ORIGINAL ARTICLE

Effects of a Postoperative Resistive Exercise Program on the Knee Extension and Flexion Torque in Children With Cerebral Palsy: A Randomized Clinical Trial

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ABSTRACT. Patikas D, Wolf SI, Armbrust P, Mund K, Schuster W, Dreher T, Döderlein L. Effects of a postoperative resistive exercise program on the knee extension and flexion torque in children with cerebral palsy: a randomized clinical trial. Arch Phys Med Rehabil 2006;87:1161-9.

Objective: To investigate the effects of resistive exercise on the knee extension and flexion torque production during the rehabilitation period after multilevel orthopedic surgery.

Design: Randomized clinical trial.

Setting: Hospital rehabilitation department.

Participants: Thirty-nine children with spastic diplegic cerebral palsy (CP) (age range, 6–16y), randomly allocated to an exercise group (n=19) and a control group (n=20). All received conventional physiotherapy (PT), and the exercise group also followed a resistive exercise program.

Intervention: A 9-month standardized home-based resistive exercise program, which started about 3 months after the surgery.

Main Outcome Measures: The Gross Motor Functional Measurement (GMFM) assessed before (E_0) and 1 year (E_1) after the surgery. The Modified Ashworth Scale and the isometric and isokinetic torque of the knee extensors and flexors were evaluated at E_0, E_1, and 6 months after the surgery.

Results: The knee extension and flexion moments had decreased 6 months after the surgery and recovered to the preoperative level 1 year after surgery. These changes were not group dependent.

Conclusions: Additional long-term, home-based, low-cost resistive exercise that starts soon after the operation of patients with CP was not more beneficial than conventional PT only, in terms of strength and GMFM.

Key Words: Cerebral palsy; Exercise; Rehabilitation; Surgery.

CEREBRAL PALSY (CP) IS A CHRONIC disorder that develops as a result of damage or abnormal development in specific brain areas during infancy. Common symptoms of CP include increased muscle tone and spasticity. Apart from the poor muscle coordination, there are other consequences of these symptoms, such as contractures, bony deformities, increased muscle stiffness, and muscle weakness.[1] In addition to physical (PT) and occupational therapy and/or medical treatment, patients with spastic CP are often treated surgically.[2] Depending on the individual patient, muscle or tendon lengthening, tendon transfer, and/or bone correction and foot stabilization aim to restore the functional range of motion (ROM), diminish muscle strength imbalance, and align the limbs to a functionally correct position.[3]

Typically, patients receive conventional PT postoperatively, consisting of passive, assisted, and active movement of the limbs and treatment according to the Bobath method.[4] Strength training has been recommended after selective dorsal rhizotomy operations; these procedures reduce spasticity but result in pronounced muscle weakness that was preoperatively masked by the spasticity.[5] Strength training has also been previously recommended for patients with CP to improve muscle strength and some functional parameters.[6] However, to our knowledge there has been no clinical trial attempting to strengthen the muscles of patients with CP after orthopedic surgery.

In previous reports, resistance training was not recommended in patients with spasticity because this might increase the muscle tone.[7] Furthermore, the insufficient motor control might impede targeted muscle activation.[8] However, children with spastic CP, in whom the isometric knee extensor moment is higher, walk faster, and the knees are extended more at foot strike.[9] This argues for strength training. It is well documented that children with spastic CP have the capacity to improve their strength: various strength training programs have shown benefits concerning muscle strength and the joint ROM without any negative effect on resistance to passive movements,[9-13] as expressed by the Modified Ashworth Scale (MAS).[14,15] Additionally, the Gross Motor Function Measurement (GMFM) score[16] has been positively correlated with the knee extensor strength level in adolescents with CP undergoing strength training.[17,18] Indeed, strength training resulted in an increased velocity, cadence, and stride length, and decreased crouch position during gait.[18,19] On the other hand, no significant increase in velocity was found before or after an isokinetic strength training program.[13]

Concerning the duration of a training protocol, specialized PT programs have shown that functional improvements can only be maintained with regular practice,[20] and the effects of intensive strength training start to disappear after a 3-month detraining period.[13] This implies that long-term training is required.

During the postoperative rehabilitation period, a significant loss of strength may occur due to the combined effects of

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muscle lengthening, pain, and temporary immobilization of the lower limbs. The problem may become more serious if the surgical treatment has to be repeated during childhood. Despite the functional benefits that the children have after orthopedic surgery, the force balance between counteracting muscles is affected and the efficiency of the surgically treated muscles further reduced.[21,22] Additionally, during development, body mass increases disproportionately to muscle strength[23]; hence, muscle weakness is more severe. For these reasons, an exercise protocol targeted to muscle strengthening could be assistive for maintaining muscle strength in children with CP after surgery. The present study was designed to test this hypothesis.

