-intervention improvements in the GMFM D (experimental mean difference = 19.63 ± 10.46; control mean difference = 2.40 ± 4.62) and E (experimental mean difference = 19.33 ± 11.82; control mean difference = 4.20 ± 6.26) between experimental and control group ($p < 0.001$). There was a significant improvement in the GMFCS level and each FMS distance for the experimental group ($p < 0.001$), but not for the control group ($p > 0.05$).

Conclusion: SPML procedure combined with functional physiotherapy improves gross motor function in children with spastic CP, by raising the degree and level of motor independence.

1. Introduction

Cerebral palsy (CP) is the leading cause of childhood motor disability worldwide, with the prevalence being around 2 cases per 1000 live births in the Greek metropolitan area of Athens, a ratio similar to that observed in Europe.[1] CP describes an impaired gross motor function, due to non-progressive lesion in the developing or immature central nervous system. Even though CP is primarily a static neurological pathology,

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secondary progressive orthopaedic pathologies develop over time, due to fixed muscle contractures from the age of 2 years.[1] The stability and/or deterioration of gross motor function at the age of about 7 years is directly impacted by the degree of secondary fixed contractures.[2] Thus, orthopaedic surgery is a sine qua non for the management of CP.[1] Given the controversy around the appropriate time to perform multilevel orthopaedic surgery, a prudent and commonly accepted practice is to wait until a child's motor development has been stabilised or deteriorates due to the development of permanent severe contractures, i.e. around the age of 5–7 years.[2] In this way, orthopaedic surgery can maintain joint alignment and muscle length, optimize movement biomechanics and, thus, accelerate gross motor function.[1]

Various surgical lengthening techniques, which are performed through open or percutaneous incision, have been described in the international literature. Percutaneous surgical lengthening is a minimally invasive surgery that is advantageous and preferable,[3] mainly due to its positive effects on muscle strength and gross motor function.[4,5] Selective Percutaneous Myofascial Lengthening (SPML) is a modern, fractional percutaneous surgery during which the release of myofascia is performed through a small skin incision, in combination with an alcohol nerve block. The main difference between SPML procedure and common percutaneous lengthening is that during SPML procedure very small cuts are made on the myofascial tissue and not on the tendon.[6,7]

The effectiveness of lower limb orthopaedic surgery in gross motor function of children with CP is well reported in the literature. However, available literature supports the effectiveness of multilevel surgical muscle-lengthening, without comparison to a non-surgical control group.[8] The results of studies vary depending on whether an open or percutaneous technique has been applied. Gross motor function appears to be lower after open lengthening, whereas it tends to improve following percutaneous lengthening.[4,5] Moreover, to our knowledge, there have been only four non-comparative studies regarding the effects of minimally invasive SPML surgery, showing important improvements in gross motor function (Gross Motor Function Measure [GMFM-88]),[9] dimensions D (standing) and E (walking, running and jumping) of the GMFM-88,[6] Gross Motor Function Classification (GMFCS) level[6,9] and functional mobility (Functional Mobility Scale [FMS]).[7,10] However, these low-quality studies provide a low level of evidence, which makes difficult to extrapolate a clear conclusion regarding the effects of SPML procedure on gross motor function in children with CP.

Until the early 1990s, post-surgical physiotherapy was based on the traditional passively directed Bobath therapy, which opposed muscle strengthening exercises for fear of increasing spasticity and developing contractures. However, studies on conventional[11] and post-surgical[4,12,13] physiotherapy programmes highlight the important role of functional strengthening[13] in gross motor function of children with CP.

Minimally invasive orthopaedic surgery at the age of 5–7 years, which will address fixed muscle contractures in a timely and effective manner, in combination with a specific protocol of functional physiotherapy, may enable children with CP to maintain or in some cases exceed their baseline gross motor function level. However, the effectiveness of such an approach has limited evidence. Therefore, the purpose of the study was to investigate the effectiveness of a combined programme of functional physiotherapy and minimally invasive SPML surgery on the gross motor function of children with spastic CP, aged 5–7 years.

2. Methods

Approval to conduct the study was obtained from the Scientific and Ethical Council of the 'Attikon' University General Hospital, Chaidari, Attica, Greece (EBΔ 2199/14-03-2017). The study was registered at the Australian New Zealand Clinical Trials Registry (ACTRN12618001535268). Informed written consent was obtained from parents before commencement of the study.

