The Use of Dynamic Assist Orthosis for Muscle Reeducation following Brachial Plexus Injury and Reconstruction

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Abstract

Keywords

- brachial plexus injury
- reconstructive nerve surgery
- dynamic orthosis

Therapeutic management of brachial plexus injuries remains complex. The impact of brachial plexus injuries on everyday human functioning should not be underestimated. Early active-assisted range of motion following such injuries may prevent myostatic contractures, minimize muscle atrophy, facilitate muscle fiber recruitment, and enable a faster return to baseline strength levels. The dynamic assist elbow flexion orthosis proposed is designed to provide patients with a graded system for muscle reeducation and function. No clinical data are currently available on the use of this orthosis design; however, this article presents a treatment option based on sound clinical reasoning to facilitate rehabilitation following this devastating injury.

Introduction

Brachial plexus (BP) injuries following trauma are rare but yet complex injuries. Following such injuries including pre- and postoperatively, as well as in cases managed conservatively, the role of hand therapy is critical. Various journal articles have elucidated the role of orthoses in maximizing upper limb function, preventing secondary contractures, and optimizing postoperative rehabilitation following BP injuries.^{1–7} However, literature describing the role of using orthosis for the purpose of muscle reeducation is still scarce. The purpose of this article is to introduce the concept of dynamic assist orthosis to facilitate and optimize muscle reeducation following BP injury. Though the focus of this paper will be on elbow flexion, the concept of the orthosis design may be applied to other deficits affecting the upper limb function, such as injuries including forearm rotation and flexion/extension of the wrist and digits.

Brachial Plexus Injuries

Etiology

BP is formed by the ventral rami of the lower four cervical nerves C₅–C₈ and first thoracic nerve T₁. The BP is responsible

for providing cutaneous and muscular innervation of the entire upper limb, with the exception of the trapezius muscle and a small patch of skin near the axilla.^{8,9} The impact of BP injuries on everyday human functioning is devastating. Common mechanisms of injury include motorcycle and motor vehicle accidents, contact sports, and penetrating wounds.^{9–12} Lesions can occur at any level from the base of the nerve roots to the divisions of the BP situated within the axilla. Lesions are most often the result of a sudden blow that simultaneously depresses the shoulder girdle while forcing the head and neck away from the shoulder producing traction injuries to the BP. In some cases, complete avulsion of the nerve root(s) from the spinal cord can result. Compression injuries may occur due to direct blunt trauma. Partial or complete rupture of one or multiple nerves is typically caused by penetrating wounds.^{9,12–15}

Clinical Presentations

Various classifications have been proposed in the literature depending on the location of the trauma to the BP. BP injuries have four main clinical presentations: (1) complete BP palsy or pan-plexopathy (C₅–T₁); (2) Erb-Duchenne palsy (C₅, C₆, or upper trunk); (3) upper-middle trunk palsy (C₅, C₆, C₇); and (4)

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Dejerine-Klumpke palsy (C_8, T_1). Complete BP palsy results in a flail and insensate upper limb. Deficits associated with Erb-Duchenne palsy include an inability to perform abduction, external rotation and flexion of the shoulder, elbow flexion, wrist extension, and supination of the forearm. In addition to deficits associated with Erb-Duchenne palsy, upper middle trunk lesions produce deficits with adduction of the arm and extension of the elbow, wrist, fingers, and thumb. Though Dejerine-Klumpke palsy is quite rare in adults, those afflicted present with an inability to flex their fingers and loss of intrinsic function of the hand causing difficulties with hand-based motor tasks.^{9,15-21}

Current Management Techniques

Operative Management

Management of BP injuries are dependent on injury type, location, and severity.^{10,17} Type, location, and severity of injuries are best identified using magnetic resonance imaging and/or computed tomography myelography.^{9,13,22} Surgical management options for reconstructive surgery of the BP include neurolysis, nerve repair, nerve grafting, and nerve transfers for traction, avulsion, and laceration injuries, as well as tendon transfers, free muscle transfers, arthrodesis, and tenodesis for avulsion injuries or other irreparable plexus injuries.^{9,13,15,17,23}

Surgical intervention is recommended in cases in which no neurologic recovery is noted at the end of the observation period, between 3 and 6 months. Traction injuries are generally observed for spontaneous recovery for 3 to 6 months, whereas complete avulsion, rupture, and lacerations will show no signs of recovery within that time frame. During this time, rehabilitative interventions are initiated, and clinical and electrodiagnostic examinations are intermittently performed to assess for neurologic recovery.^{9,13-15,17}

Most BP and peripheral nerve surgeons concur that restoring elbow flexion is crucial in the return of some level of functional use of the upper extremity. A second priority is shoulder function, focusing on shoulder abduction, external rotation, and scapula stabilization, followed by triceps function. Reestablishment of hand function post complete BP injuries is extremely challenging, and in many cases not successful if the nerve reconstruction takes place in the plexus vicinity. Most surgeons will offer a wrist arthrodesis, in these cases, along with median sensory nerve function reconstruction.^{5,6,14,23,24}

Therapeutic Management

Therapeutic management following BP injury and reconstruction remains quite challenging. Techniques often tenodesis for avulsion injuries or other irreparable include positioning, orthoses application, passive range of motion, edema control, active/active-assisted range of motion, electrical muscle stimulation, biofeedback, strengthening, desensitization, and sensory reeducation. These techniques may be implemented in cases managed operatively or conservatively.^{1-4,7,15,17,25-27}

As previously mentioned, a priority of any BP surgical reconstruction or rehabilitation program is elbow flexion.

