Objective. Tendon transfer surgery to augment hand function lost to spinal cord injury (SCI) has gained acceptance as a rehabilitation option for adults but has yet to be fully explored in children. In this study, hand function and performance of activities of daily living in an 11-year-old child with an SCI were evaluated before and after surgical transfers of the brachioradialis to the flexor pollicis longus and the extensor carpi radialis longus to the flexor digitorum profundus.

Method. With the use of a single-subject AB design, repeated measures of pinch force, the Jebsen Test of Hand Function for Children and the Grasp and Release Test were obtained before tendon transfer surgery and at 2½, 6, and 12 months after surgery. Activities of daily living were assessed with the Functional Independence Measure (FIM) and the Common Object Test (COT) before surgery and 12 months after surgery.

Results. Each assessment revealed a significant improvement in hand function after surgery. Pinch force was measurable only after tendon transfers and increased throughout the first year. By two standard deviation analyses, after surgery there were significantly more task completions for all Grasp and Release Test objects, and task completion times were shorter for the light and heavy objects of the Jebsen Test of Hand Function for Children. FIM results showed that self-catheterization and cutting food were possible only after surgery, and results of the COT revealed new unilateral and bilateral abilities that facilitated the client's independence in writing, eating, applying toothpaste, and brushing teeth.

Conclusion. This single-subject study demonstrates the benefits of tendon transfers for active grasp in a child with an SCI.
in a fashion that reinforces their abilities rather than their disabilities.

**Literature Review**

Literature on SCI in pediatrics has provided insight into etiology, prevalence, and characteristics (Apple, Anson, & Rudolph, 1993; Burke, 1976; Gordon & Marsden, 1970; Murphy, Ogden, & Buchholz, 1981; Sneed, Stover, & Fine, 1986; Triolo, Betz, Mulcahey, & Gardner, 1994); and the application of social issues (Anderson, Lubicky, & Vogel, 1994; Cohn, Mowry, Triolo, & Betz, 1992; Gordon, 1987; Mulcahey, 1992; Mulcahey, Betz, & Smith, 1994; Smith, 1985); rehabilitation (Betz & Mulcahey, 1994; Massagli, Dudgeon, & Ross, 1992; Shea, 1994); and the application of technology (Mulcahey, Smith, Betz, Triolo, & Peckham, 1994; Smith, Mulcahey, Triolo, & Betz, 1992). Although principles of pediatric SCI rehabilitation are emerging (Betz & Mulcahey, 1994), there is a paucity of literature on tendon transfers in children with SCI (Mulcahey, in press).

In the past three decades, the techniques of tendon transfers to augment upper extremity function in persons with SCI have been refined and broadened to meet the functional, cosmetic, and social needs of adults. For this population, tendon transfer options are developed with the International Classification System for Surgery of the Hand in Tetraplegia (Moberg, 1990; Vanden Berghe, Van Laere, Helings, & Vercauteren, 1991). This classification system is based on the principle that if sufficient muscle strength has been retained in two or more muscles that together are responsible for a certain movement, one of those muscles can be transferred with minimal sacrifice to the original movement. For example, a person with C5 tetraplegia who has retained at least a grade 4 muscle strength in the biceps, brachioradialis (BR), and brachialis is a candidate for a BR transfer to the paralyzed radial wrist extensors. Without jeopardizing useful elbow flexion, this tendon transfer can provide wrist extension and the development of a tenodesis that affords a person with SCI, regardless of age at injury, to perform activities of daily living (ADL) (Freehafer, Kelly, & Peckham, 1984; House, Ghwathmey, & Lundsgaard, 1976; Moberg & Lamb, 1980).

