Original Article

Intensive Pediatric Constraint-Induced Therapy for Children With Cerebral Palsy: Randomized, Controlled, Crossover Trial

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ABSTRACT

A randomized crossover trial of a new form of pediatric rehabilitation was conducted with 18 children with hemiparesis. Half were randomly assigned to receive pediatric constraint-induced therapy involving constraint of the functional upper extremity and intensive therapy with the hemiparetic upper extremity. Controls received conventional physical and occupational therapy and then were crossed over to receive pediatric constraint-induced therapy. Pediatric constraint-induced therapy produced significantly greater gains than conventional rehabilitation services. (*J Child Neurol* 2006;21:931–938; DOI 10.2310/7010.2006.00201).

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Cerebral palsy is characterized as nonprogressive motor impairment caused by injury to the developing brain and affects at least 2 children per 1000 births annually.[1,2] One of the most prevalent types of cerebral palsy is hemiparetic, an incomplete paralysis affecting one side of the body. Hemiparesis often impairs sensation, sensorimotor processing, and coordinated movements in multiple muscle groups. When hemiparesis is present from birth or the first few months of life, it typically has a profound impact on the child's ability to develop age-typical motor skills and to engage fully in play, exploration, and self-help activities.

Hemiparesis occurs in approximately 33% of all diagnosed cerebral palsy cases[1] and can present with a multitude of movement disorders, including, but not limited to, spasticity, ataxia, and dystonia. Virtually all young children diagnosed with moderate to severe forms of hemiparesis receive multiple types of treatments, usually involving many disciplines and techniques. The most common treatments involve rehabilitation therapies (eg, physical therapy, occupational therapy), despite the fact that there is little evidence that current treatment approaches yield significant benefits.[2–8]

The most widely practiced therapeutic approach in treating children with cerebral palsy used by both physical and occupational therapists is neurodevelopmental treatment.[3] Neurodevelopmental treatment is based on the theory that children with cerebral palsy need to experience the sensation of normal movement. Originally, neurodevelopmental treatment centered on specific handling techniques aimed at decreasing abnormal muscle tone and facilitating normal movement patterns and reflexes.[9] It was assumed that neurodevelopmental treatment would lead to functional gains in children; however, the American Academy of Cerebral Palsy and Developmental Medicine stated that "there is an overwhelming lack of support for Neurodevelopmental Treatment in the treatment of children diagnosed with Cerebral Palsy...."[3] It is noteworthy that the lack of scientific support for conventional neurodevelopmental treatment was recognized more than a decade ago, yet professional practices have changed little since then.[2,5,6,10–13]

CONSTRAINT-INDUCED MOVEMENT THERAPY FOR ADULTS WITH HEMIPARESIS

Constraint-induced movement therapy is a relatively new rehabilitation technique that was developed for treating adults with hemiparesis to help them regain function of the impaired upper extremity.[14–19] The constraint-induced movement therapy protocol developed from basic experimental research concerning the recovery of motor abilities after motor impairment had occurred secondary to central nervous system damage. The protocol includes (1) restraint of the nonparetic extremity combined with (2) intensive motor shaping of the paretic extremity. The current adult constraint-induced therapy protocol recommends restraint of the noninvolved upper extremity for 90% of waking hours each day while intensively training the involved upper extremity with operant training techniques for 6 to 7 hours each day for 10 to 15 weekdays over 2 to 3 weeks. In research populations, these techniques have led to increased functional abilities in the involved upper extremity.[16–18] One of the most impressive findings concerns "cortical reorganization,"[20] as demonstrated by transcranial magnetic stimulation that shows an approximate doubling in the size of the excitable cortex that corresponds to use of the more involved arm and hand in adult patients with hemiparesis after 12 days of constraint-induced therapy.

Taub and Crago suggested that constraint-induced therapy would be well suited for children with cerebral palsy, hypothesizing that neuroplasticity might even be greater in young children.[21] Constraint-induced therapy for adults was based on Taub's theory of "learned nonuse."[14,21] Taub and Crago theorized that substantial neurologic injury often causes more depressed motor function than warranted by actual central nervous system damage.[14] Taub and Crago suggested that this was caused by a reduction in the responsivity of motoneurons surrounding a central nervous system lesion that occurs during the acute phase of injury.[21] Taub theorized that during this acute period of depressed neural function, the individual is either unable to move the involved limb or makes clumsy, inefficient movement attempts.[14] The resulting motor failure then creates a powerful conditioned suppression of movement abilities available during the chronic period of recovery, which Taub termed "learned nonuse." This suppression often remains in place throughout the life span of the patient, unless techniques such as constraint-induced therapy are applied to overcome the learned nonuse, presumably by helping the patient reuse neural connections that are present and/or reestablish neural connections that were previously present.

