39 The Role of Therapy: Pre- and Post-surgery Protocols

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Introduction

One of the most anxiety-provoking topics for occupational and physical therapists is learning and understanding the complex anatomy of the brachial plexus. Knowing the proper rehabilitation techniques to treat adults with a brachial plexus lesion is essential. It must be communicated with the therapist the rehabilitation needs from the time of first evaluation through the post-surgical reconstruction period, including lifetime restrictions and expectations.

Common therapy interventions for all patients with brachial plexus injuries include:

1. Range of motion
2. Gravity-eliminated motion/strengthening
3. Slings and/or orthotics
4. Manual therapies for scar management and edema control
5. Graded motor imagery
6. Neuromuscular reeducation and activation techniques
7. Modalities
8. One-handed activities of daily living, work, and leisure

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Preoperative Rehabilitation

Therapy plays a critical role in a patient's care after a brachial plexus injury. Even if an injury to the brachial plexus has not been ascertained, the care team should be suspicious especially, when a patient sustains multi-trauma and requires sedation with significant injuries to the shoulder girdle, first rib, or axillary arteries [1]. The surgeon should ideally be in close communication with the therapist during the acute phase. In the acute phase of the injury, the therapist needs to consider instructing the patient and caregivers in a self-care management program that includes range of motion exercises, edema management, sling use, orthotic use, graded motor imagery, one-handed activities of daily living, pain management address psychosocial concerns [2].

Range of motion needs to be maintained after the initial injury. Emphasis should be placed on maintaining shoulder external rotation, shoulder elevation, elbow flexion, forearm supination, metacarpal phalangeal joint flexion, and first web space abduction while being mindful of other injuries which may preclude motion (Figs. 39.1, 39.2, 39.3, 39.4, 39.5, and 39.6). Motion can progress from passive to active assisted to active range of motion based on the pattern of injury. Even in a complete avulsion, it is imperative to maintain full passive finger range of motion to allow for future surgical reconstruction efforts if

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Fig. 39.1 Passive range of motion for shoulder elevation/flexion

Fig. 39.2 Passive range of motion for shoulder external rotation

necessary [3]. A self-management program at home is optimal to achieve the best results [3].

As nerve function returns (either spontaneously or post-surgically), a gravity-eliminated strengthening program needs to be initiated. Once the patient can perform 10–15 repetitions without fatigue or substitution patterns, resistance in the form of weights (wrist cuff, dumbbell) can be added to the gravity-eliminated position. Progression of the amount of weight should continue in the gravity-eliminated position until the patient reaches approximately 8 pounds of resistance. Working up to 8 pounds of resistance in a gravity-eliminated plane will replicate the weight of the forearm once the patient can progress to the against gravity plane. The patient can then change positions to an against gravity position without weight in the affected extremity.

Strengthening of potential donor muscles for potential future nerve or tendon transfers is also very important. For example, if the surgeon is planning on using a branch of the triceps radial nerve to the axillary nerve, the preoperative therapy should focus on strengthening of the triceps.

Sling use is important for patients with panplexal or upper trunk injuries to support the paralyzed arm, mitigate inferior glenohumeral subluxation, and maintain the length-tension relationship of the involved muscles' sarcomeres to allow each muscle to generate appropriate force [4, 5]. Common slings used include universal slings, envelope slings, or hemi slings (Figs. 39.7, 39.8, 39.9, and 39.10). The sling should position the head of the humerus in normal alignment to a slightly elevated position in

Fig. 39.3 Passive range of motion for elbow flexion

Fig. 39.4 Passive range of motion for forearm supination

the glenoid [3]. If a patient wants more security in a sling, a swath component may be included to keep the arm positioned close to the body. Another sling option is the Wilmer Carrying Orthosis and modifying the forearm component for custom wrist support. This sling has a pulley that allows for positioning the elbow in various degrees of flexion (Fig. 39.11).

Upper extremity orthoses help maintain joint alignment in a functional position and maintain the length-tension relationship of each muscle. An intrinsic plus resting orthosis should be fabricated to keep the wrist in extension, metacarpal phalangeal joints in flexion, interphalangeal joints in extension, and the thumb in palmer abduction (Fig. 39.12). This orthosis should be fabricated if the patient has lower trunk involvement or noted joint contractures in the hand. By diligently keeping full passive range of motion, the patients may not need additional procedures by such as joint manipulations under anesthesia, capsulotomies, or intrinsic tendon transfers. If the patient is beginning to lose passive range of motion, dynamic orthoses or static progressive orthoses should be considered. Common motions that become limited over time include shoulder external rotation, forearm supination, metacarpal phalangeal joint flexion, and first web space abduction. Common orthoses fabricated in our clinic include the intrinsic plus resting orthosis with thumb in palmer abduction (Fig. 39.12), web spacer or C-bar (Fig. 39.13), and dynamic

Fig. 39.5 Passive range of motion for metacarpal phalangeal joint flexion

Fig. 39.6 Passive range of motion for first web space stretch

Fig. 39.7 Hely & Weber The UpLift Support Sling

Fig. 39.8 The Ultimate Arm Sling

Fig. 39.9 The Universal Sling

Fig. 39.10 The GivMohr Sling

Fig. 39.11 Modified Wilmer Carrying Orthosis

Fig. 39.12 Intrinsic plus resting hand orthoses

metacarpal phalangeal joint flexion orthosis (Fig. 39.14).

Cortical changes occur directly after an injury to the brachial plexus [6]. In a primate model, once the nerve has been injured, the somatosensory cortex for that nerve becomes silent. Corresponding areas in the somatosensory cortex will attempt to take over this silent region. If the nerve can regenerate or is repaired, the somatosensory cortex will have continued reorganization in the silent area [6]. The primary motor

Fig. 39.13 Web spacer or C-bar orthosis

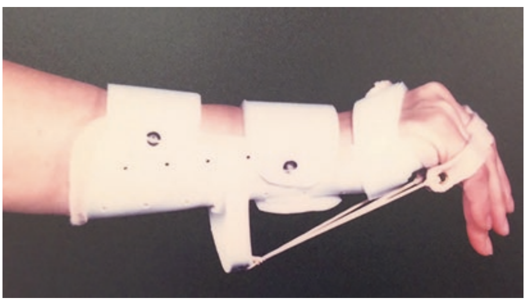

Fig. 39.14 Dynamic metacarpal phalangeal joint flexion orthosis

cortex has plasticity during motor skill acquisition. Research has shown in the adult primary motor cortex to be slowly changing and ever adapting to new motor learning [7]. If possible during the preoperative visit, neuromuscular reeducation of the potential nerve transfer should begin [4, 6]. For example, if a patient is to have a spinal accessory nerve transfer to the suprascapular nerve, activating the trapezius upper, middle, and lower should be emphasized while the patient visualizes shoulder elevation and external rotation of the arm before surgery. Adherence to the home exercise program for neuromuscular reeducation to achieve the best results is also emphasized [4, 6].