Tendon transfers for finger and thumb flexion can provide active pinch and grasp for persons with C6- and C7-level injuries (Failla, Peimer, & Sherwin, 1990; Freehafer et al., 1984; Gansel, Waters, & Gellman, 1990; House, 1985; Kelly, Freehafer, Peckham, & Stroh, 1985; Moberg & Lamb, 1980). Moberg and Lamb (1980) obtained finger flexion by transfer of the extensor carpi radialis longus (ECRL) to the flexor digitorum profundus (FDP) and thumb flexion by transfer of the BR to the flexor pollicis longus (FPL). A 10-year follow-up showed continued strong finger and thumb flexion in an adult population. Freehafer (Freehafer et al., 1984) reviewed 142 tendon transfers performed on 68 clients with SCI, which included multiple procedures to obtain finger and thumb flexion. Function of all but four of the upper extremities improved. Kelly (Kelly et al., 1985) reviewed postoperative results of opponensplasties and flexor tendon transfers on 24 adults with SCI. A total of 57 tendon transfers, 33 opponensplasties, and 22 flexor tendon transfers were performed. Palmar grasp was restored in 45% of the extremities, and lateral pinch was restored in 55% of the extremities. Kelly et al. strongly recommended that all clients with SCI, regardless of age at injury, be evaluated for surgical reconstruction of the hand. Overall, the literature on tendon transfers has revealed positive results for adults with SCI. However, there have been few studies employing objective measurements.

As pediatric rehabilitation teams begin to explore the potential value of reconstructive hand surgery for children with SCI, occupational therapists have an opportunity to establish therapeutic procedures and employ objective outcome measures that will determine the effectiveness of tendon transfers in activities associated with roles at home and school. By using single-subject research designs, occupational therapists can take advantage of this opportunity without compromising other clinical responsibilities. This article reports on the results of tendon transfer surgery and occupational therapy in a child with a C7-level SCI.

**Method**

**Client Profile**

The client is an 11-year-old boy who sustained a traumatic SCI during birth. He is classified with a C7-level, complete injury according to the American Spinal Injury Association Impairment Scale (Ditunno, 1992). The only limitation in his range of motion in the upper extremities is a 10° limitation of bilateral forearm pronation. He has a grade 5 muscle strength in bilateral elbow flexion, elbow extension, and wrist extension. His primary finger and thumb flexor muscles are paralyzed, and volitional control of his finger and thumb extensors preclude the tightening of the flexor tendons necessary for tenodesis grasp. A wrist-driven flexor hinge splint is not indicated as it would interfere with volitional finger and thumb extension and sensation. Universal cuffs and other adaptive splints were rejected by this child because of inferior function as compared to his bimanual method, cosmetics, and comfort. Therefore, most activities are performed bimanually with his palms providing the force to maintain hold of objects (see Figure 1). As a result of his bimanual hand function, he is unable to use one arm to assist with balance and his work space during activities is limited to arm's length at midline. He participates in all school and play activities but for some tasks requires adaptive equipment and assistance. Because of inadequate pinch and grasp force, he is unable to self-catheterize, open milk
Surgical Intervention and Postoperative Management

Transfers of the ECRL to the FDP and BR to the FPL were performed. The FDP tendons were synchronized to ensure a proper balanced grasp. Once the surgical procedures were completed, intraoperative electrical stimulation of these muscles confirmed performance of their new functions (Mendelson, Peckham, Freehafer, & Keith, 1988).

After surgery the extremity was immobilized for 4 weeks in a long arm cast in 90° of elbow flexion, 10° of wrist flexion, 80° of metacarpophalangeal joint (2-5) flexion, and 10° of carpometacarpal joint abduction and interphalangeal (IP) joint flexion of the thumb.

After cast removal, a splint fabricated from low-temperature plastic maintained the hand in the postoperative position for 4 additional weeks to protect the tendon transfers. During this period, the splint was removed only during two 90-min therapy sessions each day, 6 days per week. The client wore the splint at night for 3 months. During the first 2 weeks of therapy, emphasis was placed on tendon transfer reeducation, prevention of adhesions, and edema control. Early tendon transfer reeducation included educating the child about the new functions of the BR and the ECRL and facilitating active range of motion of thumb and finger flexion through play activities. Scar and retrograde massage was provided twice a day. In the third week, graded resistive activities were initiated, and by the fourth week, use of the tendon transfers during play, self-care, and simulated school activities was introduced. After 4 weeks of therapy, the client was discharged to home and returned to school where he incorporated the use of his tendon transfers into everyday activities. He returned to the hospital only for follow up and evaluation of hand function and performance in ADL.

