Choosing Upper Limb Muscles for Focal Intervention After Traumatic Brain Injury

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The upper motoneuron syndrome (UMNS) resulting from lesions of corticospinal pathways is an important source of disability after traumatic brain injury (TBI). Classic expressions of motor behavior in UMNS are of 2 kinds: (1) manifestation of muscle underactivity, termed negative signs, and (2) manifestation of a variety of forms of muscle overactivity, termed positive signs. Combinations of negative and positive signs give rise to clinical patterns of movement dysfunction such as the flexed elbow, the clenched fist, and the thumb-in-palm deformity. These clinical patterns can be viewed as reflecting a net balance of muscle forces acting across the joints of a limb. Individual muscles are amenable to a variety of focal interventions such as neurolysis, chemodenervation, or surgery. Since more than one muscle acts across most joints, choices among muscles for focal intervention are many. This article will focus on focal interventions of upper limb muscles of patients with TBI who have UMNS and will explore the theme of choosing upper limb muscles for focal interventions after TBI.

Key words: arms, chemodenervation, dynamic EMG, upper motoneuron

Lesions of corticospinal pathways resulting in an upper motoneuron syndrome (UMNS) are common after severe traumatic brain injury (TBI). The UMNS affects motor behavior and is, therefore, an important source of disability after TBI. Motor behavior is expressed through muscle contraction and, for purposes of this article, individual muscles are considered as units of structure and function. Classic expressions of motor behavior in UMNS are of 2 kinds: (1) manifestation of muscle underactivity during voluntary effort, termed negative signs, which is characterized clinically as weakness and loss of dexterity; and (2) manifestation of a variety of forms of muscle overactivity, termed positive signs, that are characterized clinically by phenomena such as exaggerated phasic and tonic stretch reflexes, co-contraction, released flexor reflexes, associated reactions (synkinesias), and spastic dystonia. Combinations of negative and positive signs give rise to clinical motor presentations and behaviors. For example, a flexed elbow or a clenched fist deformity evoke familiar images to clinicians working with TBI patients. Muscle overactivity in flexor groups combined with underactivity in extensor groups leads to a change in the net balance of forces acting across the elbow and finger joints. The result favors flexion of these joints statically, when a patient is at rest, and dynamically, when a patient makes voluntary effort or develops reflex activity. Undoing directional preference imposed by unbalanced muscular forces acting across joints is desirable therapeutically and depends, in large measure, on identifying individual muscles that contribute to the clinical picture. An important clinical issue is how to identify offending muscles that make...
for unwanted directional preference. Since 2 or more muscles are in anatomical position to act in one direction across most joints, identification of offending muscles can be viewed as a problem of differential diagnosis. A clinician needs to know which muscles cross a particular joint and whether one or more of them contribute to movement dysfunction and deformity. Once individual muscles are focally identified, a number of focal interventions can be considered for treatment including chemodenervation, neurolysis, and neuro-orthopedic soft tissue surgeries. This article will focus on focal interventions of upper limb muscles of patients with TBI who have UMNS. Since more than one muscle acts across most joints in the upper limb, choices among muscles for focal intervention are many. This article explores the theme of choosing upper limb muscles for focal interventions after TBI (see Table 1).

**THERAPEUTIC GOALS**

In our view, 3 major therapeutic goals are served by focal interventions for positive upper limb and choices of muscles for focal intervention

Table 1. Patterns of UMNS dysfunction of the upper limb and choices of muscles for focal intervention

