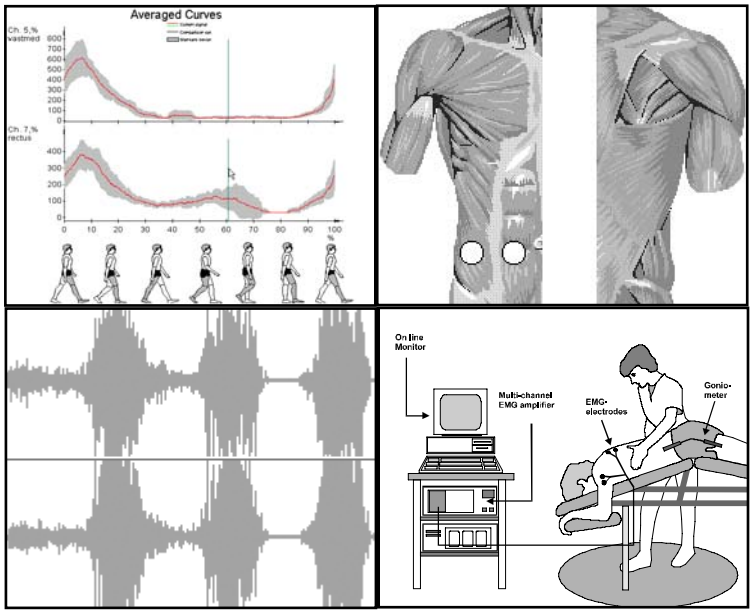
SURFACE EMG MADE EASY:

A Beginner's Guide for Rehabilitation Clinicians



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Before you start

The purpose of this manual is to make it easier for clinicians to use SEMG in their practice. The format of the book was chosen to provide a convenient way for instructors in Physical Therapy programs to incorporate SEMG evaluation and rehabilitation methods to relevant parts of their curriculum. Although it is not necessary to read the book from the beginning to the end, it is suggested that the reader takes a thorough look at the list of contents before selecting where to start.

Chapter 1. Practical considerations for clinicians using SEMG provides many suggestions for beginning users and should be reviewed by anybody not familiar with the basic concepts. The other chapters are more specific in their scope and allow the readers to focus on the applications closest to their needs. When reviewing the material for any particular body region please keep in mind that additional insight can be gained by consulting both *Chapter 3. Regional applications of SEMG to musculoskeletal problems* and *Chapter 5. Regional applications of SEMG to patients with neuromuscular conditions*.

All the electrode placement illustrations referenced in the text have been placed in the appendix and may be photocopied for personal or educational use. Brief instructions for Noraxon SEMG software and hardware use are included in the text and in the appendix. More detailed instructions are available in the User Manuals provided with each system.

Noraxon is grateful to the authors for their willingness to share decades of clinical and teaching experience in SEMG applications. Any suggestions from the readers for future editions of this manual are welcome.

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APPENDIX

Laboratory exercises are found on the pages listed below.

Lab disclaimer: Students should be cautious not to use subjects with history of regional pain or problem. Exercises need to be discontinued if the subject experiences any discomfort or difficulty.

Case examples of neuromuscular conditions with associated questions and answers begin on page 128.

Chapter 1:

PRACTICAL CONSIDERATIONS FOR CLINICIANS USING SEMG

This chapter will explore practical considerations for clinicians using surface electromyography (SEMG) with patients with neurological and musculoskeletal problems. Practitioners will gain a fundamental appreciation of patient needs, recording technique, system operation, interpretation of the SEMG display, feedback training, and data management. The material is sequenced to blend clinical and technical SEMG principles in a time-efficient manner combining narrative review with laboratory exercises.

Clinical Preparation

Patients may initially be anxious about having SEMG electrodes attached to them as well as curious as to what the SEMG machine does and why SEMG procedures are being suggested as part of the care plan. They likely will not be familiar with the anatomy and function of the muscles that are to be recorded. In addition, they may not intuitively understand the SEMG display or how to interpret cues during feedback training. Outcomes may be enhanced by performance of some preliminary steps to SEMG monitoring and feedback training.

Underlying Principles

1. Begin SEMG monitoring after you have performed a thorough intake and physical examination as appropriate to the case at-hand.

2. Identify impairments, functional limitations, and disabilities as well as relevant pathophysiological processes, if known.

3. Establish a working hypothesis as to the underlying key problems and the potential role of impairments related to muscle activity.

4. Consider SEMG assessment if:

- There is a reasonable probability that neuromuscular impairments contribute significantly to the patient's problems, which are unlikely to resolve spontaneously.
- Information regarding muscle activity is likely to influence the intervention plan.
- SEMG recordings can be performed in a cost-effective manner.

5. Following SEMG assessment, integrate the results with the other examination findings and determine a movement system diagnosis, prognosis, and intervention plan.

6. Consider SEMG feedback training if aberrant patterns of muscle activity are identified that may be amenable to change through motor learning by the patient.