2.1. Study design

This study was a non-randomised controlled trial (Fig. 1). Participants were allocated to the experimental group ($n = 26$) who received SPML procedure and functional physiotherapy, and the control group ($n = 26$) who only received routine physiotherapy care. Outcome measures were evaluated before and 9 months after SPML procedure. Pre and post intervention measures were undertaken within one to two weeks of intervention. For eliminating any diffusion of treatments and contamination effects different pediatric practices were selected for experimental and control physiotherapy interventions.[14]

2.2. Participants

The required sample size was determined using G*Power analysis programme (version 3.1.9.6 for Mac OS X, The G*Power Team, Belgium). Based on the 2X2 design of the study and for a significance level (p) of 0.05, a statistical power equal to 80%, and an effect size of $f = 0.4$, a total number of 52 participants (26 children per group) was required. The participants of the experimental group were recruited from the list of the SPML surgeries at 'Iaso' Children's Hospital, Maroussi, Attica, Greece, between 2017 and 2019. The participants of the control group were recruited from the 'Paidokinisi' private pediatric practice, Argyroupolis, Attica, Greece, who had visited the pediatric orthopaedic surgeon during 2017–2019.

The inclusion criteria were school-aged children, 5–7 years, with spastic CP, GMFCS level II-IV, with normal cognitive ability and hip extensor strength higher than grade 2 via manual muscle testing. Exclusion criteria were dyskinetic, ataxic or a mixed motor disorder; a diagnosis other than CP; botulinum toxin type A in the lower limb muscle within six months before intervention; previous orthopaedic surgery; need for concomitant osteotomy; presence of a hip flexor contracture (Staheli test) and hip extensor strength below manual muscle testing grade 3.

2.3. Experimental group

2.3.1. Minimally invasive SPML orthopaedic surgery

SPML procedure performed by a trained, specialized, and experienced pediatric orthopaedic surgeon (A.D.K.). This novel minimally invasive pediatric orthopaedic surgery was described for the first time in the 1980s by Dr Roy M. Nuzzo, a pediatric orthopaedic surgeon from New Jersey, USA. SPML surgery is a fractional percutaneous (i.e. through the skin) lengthening of myofascia, making very small parallel incisions of 2–3 mm with a sterile microsurgery blade, which mimics the mechanism of mesh skin graft. Specifically, using a scalpel blade, one or more incisions were performed at the myofascia over the musculotendinous junction or in sections of the muscle length where muscle bundles were shortened and tighten forming palpable tautened muscle "bowstrings". By cutting the myofascia, the muscle was released and lengthened. Orthopaedic evaluation of muscle length for fixed contractures was based on quantitative gait analysis, physical examination, and clinical evaluation under general anesthesia just prior to SPML surgery. Depending on the extent of muscle contractures, SPML surgery involves myofascial lengthening of medial hamstrings (i.e., semitendinosus, semimembranosus), hip adductors (e.g., gracilis, adductor longus), and gastrocnemius. Alcohol blocks of obturator and/or femoral nerves were included as an integral part of the SPML procedure, if the child was very reactive to adductor and/or rectus femoris stretch, respectively. Immediately following the SPML procedure, the lower limbs were maintained in neutral alignment and extension by a combination of removable knee immobilizers and short-leg casts (when the gastrocnemius was lengthened). The short-leg casts (if applied) were removed at the end of the third post-surgical week. Solid ankle-foot orthoses (AFOs) were then used, which were maintained for four weeks in all mobility and weight-bearing activities, and at night (along

