The Effects of Aging on Upper Limb Tendon Transfers in Patients With Tetraplegia

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Purpose To evaluate the effects of aging on hand function among patients with tetraplegia who had forearm tendon transfer surgery between 1982 and 1990.

Methods The study used a longitudinal cohort design that compared hand function outcomes in 2012 with those obtained 11 years earlier. A digital analyzer was used to measure key pinch and grip strength, and results were compared with those obtained in 2001 to determine changes in strength over time. The study also evaluated changes in participant's employment status, wheelchair use, and subjective changes in function using the Lamb and Chan questionnaire.

Results Participants had a mean key pinch strength force between 11.5 N (tenodeses) and 32.9 N (active transfers) and grip strength forces between 23 N (tenodeses) and 59 N (active transfers). Since 2001, people with active transfers either maintained strength or experienced decreased strength of 5% to 14%. Thumb tenodesis power decreased 40% to 51%, whereas finger tenodeses power increased 32% to 70%. Three activities in the Lamb and Chan questionnaire were identified by the majority of participants as being worse or much worse over the past 11 years. These were performing a pressure relief and propelling a manual wheelchair on level ground and up a ramp. These findings correspond with the increased number of participants who used a power wheelchair in 2012 (64%) compared with 2001 (26%). Close to half of the participants (46%) were employed compared with the 90% in 2001.

Conclusions Tendon transfers continued to provide pinch and grip function for individuals with tetraplegia for many years following spinal cord injury. The decrease in strength of those with active transfers over the 11-year period was within the reported aging loss for the normal population. The small number of participants with tenodesis, however, limited our ability to draw meaningful conclusions for this group. *(J Hand Surg Am. 2014;39(2):317–323.*

Type of study/level of evidence Prognostic III.

Key words Aging, hand function, tetraplegia, upper limb surgery.

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UPPER LIMB RECONSTRUCTIVE surgical procedures for individuals with tetraplegia were described by Moberg in 1975[1] and have since been adopted in many centers worldwide. The goals of surgery are to provide a person with tetraplegia sufficient pinch and/or grip strength to perform activities of daily living (ADL) more independently and without the need for adaptive equipment or orthoses. Although many centers have reported outcomes of upper limb reconstructive surgery,[2,3] little has been published on long-term outcomes.

In 1991, we reviewed 57 people with tetraplegia who had had upper limb reconstructive surgery between 1982 and 1991.[4] In 2001, we re-reviewed all people who had simultaneous bilateral tendon transfers to provide pinch and grip from the 1991 study (n = 24). We found that participants had maintained or improved their grip strength during the 12 to 18 years following surgery. Whereas changes in testing procedures for pinch strength invalidated objective comparisons with pinch strength scores recorded in 1991, other more subjective data suggested that participants had maintained pinch strength.[5]

The aim of our present study was to further review the cohort who had tendon transfer surgery between 1982 and 1991 and determine the changes in grip and pinch strength, the subjective performance of ADL, and the effects of aging on their hand function.

METHODS

Research design and study group

We used a longitudinal cohort design that compared hand function outcomes in 2012 with those obtained 11 years earlier. The study group consisted of people with tetraplegia who had received simultaneous bilateral tendon transfers from 1982 to 1991 and who also had participated in follow-up studies conducted in both 1991 and 2001.[4,5] Ethical approval for the study was obtained from our institutional review board.

Instruments and measures

We classified participants using the International Classification of Hand Surgery for Tetraplegia (ICSHT), a classification used to determine muscle and tendon transfer options for the upper limb in tetraplegia.[6] The ICSHT is considered more sensitive than the American Spinal Injury Association Impairment Scale for assessment of upper limb strength in tetraplegia.[7]

All participants performed key pinch and grip tests using a digital analyzer (DA) (MIE Medical Research Ltd, Leeds, England), a torsion dynamometer linked to a microprocessor digital analyzer. This was the same DA used to test participants in the 2001 study. We calibrated the DA prior to testing. Participants completed the Lamb and Chan questionnaire[8] and were asked to rate their change in function since 2001. The Lamb and Chan questionnaire consists of 25 questions related to the ability to perform everyday tasks using a 5-point scale: much worse, worse, unchanged, improved, and greatly improved. This questionnaire was the one used in both the 1991 and the 2001 studies.