Research Design and Data Collection

A single-subject AB design was used to measure the outcomes of tendon transfers in this child. Written, informed consent was obtained from the client and from his mother before his participation in this study. At least 10 repeat measures of pinch force, the Jebsen Test of Hand Function for Children (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969), and the Grasp and Release Test (Stroh-Waolle, Van Doren, Trotho, Keith, & Peckham, 1994) were collected during the 2 weeks before tendon transfer surgery (phase A) and for 2-week periods at 2½, 6, and 12 months after surgery (phase B). The Functional Independence Measure (FIM) (Hamilton & Granger, 1990) and Common Object Test (COT) (Stroh, Van Doren, Trothro, & Wijman, 1989) were administered 2 weeks before surgery and 12 months after surgery. During data collection at 6 and 12 months, the client and his mother were interviewed informally to obtain their perceptions of the benefits of the tendon transfers at home and school. All of the data was collected by the first author.

Physiological Data

Muscle strength data were collected according to the guidelines of Kendall and McCrea (1983). Five pinch force measurements were obtained before administering the hand function assessments. Pinch force was measured by using a pinch gauge with an extension handle with the arm adducted, the elbow flexed to 90°, and a neutral forearm position. The client was encouraged to extend his wrist to take advantage of passive pinch force during presurgery and postsurgery measurements.

cartons, squeeze toothpaste and glue bottles, run food, or unilaterally manipulate heavy objects such as hardbound schoolbooks.

In addition to disabilities related to the SCI, results of the Southern California Sensory Integration Test (SCSIT) (Western Psychological Testing), the Pediatric Examination of Educational Readiness at Middle Childhood (Levine), and the Motor Free Visual Perceptual Test (Colarusso & Hammit) indicated visual perceptual deficits, auditory processing difficulties, and impairment in selective attention in this client. His problem-solving abilities, expressive language, and social interactions often compensate for other areas and are advantageous to his enactment of family, school, and social roles.

On the basis of the results of the medical and occupational therapy evaluations and the child's desire for autonomy in catheterization, cutting food, and manipulating objects in school, tendon transfer surgery for active lateral pinch on the dominant hand was recommended.

Surgical Intervention and Postoperative Management

Transfers of the ECRL to the FDP and BR to the FPL were performed. The FDP tendons were synchronized to ensure a properly balanced grasp. Once the surgical procedures were completed, intraoperative electrical stimulation of these muscles confirmed performance of their new functions (Mendelson, Peckham, Freehafer, & Keith, 1988).

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Hand Function Data

Hand function data were collected with the use of the Jebsen Test of Hand Function for Children and the Grasp and Release Test. The Jebsen Test of Hand Function for Children is a series of seven standardized and objectively measured tasks representative of major aspects of hand function. Reliability and validity of the test have been established with children with stable hand disabilities (Taylor, Sand, & Jebsen, 1973), and the test has been employed to measure hand function in persons of different ages with a variety of disabilities (Grimm, 1976; Mazur, Menelaus, Hudson, & Stillwell, 1986; Sand, Taylor, Hill, Kosky, & Rawlings, 1974). For the present study, plastic checkers were used because wooden checkers were unavailable. This substitution may negate the reliability of the checker subtask (Rider & Linden, 1988).

Scores are based on the amount of time required to complete each subtask with a limit of 3 min. If a child is unable to complete a task within the time limit, a score of 180 sec is assigned (Taylor et al., 1973).

The Grasp and Release Test consists of the unilateral acquisition of six objects that vary in weight and size. Each object is grasped from a position lateral to midline and released at a midline position. During one trial, an object is acquired, transported, and released for 30 sec; in a single Grasp and Release Test, five trials are performed for each object. Objects are presented in random order and the number of completions is recorded for each trial.

The Grasp and Release Test (Stroh-Wuolle et al., 1994) is designed to minimize the influence of proximal control and forearm rotation and to maximize the assessment of hand function only. It has been used exclusively to measure hand function provided by functional electrical stimulation (FES) in persons with midcervical injuries (Smith, Mulcahey, & Betz, 1994; Smith et al., 1992; Stroh-Wuolle et al., 1994). Although reliability and validity have not been established, the assessment does examine grasp and release abilities, suggesting the presence of content validity.

ADL Data

The FIM was developed in the early 1980s to document severity of a disability and outcomes of medical rehabilitation (Hamilton & Granger, 1990). It measures severity of a disability on a scale from 1 to 7, with 7 representing complete independence and 1 representing complete dependence. Reliability and validity of the FIM have been established (Gray & Kennedy, 1993; Hamilton & Granger, 1990). The FIM has been recognized as a tool for treatment, quality assurance monitoring, and program evaluation. The FIM has been endorsed by the American Spinal Injury Association as the standard measure of function of persons who have sustained an SCI.