Neuropathic pain after a traumatic brachial plexus injury can be devastating. In addition to pain management, a therapist can use modalities such as transcutaneous electrical nerve stimulation, thermal modalities, total contact pressure, and desensitization techniques. Graded motor imagery (GMI) is a program to assist patients in pain management using a top-down model. It has been found that chronic pain in the affected body part influences cortical changes in the brain [8]. In phantom limb pain and complex regional pain syndrome, the somatosensory cortex is less active [8–10]. Another key concept of using graded motor imagery is the mirror neurons. Mirror neurons are active in both motor execution and observation [10]. It is thought that these mirror neurons do not fire correctly in patients with chronic pain [8].

Graded motor imagery has three phases: laterality training, visualization of hand movements, and mirror visual feedback (Figs. 39.15 and 39.16). This three-step program is used to activate the cortical motor networks and improve cortical reorganization. In the laterality phase, the patient identifies right versus left hands through flashcards. Increasing difficulty by adding more flashcards, increasing the rate of cards presented, and changing orientation of the cards is performed. The goal of this phase is to assist the brain in establishing right and left hand concepts and have an intact body schema. The second phase of GMI is the visualization of hand movements without moving the affected hand. The patient is asked to visualize the affected hand performing different hand positions. The goal of this phase is to activate the motor cortex without causing pain [8, 11]. The last phase is mirror box. In this phase, the patient places the affected hand behind a mirror box while observing the unaffected hand in the mirror reflection. While observing the mirror reflection, the patient is receiving visual feedback that not all hand movements are painful in what appears to be the affected hand [8].

One-handed activities with each patient diagnosed with a brachial plexopathy are discussed, and the patient should be educated with one-handed aids and tools. Despite advances in recon-

Fig. 39.15 Phase 1 of graded motor imagery: laterality cards

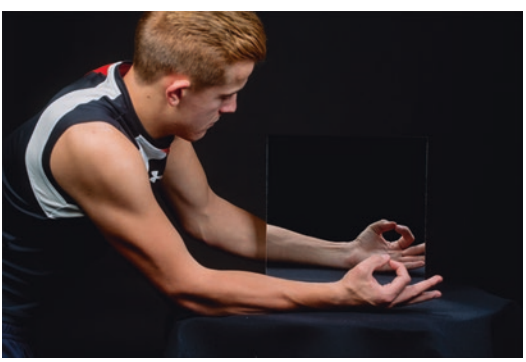

Fig. 39.16 Phase 3 of graded motor imagery: mirror box

structive procedures, the affected hand becomes a helper hand after the injury. In a study by Mancuso et al. [12], the authors encouraged rehabilitation efforts to support therapies for both the affected and unaffected extremities. It may be beneficial to have the therapies for each upper extremity separate from each other to allow the patient to fully participate in one-handed activities of daily living in one session while focusing on the affected extremity in another session [12]. Hand dominance affects the intensity of therapy for one-handed activities and compensatory techniques using adaptive equipment. Common themes in our clinic for difficult daily activities include handwriting, donning a bra for women, tying shoes, zipping a coat, and cracking an egg.

Psychosocial concerns and patient expectations impact rehabilitation outcomes for patients with brachial plexus injuries [13]. In one qualitative study assessing psychosocial factors and discussing patient expectations prior to surgery, the patients expected a decrease in pain and improvement in function for self-care, leisure, and work. These patients reported mental health effects of anxiety, depression, anger, and suicidal ideation due to the BPI. Patients have major life changes in education or employment due to the devastating injury. Finances after injury were also a major stress factor [14]. It is important to use a holistic approach as appearance and body image are important to our patients [13]. During therapy sessions, for pan-plexal, lower trunk injuries or complex injuries, it is imperative to stress that the affected hand will be a helper hand and will not return to the prior level of function. This helps set up realistic expectations for each patient. The therapist often becomes the advocate for patients who are having difficulties coping with injury and recommends visits with rehabilitation psychologists.

Preoperative rehabilitation needs a holistic approach to treat each patient. Rehabilitation needs a multidisciplinary approach to address all concerns. These concerns range from regaining range of motion and strengthening, fabricating orthoses, and fitting of slings to maintaining the length-tension relationship of muscles, beginning neuromuscular reeducation techniques for future reconstructive surgery options, assisting with pain management strategies, increasing function with daily occupations, and advocating for each patient with psychosocial concerns. It is crucial to maintain close contact with the referring surgeon to consistently keep the message the same that the affected extremity will be a helper hand and not return to normal. It is the goal of rehabilitation providers want to help increase the patient's function through the unaffected and affected extremity.

Postoperative Rehabilitation

Proper physical and occupational therapy after brachial plexus reconstructive surgery is of great importance to aid the patient in achieving their best possible functional outcome. A keen understanding of the surgical procedure(s), the timeline for healing, the future neuromuscular reeducation techniques, and the specific surgeon protocols should be communicated with the therapy team. When the surgeon and therapist are effective as a team, the optimal therapy plan can be formulated.

Common surgical procedures for brachial plexus reconstruction include nerve grafts, nerve transfers, free functioning muscle transfers (FFMT), tendon transfers, and joint fusions.

Ideally the surgical team will immediately involve the services of physical and occupational therapy postoperatively. It is important to follow surgical protocols for early immobilization and allowed range of motion. Immobilization may include casting, shoulder immobilizers, slings, or custom-made orthoses to name a few. Following immediate post-surgical immobilization, it is important that patients with upper trunk injuries continue with a hemi-sling to decrease the subluxation of the glenohumeral joint. This sling can be discontinued once appropriate reinnervation to the supraspinatus has occurred. The patient may need education in passive and/or active range of motion to the unaffected joints to be completed multiple times a day. Udina and colleagues [15] found that performing active and passive exercises of the involved limb slightly improved the amount of nerve reinnervation by increasing trophic factor release in rats. Therefore, it may be important for our patients to begin range of motion exercises of the involved joint(s) as soon as safely possible after surgery. The patient may need appropriate edema control measures immediately postoperative. The patient should be instructed in proper education in scar management techniques. In the case of a nerve transfer surgery, it is extremely important that the patient is educated early in and understands what donor muscle(s) needs to be "fired" to send the proper signal to the receiving muscle [4]. Once it is safe to do so, the patient needs to practice frequent activation techniques with the donor muscle to promote neural activation and growth [4]. The patient would also benefit from a supportive discussion regarding the short- and long-term rehabilitation expectations postoperatively. The patient needs to understand that recovery is a long, slow process and strength gains vary among individuals and may take several years for good results [4].