A single researcher (J.A.D.) experienced in the use of these instruments collected all data. For the pinch and grip measurements, we used the American Society of Hand Therapists standardized positioning protocol[9] that had also been used in 2001. Grip aids were not allowed, and the best of 3 attempts was recorded with a 1-minute rest period between attempts. For the measurement of pinch strength, the DA prongs were set 5 mm apart, which is the width of standardized pinch meters such as the Preston Pinch meter (JA Preston Corporation, Clifton, NJ). For the measurement of grip strength, the DA prongs were set 25 mm apart, which is the width of the second handle position of the Jamar dynamometer (Asimow Engineering Co, Los Angeles, CA) and the position recommended by the American Society of Hand Therapists for testing grip strength. All pinch and grip strength measurements were recorded in Newtons (N). All data were entered into an Excel spreadsheet for further analyses.

Statistical analysis

We used customary descriptive statistics to characterize the study group, that is, age, sex, duration of spinal cord injury (SCI), and years since first tendon transfer surgery. In instances in which participants had different ICSHT ratings for each arm, we classified the participant by the limb with the lowest ICSHT rating. For example, if a participant's limbs were classified OCu4 and OCu2, we classified that patient OCu2 for analysis.

We separated pinch and grip strength data by side, type of surgery, tenodesis, and active transfers and used paired t tests (≤ 0.05) to compare results. We calculated the percentage change in strength between 2001 and 2012 for each side and type of surgery.

We compressed the Lamb and Chan questionnaire scores from a 5-point scale to a 3-point scale: worse (worse or much worse), unchanged, and improved (improved or greatly improved). Although this reduced the level of resolution, it allowed us to have more participants within each response category.

We used both parametric and nonparametric tests depending on the distribution of variables under examination.

RESULTS

Study group

Of the 24 participants in the 2001 study, 19 participants were eligible for inclusion in the current study

(Fig. 1). The 2001 data from the 5 participants unavailable for the 2012 study were eliminated from the 2001 data used for comparison with the 2012 data. The characteristics and ICSHT rating for each upper limb of the participants are shown in Table 1 and Table 2.

Surgical procedures

Eighteen of the 19 participants had active elbow extension. Eleven participants had retained active triceps, and 7 participants had had previous bilateral deltoid-triceps transfers performed. The hand surgery procedures for the group are shown in Table 3.

Pinch and grip strength

Key pinch. The mean key pinch strength decreased between 2001 and 2012. In the active transfer group key pinch strength decreased 14% on the right, and slightly increased 1% on the left. In the tenodesis group, decreases in both right (40%) and left (51%) pinch strength was observed. The mean pinch strength was 11.5 N in the tenodesis group and 32.9 N in the active transfer group. Key pinch enabled by active transfer provided nearly 3 times the strength of tenodesis. Despite the percentage decreases, there was no statistical significance between the left and right active transfer and the right tenodesis groups when comparing 2001 and 2012 results. However, there was a significant statistical difference with left tenodesis measurements between 2001 and 2012 ($P = .04$).

Grip strength. Between 2001 and 2012, mean grip strength decreased between 5% (right) and 8% (left) in the active transfer group. By comparison, both left and right tenodesis grip strength increased (70% and 32%, respectively), although there were only 4 observations for the tenodesis group. In 2012, the mean grip strength was 23.0 N in the tenodesis group and 59.0 N in the active transfer group. Even with the significant increase in strength shown by the tenodesis group, active transfers provided nearly double the strength of tenodesis. Despite the percentage changes in the groups, there was no statistical significance between left and right active transfers between 2001 and/or left and right tenodesis.

Lamb and Chan questionnaire

Results from the Lamb and Chan questionnaire indicated that, for most activities, most participants believed their functioning remained unchanged between 2001 and 2012. From the 25 activities examined, participants identified only 3 that had deteriorated during the intervening 11 years. Over 50% (n = 10) of participants believed that their ability to propel their manual wheelchair on level ground or up and down a slope had deteriorated. Seven believed their ability to raise themselves from the wheelchair seat had deteriorated (Fig. 2).

The wheelchair type used by the participants changed between 2001 and 2012. In total, 12 participants (63%) used a power wheelchair for at least some of their mobility needs compared with 5 in 2001 (26%). Figure 3 compares the types of wheelchair used in 2001 and 2012.

