The Efficacy of Upper Extremity Inhibitive Casting: A Single-Subject Pilot Study

Janice L. Tona, Colleen M. Schneck

Key Words: cerebral palsy • isokinetic exercises • muscle spasticity • splints

This pilot study was designed to examine the effects of short-term (48-hr) upper extremity inhibitive casting, with an encased thermoplastic splint, on problems related to upper motor neuron damage. The subject was an 8½-year-old girl with left upper extremity spasticity. Three different measures were used: (a) rating of videotaped active movements of the child; (b) the Modified Ashworth Scale, a clinical measure of spasticity; and (c) The Biodex System, a measure of torque during passive elbow flexion and extension. After cast removal, subjective improvements were noted in the quality of active movement (through videotapes) and increased awareness and use of the casted hand by the child (through parents’ reports). A trend toward decreased spasticity was demonstrated by the Modified Ashworth Scale and a statistically significant decrease in resistance to passive movement was shown by the Biodex recordings. However, this reduction in symptoms was temporary, lasting less than 3 days. The results of this study suggest that short-term inhibitory casting may prove efficacious in the treatment of the child with cerebral palsy, although further research is needed.

Persons with upper motor neuron (UMN) damage, such as that seen in cerebral palsy, traumatic head injury, or cerebral vascular accident, face a complex, multifaceted disability. UMN syndrome may be described as consisting of positive symptoms (release phenomena or exaggerations) and negative symptoms (deficits in normal behavior and movement) (Walshe, 1961). Spasticity, which is often seen in persons with UMN syndrome, is a complex phenomenon with varying definitions in the literature (Giuliani, 1991). For the purposes of this study, spasticity is defined as “greater than normal resistance to externally imposed movements, and this resistance increases with both movement amplitude and velocity” (Powers, Marder-Meyer, & Rymer, 1988, p. 115). By this definition, spasticity would be considered a positive symptom, whereas abnormal movement patterns would be considered a negative symptom.

The relationship between positive and negative symptoms has been disputed in the neuroscience literature. The possibility that positive symptoms cause negative symptoms is one suggestion of neuroscience investigation (Corcos, Gottlieb, Penn, Myklebust, & Agarwal, 1986; Dimitrijevic & Nathan, 1967; Hoefler & Putnam, 1940). This cause-and-effect relationship has been challenged by Berger, Horstmann, and Dietz (1984) and Sahrmann and Norton (1977). These challenges include the possibility that abnormal movement patterns may be due to motor planning or execution problems (Kranz, 1981; Tang & Rymer, 1981), or changes in muscle composition (Dietz & Berger, 1983; Hufschmidt & Mauritz, 1985; Lee, Boughton, & Rymer, 1987). By these results, UMN positive symptoms should not be assumed to be the cause of negative symptoms. Although the exact relationship between spasticity (positive symptoms) and movement disorders (negative symptoms) remains unclear (Giuliani, 1991), addressing both positive and negative symptoms may be necessary when treating the person with UMN syndrome. Positive symptoms such as spasticity may contribute to excessive muscle contraction, which may then result in joint contractures (Young & Wiegner, 1987). However, negative symptoms of movement disorders may be more disabling and more difficult to address (Young & Wiegner, 1987). In evaluating a treatment technique for a person with UMN syndrome, it is therefore important to know whether the technique addresses positive symptoms, negative symptoms, or both.

Another aspect of UMN syndrome is the musculoskeletal complications that often follow the initial changes in positive and negative symptoms. These may include changes in the muscle belly or tendon lengths and in the balance of forces between the agonist and antagonist muscle groups (Feldman, 1990; Manske, 1990; Tardieu, Tardieu, Colbeau-Justin, & Lespargot, 1982). Actual changes in muscle composition are also a possibility (Dietz, Quinettm, & Berger, 1981; Tardieu, Colbeau-Justin, & Lespargot, 1982). These musculoskeletal changes
may further increase resistance to passive movement, and may further exacerbate negative symptoms as well.

