Effects of a Postoperative Strength-Training Program on the Walking Ability of Children With Cerebral Palsy: A Randomized Controlled Trial

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Objective: To investigate the effect of a postoperative strength-training program on the walking of children with cerebral palsy (CP).

Design: Randomized controlled trial.

Setting: Hospital rehabilitation department.

Participants: Thirty-nine children with CP (age range, 6–16y). After orthopedic surgery, the control group (n = 20) followed a conventional physiotherapy (PT) program, and the strength-training group (n = 19) followed a strength-training program in addition to the conventional PT. Twenty-nine age-matched healthy children were used as references.

Intervention: A 9-month strength-training program.

Main Outcome Measures: Spatiotemporal, kinematic, and kinetic parameters during gait analysis were analyzed before (E0) and 1 year after (E1) the surgery. For 22 children, a 2-year postoperative gait analysis (E2) took place as well.

Results: At E1, several kinematic and kinetic parameters improved, although there was no significant difference between the groups. Spatiotemporal parameters showed a worsening at E1 and a recovery to preoperative values at E2.

Conclusions: The examined parameters may be more substantially influenced by factors such as the surgery outcome and the variability of pathologic characteristics than by the strength-training program per se. However, a more significant effect of the strength-training may appear if more intense and short-term training protocols are used, considering factors such as patients’ motivations, ages, and postoperative statuses.

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

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CEREBRAL PALSY (CP) IS a disorder of movement and posture caused by a nonprogressive defect or lesion of the immature brain.1 The movement deviation of children with CP is attributed to abnormal motor control, restricted range of motion (ROM), and insufficient force production caused by selective muscle atrophy.2

Surgical intervention is often used as treatment in patients with CP, especially during the developmental ages. Excessive hip and knee flexion (crouch gait), hip adduction and internal rotation, and equinus feet are typical symptoms of children with CP that are often indications for surgical intervention.3 The aim of surgery is to improve the joint ROM and to adjust skeletal deformities for a more beneficial function during everyday activities. Furthermore, to restore normal muscle length and improve muscle balance, myotomies and tendon lengthenings and transfers may be undertaken, which would further weaken the already weak muscles.4,5

Despite the traditional belief that strengthening muscles causes increased spasticity levels,6 after strength-training programs children with CP can improve in strength without any significant negative effects on the spasticity level of the muscles.7 There are numerous studies8-13 that have shown muscle strength gains in children with CP. Additionally, increasing muscular strength correlates with improvement in several functional parameters.5,7,14-19 Therefore, strength training has been suggested as an additional treatment option for this patient group.

Several training methods have been recommended for children with CP. Training protocols using isokinetic devices permitting a well-controlled and optimal loading of the joints through the whole ROM20 have been shown to be beneficial in children with CP.7,10,13,15 However, isokinetic devices are not accessible for the vast population of patients. Furthermore, the isokinetic movement rarely relates to any functional movement and therefore, according to the training specificity principle,21 it is more unlikely for training benefits to be transferred into activities such as walking. For this reason more recent studies have concentrated on home-based strength-training programs without the requirement of excessive and costly equipment.5,8,14 Moreover, most training programs lasted 6 to 8 weeks and it has been argued that a 6-week training program for children with CP may be not long enough to induce functional adaptation during walking.9 To our knowledge, there is no long-term study on the effects of a functional strength-training program as an additional postoperative rehabilitation tool that was aimed at shortening the rehabilitation time and that has resulted in functional improvement and correcting gait pattern. The purpose of this study was to examine the effect of a postoperative long-term strength-training program in addition to physiotherapy (PT) in children with CP, with minimal requirements in equipment and costs and involving exercises and movements that are important in everyday life.
METHODS

Participants

Patients aged between 6 and 16 years old, diagnosed with spastic diplegia, and having an indication for surgical treatment were included in the present study. All participants were out-patients of the Department of Orthopaedic Surgery (University of Heidelberg, Germany) and their parents agreed to their participation in the study by signing the informed consent. The study was approved by the local ethics committee.

