

# Four weeks of daily stretch has little or no effect on wrist contracture after stroke: a randomised controlled trial

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**Questions:** In adults undergoing rehabilitation after stroke, does 30 minutes of daily stretch of the wrist and finger flexors for four weeks prevent or reverse contracture, decrease pain, or improve upper-limb activity? Are any gains maintained one week and five weeks after the cessation of stretching? **Design:** Randomised controlled trial with concealed randomisation, assessor blinding, and intention-to-treat analysis. **Participants:** 40 adults undergoing rehabilitation after stroke or stroke-like brain injury, who were unable to actively extend the affected wrist. **Intervention:** Both groups received routine upper-limb retraining five days a week. In addition, the experimental group received 30 minutes daily stretch of the wrist and finger flexors five days a week for four weeks. **Outcome measures:** The primary outcome was contracture, measured as torque-controlled passive wrist extension with the fingers extended. Secondary outcomes were pain at rest measured on a 10-cm visual analogue scale, and upper-limb activity measured using the Motor Assessment Scale. Outcomes were collected at baseline, post-intervention, and one and five weeks after cessation of intervention. **Results:** The mean effect on passive range of wrist extension was 5.1 degrees (95% CI -0.9 to 11.1) after 4 weeks of daily stretch, 4.1 degrees (95% CI -4.0 to 12.3) after a week of no stretch, and 3.5 degrees (95% CI -4.6 to 11.7) after a further four weeks. **Conclusion:** These data suggest that four weeks of regular stretching has little or no effect on wrist contracture after stroke. However the estimate of the size of this effect is not sufficiently precise to rule out the possibility of a marginally worthwhile effect. The stretch had no significant effect on upper-limb pain, and did not result in significantly improved upper-limb activity. [Horsley SA, Herbert RD, Ada L (2007) Four weeks of daily stretch has little or no effect on wrist contracture after stroke: a randomised controlled trial. *Australian Journal of Physiotherapy* 53: 239–245]

Key words: Randomized Controlled Trail, Stroke, Contracture, Wrist, Physiotherapy, Rehabilitation

## Introduction

Long-term disability associated with failure to regain use of the arm is a major problem following stroke (Dean and Mackay 1992, Gowland 1982, Kwakkel et al 2003). Upper-limb contractures are common (Linn et al 1999, O'Dwyer et al 1996, Pandyan et al 2003, Wanklyn et al 1996). Contracture refers to the loss of joint range of motion resulting from changes in the mechanical properties of soft tissues which cross the joint (Ada and Canning 1990, Herbert 1988, Herbert 1993, O'Dwyer and Ada 1996, O'Dwyer et al 1996). This could involve a reduction in rest length or increase in stiffness of muscles or tendons (Goldspink and Williams 1990, Gossman et al 1982, Herbert 1993, Herbert 2005) or of other tissues such as joint capsule and ligaments. Contracture becomes a problem when it impairs physical activity.

In the presence of severe loss of strength and dexterity after stroke, the wrist and finger flexor muscles are particularly at risk of developing contracture (Ada and Canning 2002) because the arm usually rests with the hand in the lap (Ada et al 2005, Ada and Canning 2002, Turton and Britton 2005). In this position the wrist and fingers are in flexion, so the flexor muscles are effectively immobilised in the shortened part of their range. They are, therefore, likely to undergo the same adaptations that have been shown to occur when animal muscle is immobilised in a shortened position (Goldspink and Williams 1990, Herbert 1988, Herbert 2005, Herbert and Balnave 1993, Tabary et al 1972, Williams and Goldspink 1978).