7. Consider use of SEMG to evaluate the effects of other interventions designed to impact muscle activity (such as therapeutic exercise prescription, orthotics, modalities, and manual therapy techniques) or to integrate SEMG training within the context of other therapeutic exercise interventions.

Patient Briefing

1. Briefly explain the rationale and goals for SEMG assessment and feedback training in terms appropriate to the patient's level of understanding.

2. Briefly explain the operation of the SEMG device.

3. Explain to the patient what he or she can expect to feel and do during the session.

Example Remarks to Patient

"*When you move, your brain sends off a series of commands that go down the spinal cord and out over nerves to muscles. Muscles do what the brain tells them to do. The brain sends these signals in the form of tiny electrical impulses – your body activates muscles with its own tiny electrical system. The equipment measures your body's own electrical impulses as they spread from the nerve over the surface of the muscle. The device shows how strong your body's signals are at the display screen – so we, you as well as me, can see how well the muscles are being activated. The equipment is very sensitive and can pick up low levels of muscle activity that we might not be able to see or that you might not feel.*

We'll be able to take some of the guesswork out of assessing your muscle function and judge if your muscles are too active, not active enough, or whether one muscle is working together with other muscles the way that it should. I'll be monitoring the results closely and put the information together with our other examination procedures. If I see a pattern of muscle activity that could be significant, I'll explain it to you and we may choose to have you watch the display and try some different things to improve the pattern. By watching the screen, you'll be able to get a better sense of how your muscles are being activated and you may be able to learn ways to activate (or relax) your muscles more effectively.

You'll feel sensors attached to your skin. They will feel like pieces of tape. There are no needles or electric shocks. The machine will not do anything to you. You won't feel anything from the machine except the sensors touching your skin.

After the sensors are attached, we'll try some different movements and see how exactly your muscles respond. I may guide you to perform some special exercises, change your posture, or experiment with different movement patterns.

Do you have any questions or concerns? ...Shall we proceed?"

LABORATORY EXERCISE 1: Patient Briefing

- Select a partner and role play a patient-therapist initial SEMG session.
- Assume any neurologic or musculoskeletal diagnosis desired (e.g. hemiparesis following cerebral vascular accident, chronic neck pain, shoulder impingement syndrome).
- Explain the rationale and goals for SEMG assessment and feedback training, operation of the SMEG device and what the patient should expect to feel and do during the session.
- Ask your partner to provide feedback regarding the clarity of your explanation.

SEMG Set-up

1. Begin in the clinic in a non-distracting environment.

2. Position the patient with appropriate postural support, so that the involved body region is visible.

3. Explain what you are doing as you attach electrodes and get the system ready for operation.

4. To avoid potentially uncomfortable manual pressure, attach electrodes to the lead wires before you place them on the patient.

5. Prepare the skin by rubbing vigorously with an alcohol swab or if preferred, a moistened abrasive paper towel.

6. Attach the reference electrode first and then place the recording electrodes in the desired locations, pressing down around each adhesive collar with your fingers to ensure good contacts.

7. Initiate monitoring, calibrate, and verify an active signal from the target muscle. Observe:

- An appropriate baseline signal.
- Increased signal amplitude when the patient performs the action of the target muscle.

Example Remarks to Patient

"*I'm going to rub your skin with alcohol over the sites that we'll be monitoring to help get the best quality signal. You'll feel me rubbing vigorously and it will be cool. After that, I'm going to attach the sensors and I'll be making adjustments to the machine so that we are ready to go."*

Once the electrodes are attached and the system on-line, direct the patient to perform the action of the target muscle:

"Note how the display goes up when you move and activate the muscle. When you relax, the signal goes down toward the bottom. The height of the signal is proportionate to the level of activity in your muscle."

LABORATORY EXERCISE 2: Electrode attachment and system start-up

- Prepare the skin for recording over your subject's biceps.
- Attach an electrode to the reference lead (black) and two electrodes to the recording leads for channel 1 and channel 2. Peel the backing from the electrodes, apply the reference electrode over the C7 spinous process.
- Apply the recording electrode pair for channel 1 as close together as possible without touching, parallel to muscle fiber direction, over the center of biceps.
- Apply the recording electrode pair for channel 2 proximal and distal to those of channel 1, as shown in FIGURE 19.
- Start the system and go to measurement screen *(See appendix for details).* Click on the global *calibration button* (yellow ruler in the top left corner of the screen) to adjust the baseline to zero.
- Ask the subject to flex his or her elbow several times. Observe an increase in signal amplitude with contraction and decrease in signal amplitude with relaxation.

Basic Display Options & Recording Principles

The SEMG display can be manipulated for optimal observation of muscle activity. Increasing the speed of the screen sweep will facilitate assessment of the timing of muscle activation and deactivation whereas slowing the sweep speed will enable capture of multiple movement trials on a single screen width. By adjusting the amplitude scale, low or high levels of activity can be fully visualized. After tracings are recorded and saved, the amplitude scales can again be adjusted, other simple statistics obtained quickly, and one tracing superimposed on another to compare activity relationships across channels. In addition, powerful reports can be generated to document activity patterns and quantify various comparisons of clinical interest.