METHODS

Participants

The study included 43 children with diplegic CP to the lower limbs, between the ages of 6 and 16 years (mean age ± standard deviation [SD], 9.7±2.8y). They were classified from level I to III according to the Gross Motor Function Classification System (GMFCS).[24] We recruited all participants as preoperative ambulatory patients from the CP clinic of an orthopedic university hospital, where the study was conducted. They had not previously had surgery and were candidates for a multilevel procedure. Patients who were mentally or physically incapable of following the exercise program were excluded. Preoperatively, 9 patients required external assistance for walking. Written informed consent for participation was obtained from the parents. The study was approved by the local ethics committee.

Study Design

We randomized the patients into 2 groups (table 1, fig 1): the exercise group and the control group. Before the beginning of the study, a member of the research team prepared 20 notes for each group assigned by the group name. These notes were sealed in 40 identical, opaque envelopes, which were mixed and stored in a safe place. While the patient was in the operating room, an independent person selected 1 envelope, which was not put back. The envelopes of patients that were originally allocated but excluded within the first 6 months of the study (due to injuries, drop-outs, missing examination dates) were prepared again and added to the envelopes that remained at the time when the decision for exclusion was made. Full datasets of all measurements were not available for the excluded patients and therefore no intention-to-treat analysis was performed.

Both groups received conventional PT after surgery as soon as mobilization was possible. During the hospital stay, the PT program was conducted by 4 physiotherapists employed at the clinic where the study was carried out. After hospital discharge, PT was carried out by the physiotherapist who had regularly treated this child before surgery. These physiotherapists were available to answer questions about the exercise program, with respect to their professional experience. If the question was too specific to the exercise program, we recommended contacting the research team.

The exercise group underwent a training program in addition to conventional physiotherapy. Strength evaluation[25] and the

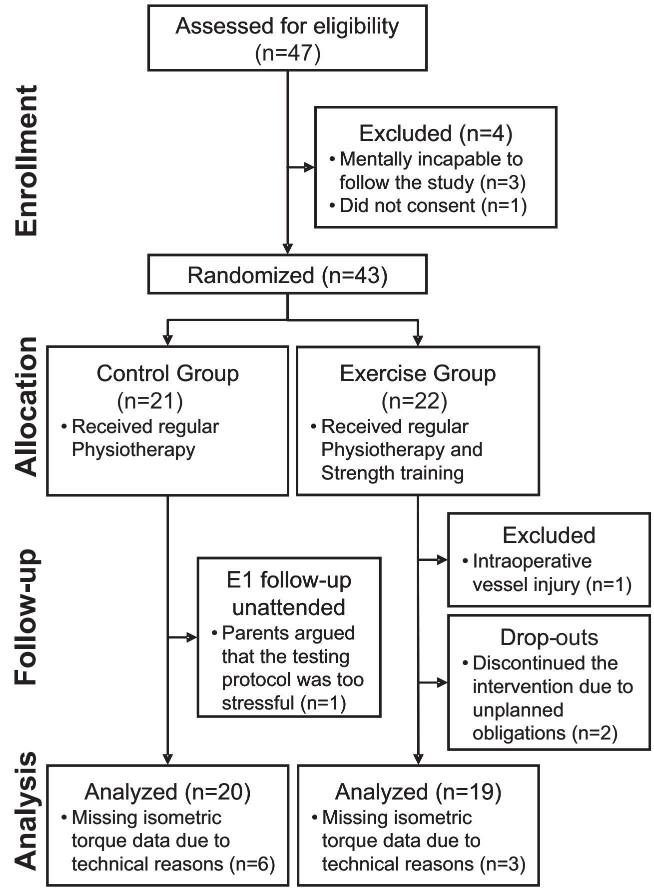


Fig 1. Flow diagram of the randomization procedure. Adapted from Patikas.[37] Reprinted with permission. ©American Congress of Rehabilitation Medicine and American Academy of Physical Medicine and Rehabilitation.

Table 1: Subject Characteristics for the Exercise Group (EG) and Control Group (CG) Before Surgery

Characteristics	EG (n=19)			CG (n=20)			EG–CG 95% CI*
Age (y)	10.6±3.3			8.9±1.9			−0.1 to 3.4
Body height (cm)	137±17			129±11			−0.4 to 18.0
Body mass (kg)	33.3±12.6			28.5±8.9			−2.2 to 11.8
Duration of the hospital stay (wk)	7.8±2.2			7.9±2.1			−1.4 to 1.4
							Chi Square
Sex (boys/girls)	13/6			14/6			χ^2 test=0.1, P=.81
Assistance during walking (with/without)	2/17			7/13			χ^2 test=2.1, P=.15
GMFCS (level and no. of patients)	I	II	III	I	II	III	χ^2 test=3.6, P=.16
	6	11	2	6	7	7	

NOTE. Values are mean ± SD.
*Statistical results of the unpaired *t* test (95% confidence intervals [CIs]) and the chi-square test for the difference between the groups.