After EMG confirmation of reinnervation, we begin patient neuromuscular reeducation in a progressive gravity-eliminated (GE) exercise program for all brachial plexus reconstruction surgeries. The progression is as follows: (1) exercises in GE positions on low friction surfaces, (2) GE with added friction or light resistance once the patient achieves a functional arc of motion, (3) against gravity exercises without resistance after the patient builds strength in GE, and lastly (4) against gravity strengthening and eventual dissociation of the donor muscle with recipient muscle co-contraction. It is important to keep in mind as reinnervation to the targeted muscles begins, the patient will be very weak and fatigue quickly due to decreased number of muscle units available and the recovering muscle physiology. Sessions should be of short duration (5–10 minutes possibly) and completed several times a day [16]. Trick motions or substitution patterns and undesired muscle co-contractions during all phases of the rehabilitation process should be watched for and corrected. Once the patient has good strength in the reinnervated muscle(s) and can use the arm functionally, they often still will note significant fatigue with repetitive tasks and with activities needing sustained contraction [17].

Through the neuromuscular reeducation program, a patient will establish new cortical mapping to gain functional use of the affected extremity [18]. A GMI program can be started with a patient before any surgical procedure to stimulate the premotor cortex and should continue after surgery. If the patient has not participated in a GMI program prior to surgery, he/she should be instructed in the process by a physical or occupational therapist shortly after surgery.

Therapy Programs for Specific Neurotizations

Spinal Accessory Nerve (SAN) to Suprascapular Nerve (SSN)

The spinal accessory nerve (SAN) to suprascapular nerve (SSN) transfer is used to help restore shoulder function. The distal portion of the SAN, which provides motor innervation to the middle and lower trapezius, is transferred to the SSN (Fig. 39.17). Immediately following surgery, the patient will be in an immobilized for 3 weeks to allow nerve coaptation to heal and should work on maintaining passive range of motion of all other available joints except the shoulder. It is important that the patient return to wearing a hemi-sling to support the glenohumeral joint while awaiting reinnervation to the supraspinatus muscle. Early neuromuscular rehabilitation begins with activation of the upper and middle trapezius muscles (shoulder rolls and shoulder blade squeezes). Detailed neuromuscular reeducation will begin with noted EMG reinnervation, typically around

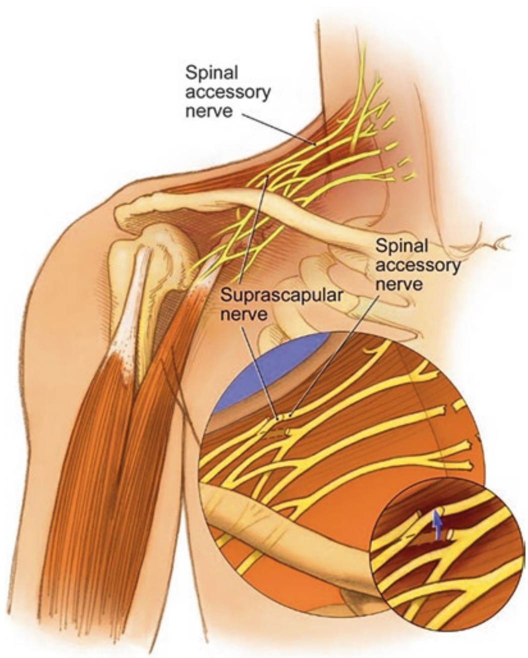

Fig. 39.17 Surgical procedure for spinal accessory to suprascapular nerve transfer

Table 39.1 Spinal accessory nerve to suprascapularnerve

Goal	Restore shoulder external rotation and abduction
Activation technique	Shoulder rolls, shoulder retraction
0–3 weeks after surgery	Shoulder immobilizer/sling for nerve healing
3 weeks after surgery	Maintain passive range of motion to all available joints
	Graded motor imagery
	Perform shoulder rolls or shoulder retraction while visualizing the arm externally rotating or abducting the shoulder
	Strengthen the trapezius
	Actively retract the scapula and passively externally rotate or abduct the shoulder
After EMG confirmation (typically 4–6 months)	Start a gravity-eliminated strengthening program for shoulder external rotation and abduction neuromuscular reeducation
	Begin biofeedback

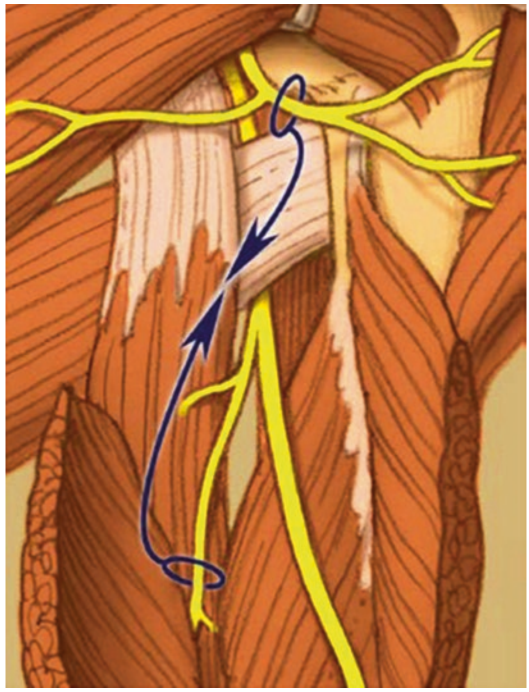

Fig. 39.18 Surgical procedure for triceps branch of the radial nerve to axillary nerve

4–6 months postoperatively. If the patient has an innervated serratus anterior, he/she should work on strengthening this muscle to assist with upward scapular rotation. During active scapular retraction, Kahn and Moore [4] advise the patient to use the uninvolved hand to passively externally rotate the involved arm to assist with developing new motor patterns. They also recommend the patient place the surgical arm in partial abduction and external rotation (ER) for short periods during the day to maintain supraspinatus/infraspinatus ideal length [4]. With further motor return, the patient should continue with gravity-eliminated or active-assisted exercises that focus on combined shoulder abduction and ER with active scapular retraction. As the patient continues to gain strength, progressing to against gravity place and hold exercises, wall slides, and other light resistance exercises are appropriate. See Table 39.1 for our protocol.