After the operation patients were randomly divided (sealed envelope method without replacement) into 2 groups (fig 1): (1) the control group, which followed a typical PT program after the operation and (2) the strength-training group, which followed a strength-training program in addition to PT. The PT program was performed 2 to 3 times a week and included exercises to improve gait and to restore the ROM of the lower-limb joints. Twenty children were evaluated for the control group (mean age ± standard deviation [SD], 8.9 ± 1.9y; height, 128 ± 11cm; body mass, 28.5 ± 8.9kg) and 19 for the strength-training group (mean age, 10.6 ± 3.2y; height, 135.6 ± 15.5cm; body mass, 32.5 ± 12.5kg). Before surgery, 2 children from the strength-training group and 7 from the control group required external assistance for walking (walker or crutches). The gait analysis data of 29 healthy children from 6 to 16 years old were used as normative references (mean age, 10.1 ± 2.8y; height, 142.3 ± 16.3cm; body mass, 38.1 ± 13.7kg).

Experimental Design

Two to 4 days after surgery, all patients started performing a regular PT program to re-establish the desired ROM of the lower-limb joints. At the same time, the strength-training program was begun explicitly for the strength-training group. During the hospital stay (duration, 1.8 ± 0.5mo), physiotherapists supervised the strength-training program. At home, the children performed the exercises with their parents. Children and parents filled in personal diaries to determine the frequency of the training sessions. The physiotherapists who treated patients during the regular PT session were well informed about the procedures of the training and were able to answer any potential questions that the patients had.

All patients were examined before the surgery, and this examination (E0) was used as reference. At E0, 3-dimensional gait analysis (kinematics, kinetics), video and clinical examination (including evaluation of the spasticity level using the Modified Ashworth Scale [MAS]), gross motor function measurement (using the Gross Motor Function Measure [GMFM]), and estimation of oxygen consumption and walking efficiency were assessed. Nine months after hospital discharge, which designated the end of the strength-training program for the strength-training group (.93 ± 0.6y postsurgery), all patients were evaluated using the same tests (E1). Additional gait analysis and video and clinical examinations were performed 2.14 ± 0.30 years after the surgery (E2). Between E1 and E2, the strength-training group children did not perform any strength-training sessions. The decision for the E2 measurements was retrospective, and therefore it was possible to measure only 22 of the 39 patients. Fourteen of these patients were able to walk without support at E0, E1, and E2.

Surgical Treatment

All patients underwent a single-event multilevel surgical treatment on both legs. The decision for operation was made after analyzing data from video, clinical examination, 3-dimensional gait analysis, and dynamic electromyography. The surgery included 271 soft-tissue (control group, n = 144; strength-training group, n = 127) and 121 bony procedures (control group, n = 56; strength-training group, n = 65). A more detailed description of the procedures and content of the surgery is available from the authors (D Patikas et al, unpublished data, 2006).

Training Protocol

The training protocol consisted of 7 exercises involving the hip, knee, and ankle extensors and flexors. If children succeeded in overcoming the resistance against gravity, elastic bands were used to increase resistance. Two sets of 5 repetitions were performed for each exercise with a low velocity to permit movement control and eccentric activation of the muscles. A more detailed description of the training protocol content is available from the authors (D Patikas et al, unpublished data, 2006).

The training sessions started 3 to 4 weeks after surgery. After hospital discharge, children in the strength-training group were trained for 40 ± 0.4 additional weeks, until E1. Each session lasted approximately 30 to 45 minutes and was performed on average 3.2 ± 0.3 times a week.

Gait Analysis

A 3-dimensional gait analysis was performed using the Helen Hayes marker set. Data were captured with a 9-camera...
3-dimensional motion analysis system using reflective markers (diameter, 14mm) applied on the skin. The children were asked to walk over a 9-m line at self-selected speeds. Kinetic data were captured using 2 forceplates and only in case a patient required no external body support during walking.

