Strength training after stroke: Rationale, evidence and potential implementation barriers for physiotherapists

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ABSTRACT

Deficits in muscles strength are common after stroke and have a strong relationship to the functional limitations people experience. This clinical commentary discusses the evidence for strength training to improve strength and increase function in people after stroke. Moderate to high intensity strength training has been strongly advocated for people with stroke, yet uptake into rehabilitation clinical practice appears limited. This review provides insight into the potential barriers to implementation of strength training at the recommended training parameters for physiotherapists and offers guidance for undertaking strength training in people with stroke.

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In New Zealand there are approximately 45 000 stroke survivors, and despite continued efforts to reduce the risk of stroke in our country, this number is predicted to rise to 50 000 by 2015 (Feigin et al 2014, Tobias et al 2007). Globally stroke is the third leading cause of disability adjusted life years for individuals (Lozano et al 2012), representing a significant burden to the person, their family, society and our healthcare system. Whilst there is considerable spontaneous recovery following stroke, ongoing deficits in muscle strength and function after stroke are common (Bohannon 2007). Over the past 20 years there has been an exponential growth in the research investigating the cause of motor impairments, their relationship to function and participation and the most effective interventions to address these limitations in people following stroke. Much of this research has addressed the issue of muscle strength.

What is muscle strength?

Muscle strength is defined as the ability to generate force against a load and is assessed as the maximum load that can be moved or the maximum torque that can be generated during a movement. Deficits in muscle strength are common in both the affected and unaffected side following stroke (Andrews and Bohannon 2000). Two other aspects of muscle strength which are effected after stroke are; 1) muscle endurance, the ability to generate torque against a load for an extended period of time and 2) muscle power, the ability to generate torque against a load at speed (Dawes et al 2005, Stavric and McNair 2012).

How does muscle strength relate to function after stroke?

Recent scientific literature demonstrates that deficits in muscle strength are one of the primary impairments which limit function following stroke, this is true for both lower and upper limb functions (Bohannon 2007, Bourbonnais and Vanden Noven 1989, Harris and Eng 2007, Harris et al 2001, Ng and Shepherd 2000). The relationship between muscle strength and function is strong (Dorsch et al 2012, Milot et al 2008, Ng and Hui-Chan 2012, Saunders et al 2008), to the extent that muscle strength can be used to predict walking speed (Nadeau et al 1999) and explains approximately 80% of variance in upper limb function (Harris and Eng 2007). Different functions place different demands on different muscles; for instance the strength of the dorsiflexor and hip flexor muscles strongly correlates with walking speed and endurance in people after stroke (Dorsch et al 2012), whilst the strength of the hip extensors, flexors and knee extensors are important for successful performance of stair climbing (Bohannon and Walsh 1991). This highlights the pivotal role of muscle strength to function following stroke.

What causes weakness after stroke?

Research in people with stroke reveals that there are neural and muscle structure and function changes following stroke which may to contribute to deficits in muscle strength. It is assumed that these changes reflect both primary impairments, directly caused by the stroke, and secondary changes due to immobility and physical inactivity.

The impact of neural changes following stroke on muscle strength is grossly quantified using voluntary activation. Voluntary activation refers to the extent to which the central nervous system is driving the muscle at the time of a muscle contraction. During a maximal voluntary contraction, voluntary activation in people without pathology is between 90 and 100%. A number of studies in people with stroke have identified marked deficits in voluntary activation, with voluntary activation of between 60-83% on the affected side and 60-95% on the unaffected side (Harris et al 2001, Newham and Hsiao 2001, Riley and Bilodeau 2002, Signal et al 2008). Deficits in voluntary activation are likely caused by neural changes in the excitability of the cortical, subcortical and spinal contributions to muscle activation (Liepert 2003, Thickbroom et al 2004), along with alterations in motor unit recruitment (Frontera et al 1997, Gemperline et al 1995). These changes are presumed to reflect the neuronal damage caused by both the brain lesion and secondary disuse (Liepert 2003, Stulin et al 2003, Thickbroom et al 2004).

Alterations in muscle structure and function following stroke are evidenced by research demonstrating; muscle atrophy, fibre type alterations and muscle structure changes after stroke (Jorgensen and Jacobsen 2001, Metoki et al 2003, Sunnerhagen et al 1999). Whilst these peripheral changes are likely to contribute to a reduction in muscle strength, a recent study acknowledged that neural changes explained a much greater proportion of post-stroke weakness than muscle atrophy (Klein et al 2010).

Strength training after stroke

Strength training has been advocated for clinically stable stroke survivors for the past 15 years and most recently in the American Heart and Stroke Association's "Physical Activity and Exercise Recommendations for Stroke Survivors" (Billinger et al 2014) and in the New Zealand "Guidelines for the Management of Stroke" (Stroke Foundation of New Zealand and New Zealand Guidelines Group 2010). Strength training is exercise involving repeated muscle contractions against a load; the load is usually provided by the individual's body weight, elastic devices such as Theraband®, free weights, machine weights or isokinetic systems such as the Biodex®, with the aim of improving muscle strength, endurance and/or power (Saunders et al 2013). The American Heart and Stroke Association recommend that strength training be conducted at 50-80% of the 1-repetition maximum (1-RM) for 10-15 repetitions for 2-3 days per week, and that resistance be increased as tolerance permits for people with stroke (Billinger et al 2014).