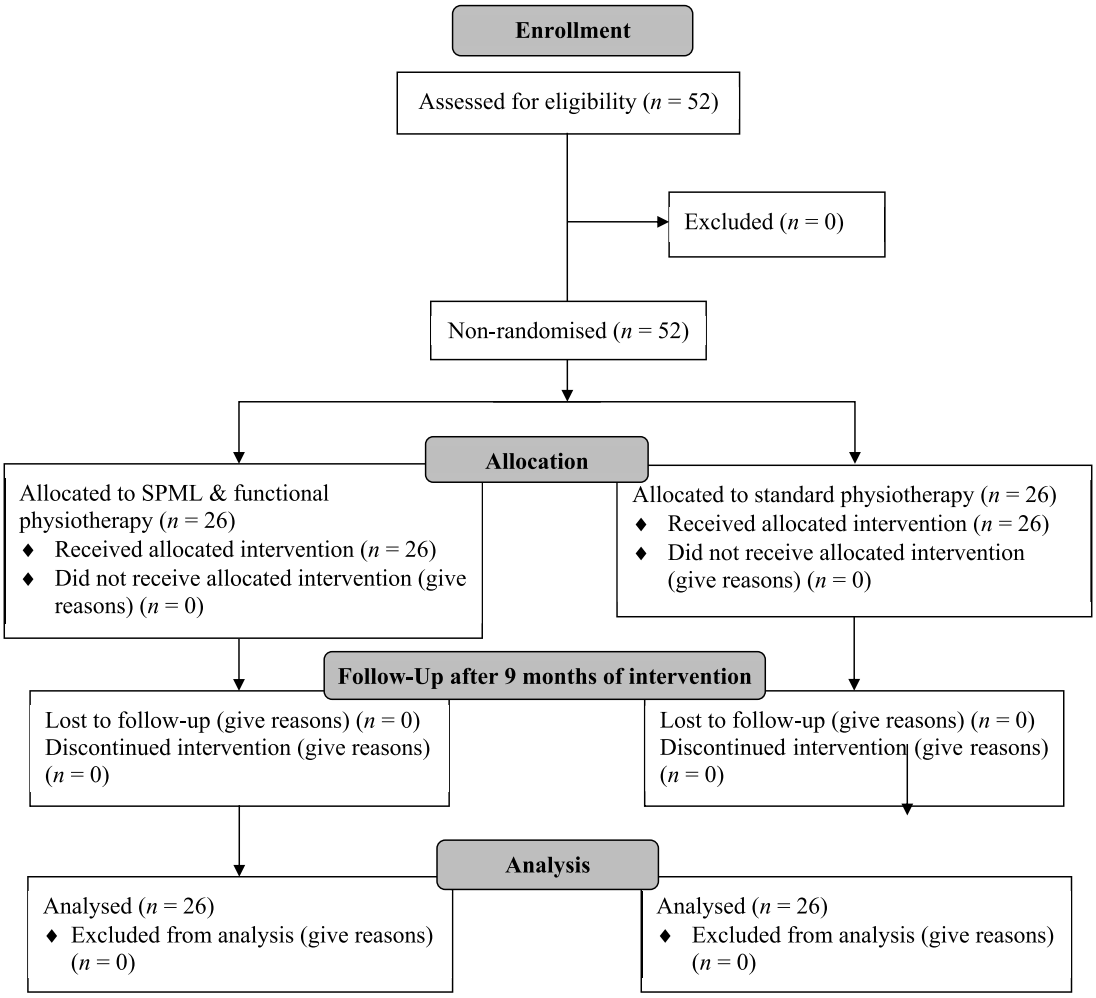

Fig. 1. The flow diagram of the study.

with knee immobilizers).

2.3.2. Post-surgical functional physiotherapy

Physiotherapy was managed by expert senior physiotherapists with clinical experience and specialisation in post-SPML treatment. Physiotherapy started on the same afternoon of the surgery day. After the removal of knee immobilizers, active-assisted range of motion (ROM) exercises for hip and knee were performed by the assistance of the physiotherapist. Then the child, wearing knee immobilisers and cast shoes, took some steps fully weight-bearing, supported by the physiotherapist.

For the first six weeks post, the frequency of physiotherapy was 5–6 sessions per week. From week 7 post-surgery onwards, the frequency was reduced to 2 and 3 sessions per week, according to the individual needs of each child. Functional physiotherapy goals were (1) the preservation of muscle length acquired from the SPML procedure, (2) the recovery and gradual improvement of muscle strength and endurance, (3) the optimization of gross motor function, including walking and, (4) promoting functional independence.[15] These goals were addressed with passive and active stretching of lower extremity muscles, and functional exercises and activities of different degrees of performance difficulty, depending on each child's level of functional strength and GMFCS (Fig. 2).

Functional exercises were performed intensively in an individualised maximum number of repetitions (as a rule, < 10 repeated in three sets). In the first three weeks after the SPML procedure, the degree of facilitation and assistance performing gross motor activities was provided using adaptive equipment (e.g., height-adjustable seat and step), external devices (e.g., handle, shoe-holder, grab-belt, harnessed body weight support systems), and/or physical assistance through light handling techniques (e.g., fingertip support, holding clothing). In this period, strength training was carried out with the use body weight as a resistance during functional exercise.