Triceps Branch to Axillary Nerve

Triceps branch of the radial nerve to axillary nerve transfer is a common technique to restore deltoid function in an upper trunk injury. This was described by Leechavengvongs in 2003 who transferred the long head of the triceps nerve branch to the anterior division of the axillary nerve [19] (Fig. 39.18). Following surgery, the patient needs to immobilize his/her shoulder and elbow for 3 weeks and work on range of motion of the uninvolved joints. At 3 weeks post-op, passive range of motion to the involved shoulder can begin with an emphasis on shoulder external rotation (ER) and scapular mobilization. Initial neuromuscular rehabilitation starts with activation of the triceps isometrically or with donor/recipient patterning via seated shoulder flexion table slides (Fig. 39.19). Kahn and Moore also instruct the patient to slide his/her affected hand on his/her thigh toward his/her knee from a seated position [4]. In our clinic, we use a light resistance band anchored just above and behind the patient for elbow extension with patterning of shoulder elevation a helpful exercise for reeducation once reinnervation is detected via EMG (typically at 4–6 months) (Fig. 39.20). To reeducate shoulder ER, the patient can be seated with his/her forearm resting on a low friction surface on a

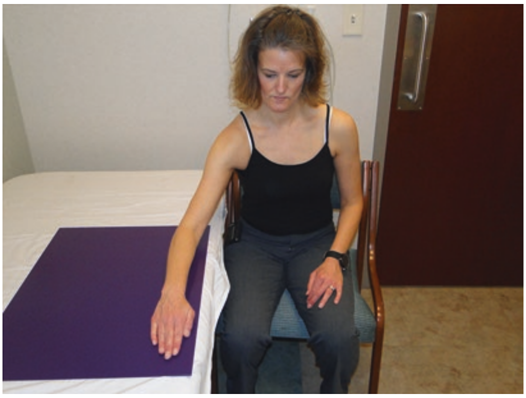

Fig. 39.19 Seated shoulder flexion slides

Fig. 39.20 Resistance band triceps activation

table. From here, gentle isometric triceps activation coupled with passive/active assistive ER is begun. Continued reinnervation often begins with the posterior deltoid; therefore, with further motor return, it is helpful to position the patient prone to work on shoulder extension and shoulder abduction. In this position, the patient will co-contract with the triceps to further flood the recipient deltoid (Fig. 39.21). The patient can also be positioned in side-lying on the unaffected side with the surgical arm on a therapy skateboard for gravity-eliminated shoulder flexion reeducation. See Table 39.2 for our protocol.

Fig. 39.21 Prone elbow extension with shoulder extension

Table 39.2 Triceps branch of the radial nerve to axillary nerve

Goal	Restore shoulder forward flexion, abduction, and extension
Activation technique	Activate with elbow extension or wrist extension
0–3 weeks after surgery	Shoulder and elbow immobilization to allow nerves to heal
	Wrist and hand range of motion
3 weeks after surgery	Passive range of motion to shoulder, emphasis on scapular mobilizations, shoulder external rotation
	Graded motor imagery
	Perform elbow extension or wrist extension while visualizing the shoulder moving in forward flexion, abduction, and extension
	Strengthen the triceps and wrist extensors
	Actively extend the elbow or wrist while passively moving the shoulder into forward flexion, abduction, and/or extension
After EMG confirmation (typically 4–6 months)	Start a gravity-eliminated strengthening program for shoulder forward flexion, abduction, and extension neuromuscular reeducation
	Begin biofeedback

Ulnar Nerve to Biceps Musculocutaneous Nerve Branch/Median Nerve to Brachialis Musculocutaneous Branch

Restoring elbow flexion is crucial as it helps position the hand for activities of daily living. The most popular nerve transfer to restore elbow flexion in an upper trunk injury with intact C8–T1 function was described by Oberlin in 1994. He transferred ulnar nerve fascicles that primarily innervated the flexor carpi ulnaris (FCU) and to the bicep motor branch of the musculocutaneous nerve [20]. Mackinnon et al. [21] desired to gain further elbow flexion strength and described a double fascicular nerve transfer by adding the transfer of median nerve fascicles to the brachialis motor branch (Fig. 39.22). They reported early reinnervation at 5.5 months after surgery [21]. Similar to the above nerve transfers, the shoulder and elbow are immobilized for 3 weeks with allowed active/passive range of motion to the involved wrist and hand. Kahn and Moore [4] instruct the patient in early activation of the donor muscles through gripping therapy putty and beginning light wrist flexion curls with a 1-pound weight. Once the shoulder immobilizer is discontinued, the patient needs to begin patterning desired elbow flexion with donor activation. This can simply be done with active finger grasp and wrist flexion/ulnar deviation during passive elbow flexion with assistance from the uninvolved arm.

With EMG confirmation of early reinnervation, gravity-eliminated elbow flexion exercises are started with the forearm positioned on a therapy skateboard or friction-reduced surface. It is important that the patient continues with activation techniques using wrist flexion/ulnar deviation and finger grasping (Fig. 39.23). Once the patient has