<table>
<thead>
<tr>
<th>Patterns of upper limb dysfunction</th>
<th>Choices of muscles for focal intervention</th>
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<tbody>
<tr>
<td>1. Adducted shoulder (often internally rotated)</td>
<td>Latissimus dorsi, pectoralis major, teres major</td>
</tr>
<tr>
<td>2. Internally rotated shoulder (often adducted)</td>
<td>Anterior deltoid, latissimus dorsi, pectoralis major, teres major, subscapularis</td>
</tr>
<tr>
<td>3. Hyperextended shoulder</td>
<td>Latissimus dorsi, long head of triceps, posterior deltoid, teres major</td>
</tr>
<tr>
<td>4. Abducted shoulder</td>
<td>Middle deltoid, supraspinatus</td>
</tr>
<tr>
<td>5. Flexed elbow</td>
<td>Biceps, brachialis, brachioradialis, extensor carpi radialis, pronator teres</td>
</tr>
<tr>
<td>6. Pronated forearm</td>
<td>Pronator quadratus, pronator teres</td>
</tr>
<tr>
<td>7. Flexed wrist</td>
<td>Flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum sublimis, flexor digitorum profundus</td>
</tr>
<tr>
<td>8. Extended wrist</td>
<td>Extensor carpi radialis, extensor carpi radialis brevis, extensor carpi ulnaris</td>
</tr>
<tr>
<td>9. Ulnar deviation (with or without flexion or extension)</td>
<td>Extensor carpi ulnaris, flexor carpi ulnaris</td>
</tr>
<tr>
<td>10. Clenched fist: Distal interphalangeal joint extended and fingernails easily seen</td>
<td>Flexor digitorum sublimis (FDS)</td>
</tr>
<tr>
<td>11. Clenched fist: Distal interphalangeal joint flexed and fingernails tucked into palm and unseen</td>
<td>Flexor digitorum profundus (FDP)</td>
</tr>
<tr>
<td>12. Partial clenched fist: One or more but not all fingers flexed into palm</td>
<td>Individual muscle slips of FDS and FDP</td>
</tr>
<tr>
<td>13. Clenched fist associated with hyperextended wrist (tenodesis effect of overactive wrist extensors)</td>
<td>Combinations of overactive wrist extensors and extrinsic finger flexors</td>
</tr>
<tr>
<td>14. Thumb-in-palm</td>
<td>Adductor pollicis, first dorsal interosseous, flexor pollicis brevis, flexor pollicis longus, Interossei, lumbricales</td>
</tr>
<tr>
<td>15. Intrinsic plus hand</td>
<td>Abductor digiti quinti minimi</td>
</tr>
<tr>
<td>16. Abducted pinky</td>
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phenomena of the UMNS: (1) Relieving signs and symptoms, (2) Alleviating problems of passive function, and (3) Improving voluntary motor behaviors and active function. The first therapeutic goal, relieving signs and symptoms, is often captured in the history of a patient’s complaints, often in the chief complaint. Common complaints related to signs and symptoms include stiffness, pain, sustained clonus that interferes with activities, embarrassing postures, psychological stress of permanent disfigurement, and a sense of spasm, sometimes painful, with or without unwelcome involuntary movements. The second and third therapeutic goals, alleviating passive dysfunction and improving active or voluntary dysfunction, are biased toward the concept of function. Although function can have a number of connotations, we think of the term function in the sense of a transformation, a change in state wrought by a process. For example, dressing oneself or being dressed by a caregiver implies that the action steps or process of dressing transform the individual from a state of undress to a new state of being clothed. A series of actions are required to achieve this transformation of state and, among other things, these action steps are highly dependent on limb movements and manipulations that are affected by an UMNS. When a caregiver dresses a patient, it is the caregiver who is active while the patient is passive. The caregiver passively manipulates the patient’s limbs during the process of dressing in order to achieve the desired dressing transformation. Being able to function successfully implies being able to carry out all action steps necessary to achieve transformation of a given element in a domain.

In rehabilitation, the most common domains of function are activities of daily living and mobility. Passive function refers to passive manipulation of limbs to achieve functional transformations, typically by caregivers, though patients without voluntary movement of a limb may also be able to manipulate that limb passively to achieve functional ends. When a patient has lost voluntary capacity, he/she may require caregiver help for passive functional activities such as dressing, bathing, hygiene, adjustment of sitting positions, transfers, and other tasks affected by limb postures and deformities that restrain or otherwise impair passive motion and positioning. Active function, on the other hand, refers to a patient’s capacity for generating voluntary motor behaviors in the service of carrying out functional tasks with limbs and body. An example of active function for the upper limb is reaching to grasp, transport, squeeze, and release an object such as a tube of toothpaste.