The evidence base for strength training includes a number of randomised controlled trials, many of which are small and not powered to detect a difference between the interventions under investigation (Flansbjer et al 2008a, Kim et al 2001, Lee et al 2008). There is also a larger body of cohort studies investigating strength training after stroke (Hill et al 2012, Ryan et al 2011). Additional evidence for the efficacy of strength training can be sourced from studies which combine strength training with other forms of training (Clark and Patten 2013, Jorgensen et al 2010, Sullivan et al 2007), such as cardiovascular endurance training or task specific training. Whilst the evidence base for strength training after stroke is growing, it is important to note that a recent meta-analysis investigating physical fitness training after stroke has indicated that there is still insufficient evidence to draw robust conclusions about the efficacy of strength training alone, as opposed to strength training combined with other forms of training, for gains in physical fitness, mobility or physical function (Saunders et al 2014).

Studies investigating the effects of strength training in people with stroke clearly demonstrate marked increases in muscle strength in response to training, with some studies describing gains from baseline in excess of 75% (Corti et al 2012, Hill et al 2012, Kim et al 2001, Lee 2010, Ryan et al 2011). Gains in strength appear to be specific to the muscle and action trained (Clark and Patten 2013, Engardt et al 1995, Lee 2010), although there is some evidence of carry over to the untrained side in response to unilateral training (Dragert and Zehr 2013, Hill et al 2012). The mechanism of these strength gains are likely to be mediated by both improvements in neural activation and muscle structure and function (Andersen et al 2011, Clark and Patten 2013, Ryan et al 2011). Studies which follow up participants to evaluate the retention of strength gains demonstrate the maintenance of gains for up to four years post-intervention (Flansbjer et al 2012, Severinsen et al 2014, Sullivan et al 2007), which is in contrast to cardiovascular training where gains tend to be lost when training is discontinued (Severinsen et al 2014).

The evidence for changes in functional ability in response to strength training is less clear, with some studies demonstrating significant gains in function (Bale and Strand 2008, Clark and Patten 2013, Duncan et al 1998, Teixeira-Salmela et al 1999, Yang et al 2006) while others are less convincing (Kim et al 2001, Lee 2010, Ouellette et al 2004, Severinsen et al 2014). Gains have been demonstrated in walking speed (Bale and Strand 2008, Duncan et al 1998, Engardt et al 1995, Lee et al 2008, Severinsen et al 2014, Sharp and Brouwer 1997, Yang et al 2006), endurance (Flansbjer et al 2008a, Hill et al 2012, Ouellette et al 2004, Yang et al 2006), sit to stand (Weiss et al 2000), stair climbing ability (Lee et al 2008, Teixeira-Salmela et al 1999) and upper limb function (Corti et al 2012, Patten et al 2013). Some of the disparity in the extent of gains seen in function may relate to the specificity of the strength training to the function being evaluated, the parameters of the training, and the population under investigation. A number of studies indicate that when training is conducted at a low intensity, short duration or with insufficient progression of load, gains in response to training are limited (Cooke et al 2010, Flansbjer et al 2008b, Kim et al 2001, Kluding et al 2011, Moreland et al 2003). It seems likely that adequate training parameters are necessary to drive a change in function.

However, the research evidence also suggests that strength training may be most effective when paired with task specific training (Andersen et al 2011, Clark and Patten 2013, Corti et al 2012, Cramp et al 2010, Jorgensen et al 2010, Patten et al 2013) or cardiovascular training (Andersen et al 2011, Jorgensen et al 2010, Lee et al 2008, Sullivan et al 2007). Combining strength training with task specific training may facilitate the transfer of strength gains to function. Recent work by Patten and colleagues comparing strength training combined with task specific training to task specific training alone in the upper limb have demonstrated superior results with the combined training (Corti et al 2012, Patten et al 2013). However, no studies comparing task specific training alone, strength training alone and combined strength and task training of the same dose and intensity have been undertaken to definitively answer the question of the best type or combination of interventions. It is also important to note there is a risk of over training if sufficient rest days are not provided with combined training (Sullivan et al 2007).

In addition to gains in strength and function, some studies investigating strength training after stroke have demonstrated gains at the participatory level and in health related quality of life (Chen and Rimmer 2011). More recent studies have also demonstrated a positive influence on other impairments such as cognitive function (Kluding et al 2011), depression (Sims et al 2009) and anxiety (Aidar et al 2012).

The uptake of strength training in clinical practice

Like many new interventions in stroke rehabilitation, such as task specific training, body weight supported treadmill training (BWSTT), constraint induced movement therapy (CIMT) and cardiovascular training, it is reasonable to expect that there may be a delay in the integration of the intervention into standard clinical practice as the research body grows and findings are disseminated to clinicians (Bayley et al 2012). Comparable with task specific training, strength training has the potential to be delivered within current resources and healthcare frameworks, therefore uptake might be expected to be faster than in interventions such as CIMT and BWSTT which require specialist equipment or changes to the healthcare framework to facilitate delivery. Yet the evidence from audit, observational and documentation studies suggests that strength training has not been well integrated into clinical practice. A number of studies in the United States, New Zealand and Europe have sought to document and categorise the scope of physiotherapy intervention for people following stroke. Whilst there appear to be regional differences in the content of therapy, often these studies do not overtly characterise strength training as part of their taxonomy of therapeutic interventions or they subsume strength training with interventions such as passive movement and selective motor control (De Wit et al 2006, DeJong et al 2004, Gassaway et al 2005, McNaughton et al 2005). A recent New Zealand study found only 58% alignment with the New Zealand Clinical Guidelines for Stroke Management 2010 recommendations for the management of muscle weakness which includes using strength training (Johnston et al 2013). In general, these studies suggest that strength training is not a core part of many physiotherapists' clinical practice.