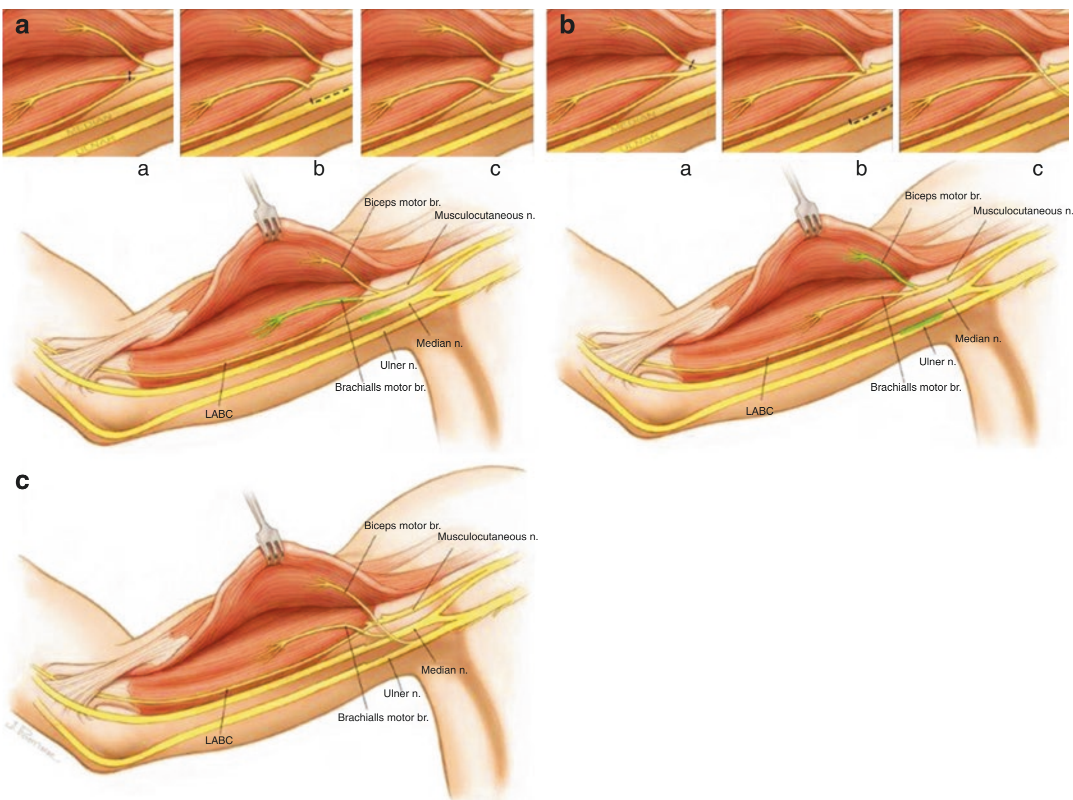

Fig. 39.22 Surgical procedure for double fascicular nerve transfer for elbow flexion. (**a**) Median nerve fascicle to the brachialis motor branch; (**b**) Ulnar nerve fascicle to the biceps motor branch; (**c**) Double fascicular transfer for elbow flexion

Fig. 39.23 Gravity-eliminated elbow flexion with ulnar deviation of the wrist activation technique while using a skateboard

gained a nearly full arc of elbow flexion in this manner, progressive weight can be added to the skateboard or the patient begins exercising without the aid of the skateboard. The patient can then progress to place and hold elbow flexion exercises against gravity and eventually the use of light handheld weights when they achieve full elbow flexion against gravity. See Table 39.3 for our protocol.

Table 39.3 Protocol for double fascilicular transfer using an ulnar nerve and median nerve fascicle to the musculocutaneous nerve

Ulnar nerve fascicle to biceps musculocutaneous nerve branch	
Goal	**Restore elbow flexion**
Activation technique	Activate with ulnar deviation of the wrist or key pinch
0–3 weeks after surgery	Shoulder immobilizer/sling for nerve healing
3 weeks after surgery	Maintain passive range of motion of all available joints
	Graded motor imagery
	Perform ulnar deviation of the wrist while visualizing elbow flexion
	Strengthen flexor carpi ulnaris
	Actively ulnarly deviate the wrist while passively flexing the elbow
After EMG confirmation (typically 4–6 months)	Start a gravity-eliminated strengthening program for elbow flexion neuromuscular reeducation
	Begin biofeedback
Median nerve fascicle to brachialis musculocutaneous nerve branch	
Goal	**Restore elbow flexion**
Activation technique	Activate with finger flexion
0–3 weeks after surgery	Shoulder immobilizer/sling for nerve healing
3 weeks after surgery	Maintain passive range of motion of all available joints
	Graded motor imagery
	Perform finger flexion while visualizing elbow flexion
	Strengthen grip specifically the flexor digitorum superficialis
	Actively grip while passively flexing the elbow
After EMG confirmation (typically 4–6 months)	Start a gravity-eliminated strengthening program for elbow flexion neuromuscular reeducation
	Begin biofeedback

Intercostal Nerve to Musculocutaneous Nerve

If a donor nerve within the brachial plexus is not available for neurotization to restore elbow flexion, intercostal nerves (ICNs) can be transferred to the musculocutaneous nerve (MCN). Typically three to four ICNs are transferred to the MCN or two to three ICNs are directly transferred to the biceps motor branch [22] (Fig. 39.24). The ICN sensory and motor components can be separated during surgery to allow for more pure motor axons being neurotized. If these nerves are transferred, it is important to understand that the patient will have lifelong restrictions regarding shoulder motion. To avoid rupturing the nerve coaptation, the patient needs to avoid shoulder abduction greater than 90°, shoulder flexion greater than 90°, and ER greater than 90°.

Early reeducation begins by instructing the patient in activation techniques for the ICNs to

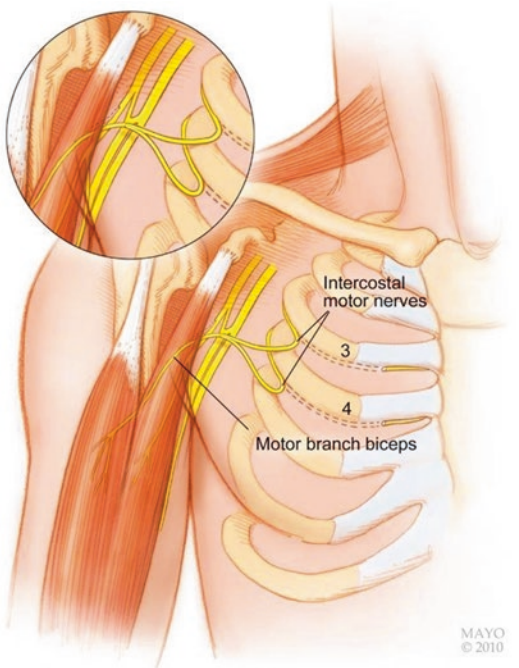

Fig. 39.24 Surgical procedure for intercostal nerve to musculocutaneous nerve transfer

Table 39.4 Intercostal nerve transfer to musculocutaneous nerve

Goal	Restore elbow flexion
Activation technique	Activate with pursed lip breathing, coughing, laughing, breathing in deeply, bearing down, trunk flexion
Permanent restrictions	No shoulder abduction, forward flexion, or external rotation with arm abducted greater than 90°
0–3 weeks after surgery	Shoulder and elbow immobilization to allow nerves to heal
3 weeks after surgery	Maintain passive range of motion of all available joints
	Graded motor imagery
	Perform breathing technique while visualizing elbow flexion
	Spirometer for respiratory exercises
	Actively perform breathing technique while passively flexing the elbow
After EMG confirmation (typically 6–9 months)	Start a gravity-eliminated strengthening program for elbow flexion neuromuscular reeducation
	Begin biofeedback

initiate biceps and brachialis muscle contraction. This would include exhalation, inhalation Valsalva, and trunk flexion. Immediately following surgery, the patient should be educated in the use of a spirometer to complete deep inspiration and exhalation exercises that will help stimulate the new neural pathway. The patient should also promptly start abdominal muscle exercises to help with ICN recruitment. In 2006, Chalidapong et al. [23] reported that patients who had undergone ICN to MCN neurotization had the greatest EMG activity in the elbow flexors during trunk flexion when compared with forced expiration, forced inspiration, and attempted isolated elbow flexion.