DISCUSSION

The aim of this study was to conduct a second follow-up of a cohort with tetraplegia who had tendon transfer surgery between 1982 and 1991 and to determine the effects of aging on grip and pinch strength provided by tendon transfers and tenodeses. The results suggest that key pinch and grip strength are maintained for many years following tendon transfer surgery. However, although the functional performance of active tendon transfers was maintained over time, the strength of these transfers decreased.

There is an association between hand strength and age in the normal population.[10] Grip strength declines are reported from age 45 onward,[11] and individuals 50 to 70 years of age experience a 15% loss in strength per decade.[12] As participants in this study were between 46 and 62 years old, it is reasonable to assume similar declines in their hand strength. Thus the declines of 5% to 14% in pinch and grip strength over the 11-year follow-up period in this study are more likely to be attributable to the aging process rather than any overuse failure of the transferred muscles. Again, advancing age in the normal population is often accompanied by a loss of physical independence due to decreases in muscle strength, sensory acuity, coordination, and energy levels[13] and may be magnified for people with SCI. Charlifue and Jha[13] suggest that physical deterioration with aging commences earlier in SCI individuals than in the normal population. In a study of people with SCI, age was a significant predictor of functional decline with additional assistance being required by these people older than 49 years.[14]

Earlier aging did not appear to be a significant factor in the current study as the decline in pinch and grip strength was similar to that in the normal population. Too few individuals had tenodeses performed and this limited both statistical analyses and any meaningful conclusions or inferences. Both range and

