Short-term progressive resistance exercise may not be effective at increasing wrist strength in people with tetraplegia: a randomised controlled trial

Joanne Glinsky[1], Lisa Harvey[1], Monique Korten[1, 2], Craig Drury[3], Shane Chee[4] and Simon C Gandevia[5]

[1]University of Sydney, Australia, [2]Maastricht University, Netherlands, [3]Royal Adelaide Hospital, Australia, [4]Prince of Wales Hospital, Australia, [5]Prince of Wales Medical Research Institute, Australia

Questions: Is an 8-week progressive resistance exercise program effective for increasing strength in the wrist muscles of people with tetraplegia? Is it effective for improving muscle endurance and participants' perceptions about use of their hands for activities of daily living? **Design**: Randomised controlled trial with concealed allocation, assessor blinding, and intention-to-treat analysis. **Participants**: Thirty-two people with tetraplegia and neurological weakness of their wrist flexor or extensor muscles. **Intervention**: The wrist muscles of one randomly-chosen hand were trained 3 times a week for 8 weeks. The control group received no intervention. **Outcome measures**: The primary outcome was strength measured as maximal voluntary isometric torque in Nm. The secondary outcomes were muscle endurance measured as fatigue resistance and participants' perceptions about use of their hands using the Canadian Occupational Performance Measure. **Results**: The mean effect on maximal voluntary isometric torque was 0.2 Nm (95% CI −0.5 to 0.8). This represents an 8% increase of mean initial strength; less than the 20% deemed clinically worthwhile at the commencement of the study. The mean effect on fatigue resistance was 0.1 (95% CI 0.0 to 0.2). The mean effect on participants' perceptions of performance was −0.3 (95% CI −1.9 to 1.2) and satisfaction was −0.3 (95% CI −1.6 to 1.0). **Conclusion**: The results indicate that progressive resistance exercise has no effect on participants' perceptions about hand function. However, it is not yet clear whether progressive resistance exercise programs improve strength and endurance in muscles with neurologically-induced weakness following tetraplegia. **[Glinsky J, Harvey L, Korten M, Drury C, Chee S, Gandevia SC (2008) Short-term progressive resistance exercise may not be effective at increasing wrist strength in people with tetraplegia: a randomised controlled trial. *Australian Journal of Physiotherapy* 54: 103–108]**

Key words: Spinal Cord Injuries, Quadriplegia, Physiotherapy, Muscle Strength

Introduction

Neurologically-induced weakness of the upper limbs is common following tetraplegia and results from partial paralysis of muscles. Partial paralysis occurs from disruption to some but not all neural pathways innervating muscles. The residual strength of partially-paralysed muscles is an important determinant of independence and function in people with tetraplegia (Drolet et al 1999). For example, strength of the wrist extensor muscles impacts on hand function in people with C6 injuries. Anecdotal evidence suggests that small improvements in strength make a substantial difference to the ability of these patients to use their hands. Not surprisingly, therefore, physiotherapists devote large amounts of time and effort to strengthening the partially-paralysed upper limb muscles of people with tetraplegia. Typically, strengthening is carried out using the principles of progressive resistance exercise (Jacobs and Nash 2004, Kraemer et al 2002).

Progressive resistance exercise is an effective way of increasing strength in the neurally-intact muscles of able-bodied individuals provided that training is performed with sufficient resistance and it is appropriately progressed (Feigenbaum and Pollock 1999, Munn et al 2005a). Whilst the optimal parameters continue to be debated, typically the recommended intensity for dynamic training is 1–3 sets of 8–12 repetition maximum (resting for 1–3 minutes between sets), 2–3 times a week (American College of Sports Medicine 2005). The weight lifted during repetition maximum increases progressively as strength improves over time (Kraemer et al 2002). However, it is less clear whether resistance exercise is also effective in muscles with neurologically-induced weakness following spinal cord injury. Only one randomised controlled trial has attempted to examine this issue (Hicks et al 2003). The results of this trial were complicated by the inclusion of patients with and without neurologically-induced weakness. Hence our research questions were:

1. Does 8 weeks of progressive resistance exercise increase the strength of the wrist muscles in people with neurologically-induced weakness following tetraplegia and is there a contralateral training effect in the other wrist?
2. Does progressive resistance exercise carry over to muscle endurance and participants' perceptions about use of their hands for activities of daily living?