Table 2: Surgical Procedures Carried Out in the Exercise Group (n=38 limbs) and Control Group (n=40 limbs)

Procedure	EG	CG
Soft-tissue procedures (total)	127	144
Intramuscular psoas tendon lengthening	5	3
Proximal intramuscular rectus femoris recession	5	13
Distal transfer of the rectus femoris tendon	34	38
Hamstring lengthening (total)	31	33
Medial hamstring lengthening only	25	31
Medial and lateral hamstring lengthening	6	2
Equinus correction (total)	27	38
Baumann procedure	21	32
Strayer procedure	4	4
Open Achilles' tendon lengthening	2	2
Additional soft-tissue procedures for foot-deformity correction	25	18
Bony procedures (total)	65	56
Pelvic osteotomy (Dega/Pemberton)	0	4
Femoral derotation osteotomy (total)	33	24
Supracondylar	26	19
Intertrochanteric	7	5
Tibial derotation osteotomy	2	7
Additional bony procedures for foot-deformity correction	30	21
Overall total	192	200

MAS[14,15] were assessed before surgery (E_0) and approximately 6 months ($E_{1/2}$) and 1 year (E_1) after surgery ($E_{1/2}$, .41±.05y; E_1, .93±.06y). For the exercise group, the examination dates $E_{1/2}$ and E_1 corresponded to 12.8±1.4 and 40.3±1.9 weeks of training at home, respectively, and E_1 was conducted as soon as the training program ended. GMFM scores were assessed only at E_0 and E_1.[26] The study period, from the first to last measurement, was almost 3 years (March 2001–January 2004).

Surgical Treatment

The surgical treatment for all patients (exercise group, control group) included soft-tissue and bony procedures (table 2). These procedures were performed for each patient in a single-event multilevel operation by 2 surgical teams.[27] The decision for surgical treatment was made after analyzing video data, 3-dimensional gait, and dynamic electromyographic recordings and with respect to the clinical, radiologic, and intraoperative examination results.[3]

Knee flexion deformities were corrected by intramuscular and aponeurotic lengthening. To correct the stiff gait pattern (cospasticity of the knee flexors and extensors, especially the rectus femoris),[28] the rectus femoris muscle tendon was transferred distally to the tendon of the gracilis muscle.[29,30] We corrected equinus deformities using the Baumann procedure or, in more severe cases, using the Strayer procedures; rarely, open lengthening of the Achilles' tendon was performed.[31] Bony procedures were used to correct any hip (sub)luxations, internally rotated gait, rotational deformities of the tibia, and bony foot deformities. Pes valgus, pes varus, or pes cavus deformities were corrected in order to create plantigrade and stable feet.

Training Protocol

The training sessions for the exercise group started 3 to 4 weeks after surgery, when it was no longer painful to perform the exercises and there was no danger of recurring injury. During the last 3 to 4 weeks of the hospital stay, 2 physiotherapists (members of the research group) taught and supervised the training protocol. They also gave instructions to the children's parents about executing the exercises after hospital discharge and a detailed written description of the exercises was given to the parents before the child left the hospital. The parents completed a logbook, providing information about the frequency of the training sessions at home (duration, 8.70±0.95mo). At least twice a month the research team contacted the parents at home by telephone to clarify potential issues about the assessment of the training program and to learn whether any adverse effects had developed.

We instructed the children in the exercise group to carry out the training program at least 3 times a week, with an optimal target of 4 times a week. Each training session was 30 to 45 minutes long (depending on the child), and consisted of 7 exercises for both sides (fig 2). Two sets of 5 repetitions for each exercise were performed, with approximately a 1-minute rest between each set and drill. The movement velocity was approximately 4 to 5 seconds per repetition, including slow return to the initial position in order to evoke eccentric muscle activation. The resistance was progressively increased by gradually eliminating the external support during the exercise. As soon as movements against gravity without assistance were feasible, the parents increased further the resistance for the exercises 2, 4, and 5 using elastic rubber bands.[a] Additional rubber-band layers were applied if the child could repeat a whole set without compensatory movements from other muscle groups. For exercises 1 and 7, the thighs were fastened together distally with rubber bands to prohibit excessive hip abduction.

Testing Procedures

The examinations included isometric and isokinetic tests for the knee extensors and flexors, bilaterally, using an isokinetic dynamometer.[b] The muscle groups we selected for testing were surgically treated in most patients (see table 2) and are functionally important during gait. The patients sat on the dynamometer chair, strapped over the trunk and distally to the thigh. The dynamometer pad was fixed above the malleoli.