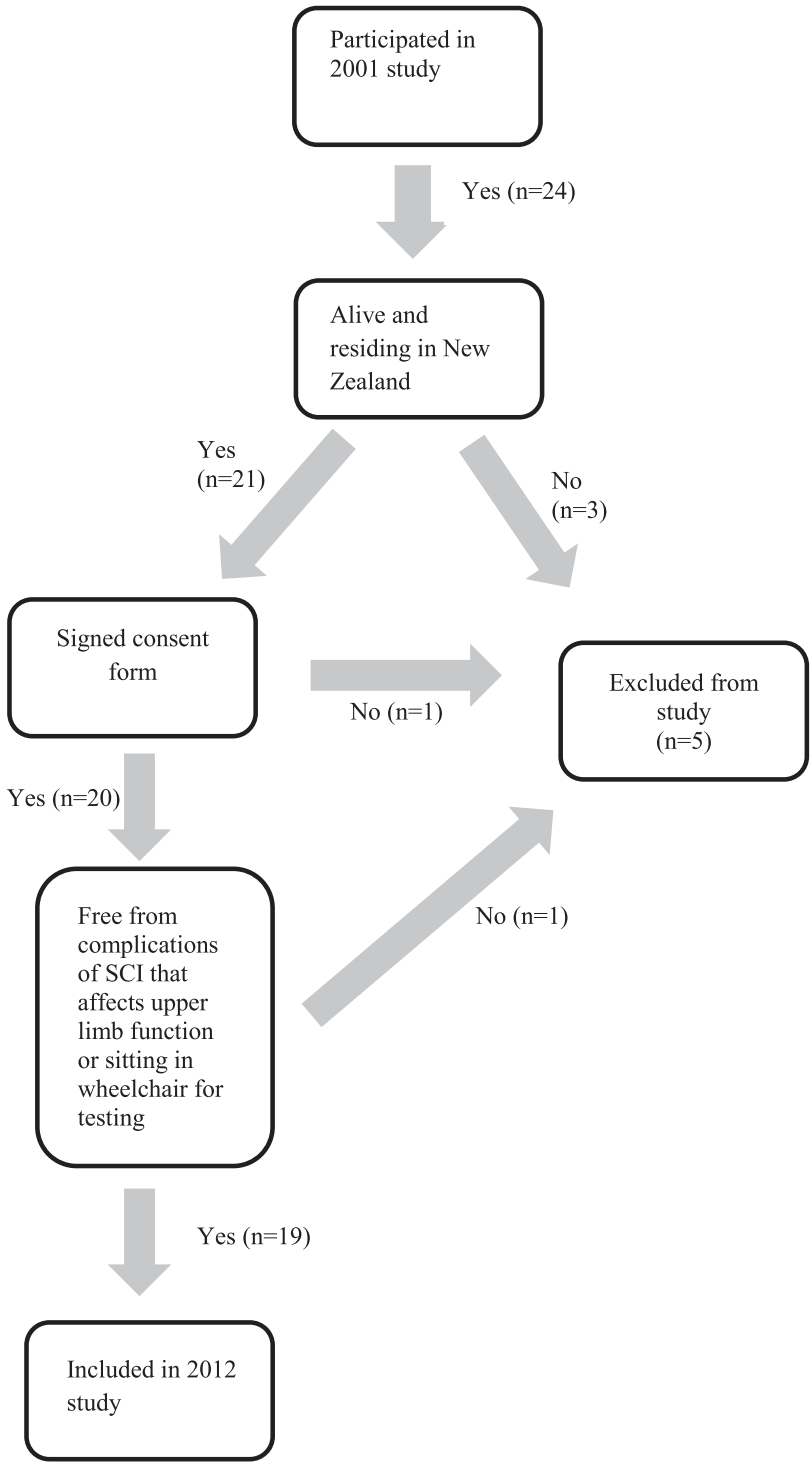

FIGURE 1: CONSORT diagram for recruitment.

strength of wrist extension and the length of the tenodesed tendon provide the strength of the tenodeses. Therefore, a reduction in tenodesis strength may be due to a reduction in either wrist extension strength, range of movement, or possible stretching of the tenodeses over time. A study by Vastamaki[15] of 10 people with tetraplegia with thumb tenodeses found that the strength had deteriorated by 21%, from a mean of 1.4 kg to 1.1 kg over a 21-year period. It was associated with a decrease in wrist extension strength from 9.0 kg to 7.2 kg, which he believed accounted for the reduction in key pinch strength. As neither wrist extension strength nor range of movement was measured in this study, we are unable to draw any

TABLE 1. Study Group Characteristics (n = 19)

Characteristic	Value	Range (y)
Mean age, y (± SD)	53 (± 4)	47–62
Mean time since SCI, y (± SD)	31 (± 4)	26–39
Mean time since first upper limb surgery, y (± SD)	26 (± 2)	23–30
Sex		
Male	18	
Female	1	
Ethnicity		
NZ European	18	
NZ Maori	1	
Level of SCI		
C5	3	
C6	9	
C7	7	
Employment status		
Employed	9	
Not employed	2	
Voluntary	3	
Homemaker	1	
Retired	4	
Relationship status		
Married/de facto	11	
Widowed/divorced	6	
Never married	2	

TABLE 2. ICSHT of Participants

ICSHT Classification	Right (n = 19)	Left (n = 19)	Total (n = 38)
O1	2	2	4
O2/OCu2	2	3	5
O3/OCu3	2	4	6
OCu4	9	5	14
OCu5	4	4	8
OCu6	0	1	1

TABLE 3. Surgical Procedures

Key Pinch		Grip	
BR to FPL	27	ECRL to FDP	20
PT to FPL	4	BR to FDP	7
FPL tenodesis	6	FDP tenodesis	4
Total	37	Total	31

BR, brachioradialis; ECRL, extensor carpi radialis longus; FDP, flexor digitorum profundus; FPL, flexor pollicis longus; PT, pronator teres.

conclusions about the reasons for the reduction in thumb tenodeses strength.

In contrast, finger tenodesis strength increased between 32% and 70% for the right and left hands, respectively. All 4 hands had developed noteworthy proximal interphalangeal joint contractures, but it is uncertain what role, if any, the contractures had in the increased grip strength. Subjectively, participants reported that the tightness of their fingers limited their passive extensor tenodesis action, limiting their ability to grasp and release large objects with one hand, and thus impairing their hand function. We do not know if this is a common long-term complication.

Despite the reductions in pinch and grip strength, the Lamb and Chan questionnaire results demonstrated that the majority of participants reported that their function in ADL had remained the same over the past 11 years. A study by Smaby et al[16] calculated the pinch forces required for execution of functional activities performed by a person with tetraplegia and found that these ranged from 1.4 N to push a button on a remote, to 31.4 N to insert a plug into an outlet. Given that the majority of the everyday tasks tested in this study (eg, zippers, key, automatic teller machine card, stabbing food with a fork) required less than 10.5 N of pinch force, this could explain why our participants' subjective functioning remained unchanged.