Evidence from animal studies suggests that provision of intermittent stretch for 30 minutes per day provides an adequate stimulus to prevent these adaptations (Williams 1990, Williams 1988, Williams et al 1988). It is reasonable to speculate that a similar 30 minute daily stretch could prevent contracture developing after stroke. However clinical trials investigating the effect of this intervention on upper-limb contracture following stroke have not yet yielded definitive results (Ada et al 2005, Dean et al 2000, de Jong et al 2006, Gustafsson and McKenna 2006, Turton and Britton 2005). The pooled estimate of the effect of stretching on passive shoulder external rotation range of motion from these five trials (fixed effect model) is that stretching increases range by a mean of 4 degrees (95% CI -1 to 10 degrees). The most optimistic confidence limit about this estimate (10 degrees) is, arguably, a clinically worthwhile effect, given the typically limited duration of intervention in these trials (4 to 8 weeks). Consequently, while the existing data suggest stretching has little effect on range of motion after stroke, they do not definitively rule out a worthwhile effect. This conclusion is subject to additional uncertainty because only one of the five trials (Turton and Britton 2005) measured range of motion at a controlled torque. It is necessary to measure range of motion at controlled torques to ensure that any effect of stretch reflects a change in mechanical properties of soft tissues (Folpp et al 2006). The application of the same torque at each measurement session ensures that any change in passive range of motion measured is due to a change in muscle length and stiffness rather than to a change in the applied torque or to a change in the individual's tolerance to stretch.

Therefore, our research questions were:

1. In adults undergoing rehabilitation after stroke, does 30 minutes of daily stretch of the wrist and finger flexors for four weeks prevent or reverse contracture, decrease pain, and improve upper-limb activity?
2. Are any gains maintained one week and five weeks after the cessation of stretching?

## Method

### Design

A parallel-group, randomised trial was conducted. Participants were recruited to the trial on commencement of their rehabilitation program. Baseline measures were collected prior to randomisation into either the experimental or the control group. A computer-generated randomisation table was kept by a person who was remote from the study site and independent of recruitment, and group allocation was revealed by phone call. Participants in the experimental group received a daily 30 minute stretch of the wrist and finger flexors, five days a week, for four weeks. Usual upper-limb rehabilitation continued for both the experimental and control groups throughout the study period. The daily stretch was ceased at the end of four weeks and outcome measures were collected at least one day after the last stretch. Outcome measures were collected again at five weeks, after which time the therapists and patients were informed that stretching could be resumed for the experimental group or commenced, in the case of the control group, as they decided. At nine weeks, final outcome measures were collected, again at least one day after the last stretch. Outcome measures were collected by therapists trained in the measurement procedures who were blind to group allocation. To maintain blinding, participants were asked not to discuss any aspect of the trial with assessors. The study received ethical approval from the appropriate institution and informed consent was obtained from all participants.

### Participants

All patients admitted to the rehabilitation service were screened for eligibility. Patients were included if they presented with stroke or stroke-like brain injury (ie, subarachnoid haemorrhage resulting in hemiplegia, but not traumatic head injury or Parkinson's disease), were 18 years of age or older, and were unable to actively extend the affected wrist past neutral (since this was deemed likely to pose a risk of contracture). Patients were excluded if they had language, comprehension, or cognitive problems which prevented informed consent, if they had co-existing upper-limb conditions which directly affected movement (eg, fractures, inflammatory arthritis, peripheral nerve injury), or if they were not able to participate in upper-limb rehabilitation.

### Intervention

The experimental group received 30 minutes of stretch of the wrist and finger flexors of the affected arm, five days a week, for four weeks. The stretch used was a seated, weight-bearing stretch of the arm, with the shoulder positioned in external rotation, slight abduction and extension, the elbow in maximum extension, the forearm in supination, and the wrist and fingers in maximum extension (Figure 1). Participants were instructed to hold the stretch at the point where they felt tightness or stretch, but not pain.



**Figure 1.** Seated weight-bearing stretch with wrist and fingers in maximum extension, elbow extended, and shoulder in some external rotation.

Physiotherapists who were working in the rehabilitation unit supervised or assisted with stretches as required. This stretch was delivered routinely in the rehabilitation unit because it was efficient; many patients were able to maintain the stretch independently without the therapists giving hands-on assistance. If, during the intervention period, a participant was not able to carry out the seated weight-bearing stretch due to pain or was confined to bed, the stretch was administered either manually in sitting or in supine (therapist-applied stretch), or by using a hinged arm board (instrument-applied stretch). The duration and type of stretch used for each participant was recorded by the administering physiotherapist after every session. The control group did not receive any stretch of the wrist and finger flexors during the intervention period.