Theoretically, children who sustain a central nervous system insult in pre-, peri-, or early postnatal periods can actually fail to develop or activate neural pathways for controlled, volitional movement patterns of the impaired upper extremity. In fact, for children with hemiparesis, there is often a lack of movement input during developmental periods when movement repertoires are rapidly being acquired in typically developing children. Instead of "learned nonuse," we propose that these children are more appropriately described as having a "developmental disregard" for the impaired upper extremity. This creates a situation in which, in theory, new neural substrates for entire classes of behaviors might need to be established, refined, and coordinated. This also includes bilateral and gross motor skills that are delayed or fail to develop.

The present study is the first to test the efficacy of pediatric constraint-induced therapy via a randomized controlled crossover trial. The treatment protocol was originally developed and evaluated for a 15-month-old child with virtually no voluntary upper extremity use and a nearly total developmental disregard for her impaired upper extremity.[22] DeLuca and colleagues reported the results of pediatric constraint-induced therapy for this child, which included large and rapid changes in voluntary use of her arm and hand, including reaching, targeting and gross grasping of objects, releasing, and full-arm gestures after 15 days of treatment, with accompanying improvements in trunk control, shoulder girdle, and scapular muscle strength, as well as new functional skills, such as independent sitting and self-feeding of finger foods.

Innovations for the pediatric constraint-induced therapy protocol included use of a long arm cast, which was bivalved for easy removal, with the elbow positioned at 90 degrees and the wrist, hand, and fingers in neutral position with thumb abduction (the cast was worn for 21 consecutive days, 24 hours per day); provision of therapy in the child's natural settings while engaging in a wide range of everyday activities; use of highly motivating play activities to elicit and sustain attention while also modeling

desired new behaviors; and incorporation of an array of standard facilitation techniques, such as hand-over-hand assistance and tactile stimulation to prompt movement and increase sensory awareness of the upper extremity. Consistent with the original adult form of constraint-induced therapy, the pediatric form constantly uses immediate verbal praise and reinforcement that are contingent on the child's behavior, and the therapist constantly adjusts the expectations for the child to continuously higher levels of performance, beginning with a child's primitive efforts to make a movement and advancing to performance of a task in a skillful and independent manner. The treatment length and duration were based in part on the adult version of constraint-induced therapy but also on the pilot work done with the case study, who went through two treatment epochs.[22] The first epoch involved 15 treatment days done over 3 weeks, Monday through Friday. The second epoch involved 21 consecutive days of treatment in an attempt to both maximize treatment benefits and provide treatment periods that would allow all family members to observe the treatment process (eg, a working parent).

This new therapeutic approach is attracting attention from many different sources; however, most attempts to use these techniques have focused on only a portion of the protocol described in this report.[23–26] This report involves the second phase of a study that uses the entire protocol derived from the adult constraint-induced therapy treatment for 17 children. Taub and colleagues presented phase 1 of this study in 2003.[27] This report builds on that data from phase 1 but presents entirely new data in which children who previously had not received pediatric constraint-induced therapy were crossed over and now received the entire pediatric constraint-induced therapy protocol.

METHODS

Subjects

Eighteen children were recruited from local early intervention programs, health care practitioners, and parent referrals. Eligibility criteria were a diagnosis of cerebral palsy with asymmetric involvement of the upper extremity (ie, one upper extremity significantly more functional than the other), 8 years or younger, and good health. The university's Institutional Review Board approved the study protocol, and parents signed informed consent statements. The average age of children was 41.5 months, with a range from 7 to 96 months. There were 13 boys and 5 girls. Table 1 summarizes the children in terms of demographics.

Design

In phase 1, nine children were randomly assigned to the pediatric constraint-induced therapy group and nine to the control group, which continued to receive their traditional or ongoing physical and/or occupational therapy. In phase 2, children in the control group were crossed over to receive pediatric constraint-induced therapy.

Pediatric Constraint-Induced Therapy

Pediatric constraint-induced therapy was administered for 6 hours per day for 21 consecutive days, providing intensive therapy aimed at increasing the functional abilities of the child's involved upper extremity. On the first day, the child's less involved upper extremity was casted from the upper arm to the fingertips using a lightweight fiberglass cast (Figure 1). The cast was bivalved to provide for easy weekly removal to check skin integrity, clean the arm, and allow range of motion.