SIGNS, SYMPTOMS, AND PASSIVE DYSFUNCTION

Shoulder

A number of patterns are commonly seen at the shoulder including the adducted shoulder (often internally rotated), the internally rotated shoulder (often adducted) (see Fig 1), the abducted shoulder, and the hyperextended shoulder. Patients with an adducted shoulder complain of stiffness and pain on passive motion. Symptoms often occur during passive range of motion exercises or when dressing and bathing require the limb to be manipulated passively by a caregiver for purposes of care. On examination, passive stretch of adductor muscles can cause pain (see Fig 2). Examination often reveals a tight pectoralis major tendon at the fold of the axilla in the anterior axillary line. Palpation of pectoralis major during stretch may reveal palpable contraction, consistent with spasticity. However, the examiner must remember that resistance to stretch may also come from changes in physical properties of muscle pursuant to prolonged spasticity. Muscle tissue that is statically stiff can clinically masquerade as dynamic spasticity. In chronic cases, high resistance to stretch may be a reflection of stiff static rheologic properties of muscle tissue rather than an expression of...
Figure 1. This 20-year-old woman with traumatic brain injury and an upper motoneuron syndrome has a right adducted and internally rotated shoulder as well as other common deformities.

dynamic spasticity that may actually have diminished over time. Since focal intervention by chemodenervation or neurolysis affects dynamic contraction of muscle tissue only, it is important to distinguish between the resistance to stretch offered by muscle contracting on a reflex basis versus resistance to stretch generated by the inherent physical stiffness properties of muscle tissue. Although mentioned in the context of testing shoulder muscles, this distinction needs to be made for all muscles affected by UMNS when focal intervention by chemodenervation, neurolysis, or surgery is being considered.6,11 Electromyographic (EMG) examination and diagnostic local anesthetic blocks can help make such distinctions.12

Other muscle groups that contribute to the adducted shoulder are teres major and latissimus dorsi. The tendon of latissimus dorsi along with teres major can be palpated at the axillary fold in the posterior axillary line. Rapid stretch may reveal a palpable contraction of teres major and latissimus dorsi (see Fig 3). Dynamic electromyography is useful in identifying these muscles. Our experience suggests that teres major offends more often than do pectoralis major and latissimus dorsi. All 3 of these muscles are possible internal rotators of the shoulder to which must be added anterior deltoid and subscapularis. It is clinically and electromyographically difficult to identify subscapularis because of its anatomical location underneath the scapula. We consider this muscle a potentially offending muscle when other muscles in the group have been ruled out. Anterior deltoid supports the shoulder as part of the deltoid muscle cap
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Figure 2. Painful passive stretch of shoulder adductors triggers an immediate glare toward the examiner by a young patient with traumatic brain injury.

and is primarily an abductor. It could conceivably play a role in restricting external rotation when other muscles have been accounted for but this doesn’t happen often. EMG studies and local anesthetic motor point block are helpful. Patients who complain of shoulder pain on motion may not have pain of spastic origin. Capsule tightness, impingement, rotator cuff strains, and other conditions may be contributory.

Figure 3. A series of 5 passive stretches of shoulder adductors of the patient shown in Figure 2 reveals spastic reactivity of pectoralis major, teres major, and latissimus dorsi.
The abducted shoulder, often combined with a flexed elbow, is most often a problem during walking (see Fig 4). Patients’ history will indicate that they problematically knock into various parts of furniture, doorways, and motor vehicles, sometimes injuring themselves significantly. In addition, they bump into other people during community ambulation on busy streets, in crowded shopping malls, and elsewhere. Supraspinatus and middle deltoid are potentially overactive. Electromyography and local anesthetic blocks are useful assessment procedures. Wire electromyography is necessary to record from supraspinatus because it lies deep to the trapezius.