Participants in both groups received the usual upper-limb rehabilitation provided by the physiotherapists and occupational therapists in the rehabilitation unit. Upper-limb rehabilitation was not standardised or monitored. However, treating therapists were instructed that, with the exception of the stretches administered to the experimental group in accordance with the trial protocol, wrist and finger stretches were not to be administered. Rehabilitation usually involved both group and individual sessions conducted five days a week, and consisted of strengthening and task-specific practice of upper-limb activities.

### Outcome measures

The primary outcome was contracture measured as passive wrist extension in degrees. Torque-controlled measures of passive wrist extension with the fingers in extension were obtained using the procedure described by Harvey et al (1994). Repeated measurements of a standardised

**Table 1.** Baseline characteristics of all participants and participants lost to follow-up.

Characteristic	All participants		Participants lost to follow-up	
	Exp (n = 20)	Con (n = 20)	Exp (n = 2)	Con (n = 1)
Diagnosis, number (%)				
Stroke	19 (95)	18 (90)	2 (100)	1 (100)
Subarachnoid haemorrhage	1 (5)	1 (5)	0 (0)	0 (0)
Meningitis	0 (0)	1 (5)	0 (0)	0 (0)
Age (yr), mean (SD)	61 (21)	62 (17)	69	88
Gender (M:F)	6:14	13:7	0:2	1:0
Side of hemiplegia (R:L)	7:13	10:10	0:2	0:1
Chronicity (days), mean (SD)	23 (27)	35 (44)	27	4

protocol were averaged in order to decrease variability of the measures (see Appendix 1 on the eAddenda for details of the trial method).

Secondary outcomes were pain and upper-limb activity. A 10-cm visual analogue scale, with 0 cm representing 'no pain' and 10 cm representing 'worst pain' (McCaffery and Pasero 1999), was used to measure pain at rest. Participants were asked to rate the pain they were experiencing at the time of testing only. A composite of the three upper-limb items of the Motor Assessment Scale (Carr et al 1985, Lannin 2004) was used to score upper-limb activity between 0 points (no activity) and 18 points (best possible score/good activity). It was administered following the measurement of pain and prior to the measurement of torque-controlled passive wrist extension.

### Data analysis

The minimal clinically-worthwhile effect on the primary outcome measure (ie, maximum passive wrist extension) was set *a priori* at 10 degrees since this amount of passive wrist extension was considered by a group of clinicians to be sufficient to positively affect upper-limb activity. A predictive power calculation estimated that a sample size of 40 would be adequate to provide an 80% probability of detecting a 10 degree effect, based on the assumption of a standard deviation of 10 degrees and allowing for a worst case loss to follow-up of 20%.

Analysis of covariance using baseline scores as covariates was used to estimate the size of the effect of intervention on contracture, pain and upper-limb activity at 4 weeks, 5 weeks, and 9 weeks. Means (SDs) and mean between-group differences (95% CI) were calculated. Probabilities of less than 0.05 were considered significant. All data were analysed by intention-to-treat.