The day after casting, a trained pediatric constraint-induced therapist (with a degree in occupational or physical therapy plus specialized training from the authors) began the intervention. The therapist presented interesting and useful activities to the child in ways that provided immediate, frequent, and repetitive rewards, primarily in the form of verbal praise, smiles, and supportive gestures, with occasional food and toy incentives for each of the child's observed efforts. Treatment included tasks such as bearing weight on the arm, reaching, grasping, holding, manipulating an object, fine motor hand skills, and activities of daily living that were age appropriate (eg, dressing or undressing, eating, and grooming). The child's behavior was "shaped" to promote increasingly more advanced or sophisticated levels of performance with the impaired upper extremity. Tasks usually were divided into small component skills and then chained together as the child's ability increased. When the child demonstrated a new skill or

Table 1. Demographic Information of Participating Children

*Child**	*Age (mo)*	*Gender*	*Presenting Type of Impairment (at time of treatment)*	*Seizure Disorder*	*Developmental Delay*
Pediatric constraint-induced therapy with casting group					
CHOP	7	Male	Low muscle tone	Yes	Yes
ORMA	10	Female	Spastic	No	Yes
SEIE	18	Female	Spastic	No	No
KSAN	22	Male	Spastic	Yes	Yes
INEY	32	Male	Spastic	No	No
ELDY	50	Male	Spastic	No	Yes
NSER	53	Male	Low muscle tone	No	No
AMUS	74	Male	Spastic	No	No
DEEL	85	Male	Spastic	No	No
Traditional services/crossover group					
VEON	14	Male	Spastic	No	Yes
AHYA	16	Female	Spastic	No	No
ERLE	22	Male	Spastic	No	No
KIER	33	Male	Spastic	Yes	Yes
RSNA	36	Female	Spastic	No	No
TOON	45	Male	Spastic	Yes	Yes
ADAN	43	Male	Spastic	Yes	Yes
WNEY	96	Male	Spastic	No	No
IAIE	86	Female	Spastic	Yes	Yes

*Does not represent any identifying characteristics of the child.

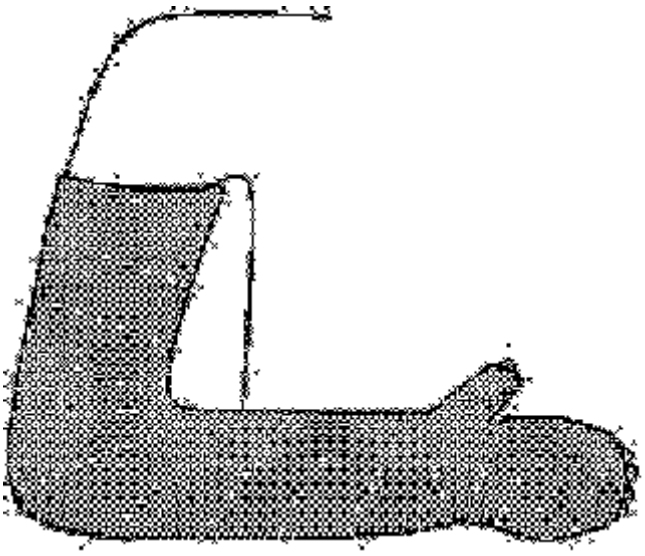

Figure 1. Long arm bivalved cast (axillary area to fingertips).

movement, the therapist proceeded to "shape" this by increasing the demands for more precision, strength, fluency, automaticity, and/or functional versatility, as well as self-initiation of the new skill or movement. For example, at the onset of reaching toward a target with the involved arm, the child would first be rewarded for any minimal movement attempt toward the target object, with increasing demands related to aspects of the movement, such as greater accuracy, control, and duration of movement. The therapist used precise verbal directions about the best way to enact the movement to help the child learn how to achieve a higher level of performance. For many activities, the therapist also helped the child by demonstrating the "next" stage of behavior and sometimes directly prompted or physically guided some of the early attempts so that the child had a working model of the target behavior and was ensured of many successes. On average, a child participated in at least two distinct upper extremity activities each hour, to keep the child interested and motivated, with many opportunities to return to favorite activities for review and continued upper extremity skill progression throughout the day and over the course of treatment.

