■ SHOULDER AND ELBOW

A quantitative assessment of the functional recovery of flexion of the elbow after nerve transfer in patients with a brachial plexus injury

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Aims

Improvements in the evaluation of outcome after nerve transfers are required. The assessment of force using the Medical Research Council (MRC) grades (0 to 5) is not suitable for this purpose. A ceiling effect is encountered within MRC grade 4/5 rendering this tool insensitive. Our aim was to show how the strength of flexion of the elbow could be assessed in patients who have undergone a re-innervation procedure using a continuous measurement scale.

Methods

A total of 26 patients, 23 men and three women, with a mean age of 37.3 years (16 to 66), at the time of presentation, attended for review from a cohort of 52 patients who had undergone surgery to restore flexion of the elbow after a brachial plexus injury and were included in this retrospective study. The mean follow-up after nerve transfer was 56 months (28 to 101, standard deviation (SD) 20.79). The strength of flexion of the elbow was measured in a standard outpatient environment with a static dynamometer.

Results

In total, 21 patients (81%) gained MRC grade 4 strength of flexion of the elbow. The mean force of flexion was 7.2 kgf (3 to 15.5, SD 3.3).

Conclusion

This study establishes that the dynamometer may be used for assessing the strength of flexion of the elbow in the outpatient department after nerve reconstructive surgery.

Cite this article: ***Bone Joint J*** **2016;98-B:1517–20.**

Brachial plexus injuries are rare but severely debilitating. Most patients with this injury are young males involved in motorcycle accidents.[1] This results not only in disability and psychological distress but also there are socio-economic implications, as many are not able to return to their previous level of activity.[2] However, with increasing understanding of the behaviour of nerves following injury, there have been changes in the management of nerve injuries from a policy of 'wait and watch' to early intervention which has led to better outcomes, in terms of function and quality of life.[3-10]

Surgery such as nerve repair and/or transfer provides the best chance of regaining the maximum use of the affected limb after brachial plexus injuries[6-10] and one of the aims of surgery is to restore flexion of the elbow.[8-12] In 1994 Oberlin et al[8] described a technique of nerve transfer to regain the strength of the elbow which involved crosslinking the ulnar nerve by redirecting one of its fascicles, normally the one destined for the flexor muscles of the wrist, to the distal end of the non-functional musculocutaneous nerve, which supplies the biceps muscle.[8] This procedure has been widely used, and modified, to restore flexion of the elbow with encouraging results.[6,8-10,13-15] One of the modifications involves a double transfer, where two donor fascicles are taken and brachialis and biceps muscles are innervated, but it has yet to be shown, in a powered study, to give clear benefits over the single transfer.[13-15]

Nerve transfers are one of a number of methods used to restore movement by directing functioning nerves to re-grow into damaged nerves. These transfers have passed through a phase of evolution and the concept is now accepted. The next objective is to improve the assessment of outcome in these patients. Initially it was acceptable to use the Medical Research Council (MRC) grading system as an outcome measure. MacAvoy and Green,[16] however, have shown deficiencies of this

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doi:10.1302/0301-620X.98B11.36113 $2.00

Bone Joint J
2016;98-B:1517–20.
Received 26 January 2016; Accepted after revision 1 August 2016

grading system by demonstrating that this discrete categorical scoring system obscures about 96% of the range of possible force within one score, namely MRC 4/5. In order to demonstrate an improvement in outcome it is necessary to adopt a continuous scale to measure the range of power that has been created through the re-innervation procedure. This can be done using a linear scale, where between any two continuous data values there may be an infinite number of others, such as force which can be measured in kilogram force (kgf) by a dynamometer.

The aim of this study was to describe the distribution of the power that has been restored to flexion of the elbow using a continuous measurement. This technique has been shown in a laboratory setting to be a functional method of examining the force of flexion of the elbow[16] and it also allows the relevant patients to be characterised.

Patients and Methods

The project was approved by our institution Project Evaluation Review Process and Research Ethical Committee and also received NHS ethical approval. A retrospective review of the Peripheral Nerve Injury Unit's prospectively maintained database was performed. Patients who underwent nerve transfer to restore flexion of the elbow between May 2006 and May 2012, with a minimum follow-up of two years, were included. There were 52 patients who had an ulnar and/or median nerve fascicle transferred to the biceps +/- brachialis muscle and 26 attended for review. All had undergone an Oberlin procedure.[17-19] This low rate of follow-up is characteristic of studies involving trauma[17-19] and reflects the national referral base of our unit, combined with an unwillingness on the patient's part to return after a two-year period.