Nonsurgical techniques, such as casting, are used to reduce positive symptoms, such as spasticity. Two types of casting used in physical medicine are serial and inhibitive or tone-reducing. Serial casting procedures are based on the biomechanics of muscle length. This type of casting may be used with contracted muscles to provide prolonged positioning in a lengthened state, allowing for changes in sarcomere distribution and increased muscle or tendon length or both (Gossman, Sahrmann, & Rose, 1982; Yasukawa & Hill, 1988) by reapplying casts at gradually increasing ranges of motion until the desired range is met. Inhibitive casting uses principles of positioning (i.e., by placing muscles in a position that has a relaxing effect on them) and of pressure application as taught by Rodd in the design of plaster or fiberglass casts (Stockmeyer, 1967; Yasukawa & Hill, 1988). The exact mechanism of spasticity reduction in casting is not known. The possibility that inhibition is due solely to an increase in muscle or tendon length without any true neurophysiological inhibition has been raised (Bohannon, 1987). The rationale most commonly used, however, is that inhibition is the result of neutral warmth and constant pressure (Feldman, 1990). Often, an approach to casting combines inhibitive positioning and serial usage to provide both relaxation and increased range of motion (Sussman & Cusik, 1979; Watt, Sims, Harckham, Schmidt, McMillan, & Hamilton, 1986; Zachazewski, Eberle, & Jefferies, 1982). This combination of inhibitive positioning and serial casting has resulted in some ambiguity as to the goals of casting, as well as in a variety of outcomes measured as a result of casting.

Throughout the literature, decreasing positive symptoms, such as spasticity, has been noted as one goal of inhibitive casting (Barnard et al., 1984; Bertoti, 1986; King, 1982; Otis, Root, & Kroll, 1985; Smith & Harris, 1985; Sussman & Cusik, 1979; Watt et al., 1986; Yasukawa, 1990). However, quantification of muscle tone is a problem in spasticity research, especially clinical research. Upper extremity casting studies that report changes in muscle tone generally rely on subjective interpretation of the resistance felt when the examiner moves the limb passively. This type of measurement may be biased by a number of conditions, such as the consistency of the patient's position, the speed of movement, the amount of force applied during the movement, the temperature of the room, and the time of day.

Lower extremity casts generally incorporate some type of inhibitive foot plate (Hinderer et al., 1988; Hylton, 1990; Sussman & Cusik, 1979) and have been investigated in several studies (Barnard et al., 1984; Cherry & Weigand, 1981; Otis, Root, Pamilla, & Kroll, 1983; Watt et al., 1986; Zachazewski et al., 1982). One study was unique in that the investigators measured resistance to velocity consistent passive motion by using an isokinetic dynamometer with a strain gauge transducer to record the resistance to passive movement at the ankle before casting, immediately after cast removal, and after a period of daytime use of bivalved casts (Otis et al., 1985). Because the resistance to passive movement was then recorded as interval data, the authors were able to use statistical analyses. These authors found statistically significant decreases in both static and dynamic muscle tone after prolonged cast use. Similar objective measurements of muscle tone have been used in other studies of lower extremity resistance to passive movement (Odeen & Knutsson, 1981; Otis et al., 1983; Powers et al., 1988; Tardieu, Tardieu, Colbeau-Justin, & Bret, 1982).

Upper extremity orthotics for spasticity reduction have traditionally been fabricated from low temperature thermoplastics (Farber, 1982; Mackinnon, Sanderson, & Buchanan, 1975; Snook, 1979). Thermoplastic splints provide inhibition through positioning but do not provide the deep pressure, sustained immobilization, neutral warmth, and protection from tactile stimulation available with casts. King (1982) described the use of serial elbow drop-out inhibitive casts, which resulted in increases in range of motion and decreased spasticity. Smith and Harris (1985) used bivalved inhibitive casts to prevent further increases of elbow flexor contractions in a 5 1/2-year-old girl with spastic quadriplegia. The authors reported a sharp decline in elbow flexion contractions immediately after casting and a slight incline thereafter. Additional findings included greater ease in positioning, handling, hypertonus reduction, hand opening, dressing, and an improvement in tolerance for weight bearing.