Therapists encouraged the parents to join in the therapy-related activities and to learn how to use the combination of facilitation techniques and frequent, immediate praise or rewards to practice and extend their child's emerging new behaviors. One of the most important and challenging aspects of this intensive form of therapy is the near-constant provision of treatment. Rather than provide the child with extended "breaks" or rest periods, the therapists learned to use natural transitions to change the pace, to hold children's engagement at high levels, and to motivate the child to be aware of and to use his or her upper extremity in all activities throughout the day. When children took naps or had an unexpected disruption of their treatment, the therapist was responsible for ensuring that the full dose of 6 hours of active treatment per day was provided (eg, by staying longer that day or by scheduling treatment for 3 hours before naptime and 3 hours after naptime). Treatment was all one on one, and the same therapist was responsible for all 21 consecutive treatment days involved with the treatment protocol for each child. Three therapists were involved with treating children during the 1½-year period of this study.

Control and Crossover Group

The children in the control group continued their participation in previously established early intervention programs, school-based therapy services, or private therapy sessions. Control children received these therapeutic interventions for a mean of 2.2 hours/week, from a reported low of one therapy session during the 21 days to a high of four 1-hour sessions per week, dosage levels that were previously prescribed by their health care provider(s) prior to enrolling in this study. The control group children were tested on three occasions (baseline, 3 weeks later, and then another 3 weeks later) before they were crossed over to pediatric constraint-induced therapy and were given the identical protocol as the pediatric constraint-induced therapy group. Eight of the nine control group children completed phase 2 (one child dropped out owing to a conflict in scheduling for the family).

Assessments

All children were assessed 1 to 3 days prior to treatment (baseline) and then again 1 to 3 days after the 3-week treatment period (post-treatment 1), with another follow-up assessment 3 weeks later (post-treatment 2). For children in the crossover condition, their last assessment session (post-treatment 2) served as their pretreatment or baseline assessment prior to pediatric constraint-induced therapy. Children in the crossover condition then participated in two more post-treatment assessments after receiving pediatric constraint-induced therapy.

Assessment Procedures

Each child was assessed in a clinical laboratory setting where one of two experienced pediatric occupational therapists administered the Quality of Upper Extremity Skills Test. Both therapists were unaware of the treatment period or group status of the children involved.

The Quality of Upper Extremity Skills Test is a tool designed to measure therapy outcomes for children with upper extremity movement disorders.[28] The test examines four domains of motor function: dissociated movements, grasp, protective extension, and weight bearing. Interobserver reliability on subscales ranges from .90 to .96. The Quality of Upper Extremity Skills Test was partially validated using the Peabody Developmental Motor Scales-Fine[29] with a correlation coefficient of .84 ($P < .001$); however, the test yields assessments of more differentiated features of upper extremity function. The subscale of primary interest for this study was the Dissociated Movement subscale for the involved arm because it examines arm, hand, and finger movements targeted by pediatric constraint-induced therapy. All items were scored as passed or failed by examiners who were not involved in any other portion of the study protocol.

The Pediatric Motor Activity Log provides parental ratings about the frequency of use and the quality of movement of the involved upper extremity on 22 distinct arm-hand functional tasks (eg, holding a bottle or cup, eating finger foods, crawling on the floor, and taking off shoes and socks) typical of young children. The parents rated their child in terms of both frequency of use ("Please rate how often your child does [task] with the involved arm.") and quality of movement ("Please rate how well your child does [task] with the involved arm."). Frequency of use ratings ranged from 0 to 5: 0 = does not use the arm; 1 = occasionally attempts to use the arm; 2 = regularly uses the arm but uses the noninvolved arm more; 3 = uses both arms about equally for the task; 4 = uses the noninvolved arm sometimes but uses the involved arm more; 5 = exclusive use of the involved arm for the given task. Similarly, the quality of movement ratings ranged from 0 to 5: 0 = does not use arm; 1 = very poor quality; 2 = poor; 3 = moderate; 4 = almost normal; 5 = normal

quality of movement. The parents completed the Pediatric Motor Activity Log at the same time the child was assessed during baseline and post-treatment. In addition, parents completed the log approximately 6 months after treatment ended. Parents were interviewed about the qualitative aspects of the child's response to the pediatric constraint-induced therapy protocol and subsequent use of the involved upper extremity.