Figure 4. The abducted shoulder, often combined with a flexed elbow, is commonly found during walking. Supraspinatus and/or middle deltoid may be overactive.
Resistance to passive flexion of the shoulder can be produced by long head of the triceps, latissimus dorsi, teres major, and posterior deltoid. Clinical palpation, diagnostic blocks, and EMG examination are helpful assessment techniques. Some patients complain of a hyperextended shoulder that displays itself under psychological stress, during ambulation, or other strong volitional efforts. The hyperextended posturing may represent an associated reaction or synkinesis. Shoulder and elbow extensor muscles are involved. Groups such as long head of triceps, teres major, latissimus dorsi, and posterior deltoid need to be considered along with lateral and medial heads of triceps and anconeus (see Fig 5). Even though directional preference is one of extension at shoulder and elbow, the examiner must be mindful of the possibility of simultaneous flexor muscle activity because focal intervention aimed at extensor muscles may cause a reversal of deformity toward flexion afterward. Clinical observation, palpation, EMG studies, and local anesthetic blocks help with the differential diagnosis.

Elbow

The flexed elbow is a common upper motoneuron pattern that may contribute to patient discomfort. A severely flexed elbow grates the skin and retains moisture, causing irritation and redness in the elbow crease (see Fig 6). Skin breakdown is ultimately possible (see Fig 7). Involuntary flexor spasm may cause the patient’s hand to strike upper chest or throat. Combinations of severe shoulder adduction and elbow flexion may result in a fist or a digit pressing into the throat or face. Flexor spasms at the elbow may awaken a patient at night. Clinical examination is often helpful in identifying biceps and brachioradialis as offending muscles. These muscles often pop up during passive stretch, indicating spastic contractile activity. Muscles such as brachialis are much more difficult to palpate because the bulk of this muscle lies beneath the biceps. EMG examination is helpful in this regard. Additional flexors that a focal interventionist considers are pronator teres and extensor carpi radialis (ECR). Both of these muscles are anatomically positioned to flex the elbow. When the wrist is flexed, ECR is relatively lengthened and this muscle can flex the elbow by a reverse origin/insertion mechanism of action. Pronator teres, often spastic and frequently contractured, provides additional resistance to passive extension of the elbow (see Fig 8). Muscle overactivity of ECR

![Rapid Alternating Motion Effort at Shoulder](image)

**Figure 5.** The electromyographic record of a patient who complained of a hyperextended shoulder. She had great difficulty performing alternating flexion and extension movements and the electromyographic record shows that she was not able to complete 32 s of alternations. Co-contraction during the flexion phase of movement is seen in such extensor muscles as long head of triceps, teres major, and posterior deltoid.
and pronator teres may account for residual resistance to passive stretch after local anesthetic blocks and other focal interventions are applied successfully to the main elbow flexors (biceps, brachialis, and brachioradialis).

**Wrist**

A flexed wrist deformity can be painful and stiff during orthotic application, therapeutic exercise, washing, and dressing. In addition, compression of the median nerve within the carpal tunnel by tight extrinsic finger flexors can produce pain in the hand. Muscles that cross the wrist include flexor carpi radialis, palmaris longus, flexor carpi ulnaris, and the superficial and deep extrinsic finger flexors. It is important to recognize that the extrinsic finger flexors can be important contributors to a flexed wrist deformity. If the finger flexors are strongly overactive, focal intervention to wrist flexors alone may not be sufficient to relieve a flexed wrist deformity.

Clinically, the wrist flexors may be tested by passive extension of the wrist, keeping the fingers flexed into the palm so that their contribution to wrist tension is minimized. Palpation of the tendons of flexor carpi radialis, palmaris longus (just medial or ulnar to flexor carpi radialis), and flexor carpi ulnaris can be performed at the wrist. Tightness of palmaris longus is variable but when taut, focal intervention is usually required. Many patients with a flexed wrist have ulnar deviation. It might be thought that when a wrist is both flexed and ulnarly deviated, flexor carpi ulnaris is the main contributor. However, extensor carpi ulnaris may also contribute to an ulnarly deviated wrist. The observed wrist flexion simply means that a net balance of forces favors flexion as a directional preference because flexors are simply stronger than extensors. Nevertheless, dynamic activity in extensor carpi ulnaris can make an important contribution to ulnar deviation along with flexor carpi ulnaris. The focal interventionist...
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Figure 7. Skin breakdown with exposed tendon in a patient with a severely flexed elbow. Although resistance to passive stretch was very high, the patient had only modest electromyographic recruitment with stretch. Static stiffness and contracture of muscle appeared to contribute to high resistance more than did dynamic spasticity.

must be aware of the possibility of 2 ulnar deviators in order to render a decision on focal treatment.