LABORATORY EXERCISE 3: Basic display options

- Follow the instructions in Lab 2 and go to measurement screen.
- Press the *S-key* (slow) and the *F-key* (fast) on the keyboard to adjust the sweep speed. With slower speed more of the tracing will fit on one screen, allowing you to keep track of what has happened. Faster speed allows for more details to be traced and is more appropriate for ballistic movements (e.g. golf swing). Note: this is just a display feature and does not affect the actual data collection at all.
- Press the *PgUp* (Page Up) and *PgDn* (Page Down) keys on the keyboard. The amplitude scaling for all channels will change in 10% increments of the original scale (e.g. 50 uV if you started with a scale of 500 uV). You can change the scaling of individual channels with the up and down arrows next to each channel. Note: this is just a display feature and does not affect the actual data collection at all.
- Click on the *Freeze* button to review the tracing and on *Continue* to continue monitoring.
- Click on the *Store* button to start recording. The tracing turns red and the test time in the right upper corner starts running. Click on the *Pause* button to return to monitoring mode. Notice that the tracing is white and the running time stops. You can continue recording in the same file by clicking on the *Continue* button. Note: a vertical red line in the data file will indicate that the Pause or Freeze function was used although the line is not visible in real time.
- Click on *Exit* button when you are done and click on *No* when asked if you want to save the data.

Recording Principles

The amplitude of the SEMG signal varies as a function of:

- Electrode placement – for a large superficial muscle, electrodes should generally be placed over the center of the muscle belly. For

small muscles, electrodes may be placed over the target muscle as far as possible from other muscles that might contaminate the signal.

- Electrode size – the larger the electrode, the lower the impedance at the detection zone and the greater the SEMG amplitude.
- Interelectrode distance – the wider the spacing between active electrodes, the broader and deeper the pick-up, and the greater the SEMG amplitude.
- Orientation of recording electrodes – most often, the recording electrodes should be positioned parallel to muscle fiber direction. Parallel orientations tend to result in more specific muscle recordings.
- Skin impedance – the greater the impedance at the skin-electrode interface, the greater and more unstable the baseline (resting) SEMG amplitude, and the less accurate the SEMG tracing during movement.
- Muscle depth and subcutaneous adipose – the more superficial the muscle and the lesser the amount of subcutaneous adipose, the greater the SEMG amplitude.
- Contraction intensity – the higher the recruitment level of motor units, the higher the SEMG amplitude.
- Contraction velocity – the greater the movement acceleration, the higher the SEMG amplitude.
- Contraction type or phase – for example, for an equivalent load, velocity, and movement arc in a healthy subject, the SEMG amplitude will always be higher during the concentric phase of movement compared to the eccentric phase.

In addition, SEMG tracings may be affected by:

- Muscle geometry as well as proportionate amounts and distribution of fiber types.
- Normal segmental and suprasegmental neurophysiological reflexes.
- Pathological central or peripheral nervous system lesions, myopathic disease.

- Cognition and emotions related to pain and disability.
- Motor skill and conditioning levels.
- “Cross talk” from other muscles, heart artifact, respiratory artifact, movement artifact; electromagnetic radiation from fluorescent lights, electric motors, video monitors and other types of electronic equipment; and on rare occasions, radio transmissions.
- Signal processing hardware and software unique to each manufacturer’s engineering design.

Single-use, disposable electrodes are recommended for ease of application and signal quality.

Care should be taken to use a consistent load, range of motion arc, and velocity when results will be compared across multiple movement trials. Use of a metronome is a simple way to regulate the pacing of movement.

Obviously, some of the above factors can be controlled by the operator or modulated by the subject and others cannot. The susceptibility of the recordings to some forms of noise and artifact may vary with the quality of the SEMG system as well as certain control features of the system hardware and software. Adhering to the basic principles of recording technique described in this manual will minimize most problems. Thus, for isolated SEMG recordings, the following should be used:

- Relatively smaller electrodes - 0.8 cm diameter circular electrodes or smaller; or bar-shaped electrodes of comparable or smaller surface area.
- Close inter-electrode distance – 2.0 cm, or less, measured from the center of one electrode to the center of the other.
- Recording electrode orientation parallel to muscle fiber direction.
- Careful placement over the target muscle, away from potentially contaminating muscles.

Sometimes, cross talk from neighboring muscles will be unavoidable. It is somewhat easier to rule cross talk out than to rule it in. Signal from the target muscle can be confirmed by asking the patient to perform the action of that muscle and observing a response at the display screen (e.g., elbow flexion for biceps). If, then, the patient clearly performs the action of neighboring muscles and there is no response in the signal for the target channel (e.g., no response from the "biceps" channel during obvious triceps contraction), cross talk is not an issue. If, however, a response from the target channel is observed during contraction of a neighboring muscle (e.g., increased biceps SEMG amplitude during triceps contraction), it is uncertain to what extent the activity seen from the target channel is due to cross-talk versus co-activation of the target muscle. Usually the magnitude of the response from neighboring muscles needs to be reasonably "noticeable" for its effects to truly "contaminate" the results.