It is also important to note that the actual average physiotherapy intervention in inpatient rehabilitation is between 35 minutes and an hour per working day (Bernhardt et al 2007, Bernhardt et al 2008, Gassaway et al 2005); with New Zealand studies indicating that in our country, people with stroke are at the lower end of this estimate (McNaughton et al 2005, Thompson and McKinstry 2009) and observational studies highlight that much of the patients' time in physiotherapy is spent inactive and working at very low intensities (Kaur et al 2012, MacKay-Lyons and Makrides 2002, West and Bernhardt 2012). Collectively this research suggests that strength training has not been well integrated into current clinical practice, and that when it has, it is likely to be being carried out at a dose and intensity of training which does not meet recommended guidelines.

What limits physiotherapists' uptake of strength training?

That strength training has not been taken up into clinical practice prompts the question; Why? Research investigating the barriers to implementing research and evidence based practice guidelines into clinical practice identifies potential systemic, team and individual barriers to implementation in stroke rehabilitation (Bayley et al 2012, McCluskey et al 2013). This clinical commentary focuses on the individual barriers to the implementation of strength training in people with stroke for physiotherapists and draws on both research evidence and our experience implementing moderate to high intensity strength training for people with stroke at AUT University (Signal et al 2014).

One frequently cited barrier to implementing evidence based practice guidelines is patient tolerance to the recommended intervention (Bayley et al 2012). Recommendations for the implementation of strength training advise that people with stroke work at an intensity of 50-80% of their 1-RM. This represents a moderate to high intensity of effort; the person should only be able to complete 8 to 14 repetitions of an exercise before they experience volitional fatigue. In order to exercise at this intensity it is necessary to work very hard; people with stroke will be sweating, concentrating fully on the exercise and at the last repetition of a set they should be unable to complete another repetition. This may be a level of exercise that many physiotherapists are unused to using with their patients and may raise concerns for the physiotherapist. However it is worth noting that many research studies and our own experience indicate that provided adequate familiarisation and initiation of training at the low end of recommended training parameters is undertaken, it is feasible to utilise strength training with people who; have severe physical disability following stroke, are older (85+ years) and have co-morbidities (Hill et al 2012, Jorgensen et al 2010, Signal et al 2014).

To apply strength training using the recommended training parameters, physiotherapists must be able to evaluate 1-RM and repetition maximum (RM) based exercise sets. Given that exercise based rehabilitation has only recently been overtly incorporated into undergraduate physiotherapy curriculums, many physiotherapists may not possess this knowledge. Research evidence and best practice guidelines provide little guidance in the pragmatics of intervention delivery (Bayley et al 2012, McCluskey et al 2013, Salbach et al 2007); most strength training guidelines do not describe how to establish 1-RM or RM sets, nor do they provide examples of specific exercises or exercise progressions and modifications for people with stroke (Billinger et al 2014, Mead and Van Wijck 2013), making implementation challenging. Physiotherapists are often more familiar with utilising body weight and alterations such as change in step or seat height to alter training intensity. However, body weight exercises do not lend themselves well to progressive overload and it is often difficult for the therapist to gauge and graduate the intensity of the exercise. Machine and free weights enable the therapist to more readily establish the 1-RM or specified RM of an exercise to ensure that strength training is at the appropriate intensity. In order to gain the practical knowledge to effectively deliver strength training in people with stroke some physiotherapists may need to seek advice from other clinicians experienced in strength training or attend post-graduate training in exercise rehabilitation.

Historically strength training was discouraged in people with neurological conditions for fear that it would exacerbate hypertonia and compensatory movement patterns (Bobath 1990), these concerns may still prevail today. Compensatory movements are thought to enable task performance but be potentially detrimental to long term recovery of function (Levin et al 2009). Early studies investigated whether strength training increased hypertonia in people with stroke and clearly demonstrated that it does not (Flansbjer et al 2008a, Sharp and Brouwer 1997, Teixeira-Salmela et al 1999). Furthermore, a recent study has shown that the Bobath approach does not result in more normal movement patterns than task specific training (Langhammer and Stanghelle 2011) and an additional study has demonstrated that when strength training and task specific training are combined, they result in a more normal movement pattern for reaching and grasping than task specific training alone (Corti et al 2012). These findings indicate that appropriately applied strength training will not increase hypertonia and is more likely to improve movement patterns, rather than reinforce compensatory movement patterns in people with stroke. The challenge for clinicians is to identify suitable strength training exercises and to utilise techniques to stabilise the patient and maintain normal movement patterns during exercise.