The Pediatric Motor Activity Log was based on a similar tool used in the research on adults receiving constraint-induced movement: the Motor Activity Log.[16] The adult log has 14 items and is psychometrically robust, yielding scores that remain stable during a 2-week period of either a placebo treatment[30] or no treatment.[31] The Motor Activity Log has high internal consistency (Cronbach's alpha = .88–.95), interrater reliability (patient compared with primary caregiver, intraclass correlation type 3,1 = . 90), and high test–retest reliability (r = .94, $P < .01$).[30,31]

Over the course of conducting this randomized controlled trial, what became apparent was the salience of many brand-new behaviors emerging in the children's repertoires. The assessment and rating procedures did not yield a summary score to capture these changes in a numerically clear manner. In addition, a rich source of data was the daily treatment log maintained for each child by the pediatric constraint-induced therapist. On completion of the trial, we devised a systematic procedure for deriving a composite measure of children's newly acquired skills on the Emerging Behavior Scale. The Emerging Behavior Scale is a list of 31 upper extremity motor patterns (eg, reaching, grasping, etc) and upper extremity functional activities. For each child, a baseline score is established on behaviors already in the child's repertoire, as observed during the clinical laboratory assessments and videotaped sessions and as rated or described in writing by parents and clinicians. Then at each subsequent assessment period, "new behaviors" are counted, based on documentation of this behavior occurring in at least two different contexts or during two different scoring or assessment procedures. The Emerging Behavior Scale thus yields a summary score of major functional movement changes that has both scientific and clinical utility. In this article, we present both absolute Emerging Behavior Scale scores and change scores (ie, total number of newly demonstrated behaviors or skills).

Data Analysis

Data analysis involved multiple steps for phases 1 and 2. First, analyses for phase 1 were done to determine if there were significant differences between groups on pretreatment assessment scores (to establish equivalency of treatment groups at baseline) using analysis of variance (ANOVA) for each measure. These analyses indicate that the initial treatment groups were not significantly different on the pretreatment scores on any of the outcome measures. All children in this study had a similar diagnosis of cerebral palsy, which, for this article, meant that the central nervous system lesion occurred prior to or no more than 1 month after birth; no more formal definition of etiology was obtained. No significant correlation between outcome and age was observed.

Next, to test for the main effects of the intervention in phase 1, analysis of covariance and multivariate analysis of covariance were conducted. In all analyses, the multiple post-treatment scores were used as outcome measures with pretreatment scores as covariates. This approach was used in recognition that pretreatment scores (which varied considerably among these children with hemiparesis) might account for some of the variance in the post-treatment scores. The main assumptions of this test were met, including the homogeneity of variance and the homogeneity of pretreatment scores between groups. Once the main effects for group were evaluated, then the results for differences across measurement occasions within each group were reviewed to determine the statistical significance of changes for each treatment group. Partial reporting of the results from phase 1 appears elsewhere[26]; the analyses reported here are presented for the first time.

Analyses for phase 2 replicated the last step in phase 1 and included tests to determine if differences across measurement occasions could be determined when children in the initial control group were crossed over to receive pediatric constraint-induced therapy.

RESULTS

Adaptation to the Pediatric Constraint-Induced Therapy Protocol

All 17 children receiving the long-arm casting procedure adapted readily to the constraint, sometimes almost immediately and for others, particularly the toddlers, within 1 to 2 days. The therapists reported that almost all of the children appeared to be very cooperative on the next day when they presented highly focused and fun activities to encourage the child to use the impaired upper extremity. Although some parents had expressed concern that the 6 hours of intervention per day might be too demanding, in fact, almost all of the children showed positive reactions to the intensive intervention. This was not surprising given the flexibility of the intervention activities, the diversity of settings and rewards used, and the highly energetic and engaging behavior of the therapists. There were, however, some times when children wanted to stop "trying" so hard. Under these conditions, the therapists used a combination of approaches, from encouraging continuation for at least a while longer to shifting activities and allowing the child to select something else to do. Over the course of the 21 days, the therapists joined the children and families for many everyday activities, including mealtimes, dressing and undressing, playing with friends and relatives, and going to playgrounds, restaurants, stores, birthday parties, and schools. The only serious difficulties encountered related to behavior control problems that occurred for two children who had an extensive history of behavior management challenges prior to this intervention. The therapists continued the treatment protocol as best as possible when these outbursts occurred; over the 3 weeks, the behavioral problems reduced markedly for these two children.

Once a week, when the bivalved cast was removed to check skin integrity and range of motion with the uninvolved upper extremity, any problems were noted. For three children, there were minor skin irritations that the therapist treated by applying medicated ointment, a small bandage, and additional padding inside the cast. Children maintained full range of motion and showed no loss of functional movement skills over the 3 weeks or thereafter, based on evidence from direct assessment and from parental report.