Method

Design

An assessor-blind randomised controlled trial with pre-and post-measurements was conducted. Inpatients and outpatients from three spinal cord injury units in Australia (Sydney and

Adelaide) were recruited from a sample of convenience and invited to participate in the trial. Recruitment was carried out prior to group allocation. A computer-generated random allocation schedule was produced prior to the trial by a person not otherwise involved in subject recruitment or allocation. Allocations were placed in opaque, sequentially numbered envelopes and sealed. They were opened after each participant's baseline measurement was completed. The randomisation had two tiers. Initially, participants were randomly allocated to either the experimental (progressive resistance exercise) or control (no progressive resistance exercise) group. Experimental participants carried out a progressive resistance exercise program for one wrist only, which was determined by a second randomisation. Control participants received no training. Outcome measures were collected at the start and end of the eight-week training period. Final measures were collected less than 4 days after completion of the 24 treatment sessions. The assessor was blinded to group allocation and participants were asked not to discuss any aspect of the trial with the assessors in order to maintain blinding. Prior to the study commencing, participants were made aware that the intervention may or may not result in strength gains.

Participants

To be eligible for inclusion, patients were required to have a complete or incomplete cervical lesion as defined by the American Spinal Injury Association classification, be more than 2 months post spinal cord injury, and have bilateral weakness of their wrist extensor or flexor muscles (Grade 2–4 out of 5; O'Brien 2000). In participants with weakness in both the wrist extensor and wrist flexor muscles, the wrist extensor muscles were selected for training, ie, participants trained only one muscle group. Participants were required to have symmetrical weakness in the target muscle of both wrists (ie, within one muscle grade of each other) to enable quantification of any contralateral effect of training (Munn et al 2005b). Participants were excluded if they had a recent history of trauma to the forearm or hand; had contractures limiting wrist range of motion; were unlikely to remain within the Sydney or Adelaide metropolitan area for 8 weeks; or were unlikely to comply with the intervention. Likelihood to comply was gauged by participants' compliance with other aspects of their ongoing rehabilitation and care).

Intervention

The experimental group carried out a progressive resistance exercise program on one wrist (as determined by random allocation) 3 times a week for 8 weeks. It consisted of three sets of 10 repetition maximum of one wrist muscle group (extensor or flexor muscles). The resistance was adjusted to ensure that participants could only lift the weight 10 times through a full range of motion, ie, if participants could lift the weight more than 10 times the weight was too light and was increased, and if participants could not lift the weight 10 times the weight was too heavy and was decreased. Participants received a 1–3 minute rest before repeating the 10 repetitions a second and third time. The weight was increased over the 8-week training period as soon as participants could perform more than 10 repetitions in a set. In this way, training was progressed as strength improved so that participants always trained with a 10 repetition maximum. All training sessions were supervised by either a physiotherapist or a physiotherapy student (trained in trial procedures) who recorded the progression of weights in a diary.

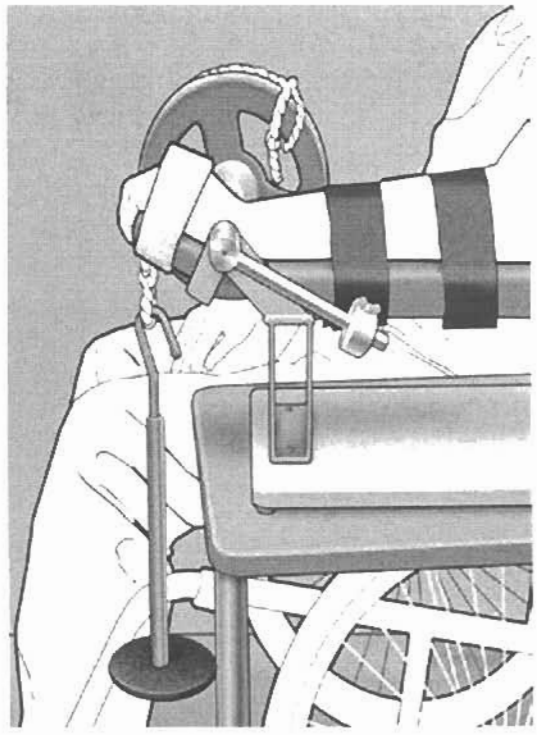

Figure 1. Wrist strengthening device. (Reproduced with permission from www.physiotherapyexercises.com)

The progressive resistance exercise program was performed with a device specifically designed for the purpose (Figure 1). It enabled very weak patients to move all the way through range in an anti-gravity position while ensuring that the resistive torque was constant throughout (Harvey 2008). The device consisted of a forearm support and pivoting hand-piece attached to a wheel. The centre of rotation of the hand-piece and the wheel were aligned such that the two rotated together. The hand was secured to the hand-piece. Resistance was applied to the wrist by hanging weights from a rope that circled the wheel. An adjustable counterweight was attached to the wheel. The counterweight was adjusted to match the weight of the hand and pivoting hand-piece. Small resistive torques could then be used to progress training without a change in hand position. Participants were seated in a wheelchair or chair with the forearm in pronation when training the wrist extensor muscles. The forearm was placed in supination when training the wrist flexor muscles.