Recently, upper extremity casts have included the hand (Cruickshank & O'Neill, 1990; Feldman, 1990; Law et al., 1991; Yasukawa, 1990; 1992; Yasukawa & Hill, 1988). Positioning for these casts may include submaximal range of motion for greater relaxation of the limb (Feldman, 1990). Yasukawa (1990) used a sequence of three phases of treatment on a 15-month-old girl with spastic hemiparesis. The first phase consisted of a short arm cast with serial application of 1 week each for 4 weeks, followed by a second phase of casting the uninvolved extremity to encourage active usage of the involved extremity, followed by a third phase of bivalved long arm splint at night on the involved arm. After 1 1/2 years, the author reported increased scapular stability, increased use of humeral flexion, use of the involved limb during transitions, and spontaneous use of the involved limb during bilateral tasks.

The efficacy of short arm casts extending from below the elbow to the palm of the hand was studied in 73 children with cerebral palsy (Law et al., 1991). The subjects were divided into 4 groups receiving either regular neurodevelopmental treatment (NDT), regular NDT plus a cast, intensive NDT, or intensive NDT plus a cast. Although no quantitative differences in movements were found between groups according to the Peabody Developmental Motor Scales, improvements were noted in the
quality of movements between the casted and uncasted groups, as measured by the QUEST (a rating scale designed for the study) and in wrist extension of the casted versus noncasted arms of the children that received casts.

Another study of upper extremity casts that included the hand was reported by Cruickshank and O'Neill (1990). These authors described an 11-year-old boy with spastic quadriplegia who demonstrated improved elbow range of motion with plaster casts, but decreased elbow range of motion in plaster as well as fiberglass casts with a plastic hand splint attachment. The authors postulated that the decrease in range of motion may have been due to stretching spastic muscles across three joints or to the use of fiberglass, which was less rigid and did not provide as much neutral warmth as the plaster.

Although several splints fabricated from thermoplastic materials have been identified in the literature as having tone-reducing effects on the upper extremity (Farber, 1982; Doubilet & Polkow, 1977; MacKinnon et al., 1975; Snook, 1979), the use of thermoplastic inhibitive splints encased within a plaster cast has not been studied. Such a splint incorporated into the upper extremity inhibitive casting at submaximal range of motion should provide maximum upper extremity inhibition in much the same way as the foot plate aids in tone-reduction in the lower extremity (Hylton, 1990; Sussman & Cusik, 1979). This single-subject study was designed to measure the efficacy of an upper extremity cast with an encased thermoplastic inhibitive splint when worn for a short period of time. Both positive symptoms (spasticity) and negative symptoms (abnormal movement patterns) were observed to determine whether such a cast worn for 48 hr resulted in changes in these parameters and, if so, how long these changes were in effect.

Method

Subject

The subject of this single-case study was a girl aged 8 years 6 months with cerebral palsy. The child was referred to this study by her physical therapist and was accepted after a referral was written by her physiatrist and an approved consent form was signed by her parent. The child had spasticity in both lower extremities and in the left upper extremity. A second subject, an 8-year-old girl without pathology, was studied to determine normal response to the Biodex apparatus.

Instruments

Negative symptoms. Negative symptoms of active movement of the left upper extremity were observed in three ways: (a) while being used as an assist when drawing a circle with the right hand, (b) while grasping plastic shapes, and (c) while releasing the shapes. These movements were videotaped from a frontal view while the child was sitting at a table on a high-backed stool. The child was asked to (a) draw a circle on standard 8½-in. by 11-in. sheet of white paper with the right hand holding a large crayon, using the left hand as an assist; (b) grasp shapes from a shape sorter bucket off a table top using the left hand; and (c) release these shapes into an 8-in. open bowl using the left hand. After the videotapes of each study day were randomized, they were viewed and rated by an occupational therapist who was experienced in observing and scoring videotaped movements of children with spasticity and who was not familiar with the design of this study. The movements were scored according to a rating scale (see Figure 1) based on expectations from a non-dysfunctional child for both quality and quantity of movement. A movement quality rating and a movement quantity rating were given for each joint movement and each activity.

