

Original article

Do ‘*sliders*’ slide and ‘*tensioners*’ tension? An analysis of neurodynamic techniques and considerations regarding their application

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Abstract

Despite the high prevalence of carpal tunnel syndrome and cubital tunnel syndrome, the quality of clinical practice guidelines is poor and non-invasive treatment modalities are often poorly documented. The aim of this cadaveric biomechanical study was to measure longitudinal excursion and strain in the median and ulnar nerve at the wrist and proximal to the elbow during different types of nerve gliding exercises. The results confirmed the clinical assumption that ‘*sliding techniques*’ result in a substantially larger excursion of the nerve than ‘*tensioning techniques*’ (e.g., median nerve at the wrist: 12.6 versus 6.1 mm, ulnar nerve at the elbow: 8.3 versus 3.8 mm), and that this larger excursion is associated with a much smaller change in strain (e.g., median nerve at the wrist: 0.8% (sliding) versus 6.8% (tensioning)). The findings demonstrate that different types of nerve gliding exercises have largely different mechanical effects on the peripheral nervous system. Hence different types of techniques should not be regarded as part of a homogenous group of exercises as they may influence neuropathological processes differently. The findings of this study and a discussion of possible beneficial effects of nerve gliding exercises on neuropathological processes may assist the clinician in selecting more appropriate nerve gliding exercises in the conservative and post-operative management of common neuropathies.

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1. Introduction

The prevalence of carpal tunnel syndrome (CTS) is around 3% in the general population (Atroshi et al., 1999) and up to 15–20% in occupations that involve repetitive forceful hand tasks, such as meat processing (21%) (Gorsche et al., 1999) and ski manufacturing (15%) (Barnhart et al., 1991). Despite this high prevalence and the major socio-economic impact of

CTS, the quality of clinical practice guidelines in hand therapy is poor (MacDermid, 2004).

The Cochrane Database of Systematic Reviews evaluated the clinical efficacy of the conservative management of CTS. O’Connor et al. (2003) concluded that there is significant short-term benefit from oral steroids, ultrasound, splinting, yoga and carpal bone mobilisation. However, Gerritsen et al. (2002) concluded that there is conflicting evidence for oral steroids and ultrasound, and that diuretics, vitamin B6, yoga, non-steroidal anti-inflammatory drugs, and laser acupuncture are ineffective in providing short-term symptom relief. Local corticosteroid injections provide short-term relief, but there is no benefit compared to placebo beyond one month (Marshall et al., 2002). In general,

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long-term outcomes are poor (Wilson and Sevier, 2003), which prompts the question whether traditionally advocated modalities for CTS are adequate (Seradge et al., 2002).

Most studies which examined the clinical efficacy of nerve gliding exercises in CTS (Rozmaryn et al., 1998; Tal-Akabi and Rushton, 2000; Akalin et al., 2002; Seradge et al., 2002; Pinar et al., 2005; Baysal et al., 2006) were not included in the Cochrane review. However, several other reviews do suggest the use of nerve and tendon gliding exercises in the conservative treatment of CTS (Osterman et al., 2002; Burke et al., 2003; Michlovitz, 2004; Muller et al., 2004). Also in the post-operative management following carpal tunnel release, nerve and tendon gliding exercises are recommended (Nathan et al., 1993; Cook et al., 1995).

The nerve gliding exercises included in the above-mentioned studies aimed to induce sliding of the median nerve relative to its surrounding structures by performing joint movements that elongate the nerve bed (the tract formed by the structures that surround the nerve). The nerve bed was elongated at either the hand and wrist (Rozmaryn et al., 1998; Akalin et al., 2002; Pinar et al., 2005; Baysal et al., 2006) or over a longer section of the median nerve (Seradge et al., 2002), or by using the neurodynamic test for the median nerve as a mobilisation manoeuvre (Tal-Akabi and Rushton, 2000). There is indeed ample evidence that elongation of the nerve bed induces nerve gliding (Szabo et al., 1994; Byl et al., 2002; Dilley et al., 2003; Coppieters et al., 2006). Lengthening of the nerve bed also elongates the nerve which increases nerve tension and intraneural pressure. Whereas sustained elevated intraneural fluid pressure reduces intraneural blood flow in oedematous neuropathies (Myers et al., 1986), a dynamic variation in intraneural pressure when correctly applied may facilitate evacuation of intraneural oedema and reduce symptoms (Burke et al., 2003). In contrast, the increase in nerve strain associated with elongation of the nerve bed may also trigger ectopic discharges from mechanosensitive abnormal impulse generating sites (Dilley et al., 2005) and exacerbate symptoms.

Techniques which facilitate nerve gliding by elongation of the nerve bed no longer cover the wide spectrum of nerve gliding exercises currently advocated. Combinations of movements in which elongation of the nerve bed at one joint is simultaneously counterbalanced by a reduction in the length of the nerve bed at an adjacent joint (*'sliding techniques'*) have been promoted (Butler, 2000; Coppieters et al., 2004; Shacklock, 2005). The clinical assumption is that these sliding techniques result in a larger longitudinal excursion of the nerve with a minimal increase in strain. Although anatomical/bio-mechanical studies contributed to the validation of neurodynamic tests (Kleinrensink et al., 2000; Byl et al., 2002; Coppieters et al., 2006), to the best of our

knowledge, excursion and strain in peripheral nerves have never been evaluated from a therapeutic perspective. The aim of this study was to evaluate excursion and strain in the median and ulnar nerve for different types of nerve gliding exercises for CTS and cubital tunnel syndrome. The selected techniques reflect the different types of exercises suggested by Butler (2000), Coppieters et al. (2004) and Shacklock (2005).