Control participants did not receive progressive resistance exercises to either wrist. All participants continued to receive routine care which included physiotherapy and occupational therapy but no progressive resistance exercise program for the wrist.

Outcome measures

The primary outcome was strength measured as maximal voluntary isometric torque of the wrist extensor or flexor muscles in Nm. Isometric strength, rather than dynamic strength, was measured because it is difficult to measure the dynamic strength of very weak muscles (ie, Grade 2 out of 5) reliably. Maximal voluntary isometric force was measured using a myograph which consisted of a

load cell (100 N), a peak-and-hold meter and a visual feedback monitor. Participants were seated with their arm positioned in the myograph. The forearm was secured in a semi-pronated position with the wrist in neutral extension. The hand was clamped at the metacarpophalangeal joints (Figure 2). Attention was directed at ensuring the arm was positioned in the same way at pre- and post-assessments. The blinded assessor instructed and loudly encouraged participants to exert themselves maximally during testing. A visual feedback device (LED bars) was used to further encourage maximal effort. A target on the feedback monitor was set above the predicted peak force prior to testing. Peak force was recorded for 8 maximal voluntary contractions. Each contraction was 4 seconds in duration with a 1-minute rest between contractions. The average of the 3 best contractions was calculated. Force output (N) was multiplied by the distance between the clamp at the metacarpophalangeal joints and the wrist (m) to produce torque (Nm). The myometer was assessed for reliability in people with tetraplegia prior to the commencement of the trial. Wrist flexion or extension strength was measured in 20 wrists two or three days apart by blinded assessors. The intra-class correlation coefficient (3,1) was 0.96 (95% CI 0.89 to 0.98) indicating high agreement between the 2 occasions.

Two secondary outcome measures were collected: one to reflect muscle endurance and one to reflect participants' perceptions about use of their hands for activities of daily living. Muscle endurance was measured as fatigue resistance using the same myograph and set up as for the measurement of strength. The peak effort of 23 contractions performed in rapid succession over 3 minutes was recorded. The contractions were 4 seconds in duration with 4 seconds rest between contractions. Fatigue resistance was calculated as the ratio of the mean torque of the last 3 contractions divided by the mean torque of the first 3 contractions (Hartkopp et al 2003).

The Canadian Occupational Performance Measure (Law et al 1998, Law et al 1990) was used to identify activities of daily living that participants perceived were affected by wrist weakness. Participants were asked to rate the importance of the activity, their current performance of the activity, and satisfaction with their current performance of the activity on a scale of 1 to 10. The performance and satisfaction of the three activities deemed to be most important were averaged for each participant (Law et al 1990). The measure has good reliability and validity for people with disabilities; its psychometric properties have not been formally tested in people with spinal cord injury, however, this measure is used widely in this population (Carswell et al 2004, Marino 2007).

Data analysis

The minimal clinically-worthwhile between-group difference in improvement in maximal voluntary isometric strength was set *a priori* at 20% of initial strength. However, it was not possible to predict the initial strength of participants accurately and no published data were available from which to calculate the SD of the effect of intervention. For this reason an estimate of initial strength (mean 0.8 Nm, SD 0.6) was made from unpublished data collected by the authors and others (Hartkopp et al 2003). The power calculation indicated that a sample size of 32 would be sufficient to detect a between-group difference of 20% of mean initial strength. This calculation assumed an alpha of 0.05 and a drop out rate of 20%. The minimal clinically-worthwhile between-group difference in endurance was set *a priori* at 20% of initial fatigue resistance and participants' perceptions at 2 points on the 10-point Canadian Occupational Performance Measure scale respectively (Law et al 2005).