## Results

### Flow of participants through the trial

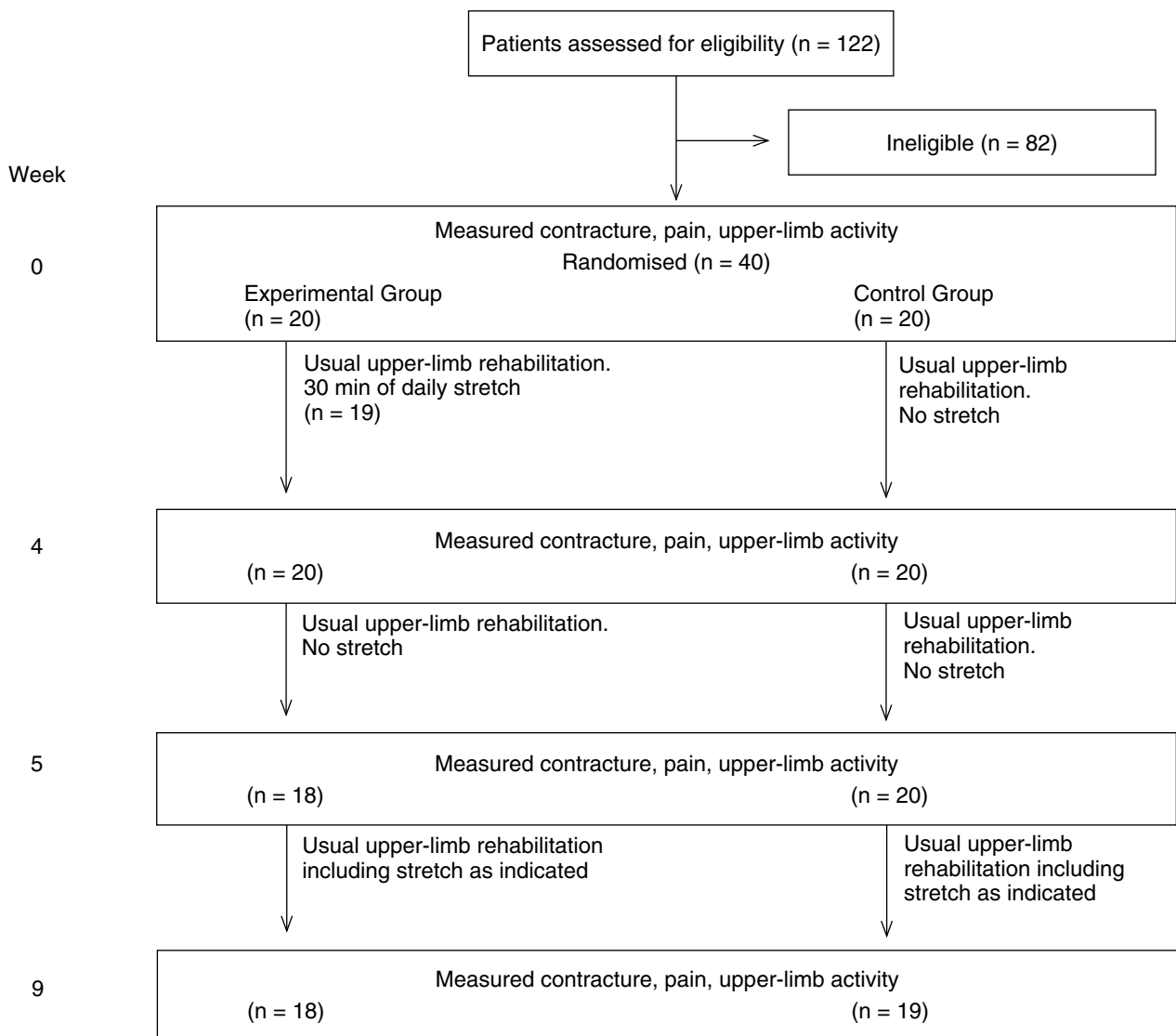
One hundred and twenty-two patients consecutively admitted to the rehabilitation service following stroke or stroke-like brain injury were screened for eligibility. Seventy-three were excluded because they were able to actively extend the affected wrist past neutral, four because they had co-existing upper-limb conditions, and four because they were unable to participate in rehabilitation programs due to an unstable medical condition or to severe communication and cognitive problems. One patient with chronic stroke was

also excluded because he was not participating in upper-limb rehabilitation. The 40 eligible patients were randomised to groups (20 to the experimental group, 20 to the control group). Participants in the experimental and control groups were similar in diagnosis, age, side of hemiplegia, and chronicity (Table 1). The mean age of participants was 62 years (SD 19) and the mean time since stroke was 29 days (SD 37).

The flow of participants through the trial is shown in Figure 2. During the intervention phase, one participant self-discharged from the rehabilitation unit and refused to continue the intervention due to increased arm pain. This participant attended the Week 4 measurement session and although the measure of wrist extension was limited by pain, it was included in the intention-to-treat analysis. However, this participant then withdrew from the study so subsequent measures could not be obtained. Primary outcomes were not available at Week 5 from one other participant from the experimental group who went home on holiday, and two other participants at Week 9, because one participant from the experimental group was discharged to a remote hospital due to medical problems and one participant from the control group died. Consequently, the primary outcome measure was obtained from 100% of participants at Week 4, from 95% of participants at Week 5, and from 93% of participants at Week 9.