SEMG, Force, and Fatigue Relationships

There tends to be a directly proportional relationship between SEMG amplitude and force under isometric, non-fatiguing conditions. As the intensity of contraction increases, both the SEMG amplitude and force increase in a predictable and linear manner. However, this relationship does not hold under dynamic conditions. The relationship between the SEMG amplitude and force will be unknown in the clinic. In addition to the complex effects of the variables listed in the previous section, SEMG amplitude and force production may be differentially affected by changes in joint angle and consequent alterations in muscle length-tension relationships and angle of tendon insertion. Fatigue may also affect the SEMG-force relationship. The SEMG device measures voltage, which when properly recorded, represents the relative level of instantaneous *muscle recruitment* but not force. A muscle may be said to be more or less active as the SEMG amplitude increases or decreases, respectively, but under dynamic conditions, inferences can-

not be drawn about resultant forces unless dynometric measurements are made also.

Intuitively, one might expect the SEMG amplitude to decline progressively with fatigue. Although the SEMG amplitude will eventually decrease with fatigue, the onset of fatigue *cannot* be reliably determined solely by observing an amplitude tracing. In fact, if fatigue is defined as the loss of the ability to sustain a constant force level, the SEMG amplitude may typically remain steady or increase at fatigue onset. Fatigue relationships may be studied profitably by examining shifts in the frequency content of the SEMG signal, an advanced topic that is introduced later in this chapter (see page 13).

Thus, the SEMG amplitude is not itself an indicator of force, strength, or fatigue. However, when properly performed, analysis of the SEMG amplitude is a reliable and valid tool for qualitative and quantitative observations of recruitment intensity as well as the timing of muscle activation and deactivation.

LABORATORY EXERCISE 4: Fundamental Principles

Use the set-up described in Laboratory Exercise 3: Basic Display Options for the following exercise. For each task, remember to adjust the amplitude scale to optimally visualize the level of muscle activity.

- Tap on the electrodes. Jiggle the lead wires. Do you observe movement artifact? How could you minimize the effects of movement artifact?
- Unsnap one of the active electrodes (you will not harm the subject nor the machine). What happens to the SEMG display for that channel? This is also the way the display typically appears if an electrode pulls lose or otherwise makes faulty contact – a common problem to be aware of.
- Ask the subject to perform several repetitions of active elbow flexion. Which channel shows the greater amplitude, the channel with

the narrower active electrode placement or the channel with the wider active electrode placement? Why?

- Provide gentle resistance as the subjects performs a modest elbow extensor contraction. Which channel shows the greater amplitude, the channel with the narrower active electrode placement or the channel with the wider active electrode placement? Why?
- *NOTE:* see the appendix for instructions if you want to record the measurement rather than simply observe the signal in the monitoring mode as before.
- Focus on the display from Channel 1 and ask the subject to perform several repetitions of elbow flexion/extension against gravity at a moderate rate. Observe the concentric versus eccentric phases of movement. Which phase is associated with higher SEMG amplitude? Is this what you would expect? Which phase would be associated with greater peak torque if maximal resistance were applied to the movement? How can you explain the results?
- Ask the subject to flex the elbow rapidly and then very slowly. Which trial results in greater SEMG amplitude? Which trial would result in greater peak torque if maximal resistance were applied during the movements? How can you explain the results?
- Manually muscle test the subject's maximal voluntary effort for resisted elbow flexion. Perform three contractions, about 6 seconds each and separated by at least 30 seconds of rest (do not perform this exercise if the subject has neck or shoulder pain or otherwise might be injured). Test isometrically with the limb positioned in the shortened range, mid-range, and the lengthened range. Which position is associated with the greatest SEMG amplitude? Repeat testing if you need to confirm the results. Which position would you expect to be associated with the greatest peak torque? It should be apparent now that the SEMG amplitude cannot be equated with force.
- Maximally resist the subject through several repetitions of a functional task, such as feeding. Does the value for peak biceps activation change? If so, why?
- Add quick stretches during the task. Does the value for peak biceps activation change? If so, why?

- Perform several tapping repetitions over the bicipital tendon, as if you were testing the biceps reflex. Change the amplitude scale so that you are able to clearly visualize deflection of the SEMG signal with each tap. What two things might be responsible for the transient increase in amplitude that accompanies each tap? Is there anything you could do to distinguish between the two effects?