Gross Motor Function Measurement

GMFM scores were assessed at the E0 and E1 examinations. The overall and individual scores of the 5 GMFM sections (A, lying and rolling; B, sitting; C, crawling and kneeling; D, standing; E, walking, running, and jumping) were evaluated and the results were expressed as a percentage of the maximum possible score. A mean of all sections represented the total score, and sections D and E were analyzed separately.

Walking Efficiency

The heart rate, breathing frequency, and oxygen consumption (VO$_2$) were measured online. Patients walked twice for 5 minutes around a 25-m-long pathway (8–12 rounds for each 5-min walk, depending on walking speed). After each 5-minute walk, children rested while sitting for 2 to 5 minutes, until the resting heart rate was reached. The resting VO$_2$ was subtracted from the VO$_2$ during walking and this value was normalized to the body mass and distance that each patient walked. Furthermore, the Energy Expenditure Index (EEI) was calculated using the following formula:

$$\text{EEI} = \frac{\text{HR}_{\text{walking}} - \text{HR}_{\text{rest}}}{\text{walking velocity}}$$

where HR$_{\text{walking}}$ and HR$_{\text{rest}}$ are mean heart rates in beats per minute during walking and at rest, respectively. The strong linear relation between oxygen uptake and heart rate in different velocities supports the use of the EEI as a walking efficiency indicator.

Data and Statistical Analysis

Means and SDs of the averages from both sides were calculated for all dependent variables. The spatiotemporal, kinematic and kinetic parameters and the normalcy index were processed with tools developed in Matlab. To eliminate the effect of differences between the groups before surgery, a univariate analysis of covariance (ANCOVA) was assessed for each dependent variable to determine the differences between the groups at E1, using as a covariate the E0 measurement. One-way analysis of variance (ANOVA) for repeated measurements was used to determine changes between E0, E1, and E2. The significance level was set at .05, and the 95% confidence interval of the difference between the compared groups or measurements was calculated. All statistical analyses were performed using SPSS.

RESULTS

Clinical Data, GMFM, and Walking Efficiency

No difference between the groups was observed in the spasticity level at E0 and E1, as measured with the MAS (table 1). However, a significant decrease in spasticity between E1 and E0 was observed for both groups.

The GMFM score of section D (related to standing) improved significantly at E1, and no difference between the groups was observed when E0 intergroup differences were taken into account.

From the 13 control-group and 16 strength-training–group children who performed the walking efficiency test, the VO$_2$ did not change significantly between the E0 and E1 measurements or between groups. The EEI increased significantly at E1, and this change was not group dependent.

Gait Parameters

One year after the surgery (E1), the spatiotemporal parameters of both groups deviated more from the healthy children as compared with the preoperative measurements (E0) (fig 2). This fact, combined with the increased EEI at E1, led us to decide to measure as many children as possible 2 years after the operation. Because we observed no significant differences between the groups in the spatiotemporal, kinematic, and kinetic parameters (table 2), the 2 groups were merged to calculate the differences between E0, E1, and E2. Walking speed, duration of the stance phase, and stride duration improved significantly during the time period between E1 and E2.

The normalcy index was significantly reduced at E1, and a further decrease followed at E2 (fig 3). The control group had a higher normalcy index before the surgery (see table 2). When we adjusted the preoperative differences between the groups, we observed no significant difference in the normalcy index between the groups.

Concerning the hip joint, 59% of the examined lower extremities did not reach full hip extension at E0, and this deficit was regained after the operation for both groups. Preoperatively, the minimum knee flexion angle at terminal swing was increased for both groups with respect to the normative values. One year postsurgery, both groups had a significant decrease in the knee flexion angle, approaching the normative values. This decrease remained significant at E2, despite the observed increase between E1 and E2. The ankle joint during the stance-swing transition period was in the equinus position, with the control group having a higher plantarflexion angle at E0. The increased plantarflexion preoperatively was drastically reversed at E1 for both groups and tended to increase toward the normative values at E2.