Positive symptoms. Positive symptoms of resistance to passive movement were measured with both the Modified Ashworth Scale (Bohannon & Smith, 1987) (see Figure 2) and the Biodex system for multijoint testing and rehabilitation. During both of these measures, the child was seated in a medium-sized Tumble Forms chair that was inserted in the Biodex mobile chair, with her shoulder at 40° of flexion and her elbow fully extended. Internal and external rotation blocks were fabricated from tri-wall cardboard and were secured to the arm of the Tumble Forms chair.

The Modified Ashworth Scale was used as a clinical measurement of resistance to passive movement. The test was performed by an experienced physical therapist who was familiar with the study while the child was seated in the modified Tumble Forms chair inserted in the Biodex chair. The examiner performed the test as described by Bohannon and Smith (1987) (see Figure 2). The test was performed in the direction of elbow flexion, then elbow extension; three consecutive tests were performed on each trial day.

The Biodex System was used for measurement of resistance during constant velocity passive movement. An IBM personal computer with corresponding Bioware was used for data collection, storage, and analysis. A thermoplastic trough with straps was fabricated to stabilize the subject's hand and wrist on the Biodex lever arm (see Figure 3). To analyze the Biodex data, two types of information were collected. First, the lever arm of the Biodex machine was run each day for three trials without the child's arm attached. Second, an 8-year-old girl without pathology was tested one time on the Biodex for six trials.
<table>
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<th>Grasp of Shapes</th>
<th>Release of Shapes</th>
<th>Stabilizer When Coloring With R</th>
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<tr>
<td>Quality</td>
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<td>Shoulder abduction</td>
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Movement Quality Rating:
2. Movement appears somewhat stiff but is continuous.
3. Movement appears somewhat stiff with discontinuity and unexpected jerking or stops.
4. Movement is stiff with no motion at the joint despite expected movement.

Movement Quantity Rating:
1. Movement is performed to fullest range of motion expected.
2. Movement is somewhat limited, but reaches at least half the expected range of motion.
3. Movement is present but is quite limited. Child performs less than half the expected range of motion.
4. No movement is present despite expected movement.

Figure 1. Movement rating scale. R = right hand.

under the same set of conditions as the subject. These two measures were used to determine how the Biodex recorded passive movement without resistance and passive movement with normal resistance.

Procedure

This study was conducted over 11 consecutive days, with days 1 through 4 used for baseline testing, days 5 and 6 (48 hr) used for cast application and wearing, day 7 used for cast removal and immediate testing, and days 8 through 11 used for further post-cast testing. The child was tested at the same time and place each day by the principal investigator and a licensed physical therapist. Testing each day consisted of (a) videotaping active movements; (b) recording muscle tone using the Modified Ashworth Scale; and (c) recording resistance to passive elbow flexion and extension using the Biodex system.

Before day 1 of testing the subject was introduced to the Biodex system over a 2-week period so she would feel comfortable with the system and be relaxed while being tested. When tested on the Biodex system, the subject was positioned as previously described. The left hand was strapped to the fabricated trough on the handle and stabilized with self-gripping straps and the forearm was placed at a consistent angle for pronation–supination (see Figure 3). Range of motion limits were set each day to prevent blocking of the movement by the hand hitting the child’s face or leg. Because the child demonstrated spasticity at the onset, consistent limb weight could not be attained. Therefore, the number 0 was entered as the limb weight for each trial. The Biodex was set at 60° per sec with a 4-sec rest period at the end of each movement. The child’s arm was positioned in full elbow extension...
and the child was told that the movement was about to begin. The child’s arm was then passively moved through flexion and extension at least five times, with the first two trials being used to allow the Biodex arm to accelerate to a

constant speed, and the next three trials being used for data collection. This sequence was repeated three times on each testing day, for a total of nine recorded flexion-extension graphs on each day.

Twenty-four hours after the fourth day of testing, the child’s left arm was casted from the distal two thirds of the humerus down to and including the MCP joints of the hand, with the hand positioned around a thermoplastic cone. The cast remained on for 48 hr. Although the child had full passive range of motion, complete elbow extension could not be attained due to lack of cooperation during casting. The extremity was casted in 40° of elbow flexion, with neutral supination and pronation, and 0° of wrist extension.