2. Methods

Longitudinal excursion and strain in the median and ulnar nerve during tensioning and sliding techniques and during isolated movements of the wrist and elbow were measured in two embalmed undisturbed male cadavers (age at time of death: 78 and 85 years). The study was approved by the Institutional Ethics Committee.

2.1. Excursion

A digital Vernier calliper was used to measure longitudinal excursion of the median and ulnar nerve in relation to surrounding structures. A fixed marker was screwed into the humerus and into the distal end of the radius. This marker consisted of a metal L-shaped pin which was placed perpendicularly over the nerve bed. As a mobile marker, a suture was placed around the peripheral nerve in the vicinity of the fixed marker (Byl et al., 2002; Coppieters et al., 2006).

2.2. Strain

Linear displacement transducers (Microstrain, Burlington, USA) (Fig. 1) with a stroke length of 6 mm and

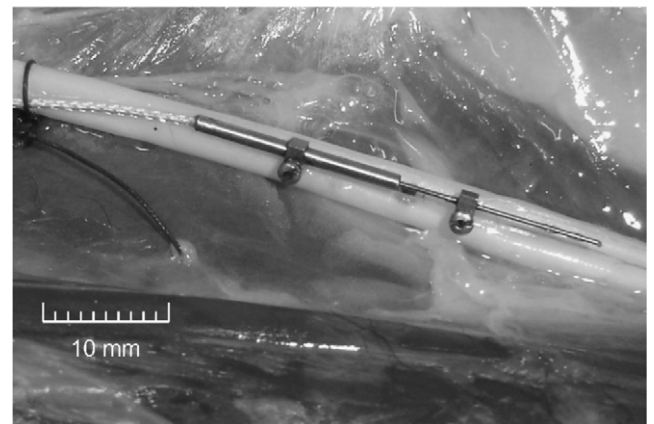


Fig. 1. The linear displacement transducer (differential variable reluctance transducer) used to calculate nerve strain shown in a fresh cadaver. Note that the nerve which runs diagonally across the image is not the median or ulnar nerve. To insert the transducers, small windows of approximately 7×4 cm were made into the skin and underlying subcutaneous tissues. Disruption of surrounding soft tissues was minimised to limit alteration of local biomechanics.

a resolution of 1.5 μm were used to measure strain in the median and ulnar nerve. One transducer was inserted into the median nerve just proximal to the carpal tunnel, while a second transducer was inserted in the nerve approximately 10 cm proximal to the medial epicondyle of the elbow. For the ulnar nerve, one transducer was inserted just proximal to the elbow. Previous studies have demonstrated the usefulness of these transducers to measure strain in peripheral nerves (Wright et al., 1996; Byl et al., 2002; Coppieters et al., 2006).

For the median nerve, the anatomical position was used as the arbitrary reference position to which changes in strain were expressed. In this reference position, the arm was positioned in 10° shoulder abduction, with the elbow in submaximal extension (170°), the forearm in supination and the wrist in a neutral position (0° extension). Because the ulnar nerve buckled at the elbow in the anatomical position, the reference position for the ulnar nerve was 90° shoulder abduction, 90° elbow flexion and the wrist in a neutral position.

2.3. Goniometry

To guarantee accurate repositioning, twin axis electrogoniometers (SG65 and SG110, Biometrics, Blackwood, UK) were attached to the wrist, elbow and shoulder.

2.4. Mobilisation techniques (median nerve)

2.4.1. Tensioning technique

With a tensioning technique, nerve gliding is obtained by moving one or several joints in such a manner that the nerve bed is elongated. In this study, the tensioning technique (Fig. 2A) consisted of simultaneous extension of the wrist (from 0° to 60°) and elbow (from 90° to 165°), followed by a return to the starting position (wrist from 60° extension to neutral (0°) and elbow from 165° extension to 90°). Full elbow extension was defined as 180°.

2.4.2. Sliding technique

A sliding technique consists of an alternation of combined movements of at least two joints in which one movement lengthens the nerve bed thus increasing tension in the nerve while the other movement simultaneously decreases the length of the nerve bed which unloads the nerve. These techniques aim to mobilise a nerve with a minimal increase in tension and are thought to result in a larger longitudinal excursion than techniques which simply elongate the nerve bed, such as tensioning techniques. In this study, the sliding technique (Fig. 2B) consisted of the alternation of elbow extension (loads the median nerve) and wrist flexion (unloads the median nerve), with elbow flexion (unloading) and wrist extension (loading). The

range of motion (ROM) was identical to the amplitudes in the tensioning technique (wrist: between 0° and 60° extension; elbow: between 90° and 165° extension).

2.4.3. Single joint movements

In addition to the combined movements (tensioning and sliding technique), the impact of isolated wrist and elbow movements was investigated. These isolated movements were performed with the neighbouring joint in a position which either unloaded (Fig. 2C and E) or pre-tensioned (Fig. 2D and F) the median nerve. In principle, these movements can be regarded as tensioning techniques as no simultaneous movement limits the lengthening of the nerve bed. Amplitudes for the wrist and elbow were identical to the ROM for the tensioning and sliding techniques mentioned above.