Once a palpable twitch is noted in the elbow flexors or with motor unit potentials reported on EMG, the patient's reeducation program needs to progress to GE exercises. These exercises can be done side-lying with the affected extremity on a bolster or a sloped support. If the patient is seated, the affected extremity is placed just below the safe position for shoulder elevation to complete GE exercise. Using low friction surfaces is important to maximize recipient muscle joint motion and minimize fatigue in the beginning. Initiating elbow flexion with donor nerve activation (trunk flexion, pursed-lip breathing, etc.) needs to continue. Once the patient demonstrates a nearly full arc of motion in the GE plane, the therapist can introduce light resistance or increase friction in the GE plane. Advancement of exercises will continue to follow the progressive program and will begin to work on separating the co-contraction of the donor muscle with the target muscle. See Table 39.4 for our protocol.

Free Functioning Muscle Transfers for Elbow Flexion

When the timing from a complete avulsion brachial plexus injury to surgery is greater than 12 months, free functioning muscle transfers (FFMT) are recommended to obtain elbow flexion. In the acute phase, FFMT can be used in

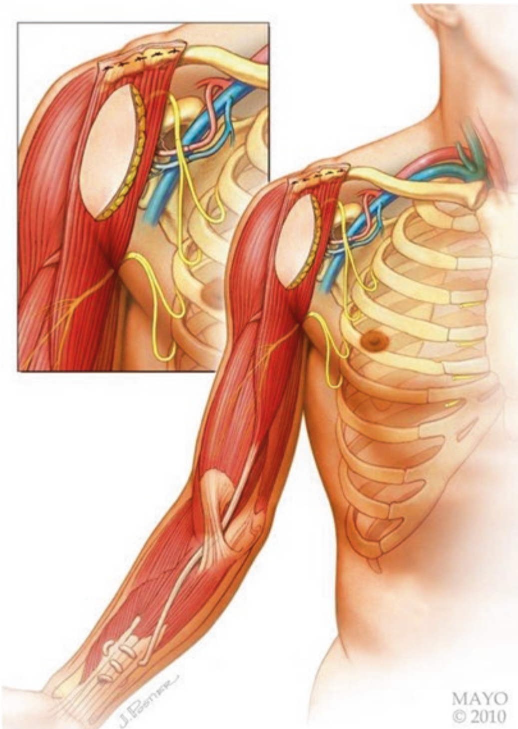

Fig. 39.25 Surgical procedure for free muscle transfer for combined elbow and finger flexion with intercostal nerve transfer

addition to other nerve transfers to restore both elbow flexion and possible graph (Fig. 39.25). The gracilis muscle is often selected because of its proximal neurovascular pedicle that allows more rapid reinnervation and its long tendon length that allows for appropriate tendon excursion [24]. For combined finger flexion and elbow flexion, a Pulvertaft weave is used to secure the gracilis tendon to the flexor pollicis longus tendon and flexor digitorum profundus (FDP) tendons to restore rudimentary grasp. To prevent bowstringing of the distal tendon at the elbow, a pulley mechanism is created by passing the gracilis muscle underneath the biceps tendon and flexor digitorum superficialis (FDS) arch [24, 25]. Nerve innervation can come from the SAN or ICNs. These patients will also have lifetime shoulder motion restrictions if the ICNs are used for reinnervation (avoid shoulder abduction greater than 90°, shoulder flexion greater than 90°, and ER greater than 90°). It is recommended

Fig. 39.26 Shoulder immobilizer with posterior elbow orthosis and dorsal blocking orthosis

to avoid any elbow extension less than 30°. This position allows for an ideal angle of pull and more appropriate length-tension relationship of the muscle, making eventual active elbow flexion easier to initiate. A wrist and thumb interphalangeal joint (IP) arthrodesis is performed several months after the FFMT to simplify the wrist/grasp mechanics to allow a single muscle to provide rudimentary grasp.

Postoperatively, the surgical arm is immobilized per surgeon protocol. Often this is with a shoulder immobilizer, posterior 90-degree elbow orthosis, and, if the FFMT was also for combined finger flexion, a dorsal blocking orthosis with the finger metacarpal joints in 70° flexion (Fig. 39.26). Patients should perform passive range of motion to all appropriate joints when it is safe to do so. This includes the shoulder and elbow (within appropriate restrictions), fingers, and thumb carpometacarpal joint (CMC). The fingers need to be moved as a group as during surgery, the finger flexors were sutured together. When the incisions have healed, it is important that the patient begins deep soft tissue mobilization over the anterior cubital fossa three to five times a day. This will minimize adhesions of the tendon and allow for better tendon gliding of the FFMT.

If ICNs are used for reinnervation, early neuromuscular reeducation begins shortly after surgery and is similar to the above ICN to MCN neurotization with various breathing techniques

Fig. 39.27 Gravity-eliminated elbow flexion with skateboard

and/or trunk flexion exercises. If the SAN nerve is used, the patient is advised to practice scapular retraction while palpating the biceps/repaired gracilis tendon for tension [25]. Often it takes 6–9 months for early reinnervation to be noted clinically or through an EMG study, and further recovery is a long, slow process. When there is evidence of reinnervation (M1 strength) to the FFMT, it is important that the patient begins a concentrated program of neuromuscular reeducation under the supervision of a physical or occupational therapist. Exercises will follow the progressive GE rehabilitation program on low friction surfaces with continued education in activation techniques for elbow flexion (Fig. 39.27). Initially it may be easiest to generate muscle power in a moderate amount of elbow flexion and gradually work toward less elbow flexion (reminder, patients should have a 30-degree elbow flexion contracture). Resistance can be added into GE exercises when the patient demonstrates a functional arc of elbow flexion, and the program continues to progress as the patient gains muscle strength. See Tables 39.5 and 39.6 for our protocols.