### Compliance with trial method

Each experimental participant should have completed 20 stretches (ie, one stretch five days a week for four weeks) so that the 20 participants in the experimental group should have completed 400 stretches. However, since the stretches were supervised by therapy staff, they were not carried out on public holidays, accounting for nine missing stretches, and bringing the possible number to be carried out down to 391. Since 377 were carried out, the overall compliance was 96%. Ten participants carried out all 20 stretches, six carried out 19 stretches, and three carried out 18 stretches. One participant who withdrew from the study during the intervention period carried out only nine stretches. Stretches were not carried out on two occasions when patients did not attend outpatient appointments due to transport problems, and on one occasion when a patient was too unwell to participate. When stretches were carried out, they were maintained for the required 30 minutes. Of the stretches carried out 76% were the seated weight-bearing stretch, 22% were therapist-applied stretches, and 2% were instrument-applied stretches.



**Figure 2.** Design and flow of participants through the study. One participant from the experimental group withdrew from the intervention but his outcome measures at Week 4 were obtained. Pain was unable to be measured from two participants from the control group on all occasions due to communication problems.

### Effect of intervention

Group data for the four measurement occasions, within- and ANCOVA-adjusted between-group data are presented in Table 2. Individual data can be found in Table 3 (see eAddenda for Table 3).

Over the intervention period, between Week 0 and 4, maximum passive wrist extension stayed the same in the experimental group and decreased slightly in the control group but there was no significant difference between groups ( $p = 0.09$ ). The ANCOVA-adjusted estimate of the difference between groups was 5.1 degrees (95% CI  $-0.9$  to 11.1) in favour of the experimental group. During the following week, the experimental group lost range so that by Week 5, there was even less difference between the groups ( $p = 0.31$ ). The ANCOVA-adjusted estimate of the difference between groups was 4.1 degrees (95% CI  $-4.0$  to 12.3) in favour of the experimental group. For the next four weeks, there was a small loss of range in both groups so that at Week 9, there was even less difference between the

groups ( $p = 0.38$ ). The ANCOVA-adjusted estimate of the difference between groups was 3.5 degrees (95% CI  $-4.6$  to 11.7) in favour of the experimental group.

Over the intervention period, between Week 0 and 4, there was no significant difference in pain scores between groups ( $p = 0.76$ ). The ANCOVA-adjusted estimate of the difference between groups was 0.2 cm (95% CI  $-1.0$  to 1.3) in favour of the control group. By Week 5, there was still no significant difference between the groups ( $p = 0.36$ ). The ANCOVA-adjusted estimate of the difference between groups was  $-0.3$  cm (95% CI  $-1.1$  to 0.4) in favour of the experimental group. By Week 9, there was also no significant difference between the groups ( $p = 0.78$ ). The ANCOVA-adjusted estimate of the difference between groups was 0.2 cm (95% CI  $-1.5$  to 2.0) in favour of the control group.

Over the intervention period, between Week 0 and 4, upper-limb activity improved in the experimental group and stayed the same in the control group but there was no significant difference between groups ( $p = 0.10$ ). The ANCOVA-

**Table 2.** Mean (SD) of each group, mean (SD) change within groups, and ANCOVA-adjusted mean (95% CI) difference between groups for all outcome measures.