2.5. Mobilisation techniques (ulnar nerve)

2.5.1. Tensioning technique

With the wrist in 60° extension, the elbow was flexed (from 150° to 65°) and the shoulder abducted (from 60° to 100°). The technique was performed with supination as the forearm could not be pronated due to stiffness of the elbow joint.

2.5.2. Sliding technique

Elbow extension (unloads the ulnar nerve) and shoulder abduction (loads the ulnar nerve) were alternated with elbow flexion (loading) and shoulder adduction (unloading). Throughout the sliding technique, the wrist was maintained in 60° extension and the forearm in supination. The ROM for the elbow and shoulder were identical to the amplitudes used in the tensioning technique (elbow: between 65° and 150°; shoulder: between 60° and 100° abduction).

2.6. Data collection and analysis

The output from the strain gauges and electrogoniometers was connected to a data acquisition system (Micro 1401, Cambridge Electronic Design, Cambridge, UK) which sampled at 100 Hz using Spike 2 software. The uniqueness of this set-up was that continuous strain recordings could be made throughout the entire ROM. This allowed the construction of line figures expressing nerve strain in function of ROM, rather than only reporting discrete values associated with the start or end position of a technique. To our knowledge, this method has not yet been employed by other research groups to document variations in nerve strain. Another advantage of the set-up was that the investigator received real time feedback of the position of the wrist, elbow and shoulder via a computer screen, which also displayed the target angles. This method promoted accurate

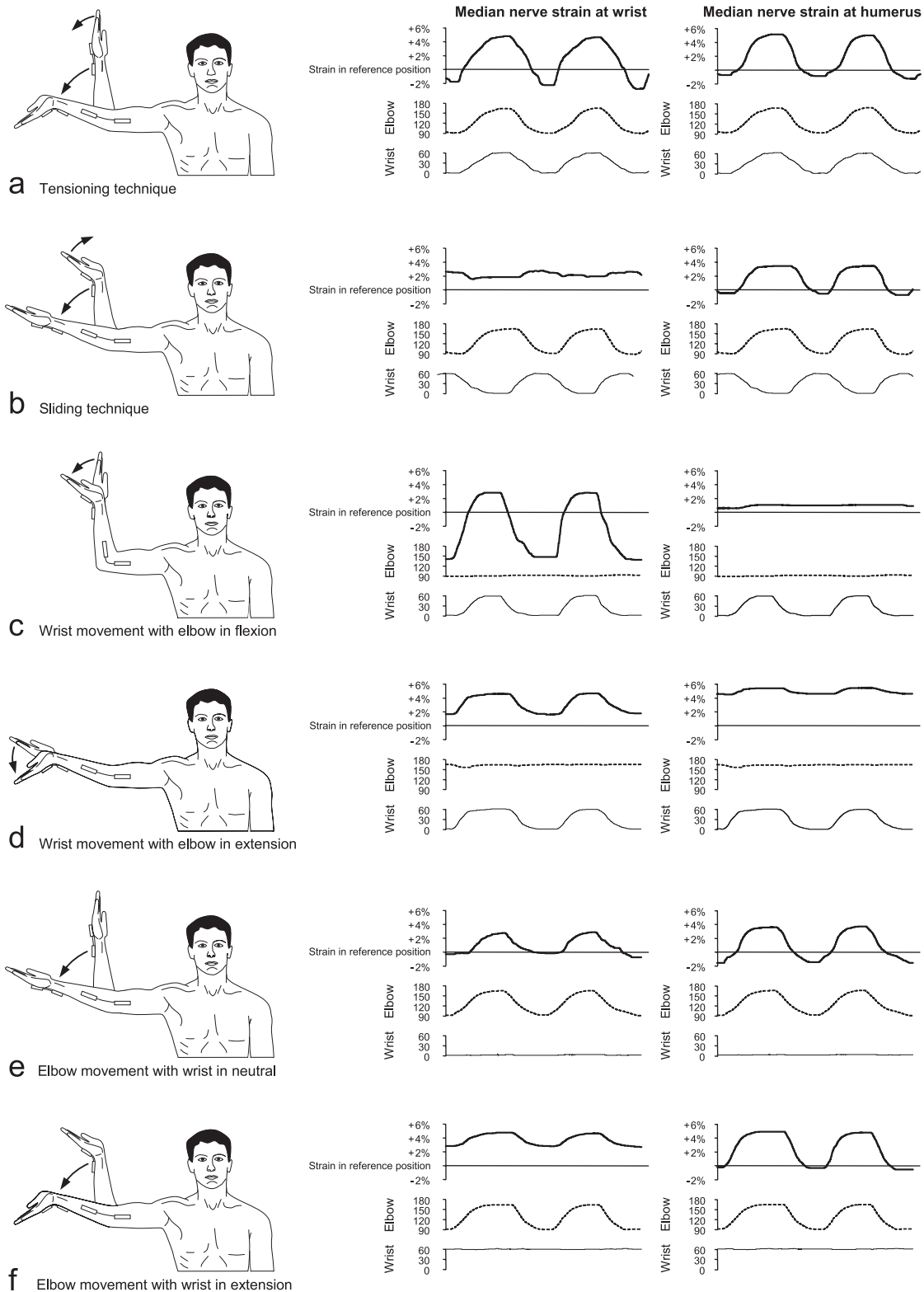


Fig. 2. Mobilisation techniques and changes in strain in the median nerve. For each mobilisation technique, the corresponding diagrams in the middle and right column consist of three waveforms: the top waveform (—) represents the change in strain in the median nerve at the wrist (middle column) or at the humerus (right column). The middle waveform (---) shows the angle at the elbow and the bottom waveform (—) demonstrates the angle at the wrist. For the elbow, 180° corresponds with full extension; for the wrist, 60° represents extension. For a detailed discussion, see text.