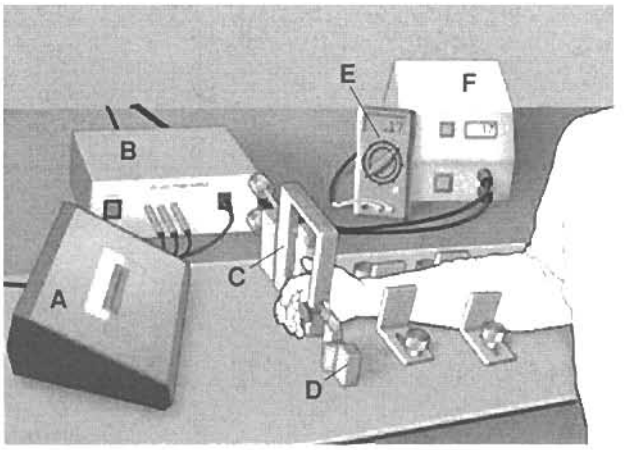

Figure 2. Myograph consisting of (A) visual feedback monitor, (B) power box, (C) clamp system, (D) 100 N load cell, (E) multi-metre measuring V, and (F) peak-and-hold metre measuring N. (Reproduced with permission from www.physiotherapyexercises.com)

Data were analysed with factorial analysis of covariance using a linear regression approach (Vickers and Altman 2001, Munn et al 2005a). All data were analysed by 'intention to treat' (Pocock 1983). Significance for all statistical analyses was set at $p < 0.05$.

Results

Flow of participants through the trial

Thirty-two participants with tetraplegia were randomised into the trial. Participants had complete and incomplete lesions with a motor level of C4–C7 as defined by the American Spinal Injury Association classification. The characteristics of participants in each group are detailed in Table 1. The flow of participants through the trial is given in Figure 3. One participant (from the experimental group) dropped out of the trial after 8 training sessions and was unavailable for the Week 8 measures. In addition, two participants were unable to complete the Canadian Occupational Performance measure. These missing data were not imputed but all other data for these two participants were included in the analyses.

Compliance with trial method

The study protocol dictated that participants receive 24 training sessions over 8 weeks. However, there were some deviations. One participant missed 3 training sessions, 2 participants missed 2 training sessions and one participant missed 1 training session. Training sessions were missed primarily because participants undergoing rehabilitation had difficulties finding time and in one case because the participant was unexpectedly discharged to a rural area. So in practice, participants received a mean of 23 (98%) training sessions (SD 1) administered over a mean of 8 weeks (SD 1). In the first week of training, participants in the experimental group trained with a median torque

Table 1. Characteristics of participants.

Characteristic	Experimental Group n = 15	Control Group n = 16
Age *(yr)*, mean (SD)	37 (16)	47 (20)
Male participants, n (%)	12 (80)	15 (94)
Time since injury *(yr)*, median (IQR)	1 (3.7)	0.4 (0.9)
Wrist muscle trained, n (%)		
Extensors	13 (87)	15 (94)
Flexors	2 (13)	1 (6)
ASIA Scale, n (%)		
A	9 (60)	6 (38)
B	0 (0)	4 (25)
C	3 (20)	2 (12)
D	3 (20)	4 (25)
Initial muscle grade, n (%)		
2	4 (27)	0 (0)
2.5*	–	2 (12)
3	5 (33)	7 (44)
3.5*	–	3 (19)
4	6 (40)	4 (25)

ASIA = American Spinal Injury Association; * = half grades due to the average of the two control hands