A dynamometer (model D60107MK1 Penny and Giles Transducers, Christchurch, United Kingdom), which was calibrated at our Biomechanical Institute, was used for measuring the strength of the re-innervated biceps muscle quantitatively. Patients were seated with the elbow flexed at 90° and the forearm resting on a table. The cup of the dynamometer was placed at a fixed point, 10 cm proximal to the distal wrist crease and the examiner applied a force against the patient. The readings, in kgf, were recorded in three different positions; full supination, neutral and full pronation.

An independent observer (AKS) measured the force of flexion of the elbow in the clinic. The measurements were repeated twice and were then averaged, as the strength varied in different positions of the forearm and sometimes there was no active flexion in a particular position. The strength of flexion was compared with that of the contralateral elbow and expressed as a percentage.

The activity in the brachioradialis and triceps muscles during flexion of the elbow was assessed by inspection and palpation. The MRC grade of flexion at six, 12 and 24 months post-operatively was recorded from the notes.

Statistical analysis. This was performed using SPSS software package (version 19; IBM, Chicago, Illinois). All continuous data were expressed as a median, mean and standard deviation (SD). A two-tailed p-value was determined, with a level of statistical significance set at < 0.05. The analysis also compared the outcome as a percentage of the strength of flexion of the contralateral elbow.

Results

There were 23 male and three female patients. The mean age at the time of referral, was 37.3 years (16 to 66). The median time between injury and the Oberlin procedure was 18.7 weeks (one day to 64.1 weeks). There were 23 patients who had a single and three who had a double transfer. The decision to perform single or double transfers was made by the surgeon. A total of 21 patients underwent quantitative assessment for the strength of their re-innervated biceps muscle as they had attained flexion of MRC grade 4 (the ability to flex against resistance).

There were 15 patients with left-sided and 11 with right-sided brachial plexus injuries. Of these, 12 were on the dominant side and 14 on the non-dominant side. A total of 24 had sustained the injury in a road traffic incident, of whom 17 were riding a motorcycle. Another patient sustained an injury playing rugby and one had an iatrogenic injury at the time of an intrascalene block. A total of 17 patients had an injury to the upper trunk (C5-C6) and seven had involvement of both the upper and middle trunks (C5-C6-C7); the remaining two patients had an infraclavicular injury to the musculocutaneous nerve. Most patients also had other nerve transfers and procedures, which were performed at the time of the ulnar/median nerve transfer to the musculocutaneous nerve. These procedures included 16 patients who had a transfer of the spinal accessory nerve to the suprascapular nerve, two who had transfer of an intercostal nerve to the long head of triceps, two who had nerve grafting between the C5 root and the anterior division of upper trunk, one who had transfer of the spinal accessory nerve to the serratus anterior muscle and the thoracodorsal nerve and one who had an axillary artery repair with saphenous vein graft.

At a mean follow-up of 56 months (28 to 101) the mean strength of flexion of the elbow was 7.2 kgf (3 to 15.5; SD 3.3). The strength was a mean of 34.7% (median 33%, interquartile range 11.9% to 66.5%) compared with the contralateral side. Figure 1 shows the values for the strength of flexion of the elbow obtained for the group with MRC grade 4. The variables followed a normal distribution pattern and a Gaussian curve was obtained.

There were contractions in the brachioradialis muscle in most (ten) patients during attempted flexion of the elbow; this was greatly reduced when flexion was attempted in full supination. Co-contraction of triceps was observed in two patients. The strength of flexion gradually improved post-operatively. Patients usually noted that a flickering movement or movement with gravity was eliminated at six months, movement against gravity or resistance at 12 months and movement against resistance to a potential maximum strength by 24 months.