Outcome	Groups						Difference within groups						Difference between groups *								
	Wk 0		Wk 4		Wk 5		Wk 9		Wk 4 minus Wk 0		Wk 5 minus Wk 0		Wk 9 minus Wk 0		Wk 4 minus Wk 0		Wk 5 minus Wk 0		Wk 9 minus Wk 0		
	Exp (n = 20)	Con (n = 20)	Exp (n = 20)	Con (n = 20)	Exp (n = 18)	Con (n = 20)	Exp (n = 18)	Con (n = 19)	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	Exp	Con	
Max passive wrist ext (deg)	69.5 (13.6)	65.7 (13.1)	69.8 (11.1)	61.7 (15.1)	66.2 (15.6)	59.1 (17.1)	63.4 (14.7)	57.0 (15.9)	0.3 (10.4)	-4.0 (10.6)	-3.1 (10.2)	-5.6 (13.4)	-6.9 (10.1)	-8.7 (14.4)	5.1 (-0.9 to 11.1)	4.1 (-4.0 to 12.3)	3.5 (-4.6 to 11.7)				
Pain at rest on VAS (cm)	1.1 (1.8)	0.4 (1.1)	1.1 (2.2)	0.6 (1.3)	0.3 (1.2)	0.5 (1.1)	1.5 (2.6)	1.0 (2.4)	0.0 (2.3)	0.2 (1.3)	-0.8 (1.7)	0.1 (1.5)	0.6 (2.3)	0.6 (2.9)	0.2 (-1.0 to 1.3)	-0.3 (-1.1 to 0.4)	0.2 (-1.5 to 2.0)				
Upper-limb activity, MAS (0 to 18)	0.9 (1.8)	0.3 (0.6)	4.0 (5.5)	0.9 (1.7)	4.2 (6.2)	1.5 (2.0)	5.9 (6.6)	1.9 (3.3)	3.0 (4.6)	0.6 (1.3)	3.1 (5.1)	1.2 (1.7)	4.7 (5.6)	1.6 (2.9)	1.7 (-0.4 to 3.8)	0.9 (-1.4 to 3.1)	2.3 (-0.7 to 5.3)				

\* = estimates of effect from linear regression adjusted for Week 0 scores. ext = extension, VAS = visual analogue scale, MAS = Motor Assessment Scale

adjusted estimate of the difference between groups was 1.7 points (95% CI -0.4 to 3.8) in favour of the experimental group. During the following week, upper-limb activity stayed the same in the experimental group and improved slightly in the control group, so that by Week 5, there was less difference between the groups ( $p = 0.44$ ). The ANCOVA-adjusted estimate of the difference between groups was 0.9 points (95% CI -1.4 to 3.1) in favour of the experimental group. For the next 4 weeks, there was a small improvement in upper-limb activity in the experimental group, and the control group stayed the same, so that by Week 9, there was still a small difference between the groups ( $p = 0.12$ ). The ANCOVA-adjusted estimate of the difference between groups was 2.3 points (95% CI -0.7 to 5.3) in favour of the experimental group.

## Discussion

The best estimate of the effect of four weeks of daily stretch was that it increased range of motion by 5 degrees. However, given the precision of the estimate, it is quite possible that the true effect of stretch could lie anywhere between a negative effect of 1 degree and a beneficial effect of 11 degrees. We decided *a priori* that stretching must have an effect of 10 degrees to be clinically worthwhile. By this criterion, our data suggest stretching does not have a worthwhile effect, although we cannot definitively rule out a marginally-worthy effect.

While animal studies have found that 30 minutes of stretch a day is sufficient to prevent muscle shortening (Williams 1988, Williams 1990), this study failed to produce a similar effect in humans. In addition to the greater variability in humans, there may be differences in the rate of muscle adaptation between species (St Pierre and Gardiner 1987) and differences in the critical stimulus for adaptation of muscle length between humans and animals. The development of contracture may be slower and the effect of stretch on contracture may be smaller in humans. A more frequent, higher-intensity stretch over a longer duration may be required to produce similar muscle adaptations in humans to those found in animals. Further research is required to determine whether there is an optimal frequency, duration and intensity of stretch which effectively prevents or reverses contracture following stroke.

On average, neither the experimental nor the control group developed clinically-significant degrees of contracture. Even after nine weeks, the average loss of passive range of wrist extension in the control group was only 9 degrees. This is in contrast to other studies where the control groups have developed more severe contractures (Ada et al 2005, de Jong et al 2006, Pandyan et al 2003). It suggests that, in the current study, passive wrist extension was maintained to some extent by factors other than stretch. For example, patients routinely received at least an hour of upper-limb rehabilitation daily, upper-limb group classes were held routinely, electrical stimulation was used routinely to enhance wrist and finger extension, and it was routine for patients to be given upper-limb tasks to practise without supervision from a therapist. On the other hand, participants received less than 12 minutes a day of upper-limb rehabilitation in the studies by Ada et al (2005) and de Jong et al (2006). This may explain why the effect of stretch in the current study is small compared to some studies where stretch has prevented more significant degrees of contracture (Ada et al 2005, de Jong et al 2006).