It is also worth noting that for most neurological physiotherapists, the construct of neural plasticity underpins their clinical practice. Much of the evidence from neural plasticity literature has highlighted the importance of dose of training to achieve gains in people with stroke (Kwakkel et al 2004), meaning that the focus is often on increasing the number of repetitions of an exercise. However, recently the importance of intensity of training has been emphasised (Bowden et al 2013).This is a key issue in relation to strength training as research in healthy people indicates that strength gains can be achieved with as little as one set, provided the intensity is sufficient (Garber et al 2011). The maintenance of intensity in strength training requires regular re-assessment of the 1-RM or RM to ensure that the intensity of training is maintained and progressed as the person gains strength.

It has previously been suggested that physiotherapists are overly precautionary in their rehabilitation of people with stroke for fear of adverse events and negative symptoms (Brazzelli et al 2011, Rose et al 2011). Few studies report adverse events in response to strength training in a detailed manner (Hill et al 2012, Lee et al 2008, Ouellette et al 2004, Stuart et al 2009, Sullivan et al 2007). No fatal adverse events have been reported in the literature and strength training in people with stroke is considered a safe and relatively low risk intervention (Billinger et al 2014). To minimise any risks, pre-exercise evaluation should include medical practitioner clearance, a complete medical history and assessment to identify absolute and relative contraindications to exercise, and the patients' functional level and motor, sensory, cognitive and perceptual impairments (Dennis et al 2012).

As reporting of adverse events is limited, there is little information to guide therapists in relation to normal and abnormal responses to strength training in people with stroke. Our clinical experience indicates that people with stroke can experience symptoms such as dizziness and pain in response to strength training (Signal et al 2014). Whilst generally not of the severity to be deemed an adverse event or require termination of the intervention, these symptoms have the potential to impact the patients' engagement with rehabilitation if not carefully managed and may require modification of the exercise or training parameters.

Although strength training interventions may result in a medium and long term decrease in cardiovascular risk factors (Mead and Van Wijck 2013), the immediate effect of strength training is cardiovascular stress which results in an increase in both diastolic and systolic blood pressure. The magnitude of this cardiovascular stress is a function of the percentage of 1-RM, the muscle mass being worked, the duration of the contraction and rest periods, and whether the person's attempts to utilise a Valsalva manoeuvre during the exercise (Lamotte et al 2010, Sorace et al 2012). Hence a therapist who is concerned about the cardiovascular stress on a patient may monitor heart rate and blood pressure prior to the training session to ensure that these parameters are within safe levels to begin exercise, begin training at a lower intensity, increase the speed and therefore reduce the duration of contractions, utilise rest periods of at least 90 seconds, utilise unilateral contractions, modify exercises as required to accommodate postural hypotension and encourage the person to focus on breathing during exercise (Dennis et al 2012, Sorace et al 2012).

The development of musculoskeletal pain in response to strength training may result from excessive loading of a joint or poor biomechanics during exercise. People with stroke appear to be more at risk of developing pain when they have a pre-existing musculoskeletal condition. Osteoarthritis (OA) is common in middle aged and older adults and is a frequent co-morbidity seen in people with stroke (Juhl et al 2014). Strength training is strongly recommended in guidelines for the management of OA and the recommended training parameters are similar to those recommended for people with stroke (Larmer et al 2014). Therefore, the progression of exercises in people who have stroke and musculoskeletal pain should be symptom limited, where exercises are progressed only when there is no increase from baseline pain in response to the intervention. Attention to exercise selection and order to ensure sufficient rest of muscle groups, and consideration of the maintenance of normal movement patterns during exercise is also important.

CONCLUSION

The research evidence indicates that strength training increases strength and has potential to improve function in people with stroke. Despite being strongly advocated in best practice guidelines; strength training at the recommended training parameters does not appear to have been well integrated into clinical practice. This commentary has focused on the potential barriers that physiotherapists may perceive and experience to the implementation of strength training in their clinical practice. Research and clinical experience indicate that strength training is safe and well tolerated in most patients with stroke, however a thorough assessment of patient risk, monitoring for negative symptoms and for some patients, modification of exercises and training parameters, may be required. Some physiotherapists may wish to seek new knowledge and practical skills in order to effectively apply strength training within the recommended training parameters for people with stroke. The research evidence, strength training guidelines and clinical experience indicate that strength training for people with stroke should be carried out;

- After a thorough evaluation of the patient which identifies absolute and relative contraindications to exercise and the patients functional limitations and impairments.
- With specificity; where the muscles exercised, their type, range and speed of action relate to the individual's functional limitations.
- Combined with other forms of training such as task specific training.
- Following a familiarisation period, with the intensity of training progressively maintained or increased as the patient gains strength.
- Whilst monitoring for negative symptoms and modifying the training parameters as required.

Using stabilising, cueing and supporting techniques to ensure the maintenance of a normal movement pattern during exercise.

At an intensity and dose sufficient to ensure training overload.

KEY POINTS

- Deficits in muscle strength are common after stroke and are strongly related to function.
- Strength training increases strength and has potential to improve function in people with stroke.
- Strength training at the recommended training parameters does not appear to have been well integrated into clinical practice.
- Barriers to the implementation of strength training in clinical practice may in part be addressed by new knowledge and practical skills.

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REFERENCES

Aidar FJ, de Oliveira RJ, Silva AJ, de Matos DG, Mazini Filho ML, Hickner RC, Machado Reis V (2012) The Influence of Resistance Exercise Training on the Levels of Anxiety in Ischemic Stroke. *Stroke Research and Treatment* 2012: 6.