The COT uses a task analysis approach to evaluate a person’s ability to perform specific phases of an activity. Each ADL is broken down into phases: There are acquire and release phases and several performance phases unique to each activity. For example, the performance phases of eating are stab, lift-lower, and bite. Each phase is assigned a score of either physical assist, adaptive equipment, self-assist, or independent on the basis of the client’s level of independence. The COT has been used to measure and compare performance during ADL with and without FES (Mulcahey et al., 1994; Stroh et al., 1989). Data on the subject were collected on four activities: writing, feeding, applying toothpaste, and brushing teeth.

Data Analysis

Physiological and Hand Function Data

A two standard deviation band method (Ottenbacher, 1986) was used to compare the client’s performance before and after surgery. A statistically significant change was considered to occur when at least two consecutive data points fell outside the two standard deviation band. Autocorrelation coefficients (which indicate the extent to which scores at one point are predictive of scores at another point in the same set of measures) were calculated for the baseline phase for each task of the Jebsen Test of Hand Function for Children and Grasp and Release Test. Results showed that none of the autocorrelation coefficients was statistically significant. This finding confirmed independence between individual measures and indicated that the two standard deviation band method could be applied. Visual analyses complemented the statistical analyses and were employed when stable baseline measurements could not be established.

ADL Data

Numerical scores were calculated for the FIM and compared across each area of ADL functioning. The independence score for each activity on the COT was analyzed descriptively across each phase as were the client’s and the client’s mother’s responses to open-ended questions.

Results

Physiological Status

Elbow flexion and wrist extension strength remained unchanged after tendon transfer. A grade 5 muscle strength was achieved throughout participation in this study. Finger and thumb flexion strength was severely impaired or absent before surgery. After tendon transfers, finger and thumb flexion was a grade 5. The client was able to flex his fingers and thumb against strong resistance (see Figure 2). An increase in finger extension strength from a grade 3 to a grade 4 was observed at 6 and 12 months after surgery.
Figure 2. Lateral pinch after tendon transfers of the brachioradialis to the flexor pollicis longus and the extensor carpi radialis longus to the flexor digitorum profundus on the left hand. Tenodesis flexion of the child's right hand is shown for comparison.

Before surgery, the client was unable to generate a measurable pinch force with tenodesis flexion. After tendon transfers, pinch forces were measurable, and they increased throughout the first year after surgery (see Figure 3).

Hand Function Status

Johsen Test of Hand Function for Children. As shown in Figure 4a, at 2 1/2, 6, and 12 months after surgery, the client required significantly less time to complete the light can task. For the heavy can task, the client was unable to successfully complete the task before surgery (see Figure 4b) but was able to complete the task in less than 14 sec at all times after surgery. Completion times on both tasks were unchanged after 2 1/2 months.

As shown in Figure 5a–c. completion times in the feeding, cards, and writing tasks were significantly longer only during the initial trials after surgery. For the feeding and card tasks, completion times were not significantly different thereafter. For writing there was a significant decrease in completion times at the end of the 2 1/2-month phase, which was not maintained in subsequent intervention phases.

Stable baselines were not obtained with the checkers and small objects tasks (see Figure 6), which precluded the use of two standard deviation analyses. However, visual analysis of these data suggests improvements in performance with both tasks. Before surgery, the small objects task could not be completed in 4 out of 10 trials but could be completed during all tests 6 and 12 months after surgery. With the checkers task, less variability in the completion times was observed after surgery: Seven of the 12 baseline data points were more than 20 sec, whereas times were always less than 15 sec after tendon transfers.

Grasp and Release Test. Before surgery, the client was unable to manipulate a weight, tape, or a fork. As shown in Figure 7a, tendon transfers provided the client with sufficient pinch force to manipulate each of these objects, with an increase in the median number of completions at 2 1/2, 6, and 12 months.

For the can, peg, and block tasks, there was a significant increase in the number of completions at 2 1/2, 6, and 12 months after surgery. As shown in Figure 7b, there was an immediate improvement with the can task after surgery. For the block and peg tasks (Figures 7c and 7d, respectively), significant improvements were realized at the end of the 2 1/2-month data collection phase.