Upper Extremity Movement Assessments

Figure 2 summarizes the Quality of Upper Extremity Skills Test dissociated movement scores for children in both phase 1 and phase 2. Phase 1 ANOVA, comparing the nine children who received pediatric constraint-induced therapy with the nine controls, revealed a treatment group main effect that approached borderline significance, $F = 3.38$, $P = .09$. Main effects testing for measurement occasions revealed the following results. Pediatric

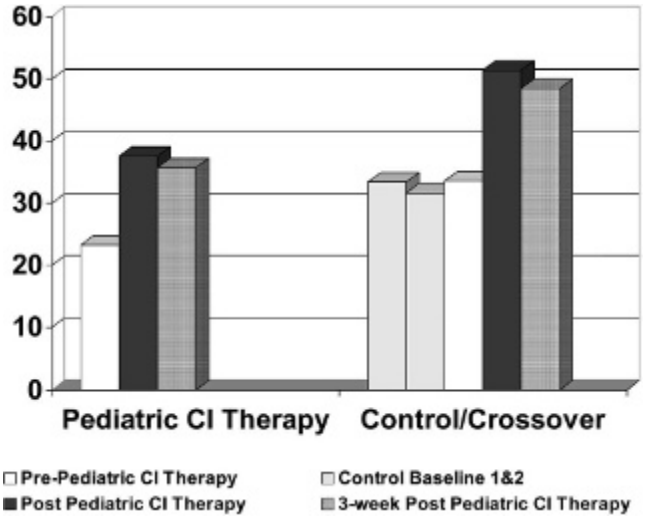

Figure 2. Quality of Upper Extremity Skills Test. CI = constraint induced.

constraint-induced therapy produced a significant measurement occasion effect for the pediatric constraint-induced therapy group, $F = 5.97$, $P = .04$, which was maintained at 3 weeks' post-treatment. Comparatively, the control group showed no significant changes over time, Fs < 1.0. Phase 2 of the study revealed similar findings (see Figure 2). A significant effect for measurement occasion was found for children in the crossover group (ie, the initial control group), indicating the benefits of pediatric constraint-induced therapy, $F = 6.35$, $P = .05$.

Figures 3 and 4 present findings from the Pediatric Motor Activity Log from phase 1 and for phase 2. Treatment group differences were detected by multivariate analysis of covariance for both measures, overall $F = 9.97$, $P = .005$. ANOVA revealed $F = 31.43$, $P < .0001$ for frequency of use and $F = 23.94$, $P < .0001$ for quality of movement. Comparisons of measurement occasions within each group revealed the following: children receiving pediatric constraint-induced therapy in phase 1 had a significant main effect for measurement occasion, $F = 25.39$, $P < .0001$. This gain was maintained on post-treatment 2 at 3 weeks' post-treatment. Comparatively, the control group children had no significant change across measurement occasions, $F < 1$. This pattern of change was also obtained for the Pediatric Motor Activity Log quality of movement scores. In phase 2, the crossover condition, children had demonstrated a very similar pattern of results on both frequency of use and quality of movement for the Pediatric Motor Activity Log scores.

Figure 5 summarizes the data from the Emerging Behaviors Scale. The repeated measures analysis of covariance revealed a significant large main effect for treatment group, $F = 60.62$, $P < .0001$. Main effects testing for measurement occasions revealed a highly significant effect, $F = 15.55$, $P = .001$. Comparatively, the control group change was not statistically significant. Phase 2 of the study revealed significant changes following pediatric constraint-induced therapy (see Figure 5), $F = 7.48$, $P = .016$. The Emerging Behavior Scale required documentation from two independent sources for a behavior to be counted as present, and post-treatment 2 provided the opportunity for only one documentation source, so exact Emerging Behavior Scale scores were not calculated. However, parents were questioned about the presence or absence of behaviors documented, and there was no significant decline.

DISCUSSION

Pediatric constraint-induced therapy proved to be efficacious, as indicated by multiple assessment strategies and by multiple informants on both the original treatment group and the crossover treatment group. All three assessments showed significant positive changes for children participating in pediatric constraint-induced therapy. The largest changes from baseline to post-treatment periods were the summary measure of new behaviors, the Emerging Behaviors Scale, and the standardized parent ratings on the Pediatric Motor Activity Log, on both quality of movement and frequency of use. Of special note is that for these two outcome measures, virtually all children were positive responders, that is, every child acquired new upper extremity behaviors, ranging from a low of 3 to a high of 15 (mean = 8.44