Table 39.5 Free functioning muscle transfer for elbow flexion with intercostal nerve transfer

Goal	Restore elbow flexion
Activation technique	Activate with pursed lip breathing, coughing, laughing, breathing in deeply, bearing down, trunk flexion
Permanent restrictions	No shoulder abduction, forward flexion, or external rotation with arm abducted greater than 90°
	Do not straighten elbow beyond 30° of flexion to create a mild elbow contracture
0–3 weeks after surgery	Shoulder immobilizer
	Passive range of motion to fingers, thumb, wrist, and forearm
3 weeks after surgery	Discontinue shoulder immobilizer and change to a support sling
	Evaluate for glenohumeral support
	90° posterior long arm elbow orthosis
	Begin passive range of motion for shoulder external rotation with the shoulder at 0° of shoulder abduction
	Begin passive range of motion for elbow full flexion to 30° of extension
	If pulley was created at antecubital fossa, place pressure on the antecubital fossa to prevent bow stringing during elbow passive range of motion
	Continue range of motion to the fingers thumb, wrist, and forearm
	Graded motor imagery
	Perform breathing activation technique while visualizing elbow flexion
	Spirometer for respiratory exercises
	Actively perform breathing activation technique while passively flexing the elbow
6 weeks after surgery	Discontinue elbow orthosis and continue with a sling except for exercises
	Initiate scapular mobilizations and continue with above ROM exercises
After EMG confirmation (typically 6–9 months)	Start a gravity-eliminated strengthening program for elbow flexion neuromuscular reeducation
	Begin biofeedback

Surgical Reconstructions that Fall Outside the Norm

At times, a patient may present to therapy following an "uncommon" brachial plexus reconstruction surgery. Other muscles have been used for FFMT such as the rectus femoris and latissimus dorsi for elbow flexion with good outcomes [25].

Table 39.6 Free functioning muscle transfer combined elbow flexion and finger flexion with intercostal nerve transfer

Goal	Restore elbow flexion
Activation technique	Activate with pursed lip breathing, coughing, laughing, breathing in deeply, bearing down trunk flexion
Permanent restrictions	No shoulder abduction, forward flexion, or external rotation with arm abducted greater than 90°
	Do not straighten elbow beyond 30° of flexion to create a mild elbow contracture
0–3 weeks after surgery	Shoulder immobilizer with orthoses worn in the immobilizer
	Forearm-based intrinsic plus orthosis; surgeons prefer this to be *dorsal* based
	90° posterior elbow orthosis
	Passive finger range of motion with the elbow at 90° of flexion Move digits as a group, concentrate on intrinsic plus position with MP flexion and IP extension
	Passive elbow range of motion with support over the antecubital fossa to support the tendon transfer limiting elbow extension to 30°. Wrist and digits in flexion
	Wrist and forearm range of motion with elbow at 90° of flexion
	With elbow at approximately 90° of flexion, squeeze the forearm muscle bellies to assist in tendon pull through to the fingers
3 weeks after surgery	Discontinue shoulder immobilizer and change to a support sling
	Evaluate for glenohumeral support
	Continue with elbow orthosis and dorsal blocking orthosis
	Passive range of motion for shoulder external rotation while keeping the shoulder at 0° of shoulder abduction
	Continue with the above 0–3 week exercises
	Graded motor imagery
	Perform breathing activation technique while visualizing elbow flexion and finger flexion
	Spirometer for respiratory exercises
	Actively perform activation breathing technique while passively flexing the elbow and fingers
6 weeks after surgery	Discontinue elbow orthosis and continue with a sling except for exercises
	Continue with forearm based orthosis for night wear
	Initiate scapular mobilizations and continue with above ROM exercises
After EMG confirmation (typically 6–9 months)	Start a gravity-eliminated strengthening program for elbow flexion and finger flexion neuromuscular reeducation
	Begin biofeedback

Rehabilitation would be very similar to a gracilis transfer once it is known what nerve(s) was used for the reinnervation. A branch of the medial pectoral nerve (MPN) can be used with a C5–C6 or C5–C7 brachial plexus injury and still preserve innervation to the pectoralis sternal head. However, drawbacks to using this nerve include its limited length and the nerve diameter difference with the MCN [22]. A branch of the thoracodorsal nerve (TDN) can also be used for neurotization to the MCN due to its sufficient length. Both of these nerves can also be used for triceps reinnervation through the radial nerve [22]. As with other neuromuscular reeducation programs, it begins with understanding the anatomical function of the donor muscle for proper activation of the target muscle. Some surgeries include reinnervation of the triceps (ICNs or SAN) to get added elbow stabilization with biceps restoration. Using the ICNs to reinnervate both biceps and triceps should be avoided [24]. Neuromuscular reeducation for both elbow flexion and extension can get complicated, and the therapist should monitor the patient for co-contraction of both muscles during the desired elbow motion.

Other Rehabilitation Considerations

In addition to previously described neuromuscular reeducation techniques for treatment of nerve repair, various modalities have been encouraged. One of the most commonly suggested modalities is electrical stimulation (functional electrical stimulation or neuromuscular electrical stimulation) following nerve injury. When working with denervated muscle, direct or galvanic stimulation is used to provide an external source of stimulation to the muscles (Fig. 39.28). The hope is that this will prolong the time before the muscle suffers irreversible changes due to denervation [2]. For electrical stimulation to be of most benefit, the parameters need to analogous to a muscle's normal "firing pattern" which has been shown in some animal models using implanted electrodes. Trials have not confirmed the use of surface electrodes for electrical stimulation [18]. However, there is little strong evidence in the literature that supports the use of direct current stimulation in humans [2, 18]. We have abandoned its use in our practice.

Single-channel or dual-channel biofeedback is another modality that is often recommended as part of a neuromuscular rehabilitation program. Biofeedback provides immediate feedback to the patient which helps them understand and learn new motor patterns. Sturma et al. [26] reported surface EMG biofeedback can be used before any noted movements as this device can provide helpful feedback of muscular activity by converting myoelectrical activity into auditory and/or visual cuing. Most often though this modality is not used until the patient begins having positive muscle reinnervation findings clinically or noted on EMG results, but it would be safe to begin much earlier. Surface electrodes are placed on the reinnervated muscle to give real-time information during muscle activation to increase muscle contraction. This tool can also be useful if an antagonistic muscle is overpowering the weaker, reinnervated muscle [18]. Here, the surface electrodes would be placed over the antagonistic muscle, and the patient is educated to decrease muscle activation during the desired motion (e.g., overpowering triceps activity during elbow flexion reeducation following an ulnar nerve fascicle to musculotaneous nerve for elbow flexion). Biofeedback is also a helpful tool if a patient is co-contracting muscles during initiation of movement (Fig. 39.29). Early in the reeducation process, patients may have trouble isolating the weaker reinnervated muscle and accidentally co-contract the stronger antagonistic muscle. Dual-channel biofeedback over both muscle groups provides immediate visual and auditory feedback assists in decreasing antagonistic muscle action while increasing focus to the reinnervated muscle [18]. When the patient can visualize and/or pal-