ADL Performance

FIM. Before surgery, the client scored a 6 on the FIM in feeding because he required adaptive equipment to complete a variety of tasks in these areas. For upper body dressing, he needed assistance from his mother to button and zip his clothing. In the area of bladder management, he scored a 1 as a result of his inability to self-catheterize. Table 1 shows the results of the FIM categories that improved after surgery. With tendon transfers, the client was able to perform all aspects of feeding and upper body dressing independently and was able to self-catheterize after the catheter and gel were placed in front of him.

COT. Results of the four activities, as measured by the COT are shown in Table 2. Before surgery, the client needed two hands (self-assist) to acquire, hold, and release objects for writing, applying toothpaste, and brushing teeth. With tendon transfers, he used one hand (independent) to acquire, hold, and release each object without using this two-handed compensatory pattern.
Figure 4. Completion times for (a) light can and (b) heavy can tasks of the Jebsen Test of Hand Function for Children. Inability to complete the task is denoted by an X. The mean completion time (solid line) and two standard deviation band (dotted lines) of the presurgery data are shown extended into the postsurgery measurement phases. After surgery, completion times were significantly shorter for the light can, and the heavy can task was possible only after surgery.

Discussion

The results of this single-subject study demonstrated that tendon transfers significantly improved this client’s pinch force, prehensile abilities, and performance in ADL as measured by several objective, established assessments. The tools employed were carefully chosen to create a

Table 1

Functional Independence Measure Categories That Improved After Tendon Transfers

<table>
<thead>
<tr>
<th>Category-Activity</th>
<th>Before Surgery</th>
<th>12 Months After Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self-care</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feeding</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Grooming</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Bathing</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Dressing: upper body</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Dressing: lower body</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>toileting</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sphincter control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bladder management</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Bowel management</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: Boldface numbers indicate areas of greater independence after client’s tendon transfer surgery (7 = complete independence; 1 = complete dependence).

Table 2

Results of the Common Object Test for Writing, Eating With a Fork, Applying Toothpaste, and Brushing Teeth Before and 1 Year After Surgery

<table>
<thead>
<tr>
<th>Task</th>
<th>Presurgery</th>
<th>1 Year After Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writing</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Acquire</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Hold</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Write</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Release</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Eating With a Fork</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Hold</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Stab</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Lift-lower</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Bite</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Release</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Applying Toothpaste</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Hold</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Squeeze</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Lift-lower</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Cap on-off</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Release</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Brushing Teeth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Hold</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Squeeze</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Lift-lower</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Cap on-off</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Release</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Brushing contralateral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acquire</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Hold</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Squeeze</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Lift-lower</td>
<td>IN</td>
<td>IN</td>
</tr>
<tr>
<td>Cap on-off</td>
<td>SA</td>
<td>IN</td>
</tr>
<tr>
<td>Release</td>
<td>SA</td>
<td>IN</td>
</tr>
</tbody>
</table>

Note: Boldface indicates phases in which independence scores improved after surgery. SA = self-assist; IN = independent.
Figure 5. Completion times for (a) simulated feeding, (b) cards, and (c) writing tasks of the Jebsen Test of Hand Function for Children. The mean completion time (solid line) and two standard deviation band (dotted lines) of the presurgery data are shown extended into the postsurgery measurement phases. For all three tasks, completion times were significantly longer in the first few trials conducted immediately after rehabilitation but were not significantly different thereafter. This finding may indicate a postoperative learning period associated with performance of these tasks.

Figure 6. Completion times for small object and checker tasks of the Jebsen Test of Hand Function for Children. Baseline measurements were not stable, which precluded use of two standard deviation analyses. However, by visual inspection, it appears that performance on these tasks was less variable after surgery. Inability to complete the small objects task is denoted by an X above the data point.

battery of assessments that were complementary and easily administered. In combination, the Jebsen Test of Hand Function for Children and the Grasp and Release Test assessed manipulation skills that are analogous to hand patterns employed during ADL. The established validity, reliability, and norms of the Jebsen Test of Hand Function for Children are important features of the assessment that strengthened our confidence in the outcomes of this client’s prehensile abilities. Likewise, the specificity of the Grasp and Release Test for measuring hand function in SCI provided applicable and relevant information toward an understanding of this child’s upper extremity abilities. Coupled with actual ADL performance, these assessments yielded important data on the enhancement of grasp abilities after tendon transfers.