Given that there was little effect of stretch on contracture in this study, it is not surprising that there was also little evidence of an effect on pain. Stretching neither increased nor decreased pain at rest, suggesting that stretch does not produce painful adverse effects. Over the nine weeks, participants in the control group experienced only a small increase in pain of 0.6 cm. This finding is in line with those of other studies (Dean et al 2000, Gustafsson and McKenna 2006).

The difference between groups of 1.7 points at 4 weeks for upper-limb activity favoured the experimental group. However, the wide 95% confidence intervals indicate a large degree of uncertainty in the size of the effect, and include no effect. The sample size is, therefore, too small to rule out clinically-worthwhile effects on upper-limb activity. Other studies of stretch in adults after stroke have shown similar inconclusive results (Ada et al 2005, Dean et al 2000, de Jong et al 2006).

It is possible that contracture may have developed more slowly and been less severe in this study because upper-limb retraining reduced the amount of time the wrist and finger flexors were immobilised in shortened positions. If this is the case, the risk of contracture for people who have not regained upper-limb strength and activity would be greater after discharge from intensive rehabilitation programs. The effectiveness of stretch over the long term, after intensive rehabilitation has ceased, requires further investigation.

Although a predictive power calculation was conducted to estimate the required sample size prior to commencement of the study, the sample size was insufficient to provide definitive evidence of an effect or lack of effect. The confidence interval spans the range from a below zero to a clinically-worthwhile effect. Therefore, both the possibility that there could be no effect, and the possibility that there could be a small but clinically-worthwhile effect are consistent with the data. We are unable to discriminate between these possibilities.

A further limitation of this study is that, while all measurement procedures were conducted by blinded assessors, participants were aware if they were receiving a stretching program. The participants were, therefore, not blinded to the intervention. This provides a potential source of bias.

In conclusion, this study suggests that a program of 30 minutes daily stretch of the wrist does not have clinically-worthwhile effects on wrist contracture after stroke. We cannot, however, definitively rule out the possibility that the stretch has a marginally-worthwhile effect.

**eAddenda:** Appendix 1 and Table 3 available at [www.physiotherapy.asn.au](http://www.physiotherapy.asn.au)

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## References

- Ada L, Canning C (1990) Anticipating and avoiding muscle shortening. In Ada L, Canning C (Eds) *Key Issues in Neurological Physiotherapy*. Oxford: Butterworth-Heinemann, pp 219–236.
- Ada L, Canning C (2002) Management of skeletal muscle after stroke. In Preedy V, Peters T (Eds) *Skeletal Muscle. Pathology, Diagnosis and Management of Disease*. London: Greenwich Medical Media, pp 639–648.
- Ada L, Goddard E, McCully J, Stavrinou T, Bampton J (2005) Thirty minutes of positioning reduces the development of shoulder external rotation contractures after stroke: a randomized controlled trial. *Archives of Physical Medicine and Rehabilitation* 86: 230–234.
- Carr J, Shepherd R, Nordholm L, Lynne D (1985) Investigation of a new motor assessment scale for stroke patients. *Physical Therapy* 55: 175–180.
- Dean C, Mackey F (1992) Motor Assessment Scale scores as a measure of rehabilitation outcome following stroke. *Australian Journal of Physiotherapy* 38: 31–35.
- Dean CM, Mackey FH, Katrak P (2000) Examination of shoulder positioning after stroke: a randomised controlled pilot trial. *Australian Journal of Physiotherapy* 46: 35–40.
- de Jong L, Nieuwboer A, Aufdemkampe G (2006) Contracture preventive positioning of the hemiplegic arm in subacute stroke patients: a pilot randomized controlled trial. *Clinical Rehabilitation* 20: 656–667.
- Folpp H, Deall S, Harvey L, Gwinn T (2006) Can apparent increases in muscle extensibility with regular stretch be explained by changes in tolerance to stretch? *Australian Journal of Physiotherapy* 52: 45–50.
- Goldspink G, Williams P (1990) Muscle fibre and connective tissue changes: associated with use and disuse. In Ada L, Canning C (Eds) *Key Issues in Neurological Physiotherapy*. Oxford: Butterworth-Heinemann pp 197–217.
- Gossman MR, Sahrman SA, Rose SJ (1982) Review of length-associated changes in muscle. Experimental evidence and clinical implications. *Physical Therapy* 62: 1799–1808.
- Gowland C (1982) Recovery of motor function following stroke: profile and predictors. *Physiotherapy Canada*. 34: 77–84.
- Gustafsson L, McKenna K (2006) A programme of static positional stretches does not reduce hemiplegic shoulder pain or maintain shoulder range of motion – a randomized controlled trial. *Clinical Rehabilitation* 20: 277–286.
- Harvey L, King M, Herbert R (1994) Test-retest reliability of a procedure for measuring extensibility of the extrinsic finger flexor muscles. *Journal of Hand Therapy* 7: 251–254.
- Herbert R (1988) The passive mechanical properties of muscle and their adaptations to altered patterns of use. *Australian Journal of Physiotherapy* 34: 141–149.
- Herbert R (1993) Preventing and treating stiff joints. In: Crosbie J, McConnell J (Eds) *Key Issues in Musculoskeletal Physiotherapy*. Oxford: Butterworth-Heinemann pp 114–141.
- Herbert RD (2005) How muscles respond to stretch. In: Refshauge K, Ada L, Ellis E (Eds) *Science-Based Rehabilitation: Theories into Practice*. Oxford: Butterworth-Heinemann pp 107–130.
- Herbert RD, Balnave RJ (1993) The effect of position of immobilisation on resting length, resting stiffness, and weight of the soleus muscle of the rabbit. *Journal of Orthopaedic Research* 11: 358–366.
- Kwakkel G, Kollen BJ, van der Grand J, Prevo A (2003) Probability of regaining dexterity in the flaccid upper limb: impact of severity of paresis and time since onset in acute stroke. *Stroke* 34: 2181–2186.
- Lannin N (2004) Reliability, validity and factor structure of the upper limb subscale of the Motor assessment Scale (ULMAS) in adults following stroke. *Disability and Rehabilitation* 26: 109–115.