Prior to each test, we conducted a trial session to familiarize the patient with the testing protocol. For the isometric measurement the knee was fixed at 90° of flexion.[9] Three knee extensions and flexions were performed, with a 30- to 60-second rest between each trial. The isokinetic test was assessed concentrically, at 60° and 180°/s, with movement ranging from

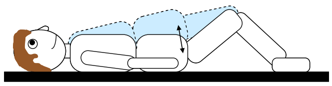
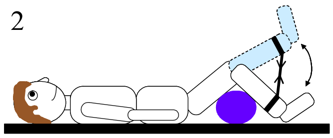
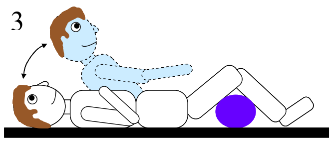
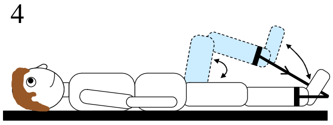
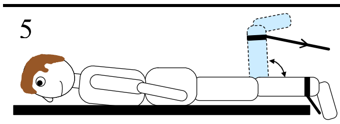
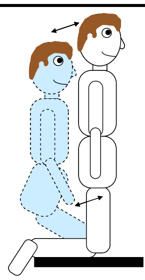
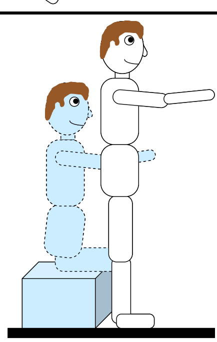
1		**Description:** Pelvis raised lying supine with knees flexed at ≈90°. The hips are fastened together to prohibit hip abduction. **Repetitions:** 2×5 **Mainly trained muscle group:** Hip extensors
2		**Description:** Unilateral knee extension lying supine with the hip flexed at 30°. Knees are supported with a pillow placed under the popliteal fossa. **Repetitions:** 2×5 each side subsequently **Mainly trained muscle group:** Knee extensors
3		**Description:** Sit-ups approaching with the hands to the left, center and right. **Repetitions:** 2×5 each position subsequently **Mainly trained muscle group:** Abdominals
4		**Description:** Unilateral hip and knee flexion from lying supine. **Repetitions:** 2×5 each side subsequently **Mainly trained muscle groups:** Hip flexors, knee flexors
5		**Description:** Knee flexion from prone position. **Repetitions:** 2×5 each side subsequently **Mainly trained muscle group:** Knee flexors
6		**Description:** Knee flexion from kneeling position (90° of knee flexion) with the trunk in upward position. If possible, the pelvis was positioned each time either to the left, center, or right. **Repetitions:** 2×5 each position subsequently **Mainly trained muscle groups:** Hip extensors, knee extensors
7		**Description:** Sitting down and standing up from a chair with the hands projecting to the front. Sitting position at 90° of knee and hip flexion. The thighs were fastened together distally to prevent hip abduction. **Repetitions:** 2×5 **Mainly trained muscle groups:** Abdominals, hip extensors, knee extensors

Fig 2. Schematic description of the training drills.

100° of knee flexion to full knee extension. We tested the knee extensors and flexors separately because some children had difficulties alternating extension and flexion movements. Three sets of 5 repetitions were assessed for each movement direction and each angular velocity. The patients rested 30 to 60 seconds between each set. If the patient failed to perform the test efficiently, we repeated the test after 2 to 3 minutes of rest and further familiarized the child with the procedure when necessary. During testing, the children were allowed to grasp the side grips of the chair,[32] had real-time visual feedback of the joint moment, and were verbally encouraged by the examiner.

The effect of gravity was considered and corrected for when calculating the joint moment. The peak joint moment was then determined and the best value from all repetitions in each testing mode and movement direction was calculated. The average of the 2 sides was statistically analyzed. For the isokinetic trials, only the isokinetic part of the movement was taken into consideration. Many of the children were unable to

Table 3: 95% CI of the Difference Between the Measurements for the MAS, Passive Knee Motion, and GMFM Scores of the Exercise Group and Control Group

