Prosthetics and Orthotics International

Application of myoelectric elbow flexion assist orthosis in adult traumatic brachial plexus injury: a retrospective clinical study

Nicholas Pulos[1], Catherine van den Berg[1], Kenton R. Kaufman[1,2] and Alexander Y. Shin[1]

Abstract

Background: Adult traumatic brachial plexus injuries (BPIs) can result in severe impairment following penetrating wounds, falls, and motor vehicle accidents or other high-energy trauma.

Objective: Quantify functional outcomes of adult patients with a BPI using a myoelectric orthosis to restore elbow flexion.

Study design: Retrospective review.

Methods: A clinic specializing in the BPI treatment at a large academic medical center tested nineteen adult patients with BPI. These patients had failed to achieve antigravity elbow flexion following their injury and observation or surgical reconstruction. They were provided a myoelectric elbow orthosis (MEO) if they had detectable electromyography signals.

Results: There was significant improvement in strength and significant reductions in function and pain when using an MEO. Following initiation of the MEO, 12 of the 19 patients had clinical improvements in muscle strength, 15 patients showed improvement in their DASH, and 13 patients reported improvements in their Visual Analog Scale.

Conclusion: The use of an MEO improves elbow flexion strength, increases function, and reduces pain in the majority of patients with BPI and inadequate elbow flexion following observation or surgical reconstruction.

Keywords

brachial plexus injury, orthosis, myoelectric elbow orthosis, MyoPro

Date received: 5 April 2021; accepted 9 August 2021.

Introduction

Adult traumatic brachial plexus injuries (BPIs) can result in severe impairment following penetrating wounds, falls, and motor vehicle accidents or other high-energy trauma. Clinically, patients present with flaccid paralysis involving some or all muscles of the upper extremity consistent with a lower motor neuron injury. In patients with complete BPI or upper trunk injuries, shoulder function and elbow flexion are severely impacted. For patients with traumatic BPI, the ability to achieve elbow flexion against gravity is paramount. In the presence of a stable shoulder with some external rotation and abduction, grade 3 or greater elbow flexion will allow the patient to bring their hand to their mouth and position their hand in space. Failure to achieve antigravity elbow flexion against resistance relegates the upper extremity to little more than a helper hand, best used to hold objects while the contralateral hand performs all other tasks.

Although some patients may demonstrate functional improvement over time, surgery is indicated when there is no clinical or electrodiagnostic evidence of recovery by 6 months or when spontaneous recovery is not possible (i.e. in an avulsion injury). Surgical options to restore elbow flexion depend on the injury type, time from injury, concomitant injuries, and available nerve donors. Options include neuroma excision and nerve grafting, nerve transfers, tendon transfers, and free-functioning gracilis muscle transfers. Even with extensive physiotherapy and active commitment of the patient, functional recovery after reconstruction may be slow or fail to progress to a functional level.[1,2] Therefore, the goals of surgery are to provide elbow flexion against gravity with some resistance, shoulder stability and external rotation, and when possible, protective sensation to the hand.[3] Current surgical treatments are often unable to return the patient to preinjury levels of function.

Scientific evidence for use of an elbow orthosis to aid elbow flexion in BPI is sparse. Kohlmeyer et al[4] provided three case reports of a unique upper-extremity orthosis consisting of a figure-eight harness composed of latex tubing attached to a forearm cuff to improve arm positioning for performance of activities of daily living. Emmelot et al[5] compared shoulder fusion combined with an elbow orthosis to a stabilizing orthosis. They reported that patients with a completely paralyzed upper limb benefit more from shoulder fusion and an elbow orthosis than from a shoulder and elbow stabilizing orthosis. Ogce and Ozylcin[6] reported in two case studies that a myoelectrically controlled powered shoulder-elbow orthosis provided patients the ability to engage in two-handed activities of daily living. There have been no other reports over the past 2 decades of orthotic care for patients with a BPI.