Concerning the kinetic data (fig 4), it was possible to capture data from 9 control-group and 15 strength-training–group children at E0 and E1 and from 14 children at E0, E1, and E2 (see also fig 1). The power absorption at the hip joint was decreased at E0 and increased gradually toward the normative values at E1 and E2 for both groups. We observed no significant difference between the groups or the examinations for the maximum knee power absorption during the loading response. Concern-
ing the ankle joint kinetics, we observed an improvement only between E1 and E2. There was a trend to decrease between E0 and E1, whereas the changes in moment and power of the ankle joint were not group dependent.

**DISCUSSION**

It is well documented that the gait patterns of patients with CP deviate from normal, taking into consideration gait analysis data. For instance, decreased power production from the plantarflexors of children with hemiplegia during walking has been previously reported, and our study supports this as well. Despite the improvement in the ankle joint kinematics at E1, the moment and power of the plantarflexors tended to decrease. This could be attributed to the decreased walking speed, which affects the power production. In addition, the increased duration of the double-support phase could also explain why the ankle moment—and consequently power—decreased at E1. The earlier-mentioned parameters recovered between E1 and E2. This shows that although joint ROM was restored at E1, it took almost 2 years to restore the preoperative power when walking. Furthermore, our study showed that 1 year after the surgery the EEI increased. Consequently, an interval longer than 1 year postsurgery is required to describe the long-term outcome of the surgery. This is in line with a very recent report that suggests that the gait evaluation should be performed at least 3 years after surgery to give the most predictive outcome of the treatment. The same research group had previously reported that triceps surae lengthening led to significant increase in the plantarflexor moment 3 years after the operation. The group that followed a specific strength-training program in addition to regular PT during the rehabilitation period failed to show any significant advantages compared with the group that had only conventional PT. This contrasts with previous studies that have documented well the advantages of strength training in patients with CP. However, there are several explanations for these contradictory conclusions.
Most of the studies in the past have used more intense and short-term training protocols, with regular supervision,\textsuperscript{12,14} which nonetheless required children to make scheduled visits to the rehabilitation center and in some cases to use special equipment, such as isokinetic dynamometers.\textsuperscript{7,10,13,15} This kind of approach is probably ideal for research purposes, but because of time and cost limitations most patients are not able to follow such a training program for a long or even short period. For this reason, and in accordance with more recent studies,\textsuperscript{5,8,14} a home-based training program was suggested in the present study. However, when practicing at home the research team has less control de facto over the frequency and intensity of training. Dodd et al\textsuperscript{8} indicated that the lack of changes in functionally important gait parameters, such as walking speed, after strength training may be attributed to the fact that training sessions were assessed at home and that the minimized therapist supervision could have resulted in a lower-than-ideal training intensity. Our results support this statement.

The strength-training protocols in most of the previous studies, which have been effective for children with CP, had durations of 6 to 8 weeks. Damiano et al\textsuperscript{9} recommended that the strength-training duration should be longer than 6 weeks to be effective. Studies of patients with spinal cord injuries also suggest long-term strength training.\textsuperscript{14} In the present study, the training program was long term (=40wk) to cover the time period after the operation when children show a loss of muscle force production (D Patikas et al, unpublished data, 2006). However, there are some objective difficulties in making such a home-based protocol as intense as possible during this long time period, and therefore it cannot be ruled out that the motivation of some children may have decreased while performing the same training protocol. This cannot rule out the possibility that subjects were “underdosed” to strength training and did not get stronger. Furthermore, the children’s mental maturity may also influence the outcome of training. The age of the children in the present study ranged from 6 to 16 years old. This imposes a noteworthy variability in the way they understand the aspect of strength training (as a part of the treatment or as an obligation for their parents). Such factors may increase the variance within the strength-training group, suppress the contrast between strength-training and control groups, and make comparisons between different studies difficult. Methods to increase children’s motivation (like exercises in the form of games) are necessary to enhance the tolerance of the strength training. It is probable that if in the present study the children had been able to choose into which group they wanted to be placed, the effects of strength training might have been more pronounced. Moreover, it should not be ruled out that some children belonging to the control group could be physically more active than some children that belonged to the training group. It was not possible to control such factors, because it would have been ethically inappropriate to force the children who participated in the study as the control group to be physically inactive.