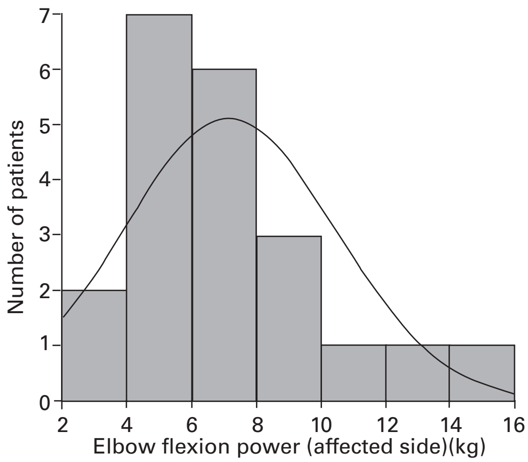

Fig. 1

Gaussian curve showing the distribution of Medical Records Council grade 4 power in the patients at mean follow-up of 56 months (28 to 101).

We found that more than four out of five patients (21/26, 80%) undergoing nerve transfer, irrespective of the level of their injury, gained MRC grade 4 strength of flexion, which when compared with the contralateral side meant that they had recovered a mean flexion power of 7.2 kgf (3 to 15.5; SD 3.3). This equates to between one-eighth to two-thirds increase in strength, and an average of up to one-third of normal.

Discussion

In 1903 Harris and Low[20] described the implantation of the distal stump of an injured C5-C6, in an end-to-side fashion, to the root of C6-C7. They discussed the technique but did not provide the outcome. There were other early reports of nerve transfer, but without sufficient follow-up.[21-22] In 1963, Seddon[23] reported the successful re-innervation (neurotisation) of the biceps muscle with T3/T4 intercostal nerves using a denervated ulnar nerve as a graft and at a one year follow-up, the patient had regained some active flexion of the elbow. In 1994, Oberlin et al[8] described the use of a healthy ulnar nerve fascicle to re-innervate the biceps muscle, avoiding the need for a nerve graft. In 2004, Teboul et al[9] presented the results of 32 patients who underwent this procedure and 20 (59%) had regained MRC grade 4 flexion of the elbow, with a median strength of 4 kgf (1 to 9) at a mean follow-up of 31 months (9 to 74). There have been other series of nerve transfers with further modifications of renervating both the brachialis and biceps muscles using a double transfer. In 2011, Carlsen et al[13] compared six single and 16 double nerve transfers patients in a biomechanical laboratory set-up and found that the mean regained strength of flexion of the elbow was 8.94 kgf (SD 5.92) and 12.54 kgf (SD 11.76), respectively (all patients were at least 12 months post-operative). This corresponded to 16% (SD 9%) and 21% (SD 18%) of the strength on the contralateral side. Ray et al[14] presented the results of 29 patients who had undergone double nerve transfers. A total of 23 recovered to a strength of MRC grade 4 or more at a mean follow-up of 19 months (8 to 68), however, they did not quantify the range for MRC grades. Martins et al[15] described a prospective study comparing single *versus* double nerve transfer with 20 patients in each group.[15] They found that the mean strength of flexion of the elbow gained in the single nerve transfer cohort was 4.14 kgf (SD 3.27) and in the double nerve transfer was 5.6 kgf (SD 2.41) (in patients at a minimum of 12 months post-operatively). This corresponds to 20% (SD 13%) and 25% (SD 10%) compared with the contralateral side.

In our study, of the 26 patients, 21 (81%) gained power of MRC grade 4 which showed a mean strength of flexion of the elbow of 7.2 kgf (SD 3.3). The mean percentage strength of flexion of the elbow compared with the contralateral side was 34.7% (SD 14.4%). There were six patients in our study who underwent nerve transfer within two weeks of their injury and they all achieved power of MRC grade 4 two years post-operatively. The mean percentage strength of elbow flexion (36.36, SD 14.69) compared with the contralateral side in these patients were similar to the rest of cohort (34.09, SD 14.79). The two tailed p-value equals 0.7537, (statistically not significant).

There are limitations to the study. First, the strength of flexion of the elbow should ideally have been measured as a torque because the force is applied across a moment formed by the distance between the trans-epicondylar axis of the elbow and the centre of gravity of the forearm, where the resistance was applied. This would have meant the identification of a centre of gravity for each patient which would have varied. Identifying a centre of gravity is only possible in a biomechanical laboratory study and we set out to demonstrate that this technique can be used in the clinic. Also, assuming that the mid-point of the forearm was the centre of gravity for measurements would have introduced error. Hence, we elected to select, arbitrarily, a fixed point of 10 cm proximal to the wrist crease, as our point for application of force. Secondly, our study was not designed to compare other issues of interest, such as the difference in outcome between those who underwent surgery early or late after injury or single *versus* double transfers. Thirdly, as with any clinical assessment tool there are inter- and intra-observer variations.[24,25]