[1]Department of Orthopedic Surgery, Mayo Clinic, Rochester, Minnesota, USA

[2]Department of Physiology & Biomedical Engineering, Mayo Clinic, Rochester, Minnesota, USA

Corresponding author:

Kenton R. Kaufman, Motion Analysis Laboratory, W. Hall Wendel, Jr., Musculoskeletal Research Professor, 200 First Street SW, Rochester, MN 55905. Email: kaufman.kenton@mayo.edu

Associate Editor: Cheryl Metcalf

DOI: 10.1097/PXR.0000000000000046

The use of a powered exoskeleton to aid in functional recovery following a BPI is a new clinical approach to be considered. Therefore, the aim of this study was to assess functional outcomes before and after implementation of a myoelectric elbow orthosis (MEO) in adult patients with traumatic BPI to determine whether the MEO resulted in improved patient-reported outcomes and improved strength. The results of this study will help determine the applicability of a MEO for lower motor neuron injuries.

Methods

Study design

After receiving institutional review board approval, a retrospective chart review was performed. Consecutive adult patients with a traumatic BPI and inadequate elbow flexion after surgical reconstruction were studied. All patients were treated at a single institution with an MEO.

Participants

Patients were included if the following criteria were met: (1) diagnosed with a traumatic BPI, (2) had detectable electromyography (EMG) signals, (3) failed to achieve antigravity elbow flexion (i.e. British Medical Research Council [BMRC] <3) following surgical reconstruction or observation, (4) and were treated with a MEO between February 2015 and April 2018. Out of 26 consecutive adult patients eligible for the study, seven had incomplete records. The cohort had 15 men and four women with a mean age of 39 years (range 18–64 years) (Table 1). The median time from injury to brachial plexus reconstructive surgery was 6 months (range 2–22 months). The median time from surgery to initiation of MEO therapy was 20 months (range 2–40 months). The median follow-up after MEO application was 10 months (range 3–47 months).

MEO training and use

The MyoPro (Myomo, Boston, MA) is a MEO that was developed initially for stroke patients with detectable biceps activity, but insufficient strength for meaningful use. This MEO detects weak EMG signals within an affected muscle group (typically the biceps), amplifies the signal via computer processor, and activates a motor to augment the intended movement. The flexion power is proportional to the EMG signal and with sustained myoelectric activity, the functional position is maintained with the aid of the orthosis. This MEO may be useful to provide functional augmentation for long-term use in patients with a BPI (Figure 1).

The indication for MEO initiation was augmentation of inadequate elbow flexion function (BMRC < 3) following surgery in 14 patients, early rehabilitation in four patients who were just obtaining signal in the free-functioning muscle or biceps, and

Table 1. Patient demographics.

Patient	Age, y	Sex	Injury mechanism	Injury type	Time to surgery (d)	Procedure	Time from surgery to MOE (d)	Follow-up post-MEO (d)
1	40	M	MCA	C5, 6, 7	216	Oberlin	769	330
2	21	M	Skiing	C5, 6, 7	155	Oberlin	525	358
3	19	M	Skiing	Complete	177	ICN to MCN	295	482
4	40	M	Snowmobile	Complete	147	ICN to MCN	981	607
5	49	F	MCA	Complete	185	ICN to MCN	711	526
6	57	M	Snowmobile	C5, 6	95	ICN to MCN	713	220
7	27	M	MCA	Complete	165	ICN to MCN	1136	376
8	25	M	MVA	Complete	171	ICN to MCN	1203	99
9	53	F	MCA	C5, 6, 7, 8	202	FFMT; ICN to MCN	580	195
10	21	F	MCA	Complete	175	FFMT	605	213
11	42	M	Logging	Complete	658	FFMT	872	268
12	42	M	MCA	C5, 6	311	FFMT	312	141
13	55	M	Motorcycle	Complete	166	FFMT	330	167
14	62	F	Fall	C5, 6, 7	183	FFMT	608	433
15	18	M	Skiing	Complete	183	FFMT	236	822
16	53	M	Snowmobile	Complete	181	FFMT	538	288
17	64	M	Fall	Complete	71	C5 graft to MCN	902	127
18	33	M	MVA	C5, 6, 7	439	Triceps to biceps tendon transfer	577	142
19	19	M	MVA	C5, 6	275	No intervention	53	1451
				Median	181		605	288
				Interquartile range	165–216		330–872	167–482

Abbreviations: FFMT, free-functioning muscle transfer; ICN,intercostal nerve; MCN, musculocutaneous nerve; MEO, myoelectric elbow orthosis.