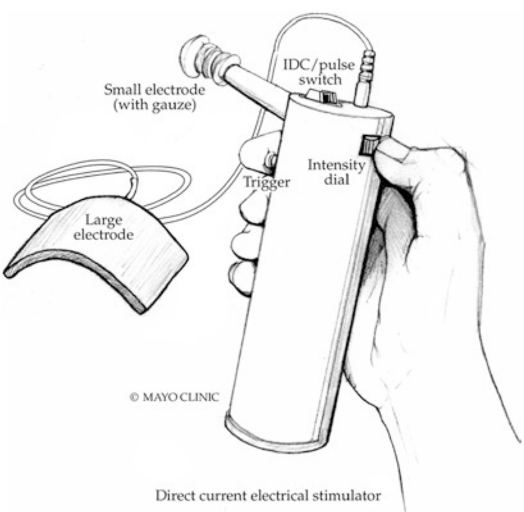

Fig. 39.28 Direct electrical stimulation

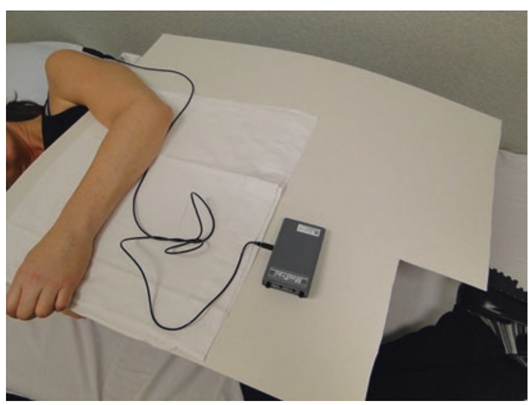

Fig. 39.29 Biofeedback device

Fig. 39.30 Aquatic therapy for gravity-eliminated elbow extension and flexion

pate their muscle contraction, they can use this option for frequent and useful feedback during exercise. Patients have reported learning how to control the reinnervated muscle and "switch off" the donor muscle to be very challenging [17]. Biofeedback can continue to be used in this later stage of rehabilitation to progressively separate activation of the reinnervated muscle with donor muscle activation [26].

Aqua therapy or pool-based exercises can be helpful in the rehabilitation process. The buoyancy of the water can assist with shoulder flexion, shoulder abduction, and elbow flexion while the patient is using proper donor nerve activation techniques. The patient can also use gravity-eliminated positions for elbow flexion and shoulder external rotation with their affected arm on a swimming kickboard for neuromuscular reeducation (Fig. 39.30). As the patient gains strength in the reinnervated muscle, they can use water for light resistance training.

Neuropathic pain management following surgical reconstruction may be an ongoing concern. Unfortunately, this can limit a patient's therapy tolerance and result in an overall negative outcome [16]. It is important that the patient's pain is managed by a multidisciplinary team approach, including a pain specialist, who can prescribe and monitor a correct medication regime [24]. Non-pharmaceutical treatment choices may include edema control if appropriate, sling use, transcutaneous electrical nerve stimulation, GMI, and relaxation/distraction techniques to name a few (see Chap. 15).

With technological advances, there have been newer therapeutic modalities available to use in rehabilitation. These include the usage of exoskeleton devices. These devices are wearable robotics that can control elbow flexion and extension and a three-point pinch [27]. Exoskeleton-type devices use bioelectric muscle activation signals detected at the surface level. Once the electrodes detect the signal, a motor produces the desired joint motion [27, 28]. These devices can use minimal muscle activation of a twitch to produce the desired motion. Collaboration with a prosthetist/orthotist is recommended. The therapist focuses on function and refining smooth motion, while the prosthetist determines appropriate signal settings, placing the sensors in the optimal positions and refining the fit of the harness and exoskeleton. Once the patient can consistently and smoothly activate the exoskeleton, the therapist will concentrate on bilateral functional movements (Figs. 39.31 and 39.32). Exoskeletons may be a temporary, wearable device until the patient achieves the desired muscle strength or the device may be a lifelong wearable orthosis to assist in activities of daily living.

There are also advances in myoelectric prosthetics and surgical procedures using targeted muscle reinnervation to achieve increased upper extremity function. In a pan-plexal injury pattern, if the patient can achieve grade 4 elbow flexion, there may be a role for an elective forearm amputation and fitting of a myoelectric prosthesis to give the patient hand function. In our experience, we see the patient initially with the prosthetist and focus on bilateral functional movements (Figs. 39.33 and 39.34). Please see Chap. 16 for more information on the use of prosthetics.

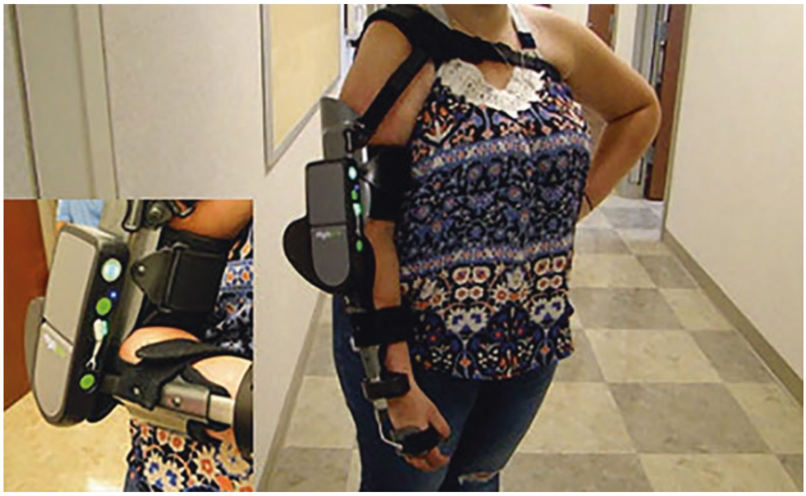

Fig. 39.31 MyoPro in extension and flexion

Fig. 39.32 MyoPro use with bilateral hand function: carrying a tray

Fig. 39.33 Myoelectric prosthetic after elective amputation

Fig. 39.34 Myoelectric prosthetic use with bilateral hand function: opening a medicine bottle

Conclusion

Traumatic, adult brachial plexus injuries are devastating and life changing. Therapy has a large role in the acute care phase to assist with range of motion, edema control, sling and/or orthotic use, pain management, one-handed ADLs, and addressing psychosocial concerns. Postoperatively, the rehabilitation and recovery will be a long, slow, challenging process. It is imperative to have an integrated team approach between the surgeon and the therapist, to guide the patient toward a successful functional outcome.

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