We have shown how a continuous quantitative measurement of regained elbow strength can be carried out in the clinic. Using the dynamometer, we have avoided MRC descriptive grading of 4-, 4+, 4++ which are neither validated nor sensitive measures. We found that the values obtained during our assessment are similar to those obtained under biomechanical laboratory conditions, which supports the use of the dynamometer the clinic. As the results have a normal distribution, it is now possible to provide a range of the strength of flexion of the elbow which might be expected to be regained following re-innervation of biceps. This will enable a meaningful discussion to take place with patients who have sustained a brachial plexus injury, adding to the process of informed consent.

We found that the distribution of the outcomes conforms to the Gaussian curve. We were expecting to encounter a log normal distribution consistent with a dose effect relationship, that is, we expected to encounter more patients with a lesser power and the incidence of those with greater power decreasing. We found a right shifted normal distribution, suggesting that this is a normal population and thus the reasons behind the generation of the power of flexion of the elbow may not be related to the number of axons regenerating at the site of repair, but something that is intrinsic to the muscle. The difference between the outcomes may therefore not be purely procedural but may be intrinsic to the muscle and to individual patient factors.

This study can also be used to stimulate further investigations into the improvement of outcomes of degenerative nerve injury. Recently, drugs such as ibuprofen[26] and methylcobalamin[27] have been shown to improve recovery and enhance regeneration of nerve injuries in murine models. The value of having a quantitative assessment of the strength which has been regained in such situations will be immense, especially when this research is translated to humans.

It is important to find methods to assess factors that patients find confuse their recovery, such as fatigue, tremor, lack of proprioception and co-contraction. There are also challenges due to the heterogeneity of patients with nerve injuries and their outcome. For example individual variation, age, the nature of the injury, the distance from the nerve transfer to the target organ, the time since injury, co-morbidities and gender. These can all be studied by using continuous quantitative measurements of outcome from muscle re-innervation, giving patients an appreciation of their recovery and also playing a key role in future research in this area.

Take home message:

This study empowers patients with information of a gain in elbow strength in quantitative terms, giving them an insight into their future functional recovery.

Supplementary material

A table showing a summary of injury pattern and outcome following Oberlin procedure can be found alongside the online version of this paper at http://www.bjj.boneandjoint.org.uk

Author contributions:

T. J. Quick: Concept, Data collection, Data analysis, Performed surgery, Writing and reviewing paper.

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M. Sinisi: Data collection, Data analysis, Performed surgery, Reviewed paper.

M. Fox: Data collection, Data analysis, Performed surgery, Reviewed paper.

A. MacQuillan: Concept, Data collection, Data analysis, Performed surgery, Reviewing paper.

The authors would like to acknowledge E. Cook for their help with the statistics.

A. K. Singh and T. J. Quick are joint first authors.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

This article was primary edited by S. P. F. Hughes and first proof edited by J. Scott.