Results of the Jebsen Test of Hand Function for Children and Grasp and Release Test lend insight into several important issues in tendon transfer rehabilitation and reflect a learning curve commonly observed during re-education of muscles after transfers. Although the client had already participated in 4 weeks of therapy, he continued to refine his prehension skills and develop strategies for object manipulation after his discharge to home. For example, for the feeding, writing, and small object tasks of the Jebsen Test of Hand Function for Children, completion times for the first few trials immediately after rehabilitation were significantly longer than those of the baseline phase and returned to within baseline values or improved in subsequent trials (see Figures 5a, 5c, and 6). In addition, for the weight, peg, and block objects in the Grasp and Release Test, performance did not improve significantly until later in the 2½-month phase. Further,
Figure 7. Median completions for each session of the grasp and release test for the (a) weight, fork, and tape; (b) can; (c) block; and (d) peg. The weight, fork, and tape tasks could be completed only after surgery. For the can, block, and peg tasks, there was a significant increase in completions across all measurement phases.

Performance with the weight, fork, and tape continued to improve throughout the first year. These results suggest the need for regular follow-up to properly evaluate the long-term outcomes of tendon transfers.

For the writing task in the Jebsen Test of Hand Function for Children, completion times were significantly shorter in the 2.5-month interval only; no significant differences were realized in subsequent intervals. This task was the only task for which this trend was observed and it may reflect how tendon transfers were employed at home. The 2.5-month measurements immediately followed the rehabilitation period during which time the client performed writing activities with the use of the tendon transfers. However, for writing activities performed at home, the client used his tendon transfers for a gross grasp rather than for lateral pinch to hold his pen. Writing data at 6 and 12 months were collected with the lateral pinch. One factor that may have influenced the method in which the client used his transfers to hold a pen was the amount of IP flexion generated from the BR transfer. At 2.5 months, the client’s thumb flexed against the radial aspect of the proximal phalanx of the index finger, which provided a surface area for him to maintain the pen. During follow-up sessions, as the client flexed his thumb to obtain pinch force to hold a pen for writing, the IP joint hyperflexed into the palm, which caused the pen to slip from his pinch. This hyperflexion of the IP joint may be attributed to an increase in strength of the BR transfer from daily use at home. Stabilization of the IP joint by splints or surgical procedures may alleviate this problem.

On both hand function tests, the client’s ability to manipulate the larger, heavier objects only after surgery indicates a newly acquired skill. This skill is evident on ADL tests as well. Only after tendon transfers was the client able to unilaterally hold a tube of toothpaste and manipulate objects associated with feeding and grooming. At home, he reported gaining the ability to manage hardbound schoolbooks and handle full soda cans.

Limitations of the Jebsen Test of Hand Function for...
Children were observed during its administration to this client, which may reflect limitations of the test’s ability to measure changes in hand function after tendon transfers in children with SCI. The test requires visual-perceptual-motor skills and selective attention, which may be impaired in children with dual diagnoses of SCI and learning disabilities or concomitant brain injury. This client’s visual-perceptual deficits and limitations in selective attention may have contributed to the unstable baseline and inconsistent completion times of the small objects task. This task appeared to be the most difficult for this client. Throughout the study, the client had difficulty maintaining visual attention to the objects and had a tendency to become frustrated in his attempts to acquire them. Another limitation of the Jebsen Test of Hand Function for Children is the requirement of midline crossing which, for this client, was not possible because of the presence of a thoracic-lumbar-sacral orthosis (TLSO), commonly prescribed for children with SCI. This client wore a TLSO for management of paralytic scoliosis, which made it difficult for him to shift his weight and reach across midline. Testing without the TLSO was not possible because of his severe scoliosis. In addition, tasks such as cards and feeding require forearm rotation, which may have extended completion times for this client because he had a 10° limitation of pronation. Paralysis of the pronator muscles or limitations of forearm rotation are common among children with tetraplegia.