When the child was improving in strength and movement, resistance was progressively provided by increasing body weight through changes in environmental setting, such as lowering the seat height, raising the step height, increasing the treadmill incline/speed, carry objects etc. As the functional strengthening programme progressed free weights were implemented, such as use of a heavy ball, weighted vest, weighted bag, ankle weights, and/or elastic resistance bands. After regular clinical evaluation, the probability of changing assistive devices to move towards independent gait was also considered. Additionally, family participation was active and essential from the beginning of the rehabilitation programme, in order to give the child the opportunity for repetitive, variable practice of specific physical activities during the day, such as walking, stair climbing, tricycle riding, aiming to achieve optimal development of muscle strength and endurance.

The post-surgical physiotherapy was conducted in the 'ENA' private pediatric practice, Chaidari, Attica, Greece, and/or other collaborating practices under the guidance and supervision of the coordinator responsible for administrating the post-surgical physiotherapy programme.

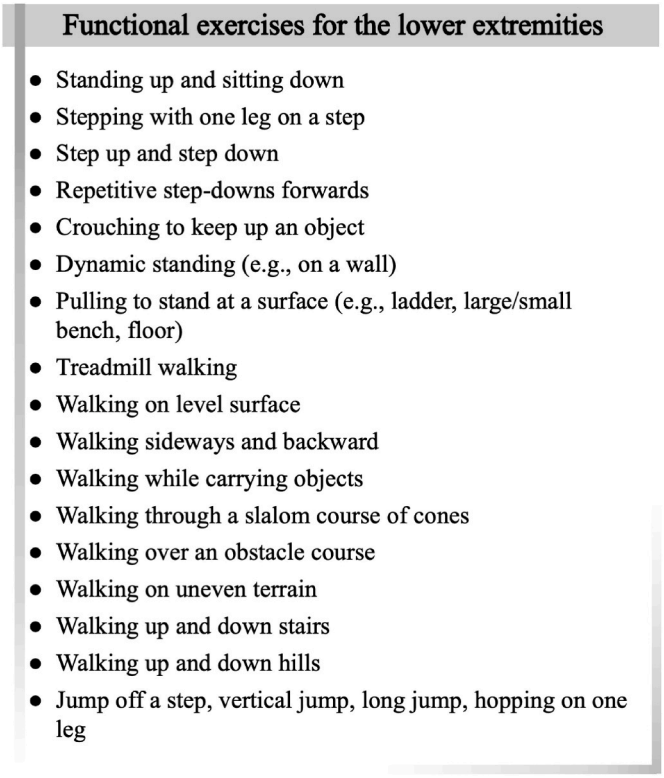

Fig. 2. Appropriate functional exercises following minimally invasive SPML surgery.

2.4. Control group

The control group continued to receive their usual physiotherapy programme (2–3 h per week), based on an eclectic intervention model consisting of a mixture of Bobath method and functional therapy. The control treatment was conducted in the 'Paidokinisi' private pediatric practice, Argyroupolis, Attica, Greece.

2.5. Outcome measures

Gross motor function level was classified according to the translated Greek version of the GMFCS.[16] The GMFCS is a valid five-level, age categorised system, which is internationally used in clinical practice and research to describe the severity level of gross motor dysfunction in children with CP. Differences between GMFCS levels are based on functional limitations (I = walking without limitations, II-walking with limitations, III = walks using a hand-held mobility device, IV = self--mobility using wheeled mobility, V = transportation by others). The GMFCS has different descriptors for five different age bands (<2 years, 2 to < 4 years, 4 to < 6 years, 6 to < 12 years, and 12 to < 18 years).[17] The original English version of the GMFCS has been demonstrated to be valid and reliable.[17] The Greek version of the GMFCS has been found to have substantial interrater reliability (Cohen's weighted kappa statistic, κ_w = 0.80; 95% confidence interval, 95% CI = 0.67–0.94).[16]

The subcategories D (standing; 13 items) and E (walking, running, jumping; 24 items) of the GMFM-88[18] were used to determine the degree of capacity of the gross motor function (i.e. what a child can do in a standardized environment).[19] These dimensions of the GMFM-88 were specifically selected as they can provide useful insights into difficulties in upright mobility experienced by school-age children. Scores of each dimension were expressed as a percentage of maximum scores for that dimension.[18] The GMFM has been shown to be a valid test with excellent interrater and intrarater reliability for each dimension and total score of the GMFM-88, with intraclass correlation coefficient (ICC) being ranged from 0.95 to 1.00.[20]