Figure 1. Patient with a left brachial plexus injury with inadequate elbow flexion with a MyoPro G device (Myomo, Inc, Cambridge, MA).

augmentation of inadequate function without prior surgical intervention in one patient. Upon initiation of the MEO, the patient met with an American Board for Certification of the Orthotic and Prosthetic Appliance Industry–certified orthotist to ensure proper fit, problem solve any difficulties with use of the orthosis, and demonstrate modes of use. A Certified Hand Therapist ensured that the patient was able to independently don and doff the device. Finally, use of the device with functional supporting activities was introduced. This included use of the extremity as a helper arm to support or hang objects from and was also dependent on the type of brachial plexus injury the patient had and what reconstructions were performed.

Data collection

Demographic and injury data were collected from medical records, computed tomography myelograms, electrodiagnostic studies, operative reports, and therapy notes. Computed tomography myelography was used to radiographically determine whether nerve roots were avulsed. Electrodiagnostic testing from preoperative, intraoperative, and postoperative tests were used to characterize the nerve injury and to monitor signs of recovery after intervention. Operative reports provided information on injury type and reconstructive procedure performed.

Therapy notes were reviewed to collect data on three outcome measures: muscle strength, upper-extremity function, and pain. These outcomes measures were collected at each clinic visit. A modified BMRC muscle grading system was used to evaluate muscle strength.[3,7] Signs of + and – were also used to highlight where the muscle strength is insufficiently described by this muscle grading system alone.[8] The Disabilities of the Arm, Shoulder and Hand (DASH) Score[9] and the Visual Analog Scale (VAS) for chronic pain were obtained as part of routine clinical evaluation preimplementation and postimplementation of the MEO. The DASH is a 30-item self-report questionnaire where patient rate their difficulty to perform certain upper-extremity activities on a 5-point Likert scale. A higher score indicates a greater level of impairment and severity. The DASH can detect and differentiate small and large changes of impairment over time after surgery in patients with upper-extremity musculoskeletal disorders. A 10-point difference in the mean DASH score may be considered as a minimal important change.[10] The DASH has been validated for patients with musculoskeletal injuries and its use in patients with BPI is common, despite its limitations.[9,11,12] The VAS is a unidimensional valid and reliable measure of pain intensity, which has been widely used in diverse adult populations.[13-15] The minimal clinically significant difference is a change of 10 mm on a 100-mm scale.[16]

Data analysis

A Student's paired *t*-test was used to compare the normally distributed continuous variables of the DASH score and the VAS before and after use of the MEO. The Wilcoxon signed-rank test was used to compare the non-normally distributed muscle strength before and after use of the MEO. A linear regression was used to assess the effect of age on strength improvement following MEO therapy. A Pearson correlation was used to determine whether there was any association between the three outcome variables. A subanalysis evaluating the role of free-functioning gracilis vs. nerve transfer for elbow flexion in obtaining functional improvement with MEO was performed to determine which surgery was most improved with MEO application. $P < 0.05$ was considered statistically significant.

Results

The outcomes of MEO therapy were assessed by changes in strength, function, and pain. Comparisons were made before and after MEO therapy.

Strength

The participants demonstrated a statistically significant ($P = 0.004$) improvement in strength following MEO therapy (Figure 2). Elbow flexion was via the biceps or free-functioning muscle transfer only. The brachialis and brachioradialis muscles were paralyzed and not reinnervated in the surgically reconstructed patients. Overall, 12 of the 19 patients demonstrated improved muscle strength. During the study period, three of the patients underwent revision surgery for failure to achieve meaningful elbow flexion strength (two triceps to biceps tendon transfers and one transhumeral amputation). For these patients, their outcome measures from the MEO were obtained before their revision surgery. Three patients achieved antigravity elbow flexion through their full passive range of motion. Five patients