Another factor that might have limited the training intensity in the present study is the nature of the performed exercises, which involved mainly more than 1 joint and were associated with functionally important everyday activities. Although the principle of specificity is an important issue for training in the healthy population, low levels of motor control may not permit the training effects to be transferred to functional tasks like gait.\textsuperscript{1} Execution of these exercises by patients with CP requires an ordinary level of motor control that may not be available. Previous studies increased the homogeneity of the examined groups by excluding more severely affected patients and taking into consideration specific gait parameters.\textsuperscript{8} In the current study no such exclusion criterion took place, probably resulting in the fact that some patients were not able to execute their training programs as efficiently as others. Another consequence of using multitjoint exercises in patients with CP is that the use of greater load to increase the training intensity is restricted, compared with studies that used single-joint movements with maximal resistance.\textsuperscript{12,14} In our study, the possibility of increasing training intensity after the surgery was limited, because most children were able to execute the exercises moving against gravity at the beginning of the training period (sometimes even with assistance) and gradually were able to use external resistance with elastic bands.

Only a limited number of studies examined the effect of strength training in children compared with a control group that did not perform strength training.\textsuperscript{8,10} In the most recent randomized controlled study,\textsuperscript{8} there was only a trend for the strength-training group to improve in the walking speed and GMFM parameters when compared with the control group.

<table>
<thead>
<tr>
<th>Measures</th>
<th>CG–SG\textsuperscript{*}</th>
<th>E1–E0\textsuperscript{†}</th>
<th>E2–E0\textsuperscript{†}</th>
<th>E2–E1\textsuperscript{†}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking speed (cm/s)</td>
<td>-13.3 to 21.9</td>
<td>-20.7 to 51.2</td>
<td>-7.5 to 0.1</td>
<td>6.0 to 51.2</td>
</tr>
<tr>
<td>Stance phase duration (% of gait cycle)</td>
<td>-4.51 to 2.65</td>
<td>0.21 to 4.96</td>
<td>-3.38 to 0.79</td>
<td>-5.65 to -2.11</td>
</tr>
<tr>
<td>Stride duration (s)</td>
<td>-0.49 to 0.29</td>
<td>0.04 to 0.55</td>
<td>-0.10 to 0.23</td>
<td>-0.44 to -0.02</td>
</tr>
<tr>
<td>Stride length (cm)</td>
<td>-7.1 to 14.8</td>
<td>-7.8 to 5.6</td>
<td>-3.3 to 11.7</td>
<td>-1.2 to 11.8</td>
</tr>
<tr>
<td>Normalcy index</td>
<td>-91 to 170</td>
<td>-168 to -27</td>
<td>-227 to -106</td>
<td>-129 to -10</td>
</tr>
<tr>
<td>Maximum hip extension (deg)</td>
<td>-3.4 to 5.0</td>
<td>-4.3 to 1.9</td>
<td>-5.4 to 1.6</td>
<td>-3.6 to 2.2</td>
</tr>
<tr>
<td>Minimum knee flexion during terminal swing (deg)</td>
<td>-2.9 to 8.4</td>
<td>-23.2 to -12.8</td>
<td>-18.8 to -10.3</td>
<td>0.4 to 6.6</td>
</tr>
<tr>
<td>Maximum plantarflexion during stance-swing transition (deg)</td>
<td>-3.0 to 5.7</td>
<td>9.1 to 20.0</td>
<td>5.7 to 17.4</td>
<td>6.3 to 0.3</td>
</tr>
<tr>
<td>Maximum hip power absorption (W/kg)</td>
<td>-0.240 to 0.192</td>
<td>-0.271 to 0.041</td>
<td>-0.592 to -0.128</td>
<td>-0.419 to -0.072</td>
</tr>
<tr>
<td>Maximum knee power absorption during loading response (W/kg)</td>
<td>-0.217 to 0.392</td>
<td>-0.240 to 0.115</td>
<td>-0.492 to 0.215</td>
<td>-0.319 to 0.167</td>
</tr>
<tr>
<td>Maximum plantarflexion moment (Nm/kg)</td>
<td>-0.131 to 0.161</td>
<td>-0.215 to 0.003</td>
<td>-0.080 to 0.087</td>
<td>0.032 to 0.186</td>
</tr>
<tr>
<td>Maximum plantarflexion power generation (W/kg)</td>
<td>-0.880 to 0.050</td>
<td>-0.609 to 0.088</td>
<td>-0.210 to 0.620</td>
<td>0.166 to 0.765</td>
</tr>
</tbody>
</table>