Elbow flexion orthosis fabrication for BP injuries was first introduced by Parry in 1966.²⁸ The aim of Parry's design, as well as all subsequent variations of his design, was to provide individuals with a fixed functional degree of elbow flexion in spite of muscle weakness or a flail arm.^{28,29}

Though Parry's orthosis design permits better use of the upper extremity, it is nonetheless a compensatory tool and not one aimed at rehabilitation. To date, no elbow flexion orthosis designed specifically for muscle reeducation tenodesis for avulsion injuries or other irreparable following BP injury has been proposed. The following introduces a new dynamic assist elbow orthosis design to facilitate and enhance muscle reeducation following BP injury.

Dynamic Assist Orthosis for Muscle Reeducation following Brachial Plexus Injury

Biomechanics of the Upper Limb, Early Active Motion, and Muscle Reeducation

For muscles to produce movement, a series of physiologic and biomechanical actions are required: (1) nervous stimulation at the neuromuscular junction; (2) contraction of muscle fibers; (3) change in the angle of the joint; (4) joint compression; and (5) rotatory action about the joint axis.⁸ In BP injuries, nerve conduction is hindered, resulting in decreased or absent stimulation at the neuromuscular junction. In some instances, nervous stimulation is decreased to such an extent that a change in the angle of the joint is not possible and no movement can be perceived. In such cases, early active muscle contraction is seldom initiated, due to this seeming lack of movement, and orthoses aimed at compensatory movement are typically prescribed.^{2-4,7,15,28,29}

Though no movement may be perceived visually, minute myostatic contractions may be detectable via electromyograph. Use of an electromyograph to search for myostatic contractions following BP injury is encouraged. Early active motion is indicated the moment any contraction of muscle fibers can be detected electromyographically.³⁰ Early active motion minimizes muscle atrophy, prevents the formation of myostatic contractures, facilitates recruitment of additional muscle fibers, and allows for a faster return to baseline strength levels.^{21,31,32}

The dynamic assist elbow orthosis proposed here is designed to allow patients with a grade 2 on the Manual Muscle Testing Scale (i.e., perceptible contraction in gravity eliminated position, but no movement) to complete full elbow flexion against gravity (grade 3), despite muscle weakness or a flail arm.³³ In addition to providing the patient with a graded system for muscle reeducation, the orthosis also allows for coordinated movement patterns and proprioceptive and visual feedbacks, which are all critical factors for cortex reorganization and neuroplasticity.^{34,35}

Biomechanics of the Dynamic Assist Splint

The forces acting on the forearm at the elbow joint with a dynamic assist splint in place are depicted in (► Fig. 1).

Fig. 1 Elbow biomechanics of a patient wearing the dynamic assist elbow splint.

The goal of the splint is to minimize the moment required by muscles, M_{muscle} , to flex the elbow. To find M_{muscle} , the moments at the elbow joint are summed:

$$\sum M_o = F_g L \sin(\theta) - T a \sin(\beta) - M_{muscle} = 0 \quad (1)$$

where F_g is the force of gravity acting on the lower arm and hand; L is the distance from the elbow joint to the center of mass of the lower arm and hand; a and b are the distances from the elbow joint to the attachment points of the elastic band on the forearm and upper arm, respectively; θ is the angle of flexion of the elbow joint; T is the tension acting on the lower arm by the elastic band; and β is the angle that the elastic band makes with the lower arm. If the elastic band exhibits a linear force-distance relationship, T can be estimated as

$$T = \begin{cases} k_e(l_e - l_0), & l_e \geq l_0 \\ 0, & l_e < l_0 \end{cases} \quad (2)$$

where k_e is the spring constant of the elastic band; l_e is its length; and l_0 is its unstretched length. Solving for l_e and β as functions of θ and rearranging (1) yield the total moment required by the muscles acting at the elbow joint to flex the elbow:

$$M_{muscle} = F_g L \sin \theta - a k_e (l_e - l_0) \sin \left[a \tan \left(\frac{b + a \cos \theta}{a \sin \theta} \right) - \frac{\pi}{2} + \theta \right] \quad (3)$$