Hand

In the clenched fist deformity, fingers are tightly flexed into the palm. When flexor digitorum profundus (FDP) is involved, fingernails often dig into palmer skin (see Fig 9). An examiner looking at such a hand may have difficulty seeing fingernails that can be almost completely buried within the palm. A side view of the fist may reveal a clenched little finger that is typically flexed 90° at the metacarpophalangeal (MCP) joint, proximal interphalangeal (PIP) joint, and distal interphalangeal (DIP) joint. When flexor digitorum sublimis (FDS) is predominantly involved, the fingers are flexed but the DIP joints are fully extended and the fingernails are easily observed (see Fig 10). However, when a patient has a clenched fist deformity with flexion of MCP, DIP, and PIP joints, FDS may still be involved. Physical examination is helpful in sorting out FDS from FDP. The length of a finger flexor varies as a function of elbow extension, wrist extension and, to a lesser extent, MCP joint extension. Therefore, initial testing at a slacker length can be performed by varying wrist and elbow angles (often, to the extent allowed by
Figure 8. Pronator teres, often spastic and frequently contractured, also provides a flexor force across the elbow. The electromyographic record shows that passive stretch of elbow flexors in a patient with traumatic brain injury yields spastic electromyographic recruitment in pronator teres along with biceps and brachioradialis.

contractures at these joints) and, later, increasing stretch tension by extending the elbow and wrist. Some examiners prefer to keep the elbow at maximum available extension and the MCP joint in neutral. Then they ratchet the wrist angle and passively extend PIP or DIP joints—maneuvers that may call for more than 2 hands! These maneuvers tighten the extrinsic finger flexors so that the examiner can appreciate differences in resistance. Passive extension of the PIP joint by the examiner preferentially tests FDS. Passive extension of

Figure 9. When flexor digitorum profundus is involved, fingernails often dig into palmer skin.
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Figure 10. When flexor digitorum sublimis is predominantly involved, fingernails are easily observed in the frontal view because the distal interphalangeal joints are extended while the proximal interphalangeal joints are flexed.

The DIP joint preferentially tests FDP. Some examiners prefer to test FDS and FDP as whole groups. But not all fingers are necessarily involved in the clenched fist deformity and involvement of FDS and FDP for different fingers can also vary. It is not unusual to find involvement of FDS for one finger and FDP for another. Observation and examination help to sort such mixed findings. Since it is possible to identify and treat different superficial and deep muscle slips corresponding to different fingers, clinical examination is an important tool for identifying different muscle slips for focal intervention. If contracture with diminished reflex activity is suspected, median and ulnar nerve blocks may be useful. A clenched fist deformity can also be brought about by tenodesis action secondary to a hyperextended wrist (see Fig 11). Focal intervention aimed at wrist extensors such as ECR, brevis, and ulnaris may help because finger flexors will become less tight and the hand will open up more easily.

The thumb-in-palm deformity may be caused by muscle overactivity in flexor pollicis longus, flexor pollicis brevis, and adductor pollicis. First dorsal interosseous also may contribute toward closing off the web space, a finding we include as part of the thumb-in-palm deformity. Flexor pollicis longus flexes the IP joint of the thumb and can be examined accordingly. Adductor pollicis closes off the web space and passive abduction can reveal spasticity of this muscle.
Figure 11. A clenched fist deformity can also be brought about by tenodesis action due to a hyperextended wrist associated with overactive wrist extensors.

Figure 12. An overactive adductor pollicis can close off the web space. Note that flexion of the interphalangeal joint of the thumb is not present in this case, indicating that flexor pollicis longus is not involved.
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Figure 13. Thumb-in-palm positions occasioned by flexor pollicis longus (FPL) (right arrow) and flexor pollicis brevis (FPB) (left arrow). FPL primarily flexes the interphalangeal joint of the thumb. FPB primarily flexes the metacarpophalangeal joint.