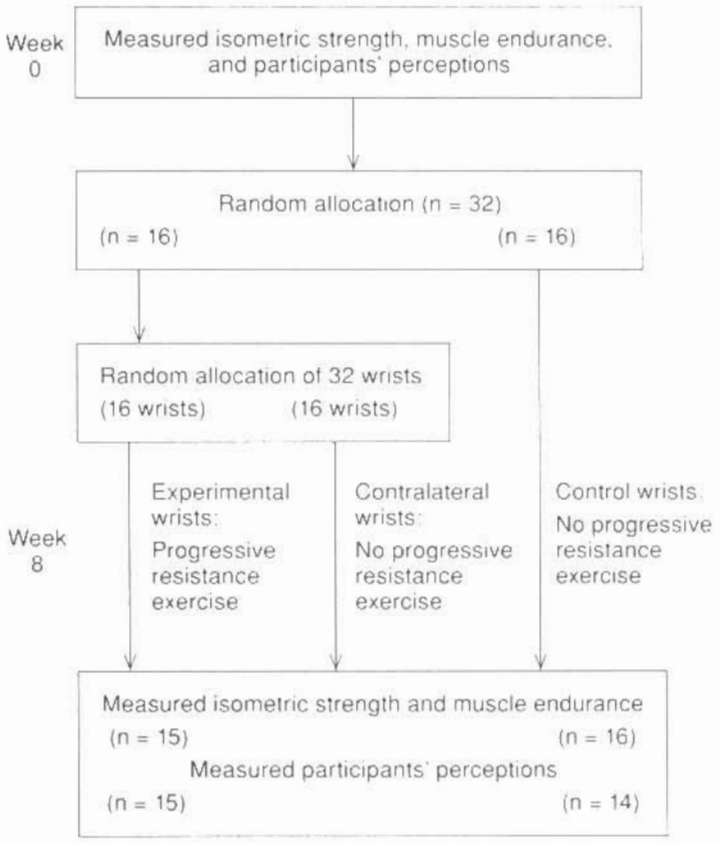

Figure 3. Design and flow of participants through trial. Measures for the control group are the average of the two wrists.

of 1.3 Nm (IQR 1.3). By the eighth week of training this had progressed to a median torque of 2.9 Nm (IQR 1.9). No adverse effects of intervention were reported.

Effect of intervention

Group data for strength, muscle endurance, and participants' perceptions about use of their hands for activities of daily living are presented in Table 2, while individual data are presented in Table 3 (see eAddenda for Table 3). The mean effect of progressive resistance exercise on maximal voluntary isometric wrist torque was 0.2 Nm (95% CI −0.5 to 0.8). This represents an 8% increase in mean initial strength (2.6 Nm) in the experimental group compared with the control group; less than the 20% deemed clinically worthwhile at the commencement of the study. There is uncertainty around the size of this estimate as reflected by the width of the 95% CI. Since there was no gain in strength, the question of whether there was a contralateral effect of unilateral training was disregarded.

The mean effect of progressive resistance exercise on fatigue resistance was 0.1 (95% CI, 0.0 to 0.2). This represents an 11% increase in mean initial muscle endurance (0.9) in the experimental group compared with the control group – less than the 20% deemed clinically worthwhile at the commencement of the study. However, again, there is uncertainty around this estimate as indicated by the width of the 95% CI.

The activities of daily living most frequently selected by participants as part of COPM assessment were using cutlery and lifting objects such as bottles and cups. The mean effect of progressive resistance exercise on these activities were −0.3 (95% CI −1.9 to 1.2) for participants' perceptions of performance and −0.3 (95% CI −1.6 to 1.0) for participants' satisfaction. The 95% CI of both perceived performance and satisfaction clearly sits below the 2 point difference deemed clinically worthwhile at the commencement of the study. This indicates that the experimental group did not perceive that progressive resistance exercise improved performance of or satisfaction with their activities of daily living compared with the control group.

Discussion

The objective of this trial was to determine whether progressive resistance exercise administered for eight weeks increases strength in the partially-paralysed wrist muscles of people with tetraplegia. The wrist was chosen for two reasons. First, wrist strength is important for hand function in people with tetraplegia and, second, the wrist extensor and flexor muscles provide a useful model to explore the more generic question about the effectiveness of progressive resistance exercise in muscles with neurologically-induced weakness following spinal cord injury, a question not previously investigated in a randomised controlled trial. The strength and endurance results of this study are inconclusive and reflect insufficient statistical power, ie, it is not clear whether progressive resistance exercise does or does not increase strength and/or endurance. In contrast, the participants' perceptions are conclusive – participants did not perceive improvements in hand function as a result of progressive resistance exercise of the wrist.

These results were unexpected. We conducted this study in the belief that progressive resistance exercise was effective and that we would have little difficulty demonstrating this.

Table 2. Mean (SD) of each group, mean (SD) difference within groups, mean (95% CI) difference between groups for strength, muscle endurance and participants' perceptions.

Outcome	Groups				Difference within groups		Difference between groups *
	Week 0		Week 8		Week 8 minus Week 0		Week 8 minus Week 0
	Exp	Con	Exp	Con	Exp	Con	Exp minus Con
Strength							
Maximal voluntary isometric torque *(Nm)*	2.2 (1.4)	2.9 (2.5)	2.7 (1.6)	3.1 (2.0)	0.6 (0.8)	0.3 (1.0)	0.2 (−0.5 to 0.8)
Endurance							
Fatigue resistance *(ratio)*	0.9 (0.2)	0.9 (0.2)	0.9 (0.2)	0.8 (0.2)	0.0 (0.2)	−0.1 (0.2)	0.1 (0.0 to 0.2)
Participants' perceptions COPM – Performance *(1 to 10)*	4.3 (2.4)	4.4 (1.6)	4.9 (2.2)	5.2 (2.3)	0.6 (2.0)	0.9 (2.3)	−0.3 (−1.9 to 1.2)
Participants' perceptions COPM – Satisfaction *(1 to 10)*	5.1 (3.1)	4.9 (2.1)	5.0 (2.6)	5.1 (2.3)	−0.1 (1.8)	0.3 (2.0)	−0.3 (−1.6 to 1.0)