References

1. **Midha R.** Epidemiology of brachial plexus injuries in a multitrauma population. *Neurosurgery* 1997;40:1182–1188.
2. **Choi PD, Novak CB, Mackinnon SE, Kline DG.** Quality of life and functional outcome following brachial plexus injury. *J Hand Surg Am* 1997;22:605–612.
3. **Kretschmer T, Ihle S, Antoniadis G, et al.** Patient satisfaction and disability after brachial plexus surgery. *Neurosurgery* 2009;65(4 Suppl):A189–A196.
4. **Bengtson KA, Spinner RJ, Bishop AT, et al.** Measuring outcomes in adult brachial plexus reconstruction. *Hand Clin* 2008;24:401–415.
5. **Kato N, Htut M, Taggart M, et al.** The effects of operative delay on the relief of neuropathic pain after injury to the brachial plexus: a review of 148 cases. *J Bone Joint Surg [Br]* 2006;88-B:756–759.
6. **Leechavengvongs S, Witoonchart K, Uerpairojkit C, Thuvasethakul P, Ketmalasiri W.** Nerve transfer to biceps muscle using a part of the ulnar nerve in brachial plexus injury (upper arm type): a report of 32 cases. *J Hand Surg Am* 1998;23:711–716.
7. **Htut M, Misra P, Anand P, Birch R, Carlstedt T.** Pain phenomena and sensory recovery following brachial plexus avulsion injury and surgical repairs. *J Hand Surg Br* 2006;31:596–605.
8. **Oberlin C, Béal D, Leechavengvongs S, et al.** Nerve transfer to biceps muscle using a part of ulnar nerve for C5-C6 avulsion of the brachial plexus: anatomical study and report of four cases. *J Hand Surg Am* 1994;19:232–237.
9. **Teboul F, Kakkar R, Ameur N, Beaulieu JY, Oberlin C.** Transfer of fascicles from the ulnar nerve to the nerve to the biceps in the treatment of upper brachial plexus palsy. *J Bone Joint Surg [Am]* 2004;86-A:1485–1490.
10. **Tung TH, Novak CB, Mackinnon SE.** Nerve transfers to the biceps and brachialis branches to improve elbow flexion strength after brachial plexus injuries. *J Neurosurg* 2003;98:313–318.
11. **Carlsen BT, Bishop AT, Shin AY.** Late reconstruction for brachial plexus injury. *Neurosurg Clin N Am* 2009;20:51–64.
12. **Shin AY, Spinner RJ, Steinmann SP, Bishop AT.** Adult traumatic brachial plexus injuries. *J Am Acad Orthop Surg* 2005;13:382–396.
13. **Carlsen BT, Kircher MF, Spinner RJ, Bishop AT, Shin AY.** Comparison of single versus double nerve transfers for elbow flexion after brachial plexus injury. *Plast Reconstr Surg* 2011;127:269–276.
14. **Ray WZ, Pet MA, Yee A, Mackinnon SE.** Double fascicular nerve transfer to the biceps and brachialis muscles after brachial plexus injury: clinical outcomes in a series of 29 cases. *J Neurosurg* 2011;114:1520–1528.
15. **Martins RS, Siqueira MG, Heise CO, Foroni L, Teixeira MJ.** A prospective study comparing single and double fascicular transfer to restore elbow flexion after brachial plexus injury. *Neurosurgery* 2013;72:709–714.
16. **MacAvoy MC, Green DP.** Critical reappraisal of Medical Research Council muscle testing for elbow flexion. *J Hand Surg Am* 2007;32:149–153.
17. **Leukhardt WH, Golob JF, McCoy AM,et al.** Follow-up disparities after trauma: a real problem for outcomes research. *Am J Surg* 2010;199:348–352.
18. **Aaland MO, Marose K, Zhu TH.** The lost to trauma patient follow-up: a system or patient problem. *J Trauma Acute Care Surg* 2012;73:1507–1511.
19. **Hansen L, Shaheen A, Crandall M.** Outpatient follow-up after traumatic injury: Challenges and opportunities. *J Emerg Trauma Shock* 2014;7:256–260.
20. **Harris W, Low VW.** On the importance of accurate muscular analysis in lesions of the brachial plexus; and treatment of Erb's palsy and infantile paralysis of the upper extremity by crossunion of the nerve roots. *BMJ* 1903;2:1035–1038.
21. **Tuttle HK.** Exposure of the brachial plexus with nerve-transplantation *JAMA* 1913; 61:15–17.
22. **Feiss HO.** On the fusion of nerves. *Q J Exp Physiol* 1912;5:1–30.
23. **Seddon HJ.** Nerve Grafting. *J Bone Joint Surg [Br]* 1963;45-B:447–461.
24. **Byl NN, Richards S, Asturias J.** Intrarater and interrater reliability of strength measurements of the biceps and deltoid using a hand held dynamometer. *J Orthop Sports Phys Ther* 1988;9:395–398.
25. **Ngoc LL, Janssen J.** Validity and reliability of a hand-held dynamometer for dynamic muscle strength assessment. http://www.intechopen.com/books/rehabilitation-medicine/validity-and-reliability-of-a-hand-held-dynamometer-for-dynamic-muscle-strength-assessment (date last accessed 01 August 2016).
26. **Fu Q, Hue J, Li S.** Nonsteroidal anti-inflammatory drugs promote axon regeneration via RhoA inhibition. *J Neurosci* 2007;27:4154–4164.
27. **Liao WC, Wang YJ, Huang MC, Tseng GF.** Methylcobalamin facilitates collateral sprouting of donor axons and innervation of recipient muscle in end-to-side neurorrhaphy in rats. *PLoS One* 2013;8:76302.