Optional fatigue test:

- Use *Escape* to exit the measurement screen or *End* to get out of the record viewer screen. Click on *Back* to return to the MyoClinical entry screen. Choose *Clinical Frequency Protocols* and click on *Next*. Type in a file name such as fatigue and click on *Measure*. Click on the yellow *Calibration* button.
- Ask the subject to assume a seated position with elbow flexed about 90 degrees. Stand above the subject's arm and resist maximal effort elbow flexion until fatigue clearly results and/or the subject wishes to stop (may require 1-2 minutes of effort). Encourage the subject to sustain maximal effort throughout the activity. Make sure to click on *Store* as soon as the contraction starts (the tracing turns red to indicate that it is being recorded). After 1-2 minutes click on *Exit* to end the recording and *Yes* to save it. Watch the SEMG amplitude carefully during the contraction. Does the SEMG amplitude increase, decrease, or remain relatively flat at the onset of observable fatigue? Can you explain the results?
- Follow the instructions on the Record Viewer screen prompting you to place two markers (vertical white lines) by double clicking in the beginning and at the end of the EMG tracing. (You can leave out the very beginning of the recording if it includes the ramp of getting to the maximum level). Click on *Continue*. The bars in the two graphs represent 2 second time intervals through out the 1-2 minute test. Compare what happens to the SEMG amplitude versus the median frequency during the contraction. You should note a relatively steady decline in the median frequency from the start of contraction. The median frequency declines in a reliable way during sustained, high intensity isometric contractions and can be used to quantify the

effects of fatigue. In clinical situations, the SEMG *amplitude* does not change in a predictable way at the onset of fatigue and should not be used to define fatigue relationships.

At the end of the lab exercise:

- Remove the electrodes for Channel 1. Support the skin with one hand while gently peeling off the electrode with the other, peeling in the direction of any hairs. Spread a thin layer of conductive gel over the recording area (use a dab of electrical stimulation gel or try to smear some gel from the electrodes if using a electrodes with low viscosity gel). Reapply the Channel 1 electrodes (use new electrodes if necessary. Tape may be required to hold the electrodes in place. Instruct the subject to perform several repetitions of elbow flexion as well as isometrically resisted elbow flexion. Does the SEMG amplitude appear different than before? Why?

LABORATORY EXERCISE 5: Heart and Respiration Artifact

- Prepare the skin for recording over the left and right crest of the upper trapezius (FIGURE 5) and also over the C7 spinous process.
- Apply one of the single electrodes for Channel 1 over the center of the crest of the left and the other on the right upper trapezius. Place the single reference electrode over the C7 spinous process.
- Ask the subject to shrug his or her shoulders several times. Observe an increase in signal amplitude with shoulder shrug and decrease in signal amplitude with release.
- Instruct the subject to sit quietly and look for the presence of heart artifact as a series of transient spikes or bumps in the baseline.
- Monitor the subject's pulse and assess if the palpable pulse rate corresponds to the deflections of the SEMG amplitude. What could you do to reduce the heart artifact?
- Remove the recording electrode from the right upper trapezius. Attach a new electrode and apply it as close as possible to the

recording electrode over the left upper trapezius, just so the two electrodes do not touch if using solid gel electrodes. (Wet gel electrodes have an adhesive area around the conductive gel and will not short even when the edges are touching.) What happens to the amplitude of the recorded heart artifact? Heart artifact is "cross-talk" from the heart, similar to the issue of volume conduction from the triceps recorded in the biceps electrodes as seen in *Laboratory Exercise 4*.

- Instruct the subject to breathe through several deep respiratory cycles. Do you observe waxing and waning of the SEMG amplitude with the respiratory cycle? Would the techniques you described to reduce heart artifact be effective in diminishing respiration artifact? Why?
- The only way to reduce respiration artifact is for the subject to change his or her breathing pattern. Might respiration artifact be helpful in training a patient to adopt a diaphragmatic breathing pattern?

SEMG Feedback Training

SEMG feedback helps patients learn to increase the activity of weak muscles, decrease the activity of overly tense muscles, or change the coordination pattern of an antagonist with its antagonists and synergists. The artificial cues derived from an SEMG visual or auditory display are far more sensitive than those derived from a subject's intrinsic sensory system. SEMG information serves as an error detection mechanism, enabling the subject to evaluate various motor strategies for those that satisfy a particular muscle activity goal. Patients repeat strategies that are successful and learn ultimately to associate intrinsic sensations with the desired movement, so that they can independently perform the task. At the same time, the subject learns how to refine motor programming rules (consciously or unconsciously). Commands from the central nervous system become more efficient in activating or deactivating muscles, or relating the amplitude and phasing relation-

ships among multiple muscles, as skill is acquired. Patients may then be guided by the therapist to transfer those skills to functional contexts to reduce disability.

Basic feedback training techniques are introduced below. Feedback training strategies for specific clinical syndromes are discussed in subsequent chapters of this text.