Exp = experimental, Con = control, COPM = Canadian Occupational Performance Measure; * = mean and 95% CI are derived from linear regression using baseline scores as covariates

The strength findings indicate that, overall, participants did not benefit from the intervention. Instead, there was a large amount of variability as reflected by the wide 95% confidence intervals. It is likely that the variability in the results reflect real differences in the way participants responded to training. For example, perhaps those with recent injuries respond better than those with chronic injuries or perhaps those with incomplete injuries respond better than those with complete injuries. There were insufficient participants to explore these possibilities with *post hoc* subgroup analyses.

Much larger numbers of participants than predicted were required to confer reasonable precision to estimates of the effect of training. Arguably, we also needed tighter inclusion criteria to reduce heterogeneity. We did not restrict our inclusion criteria because this trial was the first in the area and we did not know if particular subgroups of patients would respond more favourably than others. We therefore adopted a pragmatic approach (McMahon 2003) including all people typically provided with a progressive resistance exercise program in the clinical setting (Jacobs and Nash 2004). The obvious next step is to identify whether particular subgroups benefit more than others. However, recruiting a sufficiently large enough sample of a more homogenous group of participants will pose a real challenge to trialists.

There are other possible explanations for our failure to demonstrate a convincing increase in strength. It is possible that the training dose was insufficient and that a greater number of repetitions or more frequent training sessions were required. The most likely explanation relates to the duration of training. Long-term (9 months) progressive resistance exercise has been administered to a group of spinal cord injured patients (Hicks et al 2003). However this study included people with paraplegia who undertook progressive resistance exercise for their neurally-intact upper limbs. It therefore does not provide good evidence of the effects of progressive resistance exercise in muscles with neurologically-induced weakness. Alternatively, perhaps we failed to demonstrate a difference in strength because people with tetraplegia inadvertently self-administer a form of resistance exercise through regular practice of activities of daily living and functional tasks (Jannsen et al 1994). The daily demands of feeding, grooming, and mobilising may be an effective form of resistance exercise rendering more formal programs of progressive resistance exercise redundant. If this hypothesis is correct, then practice of functional tasks, rather than formalised progressive resistance exercise programs, could increase strength more effectively. Of course, this hypothesis needs to be tested in a randomised controlled trial.

The possibility that muscles directly affected by spinal cord injury have limited responsiveness to progressive resistance exercise cannot be discounted. Progressive resistance exercise in muscles with neurologically-induced weakness might not generate a large enough stimulus to prompt the necessary adaptations. For example, contraction of only a small proportion of the muscle mass may not induce sufficient localised ischemia to prompt hypertrophy (Devici et al 2002, Devici and Eggington 2002, Wernbom et al 2007).

Typically, interventions that target endurance specifically are somewhat different from those that target strength specifically (Tanka and Swensen 1998). However, given that progressive resistance exercise programs can have some effect on muscle endurance (American College of Sports Medicine 2005) we were interested to see if there was an effect of resistance exercise on endurance in this population. The inclusion of this outcome in the study reflects our prior confidence about the effectiveness of short-term progressive resistance exercise in people with spinal cord injuries.

The results of this study indicate that our current confidence about the effectiveness of progressive resistance exercise is not yet justified in people with neurologically-induced weakness following tetraplegia. Larger studies are now required to identify subgroups of patients with spinal cord injury who may be more responsive to progressive resistance exercise and to find the optimal training parameters. The results of this study also highlight the importance of systematically evaluating the effectiveness of all physiotherapy interventions that currently comprise

standard practice for people with spinal cord injuries.

eAddenda: Table 3 available at www.physiotherapy.asn.au

Ethics: The trial was approved by the human research ethics committee of all participating institutions and informed consent was obtained from all participants.

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Correspondence: Joanne Glinsky, Rehabilitation Studies Unit, Northern Clinical School, Faculty of Medicine, University of Sydney, PO Box 6, Ryde, NSW 1680, Australia. Email: jgli5786@mail.usyd.edu.au

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