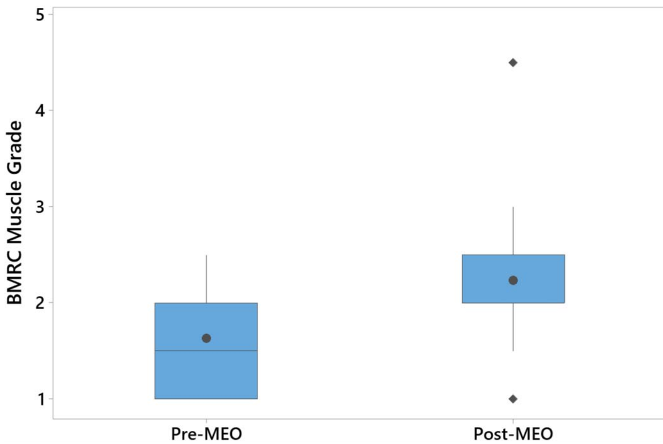

Figure 2. Preand postmyoelectric orthosis modified British Medical Research Committee Muscle grading. BMRC, British Medical Research Council.

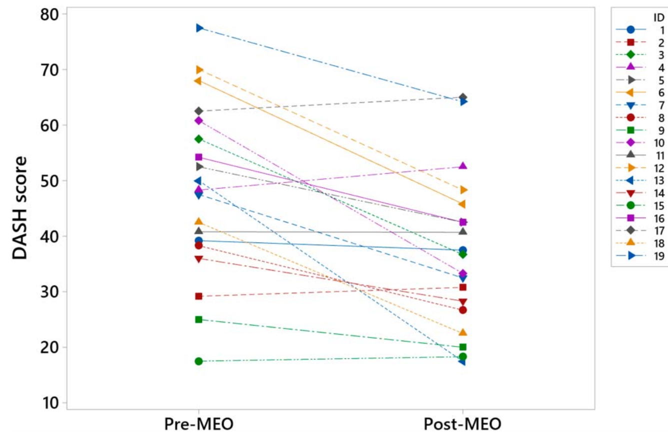

Figure 3. Premyoelectric and postmyoelectric orthosis Disabilities of the Arm Shoulder and Hand (DASH) scores—individualized. MEO, myoelectric elbow orthosis.

demonstrated partial elbow flexion against gravity, which was not present before initiation of the MEO. There was a trend toward younger age in patients who demonstrated improvement in muscle grade following MEO therapy, but this did not reach statistical significance ($P = 0.17$). The median time to initiation of MEO following surgery was 18 months in patients who showed improvement in elbow flexion strength compared to 30 months in patients who failed to improve ($P = 0.03$). Six of the seven patients treated with free-functioning muscle transfer showed improvement in muscle grading compared to three of eight patients who underwent nerve transfers ($P = 0.04$).

Function

The average DASH score before initiation of the MEO was 48 (range 18–78) (Figure 3). At final follow-up, the DASH score improved to a mean of 37 (range 18–65), a significant improvement of 11 points ($P < 0.001$). Overall, 15 patients showed improvement in their DASH following initiation of the MEO and 13 patient reported improvements in their VAS. The patients receiving a free-functioning muscle transfer had a mean 12-point improvement on the DASH. There was a positive correlation between improvement in muscle grade and improvement in DASH score ($P = 0.047$).

Pain

The mean VAS significantly improved from 5.2 to 3.8 (range, 0–10) ($P = 0.017$) (Figure 4). Overall, 13 patients reported improvements in their VAS. Two patients reported an initial score of 0 for the VAS, which was maintained at final follow-up as well. The patients receiving a free-functioning muscle transfer had no improvement on the VAS. There was no significant correlation between improvement in muscle grade or improvement in DASH and VAS.

Discussion

This study has demonstrated that the use of an MEO has utility among patients who have shown some return of elbow flexion strength but have failed to regain meaningful use of their extremity. Not only does this orthosis allow for improved use of the arm while it is being worn,[17] but also 12 patients had an increase in elbow flexion strength after a mean of 13 months of use. Patients with a shorter duration to initiation of MEO and those treated with free-functioning muscles were more likely to show gains in muscle grading.

The study has shown that use of the MEO in patients with BPI improved function and reduced pain. The DASH scores improved a mean 11 points following therapy with an MEO. The clinically important difference in DASH score has been reported as 10.83 points.[18] Ten of 19 patients in our study met this threshold for clinically important difference. VAS score similarly improved in most of the participants in this study.