Although a clenched fist typically represents overactivity in superficial and/or deep finger flexors, overactive intrinsics may also be present. Clinical expression of intrinsic muscle forces is masked, however, by the much stronger extrinsic finger flexors. However, if focal interventions are delivered to the extrinsics when masked intrinsic activity is also present, the hand may subsequently adopt an intrinsic plus posture comprised essentially of flexion at the MCP joints with full extension at the IP and DIP joints. In order to treat a dynamic intrinsic plus hand, the focal interventionist may choose the interossei, the lumbricales, or both. It is difficult to distinguish between these groups by clinical examination alone. Dynamic EMG examination of lumbricales and interossei may be useful in this regard. However, distribution of intrinsic resistance may vary across fingers and clinical examination will pick up this variation. To test resistance of intrinsics, the examiner initially positions the MCP joint in 90° of flexion and the PIP joint in full extension. The middle phalanx is grasped and pushed such that flexion of the PIP joint and extension of the MCP joint are produced simultaneously. It is
best to perform this test with the wrist flexed so that extrinsic finger tension is minimized. Infrequently, overactivity in abductor digiti quinti minimi may occur (see Fig 14). The patient complains that the little finger is always abducted and that it inadvertently hooks onto things or otherwise interferes with activities that happen on a tabletop. Only one muscle is involved in this pattern and is easily amenable to focal intervention.

ACTIVE OR VOLUNTARY DYSFUNCTION

Co-contraction is a form of muscle overactivity that is seen in UMNS and may be described as activation of antagonist muscles during voluntary activation of agonist muscles. Co-contraction can be activated and deactivated at a cortical level and it is one mechanism that normally provides joint stability. Co-contraction may also represent an impairment of supraspinal control of reciprocal inhibition in UMNS and abnormalities of Ia reciprocal inhibition have been reported for patients with UMNS that can lead to co-contraction. For patients with UMNS, a key feature of co-contraction is that it occurs during voluntary effort and that it is generated by simultaneous motor drive to agonist and antagonist muscles. Such patients appear to exert a braking action on voluntary movements they are trying to generate. Because of the braking action of pathological co-contraction, a patient’s effort to produce movement often increases, there is a decline in movement speed, amplitude, and smoothness, and movement direction may even reverse.

Figure 15 shows a patient with TBI attempting to place her hand behind her neck. The movement requires voluntary shoulder abduction and external rotation. Figure 16 shows the dynamic EMG record of her
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Figure 15. This figure shows a patient with traumatic brain injury attempting but unable to place her hand behind her neck. The motion requires voluntary shoulder abduction and external rotation.

effort. Posterior deltoid, a shoulder abductor and external rotator, is activated as an agonist muscle. However, the record also reveals simultaneous co-contraction of teres major, an adductor and internal rotator whose contraction is in position to antagonize the patient’s effort. The record also shows that other internal rotators of the shoulder were not active during the patient’s effort to externally rotate the shoulder. Based, in part, on these

Figure 16. This is the dynamic electromyographic record of the patient shown in Figure 15. Posterior deltoid, an agonist shoulder abductor and external rotator, appears to be activated appropriately, but teres major, an adductor and internal rotator, co-contracts simultaneously and is in position to antagonize (and foil) the external rotation effort. Other internal rotators of the shoulder such as pectoralis major and latissimus dorsi were not activated. Focal intervention could be considered for teres major.
Figure 17. The electromyographic record of a 21-year-old man with traumatic brain injury who had difficulty flexing his shoulder. Co-contraction of long head of triceps, a shoulder extensor, was observed during forward flexion.

findings, focal treatment of teres major might be considered. The use of dynamic EMG studies in UMNS is a useful tool to expose activation of individual muscles about a joint during a patient’s voluntary effort. Findings allow a clinician to develop hypotheses about which muscles may be antagonizing voluntary movement. Focal interventions may be

Figure 18. The electromyographic record of a patient who had difficulty flexing his shoulder forward. Co-contraction of latissimus dorsi was especially prominent during flexion.
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thought of as a way to test a given hypothesis about specific muscles. Patient improvement suggests that the interventionist has made a good choice of muscles for focal treatment.