repositioning of joint angles which justified comparison of excursion and strain between techniques. Throughout the experiment, the investigator was blinded to the output of the strain gauges.

Note that we use the term ‘*nerve gliding exercises*’ to refer to a variety of different techniques, whereas the term ‘*sliding technique*’ is exclusively used to refer to techniques where movements in adjacent joints are combined to limit elongation of the nerve bed.

3. Results

3.1. Median nerve

The amount of longitudinal excursion and differences in strain between the starting and end position for each mobilisation technique are summarised in Table 1. Fig. 2 demonstrates the continuous strain recordings in the median nerve in relation to the angles at the elbow and wrist for two consecutive repetitions for each mobilisation technique.

Clear differences were observed between the sliding and tensioning technique and isolated single joint movements. Longitudinal excursion of the median nerve at the wrist was approximately twice as large for the sliding technique (12.6 mm) than for the tensioning technique (6.1 mm). In addition, strain in the median nerve at the wrist remained relatively constant during the sliding technique (variation of 0.8%) whereas it varied strongly during the tensioning technique (6.8%).

Peak strain in the median nerve was also substantially larger for the tensioning technique (+4.7%) than for the sliding technique (+2.7%).

For single joint movements, wrist extension resulted in a slightly larger excursion of the median nerve at the wrist when the elbow was flexed (9.8 mm) compared to when the elbow was extended (8.1 mm). Wrist extension with the elbow in flexion was associated with a smaller peak strain (+2.8%) than when the wrist was mobilised while the nerve bed was already elongated by elbow extension (+4.6%). A similar pattern could be observed for elbow movements with the wrist in neutral and extension, although the excursion was larger when the elbow was moved with the wrist in extension.

Paradoxically, longitudinal excursion of the median nerve at the humerus was larger for the tensioning (16.1 mm) than for the sliding (11.1 mm) technique. However, as anticipated, the tensioning technique resulted in a larger peak strain (+5.0%) than the sliding technique (+3.5%). For single joint movements, wrist extension resulted in small longitudinal movements of the median nerve relative to the humerus (0.8 and 1.8 mm) and small changes in strain (0.3% and 0.9%). In contrast, elbow movements were associated with large excursions (12.0 and 14.9 mm) and large changes in strain (5.2% and 5.3%).

3.2. Ulnar nerve

The longitudinal movement of the ulnar nerve associated with the sliding technique (8.3 mm) was approximately

Table 1

Excursion and strain in the median nerve at the level of the wrist (A) and at the level of the humerus (B), and in the ulnar nerve, just proximal to the elbow (C)

	Excursion (mm)	Strain increase during the technique; from minimal to maximal strain value (relative to reference position)
<i>A. Median nerve at the wrist</i>		
Tensioning technique	6.1	6.8%; from −2.0% to +4.7%
Sliding technique	12.6	0.8%; from +1.9% to +2.7%
Wrist movement, with elbow in flexion	9.8	9.5%; from −6.7% to +2.8%
Wrist movement, with elbow in extension	8.1	3.0%; from +1.6% to +4.6%
Elbow movement, with wrist in neutral	1.7	3.0%; from −0.5% to +2.4%
Elbow movement, with wrist in extension	4.4	1.9%; from +2.8% to +4.7%
<i>B. Median nerve at the humerus</i>		
Tensioning technique	16.5	6.0%; from −1.0% to +5.0%
Sliding technique	11.1	4.1%; from −0.6% to +3.5%
Wrist movement, with elbow in flexion	0.8	0.3%; from +0.9% to +1.2%
Wrist movement, with elbow in extension	1.8	0.9%; from +4.9% to +5.8%
Elbow movement, with wrist in neutral	12.0	5.2%; from −1.6% to +3.6%
Elbow movement, with wrist in extension	14.9	5.3%; from −0.3% to +5.0%
<i>C. Ulnar nerve proximal to the elbow</i>		
Tensioning technique	3.8	(9.8%) ^a ; from (−6.6%) ^a to +3.2%
Sliding technique	8.3	0.4%; from +0.3% to +0.7%

The values represent the mean of three consecutive repetitions.

^aDue to buckling of the ulnar nerve in the relaxed position of the tensioning technique (shoulder adduction–elbow extension), the minimal strain value and the derived increase in strain are not precise, hence they have been placed between brackets. The maximal strain value was not affected.

double the amount of excursion observed during the tensioning technique (3.8 mm). Strain in the ulnar nerve during the tensioning and sliding technique is illustrated in Fig. 3. As for the median nerve, changes in strain with the sliding technique were minimal (0.4%) and peak strain (+0.7%) was substantially smaller than during the tensioning technique (+3.2%). Due to buckling of the ulnar nerve in the relaxed position of the tensioning technique, it was impossible to accurately determine the change in strain during the tension technique. It was however obvious that the increase in strain was substantially larger than during the sliding technique.