LABORATORY EXERCISE 6: Basic Feedback Training Techniques

- Apply two recording electrodes over the left and right **upper trapezius** (FIGURE 5). If you performed Laboratory Exercise 5, continue with the same left upper trapezius electrodes and simply add a homologous set up on the right side.
- Use the *Back* button if necessary to return to the MyoClinical entry-screen or open the MyoClinical program by double clicking on the icon if this is a new session. Click on the down arrow under Groups to select *Feedback Monitor Protocols*. Click on *Next* and *Measure.* Click on the yellow *Calibration* button. You can click on the *Split* button in the top menu bar to see both the tracing and the bargraph simultaneously. Click on the same button to view the bargraphs only.
- **Isolating activity of the target muscle.** You would use this procedure to begin training in most patient situations, perhaps by first showing a picture of the target muscle to the patient and explaining its function. Instruct the subject to activate the target muscle, in this case the left upper trapezius by shrugging the left shoulder. Orient the subject to the SEMG display and how activation and relaxation corresponds to increased and decreased levels of the signal, respectively. Check that activation of the left upper trapezius is performed without concomitant activation of the right **upper trapezius** (FIGURE 5). If you note activity from the right side, instruct the subject to concentrate on raising purely the left shoulder while simultaneously keeping the right side relaxed. In this way, you would train patients to learn how to recognize and control the action of the target

muscle, without inappropriate coactivation of other muscles. You could analogously perform this procedure with electrodes from another channel placed over the lower trapezius and teach the subject to activate the upper trapezius without activating the **lower trapezius** (FIGURE 7) during a shoulder shrug maneuver. Next, you would instruct the patient to activate the lower trapezius without coincident activation of the upper trapezius by retracting and depressing the scapula. With an actual patient, you would document the number of microvolts attained by each muscle during a representative contraction trial (or average of 3-5 trials) at the beginning and end of the training session. Alternatively, you could print out actual amplitude levels and graphs of the activity pattern of each muscle using the report function.

- **Downtraining (relaxation training) using goal markers.** Instruct the subject to just initiate a shoulder shrug and hold that level of activation steady, pretending to be a patient with hyperactivity of the upper trapezius. Adjust the amplitude scale with the *up and down arrows* below the bargraphs so that the baseline activity level falls within the bottom one-third or so of the display. *Drag* the white goal marker down to a level equivalent to about 80-90% of the running baseline amplitude. Ask the subject to try to relax so that his or her activity levels falls below the threshold. Assuming the subject succeeds, lower the threshold to a value equivalent to about 80-90% of the new running baseline. Repeat this procedure until the subject seems to be as relaxed as possible In this way, you can progressively **shape** relaxation responses in real patients. Experiment with different relaxation techniques, such as contract:relax, diaphragmatic breathing, imagining a personal place of serenity, or anything else you can think of. With an actual patient, you could document the average number of microvolts during a 1-3 minute baseline and the lowest 1-3 minute average during practice, or the lowest threshold value the patient can consistently maintain. Alternatively, you could print out actual amplitude scores and graphs of the activity pattern of each muscle using the report function.
- **Uptraining using goal markers.** Instruct the subject to initiate a moderate shoulder shrug, pretending to be a patient with poor acti-

vation of the upper trapezius. Adjust the amplitude scale so that the baseline activity level falls within the top one-third or so of the display. Set the white threshold bar to a level 10-20% higher than the amplitude associated with the shrug (you can *drag* it up and down with your mouse). Ask the subject to try to activate the upper trapezius so that his or her activity rises above the threshold. Be sure to allow adequate rest periods for example, by instructing the subject to shrug for 5 seconds and rest for 10 seconds with each trial. Assuming the subject succeeds, move the threshold to a value 10-20% higher than the original level. Repeat this procedure until the subject seems to reach maximal voluntary recruitment with the shrug maneuver. In this way, you can progressively *shape* responses in real patients. With an actual patient, you could try to facilitate recruitment using, for example PNF techniques or strong verbal encouragement. For documentation, you would record the peak microvolt levels generated at the beginning and at the end of the session (or preferably use an average of 3 trials for each), or the highest threshold value the patient can consistently attain. Alternatively, you could print out actual amplitude scores and graphs of the activity pattern of each muscle over the session by using the report function *(see User Manual for Instructions)*.

By combining uptraining of an agonist simultaneously with downtraining of an antagonist or synergists, a patient can change the coordination pattern among muscles. For example, a patient with periscapular pain might be trained to decrease the activity of the upper trapezius while increasing the activity of the lower trapezius during shoulder flexion. Another patient, with hemiparesis and spasticity, might be trained to increase the recruitment of weakened ankle dorsiflexors while decreasing the activity of hypertonic plantarflexors.