Participants rated 3 activities in the Lamb and Chan questionnaire as either worse or much worse from 2001 to 2012. These were ability to perform pressure relief, propelling a manual wheelchair on level ground, and propelling a manual wheelchair up a ramp. Accordingly, there had been increased use of a power wheelchair during the intervening 11 years. Reasons why participants were now using a power wheelchair were not specifically explored, but the aging effect on shoulder and elbow strength would affect these activities more than hand strength and is a likely explanation. In addition, fatigue can be a major issue for people following SCI.[17] However, positive associations between shoulder pain and aging in the patients with SCI and powered wheelchair use have also been reported.[18] Participants did not report a change in their ability to transfer from wheelchair to bed, probably because many participants have never transferred independently. The strength of the shoulder and elbow muscles were not tested in our current study, which from the

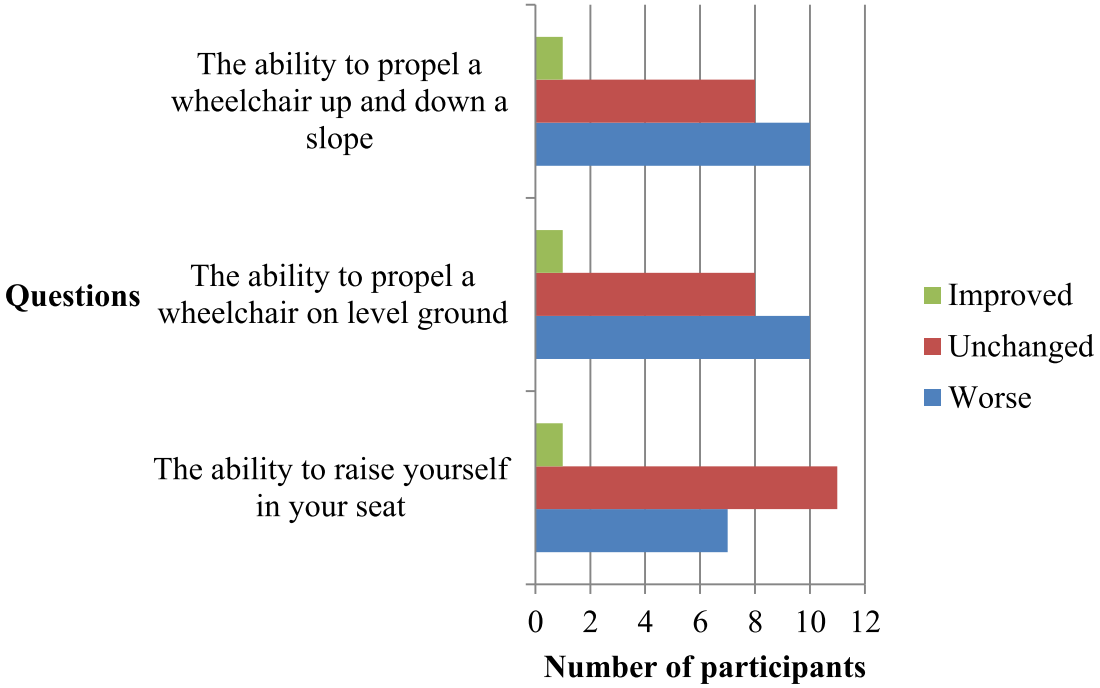

FIGURE 2: Change in ability to propel wheelchair and lift self from seat, 2001 to 2012.