4. Discussion

The findings clearly demonstrate that different types of nerve gliding exercises have largely different mechanical effects on the peripheral nervous system. Longitudinal excursion and strain associated with a particular joint movement is strongly influenced by the position or simultaneous movement of an adjacent joint. For example, when considering the median nerve at the wrist, wrist extension resulted in a distal glide of approximately 9 mm. This excursion increased by ~30% (to 12.6 mm) if wrist extension was accompanied by elbow flexion, a movement that reduces the length of the nerve bed and decreases strain in the median nerve around the elbow and thus facilitates the distal glide of the nerve at the wrist (sliding technique). Similarly, distal excursion decreased by ~30% (to 6.1 mm) if wrist extension was accompanied by elbow extension, which increases the length of the nerve bed and increases tension in the nerve at the elbow and thus hinders distal excursion (tensioning technique). A similar trend was observed for the ulnar nerve at the elbow: nerve gliding was substantially larger for the sliding technique than for the tensioning technique (8.3 versus 3.8 mm).

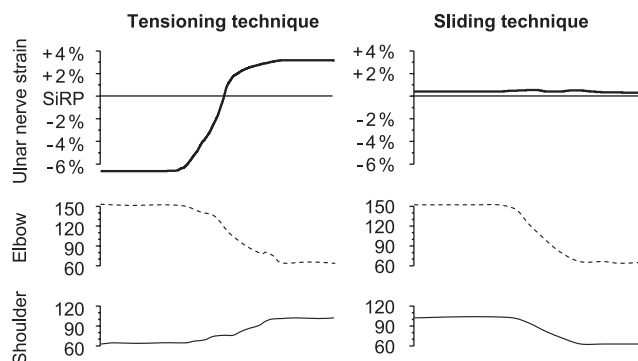


Fig. 3. Changes in strain in the ulnar nerve just proximal to the elbow during a tensioning (left panel) and sliding technique (right panel). The top waveform (—) represents the change in strain in the ulnar nerve; the middle waveform (---) shows the angle at the elbow and the bottom waveform (—) demonstrates the angle at the shoulder. Continuous data for half a cycle are presented (from the starting position to the end position).

As anticipated, the peak in nerve strain was large for techniques which involved simultaneous elongation of the nerve bed at adjacent joints. Previous research has demonstrated that nerve strain can be transmitted along a long section of a peripheral nerve (e.g., an increase in tibial nerve strain at the tarsal tunnel following hip flexion in a modified straight leg raising test; Coppieters et al., 2006). Similarly, a decrease in length of the nerve bed reduces nerve strain at adjacent joints (e.g., shoulder adduction reduces strain in the median nerve at the elbow and wrist; Wright et al., 1996). One of the advances of this study is that we demonstrated that when movements which increase and decrease the length of the nerve bed are performed simultaneously at adjacent joints, nerve gliding occurs with almost no increase in nerve strain. Facilitation of nerve gliding in this manner (sliding technique) is markedly different to inducing nerve gliding by elongating the nerve bed and increasing nerve strain (tensioning technique or isolated joint movements).

Overall, sliding techniques resulted in the largest excursion. However, median nerve gliding at the humerus revealed a cumulative effect of joint movements that elongate the nerve bed if both movements are located distally from the location of the excursion measurements. This can be explained by the fact that a nerve slides toward the joint where the nerve bed is elongated (Wright et al., 2001; Boyd et al., 2005; Coppieters et al., 2006) and a cumulative effect occurs if both movements facilitate nerve gliding in the same direction. However, this excursion was associated with a relatively large increase in nerve strain, which may be contraindicated in more acute conditions.

Reduced transverse gliding of the median nerve in the carpal tunnel has been demonstrated in patients with CTS (Nakamichi and Tachibana, 1995; Allmann et al., 1997; Erel et al., 2003), but the findings regarding reduced longitudinal gliding are less conclusive. Smaller differences in latencies of action potentials between measurements with the wrist in flexion and extension in patients with CTS compared to healthy controls were interpreted to reflect a smaller longitudinal glide during wrist movements (Valls-Sole et al., 1995). Erel et al. (2003) showed that median nerve movement following metacarpophalangeal flexion was ~20% smaller in patients with CTS. However, this difference failed to reach the level of significance and the authors concluded that longitudinal excursion in patients with CTS is normal. Tuzuner et al. (2004) measured longitudinal nerve gliding before and immediately after endoscopic carpal tunnel release and noted no immediate difference. Although these studies do not irrefutably indicate or rule out that longitudinal excursion is restricted in CTS, the beneficial effects of nerve gliding exercises for CTS and other neuropathies are unlikely to relate (solely) to restoration of restricted longitudinal nerve motion. An exploration of therapeutic

potential needs to include effects on pathophysiological processes. These effects should be considered at the site of injury, but also remotely at the dorsal root ganglion and central nervous system.