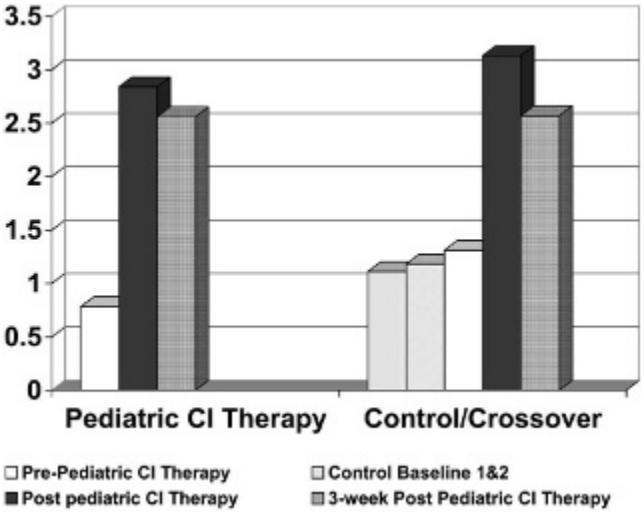

Figure 3. Pediatric Motor Activity Log, frequency of use. CI = constraint induced.

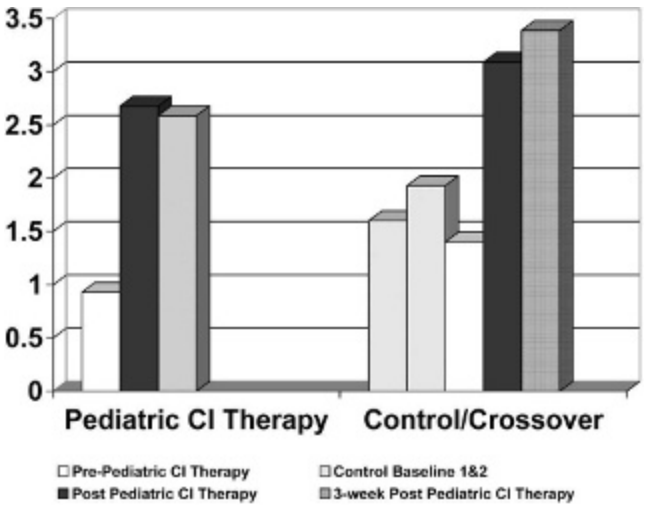

Figure 4. Pediatric Motor Activity Log, quality of movement. CI = constraint induced.

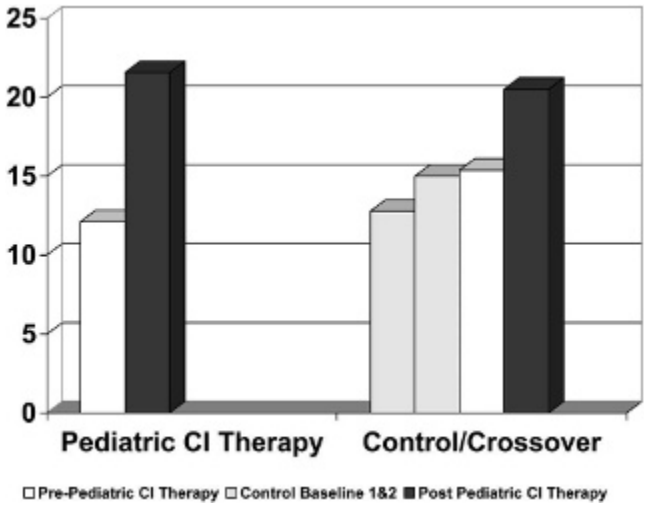

Figure 5. Emerging Behaviors Scale. CI = constraint induced.

among all children receiving pediatric constraint-induced therapy), in a matter of only 3 weeks, and all children were rated by parents as increasing their frequency of use for 22 typical upper extremity activities (from a change score low of 0.86 to a high of 3.41, representing a 1- to 3-point jump on a 6-point scale) and quality of movement (from a low of 0.71 to a high of 2.75, representing a 1- to 3-point jump on a 6-point scale). The Quality of Upper Extremity Skills Test Dissociated Movement subscale is a measure that tests specific upper extremity movements and provides a percentage score for the movements accomplished. This measure showed significant changes only when children received pediatric constraint-induced therapy. Further, the changes detected immediately after the 21-day intensive treatment were maintained for at least 3 additional weeks. All children adapted easily to the constraint imposed by the long-arm cast, showed high degrees of cooperation throughout the intensive course of therapy, and completed the full course of treatment with no injuries or other complications (the one child who dropped out did so prior to the start of treatment owing to the family's decision regarding a scheduling conflict).