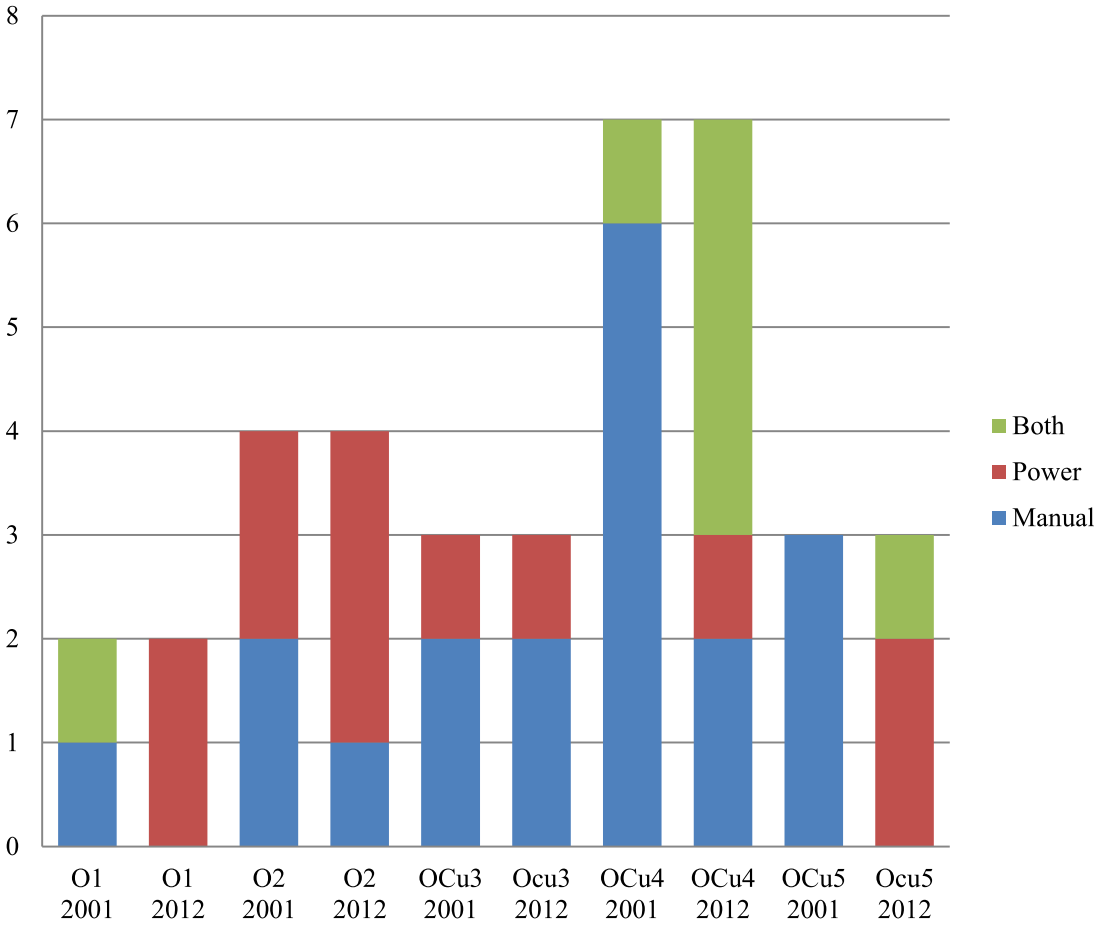

FIGURE 3: Type of wheelchair used by International Classification, 2001 and 2012.

findings of the Lamb and Chan questionnaire would have given us more information on the reasons for the subjective decline in specific tasks.

Employment rates improve with time after SCI with 35% to 56% employed at some time following their injury.[19] Therefore, the 46% employment rate in this study falls within the reported range and contrasted to the 90% employment for these same participants in the 2001 study. Again this is consistent with age attrition. Literature shows that people with SCI discontinue working at an earlier age than their non-disabled counterparts.[20] We believe that the surgical improvement of upper limb function enhances functional independence in the work place for people with tetraplegia and thus increases their chances to become or remain employed as functional limitations in the workplace negatively influence full workplace participation in the absence of adequate environmental accommodation.

This study had some limitations. First, the sample size is relatively small, which limited the statistical analyses and, in the case of the tenodesis group, any meaningful conclusions or inferences. Second, whereas the aim of this study was to determine the effects of aging on hand function outcomes following forearm tendon transfer surgery, in light of the findings from the Lamb and Chan questionnaire, it may have been useful to measure strength of key muscles in the limb (such as wrist extension and triceps). This would have provided extra information, with regard to transfers, manual wheelchair mobility, and the natural aging of upper limb muscles. Measurement of wrist extension strength and range of motion may have provided more information about the tenodeses strength and function. Finally, there are greater associations between fatigue and aging with SCI compared with normal individuals. This was not specifically addressed in this study but may contribute to some of the reported long-term outcomes such as manual wheelchair propulsion and employment. Further studies of grip and pinch strength in the tetraplegic individuals following tendon transfers could benefit from using such testing techniques as rapid exchange grip to determine the effect of fatigue on hand function.

Larger, collaborative studies between centers and countries may provide more statistically significant information from this population and enable more noteworthy conclusions.

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