The awareness that different types of nerve gliding exercises have markedly different mechanical effects on the peripheral nervous system may result in the selection of safer and pathology-targeted techniques. The data supports the contention and would allow the suggestion that a sliding technique is less aggressive and may be more appropriate for acute injuries, post-operative management and situations which may lead to nerve irritation and entrapment such as bleeding and inflammation around the nerve. A tensioning technique may reduce intraneural swelling and circulatory compromise via fluctuating effects on intraneural pressure. Dynamically altering intraneural pressure may result in a 'pumping action' or 'milking effect' with beneficial effects on nerve hydration (Rozmaryn et al., 1998). This 'milking effect' may also be present with a sliding technique, when mobilising the median nerve through areas of increased pressure, such as the carpal tunnel in patients with CTS.

We propose that the likely milking or pumping effects of sliding techniques performed with respect to reasoned pathobiology and individual patient presentation may enhance dispersal of local inflammatory products in and around nerves. Nerve inflammation is frequently associated with damaged and diseased nerves. The 'inflammatory soup' comprises fluids and cells including enzymes, acids, prostaglandins, histamine and macrophages. It creates an acidic environment which is known to enhance peripheral nerve sensitivity (Maves et al., 1995; Steen et al., 1996). Inflamed nerves are also immunoreactive, with proinflammatory cytokines such as tumour necrosis factor alpha (TNF α) capable of producing spontaneous discharge in sensory fibres by forming its own ion channels (Baldwin et al., 1996; Sorkin et al., 1997), a process enhanced by the acidic environment of inflammation. TNF α and other proinflammatory cytokines may also damage myelin and alter the blood nerve barrier (Watkins and Maier, 2002).

Nerve gliding exercises may also limit fibroblastic activity and minimise scar formation via normal and early use of mesoneurial gliding tissues (Millesi et al., 1995). They may prevent post-operative adhesions and may decrease venous engorgement and elevated endoneurial fluid pressure. Injured and irritated nerves frequently become pressurised as endoneurial fluid pressure increases. This is associated with endoneurial oedema, ischaemia, slowing and pooling of axoplasmic flow, and disruption of pressure gradients which normally allow adequate perfusion of blood into neurones (Sunderland, 1976; Myers et al., 1986; Lundborg, 1988). Patients with CTS typically show higher carpal tunnel pressures (Gelberman et al., 1981), which may have a detrimental effect on nerve function

and integrity (Rempel et al., 1999; Mackinnon, 2002; Diao et al., 2005). However, exercises that induce dynamic changes in pressure may have a positive effect. Upon full excursion of the flexor tendons of the fingers, the lumbrical muscles travel in and back out of the carpal tunnel, influencing carpal tunnel pressure (Cobb et al., 1995). When performed dynamically, the pumping effect may facilitate venous return, oedema dispersal and decrease of pressure inside the perineurium (Totten and Hunter, 1991; Burke et al., 2003). Blood flow to the wrist and hand also increased after hand exercises (Hansford et al., 1986) thereby increasing circulation, axonal transport, nutrition, and oxygenation to the median nerve in the carpal tunnel.

There may also be beneficial remote effects of sliding techniques. Ideal management of a local nerve injury reduces sensitivity and restores function, thus easing the threat value of the injury. This would be likely to minimise the potential for ion channel upregulation in dorsal root ganglia and the central nervous system, and limit the potential for dorsal horn and brain changes. Sliding techniques involve large amplitudes, can be performed passively or actively, and can be integrated into metaphorical movements or dance and as such can distract the patient from the condition (Butler, 2005). Patients with CTS are known to have altered somatosensory hand representations in the brain (Druschky et al., 2000; Tecchio et al., 2002). Sliding techniques allow large range neurally non-aggressive movements to be constructed, often allowing movement to be presented in novel ways to the brain, uncoupling learnt expectations of pain. The larger range movements are likely to decrease fear of movement and they may well assist in remapping altered representations.

A limitation of the present study is that only two cadavers were available at the time of testing. However, because a similar trend was observed for the median and ulnar nerve, and because the findings are in line with the theoretical construct, we have no reasons to believe that the findings are not representative. Additional testing is currently carried out to further evaluate the strength of the concepts presented in this manuscript. Another potential limitation is the use of embalmed cadavers. However, the magnitude of strain reported in this study is very similar to the values reported by Byl et al. (2002) who used fresh cadavers. This suggests that embalment may not dramatically alter the mechanical properties of nerves. The use of a repeated-measures design and the large relative differences between techniques also adds to the legitimacy of the main findings.