NOTE. Significant differences are in boldface.

\textsuperscript{*}Univariate ANCOVA with the E0 measurement as covariate.

\textsuperscript{†}One-way ANOVA for repeated measurements (E0 and E1).
Although all participants in the present study were diagnosed with diplegic spastic CP, we observed a considerable variance on several clinical and gait parameters, and this necessitated specialized surgical treatments, depending on the clinical status of each patient. Consequently, the surgery outcome could be neither standardized nor predicted. According to the presented data, the impact of the applied strength-training program was not sufficient to overcome the radical changes that occur in the musculoskeletal system after surgery. This can be verified by the fact that some temporal parameters that showed worsening at E1 recovered at E2, although none of the patients followed a strength-training program between E1 and E2.

**CONCLUSIONS**

The outcome of a specific strength-training protocol applied in children with CP may be affected by several factors such as the optimal duration, intensity, and frequency of the training session. These factors are still to be defined for optimization of the training effectiveness, although it is more likely that these parameters should be determined individually for each patient. The lack of differences between the groups in the present study could be attributed to the immense effect that the surgery had on both groups and should not discourage the application of strength training in children with CP. Apart from the psycho-
logic benefits that children have after such training, a specialized training protocol targeted to well-motivated patients may have the potential to counteract the obligatory muscle weakening after the operation.

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References

Fig 4. Kinetic parameters for the control and strength-training groups prior to, 1 year after, and 2 years after surgery. (A) Maximum hip power absorption, (B) maximum plantarflexor moment, (C) maximum knee power absorption during loading responses, and (D) maximum ankle power generation. The normative values with SD are represented by the continuous horizontal line and the grey zone (n=29). NOTE. Values are mean ± SD. *Significant differences between the measurements for the merged group (CG+SG) that were examined at E0, E1, and E2.


Suppliers
a. Thera-Band; Hygenic Corp, 1245 Home Ave, Akron, OH 44310.
b. Vicon 612; Oxford Metrics, 14 Minns Estate, West Way, Oxford, Oxfordshire, OX2 0BJ.
c. Kistler Instruments, 75 John Glenn Dr, Amherst, NY 14228-2171.
d. K4b2, version 3.2; COSMED USA, 2211 N Elston Ave, Ste 305, Chicago, IL 60614.
e. Version 6.5.1; The Mathworks Inc, 3 Apple Hill Dr, Natick, MA 01760-2098.
f. Version 12.0; Apache Software Foundation, 1901 Munsey Dr, Forest Hill, MD 21050-2747.