Measurements	Group	95% CI for the Difference Between the Examinations		
		$E_{1/2}$–E_0	E_1–E_0	E_1–$E_{1/2}$
MAS (0–4 nominal scale)	EG	**−1.1 to −0.3**	**−1.1 to −0.3**	−0.2 to 0.2
	CG	**−1.0 to −0.2**	**−1.0 to −0.3**	−0.2 to 0.2
Knee extension (deg)	EG	−0.9 to 8.8	−0.9 to 8.8	−3.0 to 3.0
	CG	**0.0 to 9.5**	−0.2 to 9.2	−3.7 to 2.7
Knee flexion (deg)	EG	−14.2 to 2.1	**−12.3 to −0.0**	−7.4 to 7.1
	CG	**−19.4 to −3.6**	**−12.4 to −0.4**	−1.9 to 12.2
Knee ROM (deg)	EG	−10.9 to 6.7	−9.7 to 5.2	−8.3 to 8.0
	CG	−15.4 to 1.9	−9.1 to 5.4	−3.1 to 12.8
GMFM section D (% of maximum)	EG	ND	−8.5 to 5.0	ND
	CG	ND	**6.1 to 19.3**	ND
GMFM section E (% of maximum)	EG	ND	**−13.0 to −0.4**	ND
	CG	ND	−5.5 to 6.9	ND
GMFM total (% of maximum)	EG	ND	−4.8 to 1.1	ND
	CG	ND	**0.7 to 6.5**	ND

NOTE. Significant differences are in boldface.
Abbreviation: ND, no data.

reach the angular velocity of 180°/s and, therefore, this angular velocity was not further analyzed. Furthermore, for technical reasons, data from at least 1 isometric measurement from 9 patients could not be retrieved and therefore these missing data were excluded case-wise from the statistical analysis for the isometrics.

We evaluated the resistance of the knee flexors and extensors to passive movements bilaterally using the MAS.[14,15] Furthermore, we measured the GMFM scores[16] and the passive ROM of the knee in a standardized fashion, with the subject supine and the hip extended or flexed at 90° for the knee extension or flexion, respectively.[33] All measurements in a particular subject were made by the same person. The 3 assessors were not aware of the results of previous measurements. Group allocation was concealed from the assessor measuring torque.

Statistics and Data Analysis

Joint moments were normalized to body mass[17] and the ratio of extension to flexion moment determined.[9] The GMFM sections D (standing) and E (walking, running, jumping) were analyzed separately, in addition to the total score. All GMFM scores were expressed in percentage of the maximum possible achieved scores for each section, and the total GMFM score consisted of the average of all sections.

To determine the size of the 2 groups, we conducted a power analysis with an effect size of 1, 2-tailed α of .05, and power of .80, which resulted in 17 patients per group. Considering a possible 15% drop-out rate during the experiment, we decided to recruit 20 patients per group.

The outcome variables were analyzed using a 2×3 analysis of variance (2-way), with group as a between factor (group: exercise group vs control group) and time of the 3 examinations as a within factor (time: E_0 vs $E_{1/2}$ vs E_1). To adjust the preoperative differences between the groups, we applied a 2×3 analysis of covariance (2-way ANCOVA) as a secondary analysis for the joint moment data, taking the GMFM scores (sections D, E, and total) evaluated at E_0 as covariates. In this case the estimated means were calculated and adjusted for the covariates. Post hoc tests were performed using the Bonferroni adjustment for multiple comparisons. Furthermore, we assessed the differences between the 2 groups at E_0, for age, body mass, height, and hospital stay using unpaired *t* tests and for sex, ability to walk with and without external support, and the GMFCS using chi-square nonparametric statistics. Alpha was set at .05 and the 95% confidence interval (CI) for the difference between the groups and between the examinations was calculated. The analysis was performed with the statistical package SPSS.[c]

RESULTS

Four of the 43 children (3 from the exercise group, 1 from the control group) were excluded during the follow-up because of intraoperative injury (n=1), refusal to attend the E_1 evaluation (n=1), and interruption of the training protocol (n=2). Three of these patients were excluded during the first 6 months of the study and were replaced by other participants. Consequently, the statistical analysis included 20 control group and 19 exercise group children (see fig 1). The age, body height, body mass, and duration of hospital stay did not differ significantly between the 2 groups, although children in the exercise group tended to be older, heavier and taller than the control group children (see table 1).

According to the personal logbook that was filled out at home, the training program was performed 3.2±1.4 times per week, with 13 of 19 children of the exercise group being able to perform the training program 2 to 4 times per week. Three of the exercise group children were not able to practice more than twice per week. During the experiment, no adverse effects were reported as a result of the resistive exercise or PT or the measurement methods.