Andersen LL, Zeeman P, Jørgensen JR, Bech-Pedersen DT, Sørensen J, Kjær M, Andersen JL (2011) Effects of intensive physical rehabilitation on neuromuscular adaptations in adults with poststroke hemiparesis. *Journal of Strength and Conditioning Research* 25: 2808-2817.

Andrews AW, Bohannon RW (2000) Distribution of muscle strength impairments following stroke. *Clinical Rehabilitation* 14: 79-87.

Bale M, Strand LI (2008) Does functional strength training of the leg in subacute stroke improve physical performance? A pilot randomized controlled trial. *Clinical Rehabilitation* 22: 911-921.

Bayley MT, Hurdowar A, Richards CL, Korner-Bitensky N, Wood-Dauphinee S, Eng JJ, McKay-Lyons M, Harrison E, Teasell R, Harrison M (2012) Barriers to implementation of stroke rehabilitation evidence: findings from a multi-site pilot project. *Disability and Rehabilitation* 34: 1633-1638.

Bernhardt J, Chan J, Nicola I, Collier JM (2007) Little therapy, little physical activity: rehabilitation within the first 14 days of organized stroke unit care. *Journal of Rehabilitation Medicine* 39: 43-48.

Bernhardt J, Chitravas N, Meslo IL, Thrift AG, Indredavik B (2008) Not all stroke units are the same: a comparison of physical activity patterns in Melbourne, Australia, and Trondheim, Norway. *Stroke (00392499)* 39: 2059-2065.

Billinger SA, Arena R, Bernhardt J, Eng JJ, Franklin BA, Johnson CM, MacKay-Lyons M, Macko RF, Mead GE, Roth EJ (2014) Physical Activity and Exercise Recommendations for Stroke Survivors A Statement for Healthcare Professionals From the American Heart Association/American Stroke Association. *Stroke*: STR. 0000000000000022.

Bobath B (1990) Adult hemiplegia: evaluation and treatment. Heinemann Medical Books London.

Bohannon RW (2007) Muscle strength and muscle training after stroke. *Journal of Rehabilitation Medicine* 39: 14-20.

Bohannon RW, Walsh S (1991) Association of paretic lower extremity muscle strength and standing balance with stair-climbing ability in patients with stroke. *Journal of Stroke and Cerebrovascular Diseases* 1: 129-133.

Bourbonnais D, Vanden Noven S (1989) Weakness in patients with hemiparesis. *The American Journal of Occupational Therapy* 43: 313-319.

Bowden MG, Woodbury ML, Duncan PW (2013) Promoting neuroplasticity and recovery after stroke: future directions for rehabilitation clinical trials. *Current Opinion in Neurology* 26: 37-42.

Brazzelli M, Saunders D, Greig C, Mead G (2011) Physical fitness training for stroke patients (Review).

Chen M-D, Rimmer JH (2011) Effects of Exercise on Quality of Life in Stroke Survivors: A Meta-Analysis. *Stroke* 42: 832-837.

Clark DJ, Patten C (2013) Eccentric versus concentric resistance training to enhance neuromuscular activation and walking speed following stroke. *Neurorehabilitation and Neural Repair* 27: 335-344.

Cooke EV, Tallis RC, Clark A, Pomeroy VM (2010) Efficacy of functional strength training on restoration of lower-limb motor function early after stroke: phase I randomized controlled trial. *Neurorehabilitation and Neural Repair* 24: 88-96.

Corti M, McGuirk TE, Wu SS, Patten C (2012) Differential effects of power training versus functional task practice on compensation and restoration of arm function after stroke. *Neurorehabilitation and Neural Repair* 26: 842-854.

Cramp MC, Greenwood RJ, Gill M, Lehmann A, Rothwell JC, Scott OM (2010) Effectiveness of a community-based low intensity exercise programme for ambulatory stroke survivors. *Disability and Rehabilitation* 32: 239-247.

Dawes H, Smith C, Collett J, Wade D, Howells K, Ramsbottom R, Izadi H, Sackley C (2005) A pilot study to investigate explosive leg extensor power and walking performance after stroke. *Journal of Sports Science and Medicine* 4: 556-562.

De Wit L, Putman K, Lincoln N, Baert I, Berman P, Beyens H, Bogaerts K, Brinkmann N, Connell L, Dejaeger E, De Weerdt W, Jenni W, Lesaffre E, Leys M, Louckx F, Schuback B, Schupp W, Smith B, Feys H (2006) Stroke Rehabilitation in Europe: What Do Physiotherapists and Occupational Therapists Actually Do? *Stroke* 37: 1483-1489.

DeJong G, Horn SD, Gassaway JA, Slavin MD, Dijkers MP (2004) Toward a taxonomy of rehabilitation interventions: Using an inductive approach to examine the "black box" of rehabilitation. *Archives of Physical Medicine and Rehabilitation* 85: 678-686.

Dennis JM, Best CS, Dinan-Young S, Mead G (2012) Preparing for exercise after stroke. In Mead G, Van Wijck F (Eds) Exercise and Fitness Training After Stroke; a handbook for evidence-based practice edn). Sydney: Churchill Livingstone, p 151.

Dorsch S, Ada L, Canning CG, Al-Zharani M, Dean C (2012) The strength of the ankle dorsiflexors has a significant contribution to walking speed in people who can walk independently after stroke: an observational study. *Archives of Physical Medicine and Rehabilitation* 93: 1072-1076.