Figures 17 and 18 show the EMG records of patients both of whom had complaints referable to voluntary flexion of the humerus and reaching. Clinical examination revealed effortful and slow forward reach. There was a mismatch between active flexion range of motion and passive flexion range of motion. Possibilities of weakness of flexors versus over-activity of extensors during voluntary flexion were considered. Dynamic EMG studies of individual shoulder muscles were performed to explore these possibilities. Shoulder motion is recorded with an electrogoniometer and is displayed in the bottom trace of the records. Figure 17 shows co-contraction in long head of triceps during forward flexion while Figure 18 illustrates co-contraction predominantly in latissimus dorsi. It is difficult to palpate or otherwise observe contraction of shoulder muscles during dynamic movements. Dynamic EMG studies, however, are a useful alternative that helps differentiate

Figure 19. This 24-year-old man complained of difficulty playing his guitar, 4 years after traumatic brain injury. He had difficulty abducting his shoulder to position his hand along the neck of the guitar.
activity of co-contraction among muscles. Figure 19 shows a 24-year-old man, 4 years after TBI, who complained of difficulty playing his guitar. Clinical history and examination focused the problem on shoulder abduction that was required to position the hand at different string lengths. Dynamic EMG studies (Fig 20) indicated good activation of the agonist middle deltoid as the patient positions his hand along the neck of the guitar. However, the electromyographic record also reveals activity in the antagonist latissimus dorsi that develops after movement has begun—a finding consistent with stretch-related spasticity.

The patient in Figure 21, a 20-year-old man who had a residual left hemiparesis 6 months after head injury, poses a different issue. When he attempts to adjust his sitting position in the wheelchair, he develops marked flexion posturing of the left elbow. Dynamic EMG recording of this occurrence (see Fig 22) reveals that flexors and extensors of the elbow (including even anconeus) become highly activated during this associated reaction (synkinesis). The observed flexion posturing of the elbow apparently represents a net balance of forces that favors elbow flexion. Should a clinician wish to treat this phenomenon, focal drug intervention might be difficult because of the large number of muscles involved and the difficulty of predicting what a new balance of forces might look like after intervention to any number of active muscles. Perhaps a central muscle relaxant might be a more prudent choice. Figure 23 illustrates a similar problem. A 27-year-old man sustained a gunshot wound of the brain 1 year back. He complained of severe shaking (clonus) of his elbow during reaching and preferred to move his upper limb as little as possible because of it. Figure 24 illustrates an EMG record of clonus during voluntary effort that shows clonic activity not only in medial triceps, brachioradialis, and ECR about the elbow but also as far distal as the interossei muscles of the hand. Clinically, clonus was fairly violent and it was likely that other unrecorded muscles were involved as well. An oral muscle relaxant might be the first consideration for treating a patient with diffuse muscle involvement. Nevertheless, focal intervention applied to a select number of muscles sometimes may be sufficient to modify spread of phasic reflex excitability. Diagnostic evaluation of this possibility with a local anesthetic may be helpful.

At the forearm, co-contraction of one or both pronators may restrain voluntary supination. Figure 25 is the EMG record of a patient with head injury who had hand function but always reached with pronated forearm to grasp objects. Figure 25 is a record...
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Figure 21. This 20-year-old man has a residual left hemiparesis 6 months after head injury. When he attempts to adjust himself in the wheelchair with his (uninvolved) right arm, he develops marked flexion posturing of the left elbow.

Figure 22. Dynamic electromyographic recording of the patient shown in Figure 21 reveals that flexors and extensors of the left elbow (including anconeus) become highly activated during this associated reaction (synkinesis).
of the patient’s effort to reach underhand toward a target that had to be grasped by the palm facing up. He was unable to do it. The record shows that the patient was able to activate biceps as an agonist supinator. However, he also activated pronator teres and pronator quadratus. Both of these muscles, therefore, could be considered for focal intervention. This is not always the case. Figure 26 is the EMG record of a patient with voluntary alternating motion of the wrist. This patient with TBI was asked to perform repetitive voluntary flexion and extension movements of the wrist. Good phase-related activity was

**Figure 23.** A 27-year-old man with a gunshot wound of the brain complained of severe shaking (clonus) of his elbow during reaching. He preferred to move his upper limb as little as possible in order to minimize clonus.