The results of the present study and other studies (Smith et al., 1994; Smith et al., 1992; Stroh-Wuolle et al., 1994) suggest that the Grasp and Release Test has the potential to be a useful tool for the assessment of hand function. To date, the test has been used exclusively to measure differences between tenodesis abilities and active hand function provided by FES. However, the test’s developers (Stroh-Wuolle et al., 1994) have recommended its extension to assess other interventions such as tendon transfers, splints, or orthoses. Object manipulation does not require weight shifts, midline crossing, or substantial forearm rotation. In this study, the Grasp and Release Test appeared to be sensitive to both the obvious changes from tendon transfers such as the gross manipulation of heavy test objects and to the skills needed to manipulate smaller, lighter test objects. For the three lightest test objects, significant improvements were made after tendon transfers.

Although assessments of ADL were administered to measure the client’s abilities and level of independence in selected activities in the clinic, the results of these clinic-based assessments reflect the client’s potential for performing these and other activities in the context of his own environment. The FIM is a common assessment used in SCI rehabilitation to document outcomes and monitor ADL abilities. Self-care, bowel and bladder control, and upper body dressing were the components of the scale that were sensitive to this client’s changes in hand function. For activities associated with mobility, locomotion, and wheelchair propulsion, unilateral tendon transfers did not increase independence scores. This finding appeared to be due to the lack of grip force in the contralateral hand that is needed for grasping the rim of his wheel to pop or maintain a “wheelie” or maintain hold of an assistive device during ambulation.

Tendon transfers have recently been performed on this client’s nondominant hand (see Figure 8). Preliminary results of this child’s function with bilateral tendon transfers revealed improvement in dressing, mobility, and wheelchair propulsion. Annual evaluations of the client’s abilities are planned to identify the long-term outcomes of bilateral tendon transfers.

Other than writing ability, the FIM does not assess performance in play-related or school-related activities, which are two common occupations of children. Here, other assessments are needed to supplement ADL and hand function data to gain further insight into the benefits of tendon transfers during these activities.

The COT results demonstrated improvements in four ADL. Generally, tendon transfers enabled the client to manipulate objects with one hand, without the need for adaptive equipment or physical assistance. In addition, the client’s independent unilateral manipulation of objects appeared to promote autonomy and confidence in roles at home and school. The COT results also showed another important advantage for this client. He believed that using his mouth during ADL was unacceptable and typically asked his teacher, his mother, or his friends to perform any activity that required his mouth as an assist. During the cap on-off and squeeze phases of applying toothpaste, he was able to use two hands without using his mouth to assist.

Feedback from the client and his mother provided

![Figure 8. Bilateral lateral pinch after tendon transfers of the brachioradialis to the flexor pollicis longus and the extensor carpi radialis longus to the flexor digitorum profundus. Bilateral tendon transfers provided abilities in advanced wheelchair skills such as popping a “wheelie” and negotiating curbs and ramps.](image)
information that gave further insight into his actual performance of these newly acquired activities in home and school. Spontaneous integration of the tendon transfers into his play and school activities was achieved immediately after discharge from rehabilitation. The client's mother observed positive changes in his confidence during ADL and reported less involvement on her part during his dressing and hygiene activities. She also reported shorter time requirements for ADL and writing and eating activities. Moreover, the activities that this client identified as his goals for electing to have hand surgery were achieved. After tendon transfers he was able to self-catheterize, open a milk carton, cut food, and manipulate objects in school.

Although the outcomes of this single-subject study demonstrated the efficacy of tendon transfers for an 11-year-old child, there is no pediatric SCI literature available to support or strengthen the results of this study. Clearly, multiple applications of this design or other research designs are needed to establish the standard of care for upper extremity reconstruction in children with SCI. Additional single-subject studies would help establish a clinical protocol that effectively measures outcomes of tendon transfer surgery for active grasp.

Conclusion

In this pilot study, a battery of assessments administered over a 1-year period demonstrated the utility of tendon transfers for active grasp for a child with a C7-level SCI. On the basis of the results of these clinical assessments, significant improvements in hand function occurred after tendon transfers. In addition, the client reported that he was able to perform activities at home and school that were not possible before tendon transfers. His mother observed positive changes in his autonomy and confidence during activities. As upper extremity reconstructive surgery becomes an acceptable option for children with cervical-level SCI, occupational therapists will need to employ outcome measures to determine the effectiveness of tendon transfers in activities associated with home and school.

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