The Greek translation of the FMS[21] was used to determine the degree of performance of the gross motor function (i.e. what a child actually does in his/her daily environment).[19] The FMS was administered by asking specific questions to the parent. The FMS is a six-level categorical grading system which quantifies walking performance according to the need for assistive devices, at three specific distances: 5, 50 and 500 m, representing typical distances covered by children at home, school and in the community, respectively. A rating of 6 means that the child walks independently on all surfaces, and 5 means walking independently on level surfaces. The child using a manual wheelchair (with or without help from another person) or a powered wheelchair, who may be able to do some steps supported by another person, is rated as 1. The child using a walker/frame is rated as 2. The child using two crutches is rated as 3. The child using one crutch, or two sticks is rated as 4. The Greek FMS was demonstrated to have almost perfect test-retest reliability (κ_w = 0.98–1.00) and very strong concurrent validity with the Greek GMFCS, with Spearman's rank correlation coefficient (r_s) ranging from −0.85 to −0.89.[21]

2.6. Statistical analysis

Normality of data was analysed by using a Kolmogorov-Smirnov test. When the data was parametric, means and standard deviations were used as measures of central tendency and dispersion, respectively. Medians were used when the data was non-parametric. To compare the baseline variables between the two groups, independent *t*-tests were used for numerical variables, Chi-square tests for nominal variables, and Mann-Whitney U tests for ordinal variables. Group differences in scores of the GMFM-88 dimensions D and E before and after the interventions were analysed using a 2 (group: experimental and control) x 2 (time: pre, post) analysis of covariance (ANCOVA) with age as covariate, because the mean age difference between the two groups was significantly different (p = 0.013). Dependent *t*-tests were additionally applied separately for each group to examine any difference between baseline (pre-test) and post-test scores of GMFM-88 D and E scores. Differences in GMFCS level and FMS ratings for each group were analysed using the non-parametric Wilcoxon signed-rank test. A value of $p < 0.05$ was considered statistically significant. The data were analysed using the statistical analysis software programme SPSS 26.0 for MAC OS X (SPSS Inc, Chicago, Illinois, USA).

3. Results

3.1. Study participants/baseline characteristics

All children completed the study and were analysed according to their initial allocation, and as such there were no drop-outs. Baseline characteristics of the study groups are summarized in Table 1. No statistically significant differences were found between the two groups at baseline in gender, weight, height, initial GMFCS and GMFM-88 D and E assessment measures ($p > 0.05$). However, there was significant difference between the two groups in age ($p < 0.05$). Table 2 describes the distribution of the types and number of SPML procedures performed.

3.2. GMFM-88 D and E scores

Dependent *t*-tests showed that both groups had significant improvement on the GMFM-88 D and E scores between pre- and post-measurements ($p < 0.001$ for the experimental group and $p < 0.05$ the control group) (Table 3). However, ANCOVA revealed that the experimental group exhibited significantly greater improvements on the mean change of GMFM-88 D and E scores, compared to the control group, as groups showed a significant time × group interaction for GMFM-88 D, $F(1,49) = 76.35$, $p < 0.001$, $\eta_p^2 = 0.61$ (Fig. 3), and a significant time × group interaction for the GMFM-88 E, $F(1,49) = 34.19$, $p < 0.001$, $\eta_p^2 =$

Table 1
Baseline characteristics of the participants.

Characteristics	Experimental group	Control group	Mean difference	*p*-value
Number of participants	26	26		
Demography				
Age, mean ± SD, years	6.15 ± 0.73	5.69 ± 0.55	0.46	0.013
Male/female, No	16/10	13/13		0.402
Anthropometry, mean ± SD				
Body height, cm	110.08 ± 10.36	113.15 ± 12.61	3.08	0.341
Body weight, kg	19.06 ± 4.90	20.04 ± 5.06	0.98	0.481
Body Mass Index, kg/m^2	15.58 ± 2.57	15.47 ± 1.81	0.11	0.860
Cerebral palsy type, No				0.317
Spastic tetraplegia	11	7		
Spastic diplegia	13	16		
Spastic hemiplegia	2	3		
GMFCS, No				0.069
Level II	6	13		
Level III	12	8		
Level IV	8	5		
GMFM-88, mean ± SD, %				
Dimension D	42.31 ± 25.19	54.11 ± 31.34	11.80	0.141
Dimension E	28.69 ± 26.30	42.68 ± 31.37	13.99	0.088

P-values are from tests comparing the experimental and control groups using either independent-samples *t*-test (age, height, weight, GMFM-88 D & E), Chi-square test (gender, cerebral palsy type), or Mann-Whitney *U* test (GMFCS). GMFCS, gross motor function classification system; GMFM, gross motor function measure; Dimension D, standing; Dimension E, walking, running and jumping; SD, standard deviation.