LABORATORY EXERCISE 7: Combining Uptraining and Downtraining

- Attach electrodes over the **wrist and finger flexor and extensor groups** (FIGURES 15-16).
- Use *Back* button to return to MyoClinical entry screen or double click on the icon to open the program if this is a new session. Click on the down arrow under Groups to select *Feedback Monitor Protocols* and click on *Next* and then *Measure*. Click on the yellow *Calibration* button in the top left corner of the screen to establish a true baseline.
- Instruct the subject to rest the upper extremity on a table and try to purely recruit the wrist and finger extensors without coactivating the flexors, for several trials.
- Set the white threshold bar for the extensor group about 20% above the subject's peak activity level (you can *drag* it with your mouse).
- Set the white threshold for the flexor group about 20% below the subject's peak activity level.
- Instruct the subject to try to increase extensor activity above it's threshold and while simultaneously keeping flexor activity below it's threshold.
- Continue the process of adjusting the threshold until the subject achieves maximal extensor amplitude without flexor coactivation.

Setting patients up for success

The following five tables list practical tips for the clinician to optimize SEMG feedback training with patients. Many of the suggestions will seem obvious or become intuitive as your familiarity with SEMG develops.

1. SUMMARY CONSIDERATIONS FOR PATIENT PREPARATION

- Treat any underlying acute musculoskeletal dysfunction.
- Begin in a non-distracting environment.

- Explain to the patient what he or she should expect to do and feel during the session.
- Obtain informed consent to continue.
- Position the patient with appropriate postural support, so that the involved body region is visible.
- Explain SEMG training goals and their relation to long-term function.

2. Summary considerations for feedback display setup in SEMG training

- Limit the display to one or two channels until the patient is thoroughly oriented with the training procedure.
- Consider visual feedback for one channel if it is to be the primary focus, and audio for another if it is on secondary concern.
- For visual displays, begin with a simple bar graph or line tracing.
- Ensure that the patient can see and hear the feedback display clearly.
- Demonstrate how the display operates with muscle activation and relaxation.
- Explain any changes in sensitivity/gain and smoothing.
- Use high sensitivity/gain for intense contractions and low sensitivity/gain for modest contractions.
- Use little smoothing for uptraining and coordination training, and moderate to high level of smoothing for downtraining.
- Use line tracing displays for timing and coordination training.
- Arrange multiple visual display fields, so that the left-right or top-down layout corresponds naturally to body site anatomy.
- Use separate visual fields for muscles with independent functions or overlaid fields for the left-right signals of homologous muscle pairs.

3. Summary considerations for feedback structure in SEMG training

- Begin with continuous SEMG feedback.
- Cue basic relaxation or activation schema.
- Use verbal cues, cognitive techniques, manual guidance, facilitation or inhibition techniques, and demonstration.
- Emphasize basic motor strategies to achieve the goal, as well as how to recognize goal attainment versus error.
- Use display visual and/or audio threshold markers to cue goal attainment.
- Encourage self-directed problem solving when feasible. Reinforce the usefulness of mistakes in learning.
- Ask about the patient's experiences by using directed questions regarding motor strategies, kinesthetic perceptions, and visual observations.
- After a preliminary period, alternate feedback trials with no-feedback trials; then progressively fade feedback.
- Consider using a feedback delay with patient self-assessment during the delay period.

4. Summary considerations for practice schedules

- Determine optimal session duration and frequency to begin with. Consider acuity, severity, co-morbidities, clinical pathways or protocols, patient scheduling needs, and cost efficiencies.
- Taper the visit frequency as progress ensues.
- Within each session, maximize the number of practice trials performed, without causing inappropriate symptom exacerbation or progressive performance decrements.
- Consider in the beginning of a subsequent session using settings close to the level of success in the previous session, but not so demanding that the patient cannot succeed during the first several efforts.

- If there are multiple training tasks, begin with blocked trials.
- Randomize practice tasks once the patient is oriented to each activity.
- Discontinue training when the goal outcome is attained.
- Consider early discharge with a detailed home program and telephone follow up for competent learners.

5. Summary considerations to promote skill transfer in SEMG training

- Define requisite postures, muscular synergies, movement sequences, and performance demands for function. Integrate these into training as soon as possible.
- Use part-whole training to build to a skill pattern of chained subtasks.
- Train with all skill components simultaneously for continuous coordination tasks.
- Assess skill carry-over at the beginning and end of each session.
- Progressively move display thresholds up or down to shape responses in desired direction.
- Use more complex, less natural SEMG feedback displays if available.
- Progress to busy environments with background activity, functional lighting or terrain, and interruptions.
- Add simultaneous emotional stimuli, or distractor reasoning tasks or physical activities.
- Progressively withdraw postural support. Build toward simultaneous control of multiple joint segments.
- As appropriate to function, work through increased range of motion; load; velocity; open and closed kinematic chains; and isometric, concentric, and eccentric conditions.
- Provide home assignments to practice development of motor skills. Include both full practice periods and abbreviated methods that are performed throughout the day.

- Use mental rehearsal to imagine skills in functional contexts.
- Move from predictable variations in task pacing and performance to unpredictable variations.
- Replicate or simulate functional tasks every session.
- Consider the potential cost-effectiveness of a SEMG home trainer or therapist site visit.

