Muscle synergies after stroke

Stroke is a cerebrovascular disease in which the blood supply to the brain is disrupted causing cell death from a lack of oxygen and nutrients to the brain. Every year, approximately 60,000 Australians have a new or recurring stroke.[1] The risk of stroke is increasing due to the ageing population, poor diet and physical inactivity. Stroke has become a leading cause of adult-acquired motor disability and imposes a large burden on survivors, their carers, and the community.

The initial hours post-stroke are crucial, as damage to the brain increases at an exponential rate. Natural recovery occurs most rapidly in the first four weeks post-stroke. Longer term, the human brain is capable of repairing itself to a certain extent, and this process is known as cortical plasticity.[2,3] Two examples of the mechanisms that may facilitate recovery include the unmasking of connections in the brain that are normally silent, but that can be recruited to bypass the lesion;[3] and changes in the firing patterns of brain cells that can strengthen or weaken these connections.[3] This re-wiring of the brain is an on-going process. There is growing evidence to suggest that after the brain is damaged by stroke, rehabilitation promotes recovery through cortical plasticity.

Changes do not just occur in the brain after stroke. The most common deficit after stroke is that affecting movement ability. Approximately 80% of stroke survivors have hemiparesis or a weakness on the side of the body opposite to that of the stroke.[6] This weakness is predominantly caused by a reduction in the signals from the brain to the muscles that produce movement. Over time this causes changes in the muscles themselves. The type of muscle fibres in muscles of the arms and legs can change from slow-twitch, fatigue-resistant muscle fibres to fast-twitch fatigable fibres. This alters how movements are controlled and the amount of force muscles can produce. [7]

One of the consequences of stroke is that the recruitment of muscles to perform co-ordinated movements is interrupted. In the early stages of recovery, cortical plasticity may influence the recruitment pattern of muscles needed to perform voluntary movements. Recruitment may be altered so that muscles on both the more- and less-affected side of the body are activated when patients attempt to move only the more-affected arm or leg. This limits their ability to perform unilateral movements.[4]

The pattern of muscle recruitment and activation is known as muscle synergy, or motor synergy.[8,9] Gait studies have highlighted impaired patterns of muscle recruitment during walking. The good side is relied on to be the major weight-bearing limb, resulting in an uneven gait, or limp. The foot may not lift during the swing phase requiring either a shuffling gait, or an extra lift at the hip or knee joints to prevent tripping. This movement pattern increases the energy cost of walking.[10,11] Muscle synergies are not necessarily relearnt after stroke, instead they are modified to enable as efficient a pattern of movement during walking as possible.[8]

To understand muscle synergies, sensory and motor systems must be treated separately as both systems can alter the pattern of how movement is initiated. The sensory system refers to signals arising from receptors in the skin, muscles, joints and tendons that provide information about the external environment, such as obstacles encountered during walking. The motor aspect of a synergy refers to the pattern of muscle activity. This might reflect the basic movement patterns used in a typical walking style, while other muscle groups must be able to respond to extra tasks during walking, such stepping over obstacles.[11]

Motor synergies are studied using a mathematical approach that identifies patterns of muscle recruitment, incorporating the onset, duration and magnitude of muscle activity.[12] After stroke it can be difficult to identify patterns of muscle activity due to the loss of strength and control combined with disordered command signals from the brain. In addition, movement patterns that can be clearly distinguished in healthy people become smaller and less distinct after stroke. For example when walking the foot may not be lifted off the ground and swung forward (reflecting two separate muscle synergies) but may be shuffled forward without leaving the ground after stroke in a single muscle synergy.[5]

As the basic functional organisation of the motor system, muscle synergies reflect the co-ordination of movement to perform a given task. By identifying absent synergies, or synergies with poor movement outcomes, therapists can prescribe specific tasks to target the affected area during rehabilitation. This will provide improved functional recovery to stroke patients sooner, reducing the burden on carers, the community and the health care system.

References

1. Senes S. How we manage stroke in Australia. *Australian Institute of Health and Welfare, Canberra*. 2006.

2. Hallett M. Plasticity of the human motor cortex and recovery from stroke. *Brain research Brain research reviews* 36: 169-174, 2001.

3. Jacobs KM, and Donoghue JP. Reshaping the cortical motor map by unmasking latent intracortical connections. *Science* 251: 944-947, 1991.

4. Cramer SC. Repairing the human brain after stroke: I. Mechanisms of spontaneous recovery. *Annals of Neurology* 63: 272- 287, 2008.

5. Clark DJ, Ting LH, Zajac FE, Neptune RR and Kautz SA. Merging of healthy motor modules predicts reduced locomotor performance and muscle coordination complexity post-stroke. *Journal of Neurophysiology* 103: 844-857, 2010.

6. National Stroke Association, 2012; *http://www.stroke.org/site/PageServer?pagename=hemiparesis*

7. Berniker M, Jarc A, Bizzi E, and Tresch MC. Simplified and effective motor control based on muscle synergies to exploit musculoskeletal dynamics. *Proceedings of the National Academy of Sciences of the United States of America* 106: 7601-7606, 2009.

8. Dipietro L, Krebs HI, Fasoli SE, Volpe BT, Stein J, Bever C, and Hogan N. Changing motor synergies in chronic stroke. *Journal of neurophysiology* 98: 757-768, 2007.

9. Dewald JP, Sheshadri V, Dawson ML, and Beer RF. Upper-limb discoordination in hemiparetic stroke: implications for neurorehabilitation. *Topics in stroke rehabilitation* 8: 1-12, 2001.

10. Cheung VC, Piron L, Agostini M, Silvoni S, Turolla A, and Bizzi E. Stability of muscle synergies for voluntary actions after cortical stroke in humans. *Proceedings of the National Academy of Sciences of the United States of America* 106: 19563-19568, 2009.

11. Nielsen JB, Brittain JS, Halliday DM, Marchand-Pauvert V, Mazevet D, and Conway BA. Reduction of common motoneuronal drive on the affected side during walking in hemiplegic stroke patients. *Clinical neurophysiology : official journal of the International Federation of Clinical Neurophysiology* 119: 2813-2818, 2008.

12. Tresch MC, Cheung VC, and d'Avella A. Matrix factorization algorithms for the identification of muscle synergies: evaluation on simulated and experimental data sets. *Journal of neurophysiology* 95: 2199-2212, 2006.