- Linn SL, Granat MH, Lees KR (1999) Prevention of shoulder subluxation after stroke with electrical stimulation. *Stroke* 30: 963–968.
- McCaffery M, Pasero C (1999) Pain: Clinical Manual (2nd edn). London: Mosby pp 35–99.
- O'Dwyer NJ, Ada L, Neilson PD (1996) Spasticity and muscle contracture following stroke. *Brain* 119: 1737–1749.
- O'Dwyer NJ, Ada L (1996) Reflex hyperexcitability and muscle contracture in relation to spastic hypertonia. *Current Opinions in Neurology* 9: 451–455.
- Pandyan AD, Cameron M, Powell J, Stott DJ, Granat MH (2003) Contractures in the post stroke wrist: a pilot study of its time course of development and its association with upper limb recovery. *Clinical Rehabilitation* 17: 88–95.
- St Pierre D, Gardiner PF (1987) The effect of immobilisation on muscle function: a review. *Physiotherapy Canada* 39: 24–36.
- Tabary JC, Tabary C, Tardieu C, Tardieu G, Goldspink G (1972): Physiological and structural changes in the cat's soleus muscle due to immobilization at different lengths by plaster casts. *The Journal of Physiology* 224: 231–244.
- Turton AJ, Britton E (2005): A pilot randomized controlled trial of a daily muscle stretch regime to prevent contractures in the arm after stroke. *Clinical Rehabilitation* 19: 600–612.
- Wanklyn P, Forster A, Young J (1996) Hemiplegic shoulder pain (HSP): natural history and investigation of associated features. *Disability and Rehabilitation* 18: 497–501.
- Williams PE (1988): Effect of intermittent stretch on immobilised muscle. *Annals of the Rheumatic Diseases* 47: 1014–1016.
- Williams PE (1990) Use of intermittent stretch in the prevention of serial sarcomere loss in immobilised muscle. *Annals of Rheumatic Diseases* 49: 316–317.
- Williams PE, Catanese T, Lucey EG, Goldspink G (1988) The importance of stretch and contractile activity in the prevention of connective tissue accumulation in muscle. *Journal of Anatomy* 158: 109–114.
- Williams PE, Goldspink G (1978) Changes in sarcomere length and physiological properties in immobilised muscle. *Journal of Anatomy* 127: 459–468.