**Figure 24.** Dynamic electromyographic recording of clonus during voluntary reaching effort revealed that clonic activity was present not only in elbow-connected muscles such as medial triceps, brachioradialis, and extensor carpi radialis but also as far distal as the interossei of the hand.
Figure 25. The electromyographic record of a patient who always reached to grasp objects with a pronated forearm. The electromyographic record reveals co-contraction of pronator teres and pronator quadratus, even during underhand reach.

Figure 26. The electromyographic record of a patient who had excessive ulnar deviation. This electromyographic record of flexion and extension wrist movements shows excessive activation of extensor carpi ulnaris and flexor carpi ulnaris. See text for clinical implications of this finding.
seen in ECR, which was distinctly active during the extension phase and relatively inactive during the flexion phase. The same cannot be said of extensor carpi ulnaris, which was active throughout both the phases of movement and seems to generate more activity during the flexion phase. The wrist flexors are noisy throughout but greater activity is more evident during the flexion phase. The clinical problem was marked ulnar deviation, especially during reaching. Findings from this study suggest that focal intervention for ulnar deviation be considered for extensor carpi ulnaris and, if necessary, flexor carpi ulnaris. The fact that an ulnarly deviated wrist may be occurring within the context of flexed wrist dysfunction does not mean that flexor carpi ulnaris is solely or even primarily responsible for ulnar deviation. EMG guidance is helpful to identify whether extensor carpi ulnaris is contributory.

Superficial and deep finger flexors may be affected by UMNS differentially. Figure 27 shows the EMG record of a young woman who had sustained TBI 58 months back. She complained of difficulty extending her fingers. Her EMG record shows good reciprocal activation between FDS, extensor digitorum communis, and lumbricales. (The lumbricales are active during finger extension to prevent hyperextension of the MCP joint). However, the EMG record clearly shows that FDP was active during both the phases of movement. It is not unreasonable to infer that restraint of extension by activity in FDP during the extension phase is a contributor to this patient’s clinical problem. Unlike FDP, it was noted that FDS was not active during the extension phase. The patient shown in Figure 28 illustrates that UMNS may differentially involve only a single finger. This patient had a flexed index finger. Clinical examination suggested increased resistance to passive stretch for both FDS and FDP. Her functional problem is illustrated on the left side of the figure, which shows a knuckling grasp of the soda can by an excessively flexed index finger. Chemoenervation applied focally just to

![Figure 27](image_url)

**Figure 27.** This electromyographic record reveals that superficial and deep finger flexors may be affected by an upper motoneuron syndrome differentially. The patient complained of difficulty extending her fingers. The record shows that flexor digitorum profundus is active during the flexion and extension phases of movement while flexor digitorum sublimis is active only during the flexion phase and not during the extension phase.
Choosing Upper Limb Muscles for Focal Intervention

Figure 28. The patient in this figure illustrates that upper motoneuron syndrome may differentially involve only a single finger. This patient complained solely of a flexed index finger. The patient was treated by chemodenervation solely of the index finger sublimis and profundus. Before treatment, the index finger knuckled the Pepsi can. After treatment, the index finger grasped the Coke can appropriately.

the index finger muscle slips of FDS and FDP improved the patient’s grasp as illustrated on the right side of the figure.

CONCLUSION

The pathology of UMNS does not affect all muscles of the upper limb homogeneously. Therefore, a clinical picture such as a flexed elbow or an adducted shoulder that looks similar across patients may not have the same muscles generating the deformity. Since more than 2 muscles cross upper extremity joints, choosing upper limb muscles for focal intervention becomes an issue of differential diagnosis. This article has identified a number of common patterns of UMNS dysfunction and has indicated which muscles have potential for contributing to these patterns. Techniques of identification include clinical observation of movements, palpation and other examinations, dynamic kinesiologic EMG studies, and diagnostic blocks. Focal interventions depend not only on muscle identification but also on therapeutic goals. Goals of relieving signs and symptoms, alleviating passive dysfunction, and improving active or voluntary dysfunction were also highlighted.

REFERENCES

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