Dragert K, Zehr EP (2013) High-intensity unilateral dorsiflexor resistance training results in bilateral neuromuscular plasticity after stroke. *Experimental Brain Research* 225: 93-104.

Duncan P, Richards L, Wallace D, Stoker-Yates J, Pohl P, Luchies C, Ogle A, Studenski S (1998) A randomized, controlled pilot study of a home-based exercise program for individuals with mild and moderate stroke. *Stroke* 29: 2055-2060.

Engardt M, Knutsson E, Jonsson M, Sternhag M (1995) Dynamic muscle strength training in stroke patients: Effects on knee extension torque, electromyographic activity, and motor function. *Archives of Physical Medicine and Rehabilitation* 76: 419-425.

Feigin VL, Krishnamurthi R, Barber PA, Arroll B (2014) Stroke prevention in New Zealand: Can we do better? *International Journal of Stroke* 9: 61-63.

Flansbjer U-B, Lexell J, Brogårdh C (2012) Long-term benefits of progressive resistance training in chronic stroke: a 4-year follow-up. *Journal Of Rehabilitation Medicine* 44: 218-221.

Flansbjer U, Miller M, Downham D, Lexell J (2008a) Progressive Resistance Training After Stroke: Effects on Muscle Strength, Muscle Tone, Gait Performance And Perceived Participation. *Journal of Rehabilitation Medicine* 40: 42-48.

Flansbjer UB, Miller M, Downham D, Lexell J (2008b) Progressive resistance training after stroke: Effects on muscle strength, muscle tone, gait performance and perceived participation. *Journal of Rehabilitation Medicine* 40: 42-48.

Frontera WR, Grimby L, Larsson L (1997) Firing rate of the lower motoneuron and contractile properties of its muscle fibers after upper motoneuron lesion in man. *Muscle & Nerve* 20: 938-947.

Garber CE, Blissmer B, Deschenes MR, Franklin B, Lamonte MJ, Lee I-M, Nieman DC, Swain DP (2011) American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Medicine and Science in Sports and Exercise* 43: 1334-1359.

Gassaway J, Horn SD, DeJong G, Smout RJ, Clark C, James R (2005) Applying the clinical practice improvement approach to stroke rehabilitation: Methods used and baseline results. *Archives of Physical Medicine and Rehabilitation* 86: 16-33.

Gemperline JJ, Allen S, Walk D, Rymer WZ (1995) Characteristics of motor unit discharge in subjects with hemiparesis. *Muscle & Nerve* 18: 1101-1114.

Harris JE, Eng JJ (2007) Paretic upper-limb strength best explains arm activity in people with stroke. *Physical Therapy* 87: 88-97.

Harris M, Polkey M, Bath P, Moxham J (2001) Quadriceps muscle weakness following acute hemiplegic stroke. *Clinical Rehabilitation* 15: 274-281.

Hill TR, Gjellesvik TI, Moen PMR, Tørhaug T, Fimland MS, Helgerud J, Hoff J (2012) Maximal Strength Training Enhances Strength and Functional Performance in Chronic Stroke Survivors. *American Journal of Physical Medicine & Rehabilitation* 91: 393-400.

Johnston J, Mudge S, Kersten P, Jones A (2013) Physiotherapy alignment with guidelines for the management of stroke in the inpatient setting. *New Zealand Journal of Physiotherapy* 41: 102-111.

Jorgensen J, Bech-Pedersen D, Zeeman P, Sorensen J, Andersen L, Schonberger M (2010) Effect of intensive outpatient physical training on gait performance and cardiovascular health in people with hemiparesis after stroke. *Physical Therapy* 90: 527-537.

Jorgensen L, Jacobsen BK (2001) Changes in muscle mass, fat mass, and bone mineral content in the legs after stroke: A 1 year prospective study. *Bone* 28: 655-659.

Juhl C, Christensen R, Roos EM, Zhang W, Lund H (2014) Impact of exercise type and dose on pain and disability in knee osteoarthritis: A systematic review and meta-regression analysis of randomized controlled trials. *Arthritis & Rheumatology* 66: 622-636.

Kaur G, English C, Hillier S (2012) How physically active are people with stroke in physiotherapy sessions aimed at improving motor function? A systematic review. *Stroke Research and Treatment* 2012: 9.

Kim CM, Eng JJ, MacIntyre DL, Dawson AS (2001) Effects of isokinetic strength training on walking in persons with stroke: A double-blind controlled pilot study. *Journal of Stroke and Cerebrovascular Diseases* 10: 265-273.

Klein CS, Brooks D, Richardson D, McIlroy WE, Bayley MT (2010) Voluntary activation failure contributes more to plantar flexor weakness than antagonist coactivation and muscle atrophy in chronic stroke survivors. *Journal of Applied Physiology* 109: 1337-1346.

Kluding PM, Tseng BY, Billinger SA (2011) Exercise and executive function in individuals with chronic stroke: A pilot study. *Journal of Neurologic Physical Therapy* 35: 11-17.

Kwakkel G, van Peppen R, Wagenaar RC, Dauphinee SW, Richards C, Ashburn A, Miller K, Lincoln N, Partridge C, Wellwood I (2004) Effects of augmented exercise therapy time after stroke a meta-analysis. *Stroke* 35: 2529-2539.