As shown in table 3, the MAS scores of both groups decreased significantly at $E_{1/2}$, and this decrease remained unchanged until E_1. Concerning the data from the clinical examinations, the passive knee extension deficit observed before the operation (exercise group, −5.0°±9.8°; control group, −5.0°±8.3°) was diminished at $E_{1/2}$ for both groups (exercise group, −1.1°±4.4°; control group, −0.3°±6.6°) and remained unchanged at E_1 (exercise group, −1.1°±4.7°; control group, −0.5°±8.6°). Although this increase was statistically significant only for the control group, the group by time interaction was not significant ($F_{2,74}$=.58, P=.94). The knee flexion was

Table 4: 95% CI of the Difference in GMFM Scores Between the Exercise and Control Groups at E_0 and E_1 Examinations

	95% CI for the Difference Between the Groups (EG–CG)		
Measurements	E_0	E_1	Adjusted E_1*
GMFM section D (% of maximum)	**4.6 to 15.9**	−4.6 to 15.9	−11.5 to 1.4
GMFM section E (% of maximum)	−3.1 to 32.1	−9.9 to 24.0	−13.9 to 3.7
GMFM total (% of maximum)	**0.4 to 16.0**	−3.7 to 9.2	−6.6 to 0.7

NOTE. Significant differences are in boldface.
*ANCOVA with the score at E_0 measurement as a covariate.

significantly decreased for both groups at E_1 compared with E_0, but the group by time interaction was not significant ($F_{2,74}$=1.18, P =.31). Knee ROM did not change significantly for any of the groups at any examination date.

The GMFM score for section D and total increased significantly only for the control group. In contrast, the GMFM score for section E decreased significantly only for the exercise group. However, at E_0 the exercise group had a significantly higher GMFM score for section D and total than the control group (table 4). The trend was the same for the GMFM score of section E, though not significant. Hence, the exercise group was preoperatively in better condition than the control group despite the randomization. This implies that a priori the exercise group had a narrower window for improvement (ceiling effect). We adjusted for this by performing a secondary statistical analysis (ANCOVA) using the GMFM scores at E_0 as covariates. To illustrate the importance of this adjustment, the exercise group tended to have higher GMFM scores at E_1; after the adjustment, the trend was reversed (see table 4, last 2 columns). Furthermore, after adjustment the difference between the groups at E_0 for all joint moment variables was decreased. Therefore, only the adjusted (ANCOVA) results are presented.

As shown in figure 3, the torque of the knee extensors and flexors, under isometric and isokinetic conditions for the control group, decreased significantly at $E_{½}$, followed by a significant increase at E_1. The exercise group followed the same behavior for isometric extensor and isokinetic flexor moments, but failed to show any statistically significant changes for isokinetic knee extension. Furthermore, the isometric knee flexion moment did not decrease significantly at $E_{½}$ (95% CI, −.32 to .03N·m·kg^{-1}), but showed a significant increase during the period between $E_{½}$ and E_1 (95% CI, .13–.41N·m·kg^{-1}). However, the group by time interaction was not significant for the extensor or flexor moment under isometric or isokinetic conditions.