CONCLUSION

Children in the present study demonstrated significant changes in many areas of upper extremity function in response to pediatric constraint-induced therapy. These positive changes were significantly greater than those seen in children in the control group on numerous measures that included tests of amount of use, the quality of the movement, and the functional abilities of the involved upper extremity. Children demonstrated the ability to develop entirely new upper extremity motor behaviors, and all children responded positively to treatment regardless of the severity of their individual disability prior to treatment. However, it is recognized that the children involved were from a wide age span, with limited knowledge about the lesions involved. It is also recognized that it would be advantageous to follow the two original groups of children (prior to crossover into phase 2) much farther out, perhaps for 1 to 2 years. This type of longitudinal study would provide much more detailed information about the potential benefits of this protocol in comparison with more traditional rehabilitation services.

Many components of the pediatric constraint-induced therapy protocol were likely beneficial for children in this study and will likely be beneficial for other children with hemiparetic cerebral palsy going through therapeutic processes. The two most notable components of the treatment protocol involved casting of the noninvolved upper extremity and intensive treatment for many hours each day for 3 consecutive weeks. However, pediatric constraint-induced therapy is unique because of its combination of these procedures with many other elements that are designed to best meet the needs of children (eg, operant training, treatment in the home environment, and parent involvement). Many questions remain; for example, which components of pediatric constraint-induced therapy provide the most benefit? In addition, what combinations of the varying components might be applicable in other populations of children with different types of neuromotor disabilities? Are there developmental windows of opportunity or sensitive periods during development when pediatric constraint-induced therapy might be more or less effective? Do the immediate benefits of this approach carry over and have lasting, longitudinal benefits for the children involved as they enter adolescents and adulthood, and, if so, what are the cost-benefit ratios for pediatric constraint-induced therapy in comparison with more traditional approaches? Are there neurologic changes that result from pediatric constraint-induced therapy, and/or how do the type, location, and size of a central nervous system lesion alter treatment benefits, if at all?

Perhaps the most pressing question surrounds the additive effects of the component parts of pediatric constraint-induced therapy. Pediatric constraint-induced therapy consists of and differs from more traditional therapeutic approaches on three points: (1) casting of the noninvolved upper extremity, (2) treatment in a natural setting, and (3) intensive treatment for the involved upper extremity for 6 hours each day for 21 consecutive days. Pediatric constraint-induced therapy is, in fact, unique because it combines these components into one therapeutic process. However, each of these techniques, individually, has potential efficacy on its own and is sometimes even done in various ways during traditional therapeutic settings. In fact, if you examined what is done hour by hour during pediatric constraint-induced therapy by the treating therapist to what is done hour by hour by a good traditional therapist, you would see many similarities. This leads one to question why there seems to be a disparity in the results between traditional therapeutic services and pediatric constraint-induced therapy. Is it the unique combination of these three components into one therapeutic technique? Or could it be that one of the components provides the most therapeutic promise? Most traditional therapists actively promote the participation of parents and caretakers into the therapeutic process to try to increase the intensity with which certain therapeutic events (eg, passive stretching, promotion of active use of a limb) occur in the life of the child. They strive to have their treatment techniques carried over into the child's daily life. Is that because the child needs greater, more intensive treatment, or perhaps it is because the techniques themselves need to occur in the life situation (eg, in the home) of the child? Both of these components are part of

pediatric constraint-induced therapy, but, of course, in addition, there is the casting of the noninvolved arm and what role it plays. Future studies need to break these components apart. Such an analysis will allow a better understanding as to whether pediatric constraint-induced therapy is truly a unique, individual technique, effective only with a specific predefined protocol, or a set of additive effects that can be broken apart and exploited in other treatment settings when clinically appropriate.

This process will also likely lead to very specific questions about the role of intensity. The efficacy of intensity as part of the entire protocol or as a specific treatment on its own must be analyzed in future research. If there is a definable dosage curve, what are the short- and long-term costs and benefits that go along with that curve? Furthermore, this needs to be addressed from the standpoint of the treatment's effectiveness for creating long-term benefits for the child but also from the standpoint of the treating therapist. Pediatric constraint-induced therapy is a worker-intensive process. Can the treatment hours be reduced and make the treatment more cost-effective and worker friendly? Or might children benefit from even greater intensity? In this study, pediatric constraint-induced therapy was demonstrated to be an efficacious treatment for children presenting with hemiparetic cerebral palsy. Although many questions remain and these findings need to be replicated in future studies and other laboratories, this treatment can also serve as a model for the implementation of other potentially effective interventions for children with developmental disorders.

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