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References

- Akalin E, El O, Peker O, Senocak O, Tamci S, Gulbahar S, et al. Treatment of carpal tunnel syndrome with nerve and tendon gliding exercises. *American Journal of Physical Medicine & Rehabilitation* 2002;81(2):108–13.
- Allmann KH, Horch R, Uhl M, Gufler H, Althoefer C, Stark GB, et al. MR imaging of the carpal tunnel. *European Journal of Radiology* 1997;25(2):141–5.
- Atroshi I, Gummesson C, Johnsson R, Ornstein E, Ranstam J, Rosen I. Prevalence of carpal tunnel syndrome in a general population. *Journal of the American Medical Association* 1999;282(2):153–8.
- Baldwin RL, Stolz ML, Hood L, Wisniewski BJ. Structural changes of tumor necrosis factor alpha associated with membrane insertion and channel formation. *Proceedings of the National Academy of Sciences of the United States of America* 1996;93(3):1021–6.
- Barnhart S, Demers PA, Miller M, Longstreth WT, Rosenstock L. Carpal tunnel syndrome among ski manufacturing workers. *Scandinavian Journal of Work, Environment & Health* 1991;17(1):46–52.
- Baysal O, Altay Z, Ozcan C, Ertem K, Yologlu S, Kayhan A. Comparison of three conservative treatment protocols in carpal tunnel syndrome. *International Journal of Clinical Practice* 2006;60(7):820–8.
- Boyd BS, Puttlitz C, Gan J, Topp KS. Strain and excursion in the rat sciatic nerve during a modified straight leg raise are altered after traumatic nerve injury. *Journal of Orthopaedic Research* 2005;23(4):764–70.
- Burke FD, Ellis J, McKenna H, Bradley MJ. Primary care management of carpal tunnel syndrome. *Postgraduate Medical Journal* 2003;79(934):433–7.
- Butler DS. The sensitive nervous system. Adelaide: Noigroup Publications; 2000.
- Butler DS. The neurodynamics techniques. DVD and handbook. Adelaide: Noigroup Publications; 2005.
- Byl C, Puttlitz C, Byl N, Lotz J, Topp K. Strain in the median and ulnar nerves during upper-extremity positioning. *Journal of Hand Surgery [Am]* 2002;27(6):1032–40.
- Cobb TK, An KN, Cooney WP. Effect of lumbrical muscle incursion within the carpal tunnel on carpal tunnel pressure: a cadaveric study. *Journal of Hand Surgery [Am]* 1995;20(2):186–92.
- Cook AC, Szabo RM, Birkholz SW, King EF. Early mobilization following carpal tunnel release. A prospective randomized study. *Journal of Hand Surgery [Br]* 1995;20(2):228–30.
- Coppieters MW, Alshami AM, Babri AS, Souvlis T, Kippers V, Hodges PW. Strain and excursion of the sciatic, tibial and plantar nerves during a modified straight leg raising test. *Journal of Orthopaedic Research* 2006;24(9):1883–9.
- Coppieters MW, Bartholomeeusen KE, Stappaerts KH. Incorporating nerve-gliding techniques in the conservative treatment of cubital tunnel syndrome. *Journal of Manipulative and Physiological Therapeutics* 2004;27(9):560–8.
- Diao E, Shao F, Liebenberg E, Rempel D, Lotz JC. Carpal tunnel pressure alters median nerve function in a dose-dependent manner: a rabbit model for carpal tunnel syndrome. *Journal of Orthopaedic Research* 2005;23(1):218–23.
- Dille A, Lynn B, Greening J, DeLeon N. Quantitative in vivo studies of median nerve sliding in response to wrist, elbow, shoulder and neck movements. *Clinical Biomechanics* 2003;18(10):899–907.
- Dille A, Lynn B, Pang SJ. Pressure and stretch mechanosensitivity of peripheral nerve fibres following local inflammation of the nerve trunk. *Pain* 2005;117(3):462–72.
- Druschky K, Kaltenhauser M, Hummel C, Druschky A, Huk WJ, Stefan H, et al. Alteration of the somatosensory cortical map in peripheral mononeuropathy due to carpal tunnel syndrome. *Neuroreport* 2000;11(17):3925–30.
- Erel E, Dille A, Greening J, Morris V, Cohen B, Lynn B. Longitudinal sliding of the median nerve in patients with carpal tunnel syndrome. *Journal of Hand Surgery [Br]* 2003;28(5):439–43.
- Gelberman RH, Hergenroeder PT, Hargens AR, Lundborg GN, Akeson WH. The carpal tunnel syndrome. A study of carpal canal pressures. *Journal of Bone and Joint Surgery [Am]* 1981;63(3):380–3.
- Gerritsen AA, de Krom MC, Struijs MA, Scholten RJ, de Vet HC, Bouter LM. Conservative treatment options for carpal tunnel syndrome: a systematic review of randomised controlled trials. *Journal of Neurology* 2002;249(3):272–80.
- Gorsche RG, Wiley JP, Renger RF, Brant RF, Gerner TY, Sasyniuk TM. Prevalence and incidence of carpal tunnel syndrome in a meat packing plant. *Occupational and Environmental Medicine* 1999;56(6):417–22.
- Hansford T, Blood H, Kent B, Lutz G. Blood flow changes at the wrist in manual workers after preventive interventions. *Journal of Hand Surgery [Am]* 1986;11(4):503–8.
- Kleinrensink GJ, Stoeckart R, Mulder PG, Hoek G, Broek T, Vleeming A, et al. Upper limb tension tests as tools in the diagnosis of nerve and plexus lesions. Anatomical and biomechanical aspects. *Clinical Biomechanics* 2000;15(1):9–14.
- Lundborg G. Nerve injuries and repair. Edinburgh: Churchill Livingstone; 1988.
- MacDermid JC. The quality of clinical practice guidelines in hand therapy. *Journal of Hand Therapy* 2004;17(2):200–9.
- Mackinnon SE. Pathophysiology of nerve compression. *Hand Clinics* 2002;18(2):231–41.
- Marshall S, Tardif G, Ashworth N. Local corticosteroid injection for carpal tunnel syndrome. *The Cochrane Database of Systematic Reviews* 2002;4:CD001554.
- Maves TJ, Gebhart GF, Meller ST. Continuous infusion of acidified saline around the rat sciatic nerve produces thermal hyperalgesia. *Neuroscience Letters* 1995;194(1–2):45–8.
- Michlovitz SL. Conservative interventions for carpal tunnel syndrome. *The Journal of Orthopaedic and Sports Physical Therapy* 2004;34(10):589–600.
- Millesi H, Zoch G, Reihnsner R. Mechanical properties of peripheral nerves. *Clinical Orthopaedics* 1995;314:76–83.
- Muller M, Tsui D, Schnurr R, Biddulph-Deisroth L, Hard J, MacDermid JC. Effectiveness of hand therapy interventions in primary management of carpal tunnel syndrome: a systematic review. *Journal of Hand Therapy* 2004;17(2):210–28.
- Myers RR, Murakami H, Powell HC. Reduced nerve blood flow in edematous neuropathies: a biomechanical mechanism. *Microvascular Research* 1986;32(2):145–51.
- Nakamichi K, Tachibana S. Restricted motion of the median nerve in carpal tunnel syndrome. *Journal of Hand Surgery [Br]* 1995;20(4):460–4.
- Nathan PA, Meadows KD, Keniston RC. Rehabilitation of carpal tunnel surgery patients using a short surgical incision and an early program of physical therapy. *Journal of Hand Surgery [Am]* 1993;18(6):1044–50.
- O'Connor D, Marshall S, Massy-Westropp N. Non-surgical treatment (other than steroid injection) for carpal tunnel syndrome. *The Cochrane Database of Systematic Reviews* 2003;1:CD003219.
- Osterman AL, Whitman M, Porta LD. Nonoperative carpal tunnel syndrome treatment. *Hand Clinics* 2002;18(2):279–89.
- Pinar L, Enhos A, Ada S, Gungor N. Can we use nerve gliding exercises in women with carpal tunnel syndrome? *Advances in Therapy* 2005;22(5):467–75.