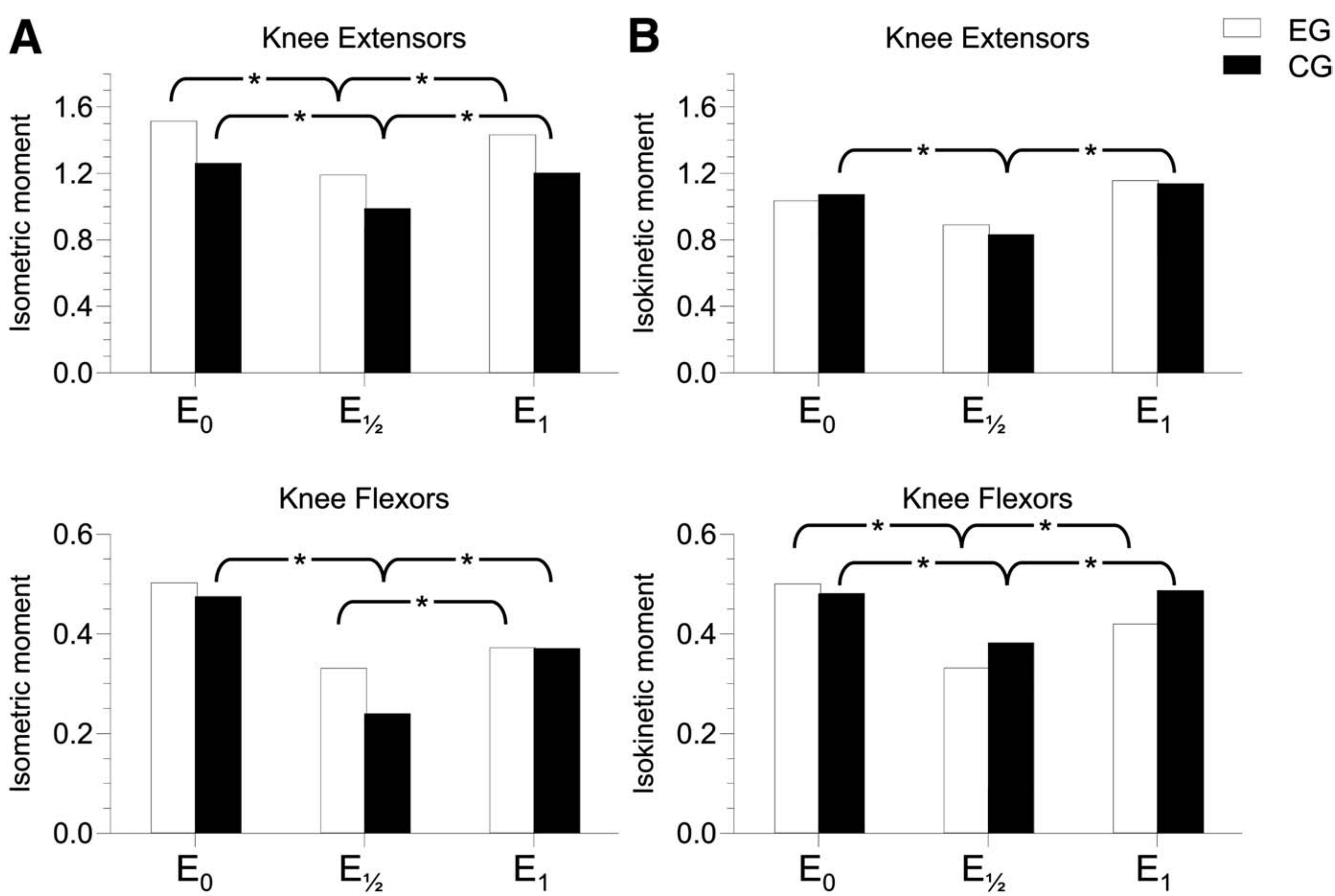


Fig 3. Estimated means for the exercise group (EG) and control group (CG) of the (A) isometric and (B) isokinetic knee flexor and extensor moments normalized to body mass (in N·m·kg^{-1}) during the different examinations: preoperative (E_0), 6-month postoperative ($E_{½}$), and 1-year postoperative (E_1). *Significant differences.

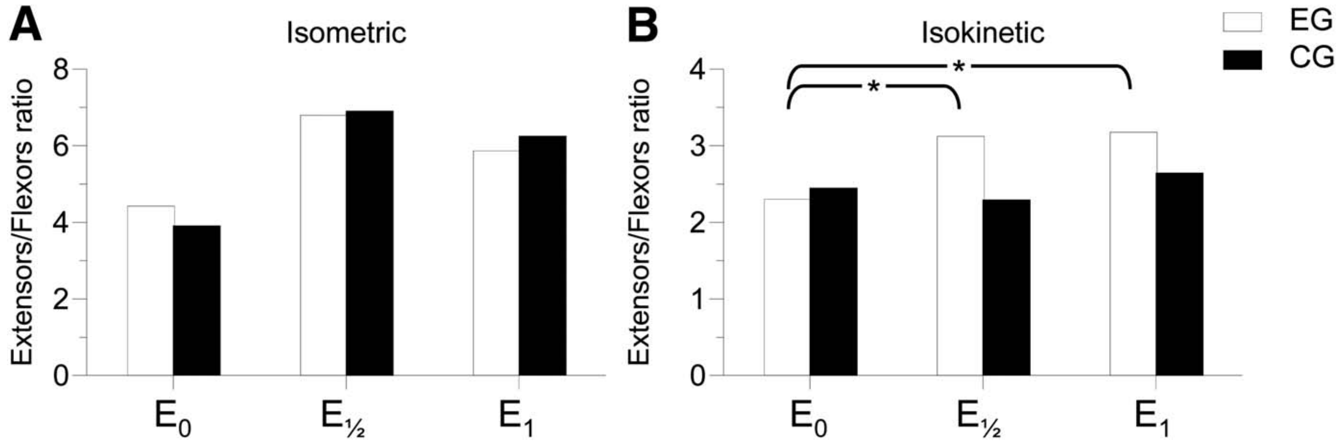


Fig 4. Estimated means for the exercise group and control group of the extensor to flexor torque ratio under (A) isometric and (B) isokinetic conditions during the different examinations: E_0, $E_{½}$, and E_1. *Significant differences.

The extensors to flexors moment ratio under isometric conditions remained unchanged in both groups during isometric conditions despite a common tendency to increase at $E_{½}$ (fig 4). The respective ratio for the isokinetic moment increased significantly only for the exercise group at $E_{½}$ (95% CI, 0.08–1.57) and remained significantly increased compared with E_0 until E_1 (95% CI, 0.09–1.66). No significant group by time interaction was observed for the isometric ($F_{2,50}$=.05, P=.95) and isokinetic ($F_{2,68}$=2.76, P=.07) extensors to flexors moment ratio.