Results

The three different daily measures (active movement, Modified Ashworth Scale, and Biodex readings) were analyzed individually to determine trends in each area. Because the movement rating scale yielded ordinal data, a frequency distribution of the movement rating scale scores was used for analysis, and these score frequencies were transformed to percentages to determine which scores were rated most frequently on each testing day (see Table 1). As Table 1 shows, the testing day in which the subject scored in the most normal range was day 7, which was the day the cast was removed. Additionally, subjective comments of the scoring therapist on the day of cast removal read “Left upper extremity looks much, much better—relaxed, open hand with more ‘natural’ looking finger extension/flexion.”

The ratings recorded from the Modified Ashworth Scale were considered ordinal data and were analyzed by first determining the median score on each day. These scores were then plotted across the 9 testing days (see Figure 4). Visual analysis revealed a trend toward less resistance to passive movement after cast removal (day 7).

Finally, the Biodex readings were analyzed with peak torque measures for each of the nine trials on each of the

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<th>Grade</th>
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<td>0</td>
<td>No increase in muscle tone.</td>
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<tr>
<td>1</td>
<td>Slight increases in muscle tone manifested by a catch and release or by minimal resistance at the end of the range of motion when the affected part(s) is moved in flexion or extension.</td>
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<tr>
<td>1+</td>
<td>More marked increase in muscle tone through most of the ROM, but affected part(s) easily moved.</td>
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<tr>
<td>2</td>
<td>Considerable increase in muscle tone, passive movement difficult.</td>
</tr>
<tr>
<td>3</td>
<td>Affected part(s) rigid in flexion or extension.</td>
</tr>
<tr>
<td>4</td>
<td>Affected part(s) rigid in flexion or extension.</td>
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Figure 3. Subject in modified Tumble Forms chair with arm attached to adapted Biodex lever arm.

Table 1

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<th>Movement Rating Scale</th>
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testing days. Recordings for day 9 of testing were lost due to technical error. The curves recorded by the Biodex on each test day were compared to the curves for the lever arm of the Biodex alone (unresisted) and for the lever arm plus the nondysfunctional child's arm (normal resistance). The curves from the nondysfunctional child demonstrated a peak torque equivalent to the weight of the lever arm and to the lever arm plus child's arm, respectively, in both flexion and extension directions. When analyzing the resistance of the spastic child, however, the expected peak torque was seen in the direction of elbow flexion only. Unexpectedly lower levels of peak torque were seen in the direction of extension. Experimentation with a hand-held dynamometer revealed that during the extension movement, a torque exerted in the direction of flexion resulted in a balancing of some of the gravitational torque. Thus, a lower torque level during extension meant that the flexors were exerting torque opposing the movement (Biodex torque recorded during extension = gravitational torque - passive muscle torque). With this formula, the resistance level was calculated for each of the 72 trials. The 9 trials from each test day were then averaged to determine a mean resistance level on each day.

The mean resistance levels for each of the 8 days are plotted in Figure 5. Because these levels were interval data, they were statistically analyzed by methods recommended by Ottenbacher (1986) for analysis of single-subject designs. First, the levels were analyzed to determine
whether serial dependency was present. Significant serial dependency was present neither in the baseline nor across phases. Next, the two-standard deviation band method was applied to determine statistically significant changes in resistance level (see Figure 5). The mean resistance level for the baseline data was 1.9, with one standard deviation being 0.1. Therefore, two standard deviations was 0.2, making the levels of 2.1 and 1.7 two standard deviations above and below the mean respectively; with the two-standard deviation band method, these points were plotted and the area within two standard deviations of the baseline mean was shaded. The pattern of data falling outside the band is considered statistically significant at the .05 level (Gottman & Leib- 

Discussion

This study demonstrated that casting the upper extremity of a child with cerebral palsy for a short time did produce a statistically significant decrease in objectively measured positive symptoms of, as well as a decrease in subjectively rated positive symptoms of, UMN syndrome. Furthermore, it demonstrated that the reduction was temporary.