Table 2
SPML procedures performed as part of 26 experimental-group children (52 lower limbs).

	No. cases	Bilateral	Unilateral	Total
Medial hamstrings	24	23	1	47
Gastrocnemius	15	13	2	28
Adductors	18	18		36
Obturator nerve alcohol block	19	19		38
Femoral nerve alcohol block	9	8	1	17
Total no. procedures				166

0.41 (Fig. 4).

3.3. GMFCS and FMS scores

Wilcoxon signed-rank test revealed a significant improvement in the GMFCS level and each FMS distance for the experimental group ($p <$ 0.001), but not for the control group ($p > 0.05$) (Table 4). The GMFCS level was unchanged in all control children (100%) but was improved in 19 experimental-group children (73%) and remained unchanged in just 7 (27%) of them. The improvements in the GMFCS level of experimental group were all by one grade. The improvements in each FMS distance were by one to three grades.

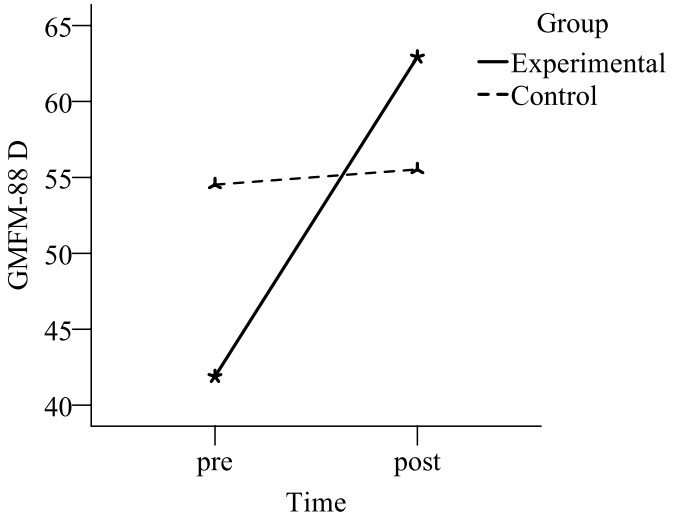

Fig. 3. Pre- and post-measurements of GMFM-88 D dimension. Values are expressed as mean.

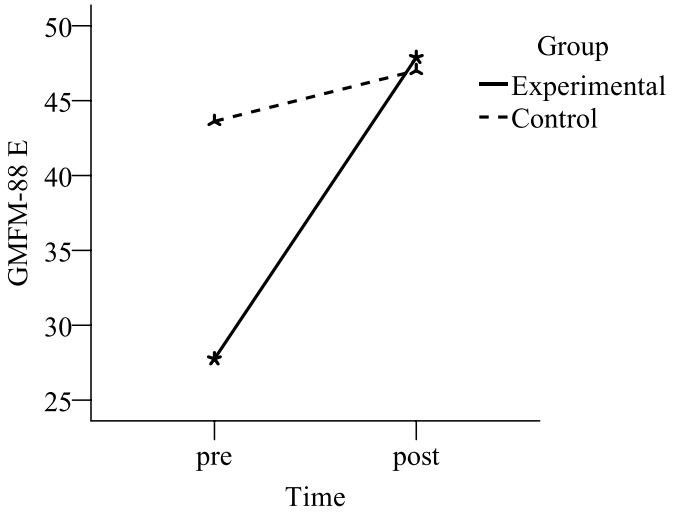

Fig. 4. Pre- and post-measurement of GMFM-88 E dimension. Values are expressed as mean.

Table 3
Mean (SD) GMFM-88 D and E % scores, mean differences (SD) in GMFM-88 D and E scores, 95% confidence intervals, and significance levels.