- Rempel D, Dahlin L, Lundborg G. Pathophysiology of nerve compression syndromes: response of peripheral nerves to loading. *Journal of Bone and Joint Surgery [Am]* 1999;81(11):1600–10.
- Rozmaryn LM, Dovel S, Rothman ER, Gorman K, Olvey KM, Bartko JJ. Nerve and tendon gliding exercises and the conservative management of carpal tunnel syndrome. *Journal of Hand Therapy* 1998;11(3):171–9.
- Seradge H, Parker W, Baer C, Mayfield K, Schall L. Conservative treatment of carpal tunnel syndrome: an outcome study of adjunct exercises. *The Journal of the Oklahoma State Medical Association* 2002;95(1):7–14.
- Shacklock MO. *Clinical neurodynamics: a new system of musculoskeletal treatment*. Edinburgh: Elsevier Butterworth-Heinemann; 2005.
- Sorkin LS, Xiao WH, Wagner R, Myers RR. Tumour necrosis factor- α induces ectopic activity in nociceptive primary afferent fibres. *Neuroscience* 1997;81(1):255–62.
- Steen KH, Steen AE, Kreysel HW, Reeh PW. Inflammatory mediators potentiate pain induced by experimental tissue acidosis. *Pain* 1996;66(2–3):163–70.
- Sunderland S. The nerve lesion in the carpal tunnel syndrome. *Journal of Neurology, Neurosurgery, and Psychiatry* 1976;39(7):615–26.
- Szabo RM, Bay BK, Sharkey NA, Gaut C. Median nerve displacement through the carpal canal. *The Journal of Hand Surgery [Am]* 1994;19(6):901–6.
- Tal-Akabi A, Rushton A. An investigation to compare the effectiveness of carpal bone mobilisation and neurodynamic mobilisation as methods of treatment for carpal tunnel syndrome. *Manual Therapy* 2000;5(4):214–22.
- Tecchio F, Padua L, Aprile I, Rossini PM. Carpal tunnel syndrome modifies sensory hand cortical somatotopy: a MEG study. *Human Brain Mapping* 2002;17(1):28–36.
- Totten PA, Hunter JM. Therapeutic techniques to enhance nerve gliding in thoracic outlet syndrome and carpal tunnel syndrome. *Hand Clinics* 1991;7(3):505–20.
- Tuzuner S, Ozkaynak S, Acikbas C, Yildirim A. Median nerve excursion during endoscopic carpal tunnel release. *Neurosurgery* 2004;54(5):1155–60.
- Valls-Sole J, Alvarez R, Nunez M. Limited longitudinal sliding of the median nerve in patients with carpal tunnel syndrome. *Muscle & Nerve* 1995;18(7):761–7.
- Watkins LR, Maier SF. Beyond neurons: evidence that immune and glial cells contribute to pathological pain states. *Physiological Reviews* 2002;82(4):981–1011.
- Wilson JK, Sevier TL. A review of treatment for carpal tunnel syndrome. *Disability and Rehabilitation* 2003;25(3):113–9.
- Wright TW, Glowczewskie Jr. F, Cowin D, Wheeler DL. Ulnar nerve excursion and strain at the elbow and wrist associated with upper extremity motion. *The Journal of Hand Surgery [Am]* 2001;26(4):655–62.
- Wright TW, Glowczewskie F, Wheeler D, Miller G, Cowin D. Excursion and strain of the median nerve. *Journal of Bone and Joint Surgery [Am]* 1996;78(12):1897–903.