The results reported in this study differ starkly from the "Patient Perspectives" study performed by Webber et al.[17] This qualitative focus group of patients studied in this report was informative by the fact that the patients reported that the MEO did not meet their expectations. They reported that the MEO had limited utility in activities of daily living because of unpredictable operation. Furthermore, the MEO provided elbow stability and support at the expense of shoulder pain after a short period of use. Thus, the dissimilar conclusions from these two studies performed on the

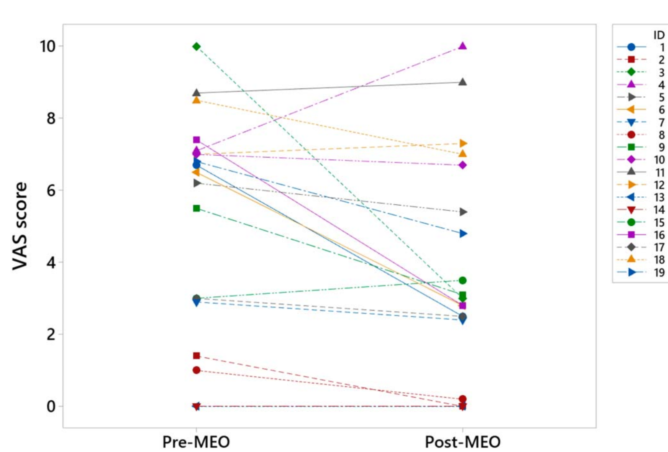

Figure 4. Premyoelectric and postmyoelectric orthosis Visual Analog Scale (VAS) scores—individualized. MEO, myoelectric elbow orthosis.

same participants highlight the importance of study design. There are several reasons for these differing conclusions. First, there are known floor and ceiling effects with patient-reported outcomes measures such as the DASH, which fail to capture patients with either extremely poor or exceptional function.[19,20] Second, several questions on the DASH ask about activities of daily living, which require only minimal or even no assistance from the contralateral limb. Thus, while the focus group interviews reported by Webber et al[17] highlight patient frustration with not returning to preinjury levels, their responses on surveys may in fact still demonstrate improvement in some activities of daily living. Finally, little has been written about the method of collecting these surveys and the timing at which they are obtained, but this is a potential source of bias when done in a postoperative setting with the surgical team. The results of these studies highlight our continued difficulty in trying to quantify subjective patient satisfaction with a commonly used outcome instrument developed as a measure of self-rated upper-extremity disability and symptoms to quantify functional outcomes, for example DASH. Clearly, this instrument does not accurately capture patient satisfaction. The differences in findings may also be because of patients answering questionnaires in a manner to please their providers, whereas when asked independently of their provider, they express entirely different outcomes. This possibility needs to be considered when collecting patient reported outcomes.

We recognize the limitations inherent in this retrospective study. Given the heterogeneity of this injury, time from injury to being seen in the clinic, and patient factors, studies in patients with adult traumatic BPI can be difficult to interpret. For example, free-functioning muscle transfers have outperformed nerve transfers for restoration of elbow flexion strength in patients with complete BPIs[21] and patients with free-functioning muscle transfers were provided an MEO earlier than those with nerve transfers in our study. There may be a potential selection bias in who was able to obtain a MEO secondary to socioeconomic factors that were not evaluated in this study. However, the indications for application of the MEO were clearly defined. Finally, the purpose of the study was to determine the applicability of a MEO for elbow flexion in patients with BPI and not to evaluate the cost and availability of the MEO.

Conclusion

This study demonstrates that the use of an MEO improves elbow flexion strength after a plateau in clinical improvement following brachial plexus reconstructive surgery in the majority of patients, with the additional benefit of improving function and reducing pain.

Funding

The authors disclosed that they received no financial support for the research, authorship, and/or publication of this article.

Declaration of conflicting interest

The authors disclosed the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: N.P, C.v.d.B, and K.R.K. have no conflicts of interest to disclose. A.Y.S serves in an unpaid capacity on the Veterans Advisory Board to Myomo (Cambridge, MA).

ORCID iDs

N. Pulos: https://orcid.org/0000-0001-8706-4522
K.R. Kaufman: https://orcid.org/0000-0002-7311-3781

Supplemental material

There is no supplemental material in this article.

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