Figure 5. Passive resistance of left arm on the Biodex.
In addition to the changes seen in positive symptoms, subjective changes in negative symptoms were noted. The scoring therapist's comments on the cast removal day indicate an improvement in the quality of upper extremity movement after casting. Additionally, the child's parents reported an increased awareness of the casted hand by the child, ability to supinate the hand when clapping, and increased use of the extremity as an assist after casting. The increased frequency of more normal movements noted by the rating scale further supports changes in active movements. However, these scores are subjective and difficult to interpret due to the lack of availability of a standardized assessment.

This study raises the question of why this cast was effective in reducing spasticity. Although the goal of this study was not to determine the cause, one may speculate on several possibilities. Firm pressure and neutral warmth may contribute to inhibition, as seen with air pressure splints (Johnstone, 1978) and with wrapping of the extremity (Twist, 1985). The design of the cast also might have contributed to the inhibition, as the hand was casted around a cone, providing deep tendon pressure (Farber, 1982). Also, inhibition could be the result of decreased sensory input from cutaneous, joint, and muscle receptors during cast wearing. This decrease in afferent input may result in spasticity reduction in a manner similar to that seen with selective dorsal rhizotomies, where the affected afferent fibers are severed to reduce exaggerated motor responses (Berman, Vaughan, & Peacock, 1990). A previous case study (Cruickshank & O'Neill, 1990) noted decreased range of motion after the attachment of a hand splint to an elbow cast. The results of this study may have differed because the hand splint was encased in the plaster cast, thus decreasing sensory input further. Finally, inhibition could have resulted from changes in muscle composition or tendon length that could not be clinically evaluated (Gossman, Sahrmann, & Rose, 1982).

If a temporary reduction in positive and negative symptoms is present after wearing of an inhibitive cast, this procedure may prove to be efficacious in the treatment of the child with cerebral palsy. A bivalved cast could be used periodically throughout the day or night, to reduce both positive and negative symptoms and to allow the child to experience more typical movements, thus aiding in his or her learning of new motor movements and development of functional skills. However, further study with larger numbers of subjects is certainly in order before efficacy may be established. The main limitations of this study were a lack of interrater reliability in the videotape assessment, and insensitivity of the Biodex system to small changes in resistance. As only whole foot pounds are recorded, future studies should control for the amount of stretch on the spastic muscle each testing day by setting consistent range of motion limits. If these limits are constant, one can analyze spasticity both by peak torque level (Odell & Knutsson, 1983; Otis et al., 1983, 1985) and by the angle at which peak torque occurred (Powers et al., 1988).

Related studies could focus on the effects of wearing a bivalved cast periodically throughout the day, as Otis et al. (1985) found an even greater decrease in spasticity after a period of bivalved cast usage. Such a study could be designed with a longer postcasting phase with alternating bivalved cast usage. Also, further studies should look at the effect of casting on abnormal motor patterns and whether periodic bivalved cast usage allows for greater relaxation of the limb and more efficacious learning of active motor movements. Current methods of evaluating upper extremity movement in children with cerebral palsy could be used (Law et al., 1991; Fetters, 1991). Cast fabrication could also be changed to encase a long (forearm) cone splint or resting splint, to control for wrist extension and allow for easier cast application. Finally, one should be cautioned to carefully choose subjects for casts similar to the cast used in this study. Generally, casts that cross several joints should be fabricated in submaximal range of motion (Feldman, 1990). Care should be taken not to overstretch the muscles, particularly the small finger muscles. Further study should be done to determine appropriate candidates for this and other types of casts.

Acknowledgments
We thank Ray Burdett, PhD, PT, Carol Giuliani, PhD, PT, Susan Rudinsky, MS, PT, Shari Facchine, MS, PT, and Mary Pat Fasick, OTR. We also thank the research subject and her family for their cooperation.

This study was supported in part through funding received from the School of Health Related Professions Research Development Fund, University of Pittsburgh, and by the U.S. Department of Education/Office of Special Education Personnel Preparation, grant number G008630136.

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