Lamotte M, Fleury F, Pirard M, Jamon A, Van De Borne P (2010) Acute cardiovascular response to resistance training during cardiac rehabilitation: effect of repetition speed and rest periods. *European Journal of Cardiovascular Prevention & Rehabilitation* 17: 329-336.

Langhammer B, Stanghelle JK (2011) Can Physiotherapy after Stroke Based on the Bobath Concept Result in Improved Quality of Movement Compared to the Motor Relearning Programme. *Physiotherapy Research International* 16: 69-80.

Larmer PJ, Reay ND, Aubert ER, Kersten P (2014) Systematic Review of Guidelines for the Physical Management of Osteoarthritis. *Archives of Physical Medicine and Rehabilitation* 95: 375-389.

Lee MJ, Kilbreath SL, Singh MF, Zeman B, Lord SR, Raymond J, Davis GM (2008) Comparison of effect of aerobic cycle training and progressive resistance training on walking ability after stroke: A randomized sham exercise-controlled study. *Journal of the American Geriatrics Society* 56: 976-985.

Lee MJ, Kilbreath, S. L., Singh, M. F., Zeman, B., & Davis, G. M. (2010) Effect of progressive resistance training on muscle performance after chronic stroke. *Medicine and Science in Sports and Exercise* 42: 23-34.

Levin MF, Kleim JA, Wolf SL (2009) What Do Motor "Recovery" and "Compensation" Mean in Patients Following Stroke? *Neurorehabilitation and Neural Repair* 23: 313-319.

Liepert J (2003) TMS in stroke. *Clinical Neurophysiology: Transcranial Magnetic Stimulation and Transcranial Direct Stimulation Supplement* 56: 368-380.

Lozano R, Naghavi M, Foreman K, Lim S, Shibuya K, Aboyans V, et al (2012) Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet* 380: 2095-2128.

MacKay-Lyons MJ, Makrides L (2002) Cardiovascular stress during a contemporary stroke rehabilitation program: Is the intensity adequate to induce a training effect? *Archives of Physical Medicine and Rehabilitation* 83: 1378-1383.

McCluskey A, Vratsistas-Curto A, Schurr K (2013) Barriers and enablers to implementing multiple stroke guideline recommendations: a qualitative study. *BMC Health Services Research* 13: 1-13.

McNaughton H, DeJong G, Smout RJ, Melvin JL, Brandstater M (2005) A comparison of stroke rehabilitation practice and outcomes between New Zealand and United States facilities. *Archives of Physical Medicine and Rehabilitation* 86.

Mead G, Van Wijck F, Eds. (2013) Exercise and Fitness Training After Stroke; a handbook for evidence-based practice. Sydney, Churchill Livingstone.

Metoki N, Sato Y, Satoh K, Okumura K, Iwamoto J (2003) Muscular atrophy in the hemiplegic thigh in patients after stroke. *American Journal of Physical Medicine and Rehabilitation* 82: 862-865.

Milot MH, Nadeau S, Gravel D, Bourbonnais D (2008) Effect of increases in plantarflexor and hip flexor muscle strength on the levels of effort during gait in individuals with hemiparesis. *Clinical Biomechanics* 23: 415-423.

Moreland JD, Goldsmith CH, Huijbregts MP, Anderson RE, Prentice DM, Brunton KB, O'Brien MA, Torresin WD (2003) Progressive resistance strengthening exercises after stroke: A single-blind randomized controlled trial. *Archives of Physical Medicine and Rehabilitation* 84: 1433-1440.

Nadeau S, Gravel D, Arsenault AB, Bourbonnais D (1999) Plantarflexor weakness as a limiting factor of gait speed in stroke subjects and the compensating role of hip flexors. *Clinical Biomechanics* 14: 125-135.

Newham DJ, Hsiao S-F (2001) Knee muscle isometric strength, voluntary activation and antagonist co-contraction in the first six months after stroke. *Disability and Rehabilitation* 23: 379-386.

Ng S, Shepherd R (2000) Weakness in patients with stroke: implications for strength training in neurorehabilitation. *Physical Therapy Reviews* 5: 227-238.

Ng SS, Hui-Chan CW (2012) Contribution of Ankle Dorsiflexor Strength to Walking Endurance in People With Spastic Hemiplegia After Stroke. *Archives of Physical Medicine and Rehabilitation* 93: 1046-1051.

Ouellette MM, LeBrasseur NK, Bean JF, Phillips E, Stein J, Frontera WR, Fielding RA (2004) High-intensity resistance training improves muscle strength, self-reported function, and disability in long-term stroke survivors. *Stroke* 35: 1404-1409.

Patten C, Condliffe EG, Dairaghi CA, Lum PS (2013) Concurrent neuromechanical and functional gains following upper-extremity power training post-stroke. *Journal of Neuroengineering and Rehabilitation* 10 DOI: 10.1186/1743-003-10-1.

Riley NA, Bilodeau M (2002) Changes in upper limb joint torque patterns and EMG signals with fatigue following a stroke. *Disability and Rehabilitation* 24: 961-969.

Rose D, Paris T, Crews E, Wu SS, Sun A, Behrman AL, Duncan P (2011) Feasibility and effectiveness of circuit training in acute stroke rehabilitation. *Neurorehabilitation and Neural Repair* 25: 140-148.