GMFM-88	*Group*	*Mean ± SD*		*Mean difference*[a] *and 95% CI of the difference*			
		Pre	*Post*	*Mean ± SD*	*Lower CI*	*Upper CI*	*p*-value
Dimension D	Experimental	42.31 ± 25.19	61.93 ± 25.74	19.63 ± 10.46	15.40	23.85	<0.001
	Control	54.11 ± 31.34	56.51 ± 32.56	2.40 ± 4.62	0.54	4.27	0.014
Dimension E	Experimental	28.69 ± 26.30	48.02 ± 29.22	19.33 ± 11.82	14.56	24.10	<0.001
	Control	42.68 ± 31.37	46.88 ± 33.79	4.20 ± 6.26	1.67	6.73	0.002

CI, confidence interval; SD, standard deviation; GMFM, gross motor function measure; Dimension D, standing; Dimension E, walking, running and jumping.
[a] Dependent *t*-test.

Table 4
Pre- and post-changes in Functional Mobility Scale (FMS) rating at all distances (5, 50, 500 m) and Gross Motor Function Classification System (GMFCS) level between the experimental and control groups.

FMS rating			6	5	4	3	2	1
5 m	Experimental	pre		6	2	5	8	5
		post	5	13		4	4	
	Control	pre	1	12	2	1	5	5
		post	1	12	2	1	5	5
50 m	Experimental	pre		2	4	4	6	10
		post	4	6	7	2	6	1
	Control	pre		8	6	2		10
		post		9	5	2		10
500 m	Experimental	pre		2	4	2	1	17
		post	4	2	7	4	3	6
	Control	pre		7	6	2		11
		post		7	6	2		11
GMFCS level			I	II	V	III		
	Experimental	pre		6	12	8		
		post	4	11	9	2		
	Control	pre		13	8	5		
		post		13	8	5		

GMFCS, gross motor function classification system; FMS, functional mobility scale: 1 = wheelchair, 2 = walker/frame, 3 = crutches without help, 4 = canes without help, 5 = independent level surfaces, 6 = independent all surfaces; m, metres.
The changes in the GMFCS level of experimental group were all higher by one grade. The improvements in each FMS distance were higher by one to three grades.

4. Discussion

The minimally invasive of SPML surgery enables immediate mobilisation and full weight-bearing exercises. Surgical muscle-lengthening between the age of 5–7 years minimises or prevents the development of severe secondary joint-skeletal changes and, thus, the subsequent tendon transfers, rotational osteotomies and/or bony stabilisation procedures.[1] These musculoskeletal surgeries result in further loss of gross motor function, and require long-term intensive rehabilitation along with delayed weight-bearing.[4,5] A functional strengthening physiotherapy programme is considered to be a catalyst for a successful surgical outcome. Studies of multilevel surgery are increasingly highlighting the importance of strengthening in post-surgical rehabilitation protocols.[4,12,13,22] Indeed, current literature data confirms, the effectiveness of functional strength training intervention in improving gross motor function in children with CP.[11]

To our knowledge, this is the first controlled trial examining the effects of a minimally invasive SPML surgery on gross motor function in children with CP. The findings of this study demonstrated a significant difference in the level (GMFCS) and degree of capacity (GMFM-88 D and E) and performance (FMS) of gross motor function in children with spastic CP following a combined programme of SPML procedure and 9-month functional physiotherapy, compared to children in the control group continuing their standard physiotherapy.

It is generally recognised that the GMFCS level is relatively stable (72% of the children)[23] and does not change after multilevel surgery. Large retrospective studies have shown that the GMFCS remains stable in about 95% of children following multilevel surgery within the rehabilitation stage of the first 12 months and improves by one level only in 5% of cases.[24] However, our study has shown more pronounced changes compared to these studies, indicating that the GMFCS level was improved by one grade in 73% of the children following the SPML procedure and functional physiotherapy, without any improvement for the control group. The improvements in the GMFCS level of the experimental group are reflected by significant increases in GMFM dimension E score, which is the best predictor of a child's GMFCS level.[25] These findings are in agreement with the previous results of uncontrolled studies of SPML[6,9] and multilevel soft tissue surgery.[26]