It is difficult to find an analytical solution to minimize (3). However, if the splint is configured such that $a \ll b$ and $l_0 \ll b$ (i.e., the elastic is prestretched a large amount relative to its resting length), then $\beta \approx \theta$ and (1) simplifies to

$$M_{muscle} = F_g L \sin(\theta) - T a \sin(\theta) \quad (4)$$

In addition, the change in length of the elastic in this configuration will be minimal compared with its stretched length, and tension in the elastic will be approximately constant and equal to $T \approx k_e(b - l_0)$. Setting $M_{muscle} = 0$ and substituting this approximation for T into (4) yield an estimate of the stiffness of the elastic required:

$$k_e \approx \frac{F_g L}{a(b - l_0)} \quad (5)$$

Fabrication of Dynamic Assist Elbow Orthosis

Material

1. Thermoplastic orthosis material
2. Incremental elbow hinge (x2)
3. Chicago screws (x8)
4. Chicago screw covers (x8)
5. Velcro
6. Strapping
7. Elastic bands

Fabrication

1. Fabricate a thermoplastic component on the dorsum of the upper arm. Ensure that the distal end is flared to accommodate the medial and lateral humeral epicondyles. The length of the upper arm component should be approximately two-thirds the length of the upper arm (**► Fig. 2**).
2. Fabricate a thermoplastic component on the dorsum of the forearm. The distal portion of the forearm component should end slightly proximal to the metacarpophalangeal joints and position the wrist in a neutral position (**► Fig. 3**).

Fig. 2 Fabricate posterior arm and forearm thermoplastic splint covering two-thirds of the circumference.

Fig. 3 Place the elbow hinge at the axis of rotation and fix both arms of the hinge on the proximal and distal thermoplastic segments of the splint, using two Chicago screws.

Fig. 4 Apply two straps on the forearm and arm thermoplastic splint to secure the splint on the upper extremity. Block elbow extension at 45 or 60 degrees with an adjustable blocker provided by the supplier (arrow).

Fig. 5 Fabricate a hand-based splint and affix the wrist hinge as shown in the diagram.

Fig. 6 Install a dynamic outrigger component for finger slings. Drill hole and attach a Chicago screw for dynamic pull for the wrist

3. Mount the first incremental elbow hinge on the lateral side of the upper arm component and the forearm component using four Chicago screws. Ensure that the axis of rotation of the incremental elbow hinge aligns with the axis of rotation of the elbow (►Fig. 4).
4. Mount the second incremental elbow hinge on the medial side of the upper arm component and the forearm component using four Chicago screws. Again, ensure that the axis of rotation of the incremental elbow hinge aligns with the axis of rotation of the elbow (►Fig. 5).
5. Apply Velcro pieces and strapping accordingly to secure both the proximal and distal ends of the upper arm component. Apply Velcro pieces and strapping to secure the proximal forearm, wrist, and hand of the forearm component (►Fig. 6).
6. Place elastic bands on the lateral side of the orthosis, securing them to the Chicago screw covers. Additional elastic bands strips may be placed on the medial side of the orthosis as required.

Recommendation of Elbow Dynamic Assist Orthosis

Orthosis wear is initiated when muscle fiber contractions of the elbow flexors can be detected electromyographically with a few nascent polyphasic motor units. Initially, elastic bands are used to eliminate gravitational forces and maximize existing muscle contractions, as well as blocking full extension to maximize the rotational torque generated by the still weak elbow flexors. Note that the patient should be able to complete full elbow flexion within the orthosis.

As the patient makes gains in strength, the number of elastic bands is gradually decreased, and so is the extension block, with full extension being the ultimate goal. A reduction in the total number of elastic bands will decrease the antigavity effect of the orthosis. As a result, recruitment of additional muscle fibers is required to complete elbow flexion. The orthosis is discontinued once the patient is capable of independent elbow flexion against gravity (grade 3 on the Manual Muscle Testing Scale).

Fig. 7 Upon completion of splint fabrication, attach Thera-Band strips to assist flexion of the elbow.

Fig. 9 Four months post double nerve transfer for elbow flexion; elbow flexion graded at 3 on the MRC scale. Patient able to overcome resistance with the assistance of the orthosis.

Fig. 8 Three months post double nerve transfer for elbow flexion; elbow flexion graded at 2 on MRC scale. **(A)** Patient unable to actively flex the elbow against gravity; **(B)** possible elbow flexion with activation of donor nerve and assistance of uninjured hand; **(C)** elbow flexion assisted by dynamic orthosis; **(D)** nearly full elbow flexion within the orthosis.

Conclusion

Therapeutic management of BP injuries and reconstruction is complex. A therapeutic strategy comprises a combination of early active-assisted range of motion and use of the dynamic assist elbow flexion orthosis proposed here, which can provide patients with a graded system for successful return to function. Although no clinical data are currently available on the use of this orthosis design, this article shows sound clinical

evidence that a combination of exercises and a dynamic-assist orthosis accelerates rehabilitation and allows for better outcomes based on biomechanical principles. A randomized clinical trial of this orthotic method may provide evidence that this orthosis design enhances and facilitates muscle reeducation, thereby improving rehabilitation outcomes.

Conflict of Interest

None.

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