Ryan A, Ivey F, Prior S, Li G, Hafer-Macko C (2011) Skeletal muscle hypertrophy and muscle myostatin reduction after resistive training in stroke survivors. *Stroke* 42: 416-420.

Salbach NM, Jaglal SB, Korner-Bitensky N, Rappolt S, Davis D (2007) Practitioner and organizational barriers to evidence-based practice of physical therapists for people with stroke. *Physical Therapy*.

Saunders DH, Greig CA, Young A, Mead GE (2008) Association of Activity Limitations and Lower-Limb Explosive Extensor Power in Ambulatory People With Stroke. *Archives of Physical Medicine and Rehabilitation* 89: 677-683.

Saunders DH, Sanderson M, Brazzelli M, Greig CA, Mead GE (2014) Physical fitness training for patients with stroke: An updated review. *Stroke* 45: e54-e55.

Severinsen K, Jakobsen JK, Pedersen AR, Overgaard K, Andersen H (2014) Effects of resistance training and aerobic training on ambulation in chronic stroke. *American Journal of Physical Medicine & Rehabilitation* 93: 29-42.

Sharp SA, Brouwer BJ (1997) Isokinetic strength training of the hemiparetic knee: Effects on function and spasticity. *Archives of Physical Medicine and Rehabilitation* 78: 1231-1236.

Signal N, Lewis G, McPherson K, Taylor D (2014) Strength for Task Training: A pilot randomised controlled trial. *Unpublished raw data*.

Signal N, Taylor D, McNair P (2008) The relationship between voluntary activation, strength and physical function in people with stroke. [Abstract]. *New Zealand Journal of Physiotherapy* 36: 92.

Sims J, Galea M, Taylor N, Dodd K, Jespersen S, Joubert L, Joubert J (2009) Regenerate: Assessing the feasibility of a strength-training program to enhance the physical and mental health of chronic post stroke patients with depression. *International Journal of Geriatric Psychiatry* 24: 76-83.

Sorace P, Churilla JR, Magyari PM (2012) Resistance training for hypertension: design safe and effective programs. *ACSM's Health & Fitness Journal* 16: 13-18.

Stavric VA, McNair PJ (2012) Optimizing muscle power after stroke: a cross-sectional study. *Journal of NeuroEngineering and Rehabilitation* 9: 1-8.

Stroke Foundation of New Zealand and New Zealand Guidelines Group (2010) Clinical Guidelines for Stroke Management 2010.

Stuart M, Benvenuti F, MacKo R, Taviani A, Segenni L, Mayer F, Sorkin JD, Stanhope SJ, MacEllari V, Weinrich M (2009) Community-based adaptive physical activity program for chronic stroke: Feasibility, safety, and efficacy of the empoli model. *Neurorehabilitation and Neural Repair* 23: 726-734.

Stulin I, Savchenko A, Smyalovskii V, Musin R, Stryuk G, Priz I, Bagir V, Semenova E (2003) Use of transcranial magnetic stimulation with measurement of motor evoked potentials in the acute period of hemispheric ischaemic stroke. *Neuroscience and Behavourial Physiology* 33: 36-40.

Sullivan KJ, Brown DA, Klassen T, Mulroy S, Ge T, Azen SP, Winstein CJ, Physical Therapy Clinical Research N (2007) Effects of task-specific locomotor and strength training in adults who were ambulatory after stroke: results of the STEPS randomized clinical trial. *Physical Therapy* 87: 1580-1602.

Sunnerhagen KS, Svantesson UM, Lonn L, Krotiewski M, Grimby G (1999) Upper motor neuron lesions: Their effect on muscle performance and appearance in stroke patients with minor motor impairments. *Archives of Physical Medicine and Rehabilitation* 80: 155-161.

Teixeira-Salmela LF, Olney SJ, Nadeau S, Brouwer B (1999) Muscle strengthening and physical conditioning to reduce impairment and disability in chronic stroke survivors. *Archives of Physical Medicine and Rehabilitation* 80: 1211-1218.

Thickbroom G, Byrnes M, Archer S, Mastaglia F (2004) Motor outcome after subcortical stroke correlates with the degree of cortical reorganisation. *Clinical Neurophysiology* 115: 2144-2150.

Thompson R, McKinstry W (2009) Research Report-How do rehabilitation patients spend their days? An investigation into the effect of a group therapy programme on time use. *New Zealand Journal of Physiotherapy* 14: 122.

Tobias M, Cheung J, Carter K, Anderson C, Feigin VL (2007) Stroke surveillance: population-based estimates and projections for New Zealand. *Australian and New Zealand Journal of Public Health* 31: 520-525.

Weiss A, Suzuki T, Bean J, Fielding R (2000) High intensity strength training improves strength and functional performance after stroke. *American Journal of Physical Medicine & Rehabilitation* 79: 369-376.

West T, Bernhardt J (2012) Physical Activity in Hospitalised Stroke Patients. *Stroke Research and Treatment* 2012. DOI: 10.1155/2012/813765

Yang YR, Wang RY, Lin KH, Chu MY, Chan RC (2006) Task-oriented progressive resistance strength training improves muscle strength and functional performance in individuals with stroke. *Clinical Rehabilitation* 20: 860-870.