DISCUSSION

The notion that resistance training might increase spasticity[7] is not supported by the present study, which is in good agreement with previous studies.[13] However, it is likely that the decline in the MAS scores in both groups was a consequence of the surgery.[3] Muscle lengthening decreases muscle tension of the spastic muscles and diminishes resistance to passive stretch as well.

The present home-based, low-cost, long-term training protocol involves easy-to-learn movements that have functional impact on everyday life, with only minimum required equipment. After surgery the joint moments of the control group decreased at $E_{½}$ and recovered at E_1. The exercise group showed a similar behavior, but no significant decrease was observed at $E_{½}$ for knee flexor isometric and extensor isokinetic joint moment. However, this distinction from the control group was not strong enough to cause a significant interaction, that is, the 2 groups showed the same joint moments at different examination points.

Concerning the extensor to flexor moment ratio, it was previously reported that children with CP have a greater strength deficit in the knee flexor than in the knee extensor joint moment as compared with healthy children.[9] The augmented extensor to flexor ratio observed at E_0 in the present study supports the argument that knee flexors are weaker than knee extensors. In the exercise group, the ratio increased at $E_{½}$ and E_1 under isokinetic conditions, deviating further from the normative values and suggesting that a more intensive loading of the knee flexors during training might be indicated.

Study Limitations

There are several limitations of this study to be discussed. Although the sample size selected was large enough to achieve a power of 0.8 for a single factor, the power for the group by time interaction was much lower (≈0.4). Hence, even if an interaction effect did exist, it would be unlikely to be detected. To increase the power for the interaction (>0.8), a sample of 100 patients should be randomized; however, this could not be achieved during this 3-year, single-center research project.

Surgical intervention considerably reduces muscle efficiency in the postoperative stage. On the other hand, the training intensity that could be applied was probably not sufficient to overcome this deficit. To achieve adaptations after strength training, at least 65% of maximum load is required.[34] In 4 of 7 exercises from the current study, the load was not progressively increased until the patient could execute the exercise without assistance. Even though our aim was to improve the muscle strength in the sense of explicit strength training, we had to make a compromise concerning the intensity of training, taking into account the special situation of neuromuscular disorder and the difficulties during the postoperative phase. For this reason we differentiate our training from the typical strength training, by calling it "resistive exercise." Furthermore, the resistance of the rubber band increases proportionally with distance and this could be less optimal than isokinetic[12,13] or isotonic[9-11] loading at different joint angles. Moreover, according to the principle of training specificity, the gain in torque for the exercise group may be underestimated because the muscular strength was not measured under the training conditions. Finally, it is ethically inappropriate to discourage or forbid the control group children to be more physically active because there is no argument to support that this could have any adverse effects for children with CP.

Concerning the homogeneity of surgical treatment, although distal transfer of the rectus femoris tendon and lengthening of the knee flexors was performed in almost all patients, the qualitative and quantitative discrepancy between the different surgical procedures among the patients (see table 2) and the outcome of the surgery could only be predicted to a certain degree. It is worth mentioning that, despite the higher GMFM scores, more bony procedures were performed in the exercise group than in the control group (56 vs 65), procedures which generally require a longer low weight-bearing and rehabilitation period.

The above limitations may bias the contrast between the 2 groups and therefore no systematic between-groups differentiation was observed. Such limitations were not present to this extent (if at all) in previous nonrandomized, short-term studies, or even studies without a control group (for a review, see Dodd et al[6]). Only recent published studies[35,36] attempted to create randomized groups and compare the effects of strength training taking a control group of patients with CP as a reference. According to these studies, patients with an age range similar to those in the present study underwent a home-based, 12-week strength training program and showed a marginal improvement in strength, although the functional and psychologic benefits leading to improvement in quality of life should be remarked.

CONCLUSIONS

The additional resistive exercise program had only marginal effects on preventing muscle weakness during the postoperative rehabilitation period. The goals of the present study may have been too ambitious: long-term, low-cost, home-based training protocol, shortly after the operation. Taking into account the limitations of the present study, it cannot be ruled out that a modified form of training might be effective during the postoperative period. More intensive training programs of shorter duration (4–6wk) may result in more direct strength benefits and might encourage the children to comply with such a program for a longer time. In our experience, it is difficult to apply a more intensive training program soon after surgery (3–4wk). Therefore, we suggest a longer interval between the operation and the onset of the training (6–9mo). Finally, the selected exercises should be targeted to improve the balance of forces between agonist and antagonist muscles and this may depend on each subject.

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Suppliers

a. Thera-Band; Hygenic Corp, 1245 Home Ave, Akron, OH 44310.
b. Biodex System 3; Biodex Medical Systems Inc, 20 Ramsay Rd, Shirley, NY 11967-4704.
c. Version 12.0; Apache Software Foundation, 1901 Munsey Dr, Forest Hill, MD 21050-2747.