At 9 months post-intervention the experimental group had a significant improvement in GMFM-88 D and E by 46% and 67%, respectively, whereas the control group had a slight increase of 4% and 10% respectively. Although the changes in both the experimental and control group are considered clinically important,[27] the objectively higher scores in the experimental group reflect the major change observed in the GMFCS level and FMS ratings. This non-randomised controlled study confirms previous studies with no control group, that minimally invasive SPML surgery improves the gross motor function and mobility level in children with spastic CP.[6,7,10] However, these results are in disagreement with previous comparative studies of multilevel soft tissue and bony surgery (after the age of 6 years) in gross motor capacity, where the total GMFM score was significantly decreased[4] or showed no significant change[5,12] at 12 months post-surgery. A recent pooled analysis of cohort studies also revealed a deterioration in total GMFM score in the first 12 months after multilevel surgery, followed by a return to condition at 12–24 months post-surgery, and potentially further amelioration in the longer-term.[8] These differing findings compared to our results may be explained by the different age composition of the samples and surgical procedures applied. Older age has been shown to have more severe fixed muscle contractures and lower post-surgical gross motor development potential than the younger age.[22] The surgical correction of severe musculoskeletal deformities may not compensate for the severe abnormal movement and posture patterns established.[1] Muscle weakness is a potential problem of myotendinous lengthening, which may have a severe impact on gross motor function, as the total GMFM-88 and dimension E scores may not reach the pre-surgical values.[4] Myofascial lengthening is likely to preserve or even increase the muscle strength of lower limbs, due to myofascial (and not tendinous) recession performed through percutaneous micro incisions, the limited period of immobilisation, and the immediate initiation of a functional strengthening physiotherapy program.[3,6] Although some authors state that the gains in gross motor function in children with CP under the age of 6 years result from the natural motor skill acquisition, rather than just the orthopaedic surgery,[28] such claims cannot be verified by our study, considering the controlled design of the study as well as the mean ages of 6.154 and 5.692 years in the experimental and control groups, respectively.

It is established that gross motor capacity has a high correlation with gross motor performance, particularly in children aged 4–7 years with severe CP (bilateral spasticity) and severe functional limitations (GMFCS levels III, IV and V).[29] Nevertheless, it has been shown that it should not be assumed that changes in gross motor capacity automatically translate into changes in performance.[19] The FMS is an appropriate and simple tool of assessing gross motor performance with regard to walking and usual mobility aids used at home (5 m), school (50 m) and in the community (500 m).[21] Our results showed a clinically important improvement by one to three levels in each FMS distance at 9 months in all children of the experimental group, including the children with a stable post-surgical GMFCS level. However, the FMS scores for the control group did not change at 9 months, except for the improvement of one child from rating 4 to rating 5 in the FMS 50 m distance. These results are consistent with previous uncontrolled studies of SPML,[7,10] but contrasts with the majority of studies of multilevel surgery. Here, the children returned to baseline ratings in each FMS distance at twelve months, after initially worse ratings post-surgery, and improved at 24 months post-surgery.[12,30] The more rapid and greater changes in FMS ratings observed following SPML surgery may be due to the early mobilisation, the intensive walking training, the direct functional strength training as well as to the daily practice of physical activities immediately after the surgery.

4.1. Limitations

This study has some limitations. There was no randomisation of children to the study groups. Since SPML procedure was individualised

for each participant of the experimental group, there was variability in the muscles being operated. There was no short- (≤3 months), intermediate- (3–9 months) or long-term (>9 months) follow-up to evaluate the changes over time. The participants represented the study hypothesis and focused on children, aged 5–7 years, in GMFCS levels II-IV who underwent SPML procedure and functional physiotherapy, so the findings should only be generalised for this population.

4.2. Clinical implications

The findings of this study offer a new perspective in the clinical management of children with spastic CP. Minimal invasive SPML surgery and functional physiotherapy appear to break the deadlock clinicians often face to overcome the plateau or decline in gross motor function of children with spastic CP. This combined programme of functional physiotherapy and minimally invasive orthopaedic surgical approach may address early the secondary muscular consequences and the subsequent deterioration in gross motor capacity and performance in children with spastic CP.

5. Conclusions

This is the first non-randomised controlled study that investigated the effects of the minimally invasive SPML surgery combined with a 9-month post-surgical functional physiotherapy. This study provides important evidence that a combined programme of functional physiotherapy and minimally invasive SPML surgery promotes the gross motor function in children with spastic CP, by increasing the degree of functional independence. Future studies with longer follow-up assessment are needed to determine whether these positive changes in gross motor function are sustained, augmented, or reversed long-term after the surgery.

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Declaration of interest

None.

Declaration of competing interest

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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