Useful phrases to use while teaching patients to use SEMG feedback with new motor strategies include:

- *"What do you feel; can you describe it?"*
- *"Where do you feel it?"*
- *"How strong is the sensation compared with what you could feel before?"*
- *"That's good. Think about what your muscles are doing."*
- *"What happens inside your body when the display goes up like that?"*
- *"What did you do to make the signal go down that time? Can you tell me what you did that was different?"*
- *"Have you changed your posture or shoulder position to change the feedback signal that way?"*
- *"Good job. Note how the timing of the two muscles changed when you moved your arm that way. Now that you've got the basic idea, can you figure out how to make the response smoother and larger?"*
- *"Could you tell whether you were doing this correctly without feedback machine? How?"*
- *"If you (patient) were teaching me (therapists) how to do this task, what would you tell me to do?"*
- *"How would I know, without the feedback machine, whether I was doing it right?"*
- *"What would I feel?"*

Data Reporting

SEMG recordings enable clinicians to make a variety of qualitative and quantitative judgments about muscle activity. These conclusions range from simple to very complex and depend on the nature of the clinical question, conditions of movement testing, capabilities of the SEMG system, and skill of the operator.

Qualitative Assessments

Qualitative questions that can be answered with SEMG include:

- Is a target muscle active during a particular functional activity, performance of a prescribed exercise, etc?
- Is the muscle activated promptly on command to contract?
- Is the muscle deactivated promptly on command to relax?
- Does muscle activity make a complete recovery to baseline during rest periods?
- Is there approximate response consistency across movement trials?
- Is there approximate left/right symmetry of muscle activity for symmetrical tasks?
- Does a shift in postural alignment, application of an orthotic, alteration of emotional state or thought pattern, performance of a manual facilitation or inhibition technique, etc., result in a gross change in muscle activity?
- Can the patient learn fundamentally to increase the activity of a weak muscle during a functional task?
- Can the patient learn fundamentally to decrease the activity of an overly tense muscle during a functional task or assisted stretching or joint mobilization program?

LABORATORY EXERCISE 8: Qualitative Assessments with SEMG

- Prepare the skin and attach electrodes over the left and right **medial hamstrings** (FIGURE 36).
- *(see appendix for system setup if necessary)* Double click on Myo-Clinical icon to open the program. Click on the down arrow under Groups to select *Coordination Protocol*. Click on *Next* and *Measure*. Click on the yellow *Calibration* button in the top left corner to establish a true baseline.
- Instruct the subject to assume a standing position and flex the knee against gravity, maintaining the hip in a neutral position. Then ask the subject to return the leg to a resting position for about 5 seconds and repeat several times. Make sure that the subject moves at an approximately constant speed and through an approximately equivalent movement arc each trial.
- Are the hamstrings active during movement? Do the hamstrings activate promptly as movement is initiated and deactivate promptly as the leg returns to a resting position? Does the SEMG amplitude return to the original baseline level in between repetitions? Does the flexion response appear to be consistent across trials? How might the responses differ if you were performing these tasks with a patient with knee flexor spasticity?
- Instruct the patient to stand with equal weight-bearing over each foot and then perform a partial squat to about 70 degrees of knee flexion, return to standing for about 5 seconds and repeat several times. Make sure that the subject moves at an approximately constant speed and through an approximately equivalent movement arc each trial.
- Are the hamstrings active during movement? Do the hamstrings activate promptly as movement is initiated and deactivate promptly as the leg returns to a resting position? Does the SEMG amplitude return to the original baseline level in between repetitions? Does the response appear to be consistent across trials? Does your subject activate his or her hamstrings more during the first or second movement condition? Are the hamstring components activated symmetri-

cally? Are the hamstrings more active during the decent or ascent phase of the squat maneuver? Why? Thinking of the attachments of the hamstrings across the hip and knee, what biomechanical role does the hamstrings play while arising from a squat?

- Instruct the subject to repeat the squat maneuver several times with his or her weight shifted forward versus backward (i.e., with his or her center of mass shifted anterior versus posterior). Repeat several trials with each condition, moving at an approximately constant speed and through an approximately equivalent movement arc. Is there a difference in the pattern of hamstring activation?
- Instruct the subject to perform several repetitions of seated knee extension with the electrodes clear of the seat contact. Make sure that the subject moves at an approximately constant speed and through an approximately equivalent movement arc each trial. Are the hamstrings active during movement? If yes, at what point in the range of motion arc do the hamstrings seem to become active? Now that hip motion has been eliminated, speculate as to what arthokinematic purpose hamstring activation might serve during knee extension?
- Instruct the subject to lie supine, flex the hip by holding with both hands behind the thigh, and actively extend the knee through the fully available range of motion arc. Make sure that the subject moves at an approximately constant speed and through an approximately equivalent movement arc each trial. Are the hamstrings active during movement? If yes, at what point in the range of motion arc do the hamstrings seem to become active? Is the response you see here consistent with what you observed with seated knee extension? Do you think there might be different responses among subjects with very tight or lengthened hamstrings?
- Experiment with different stretch positions and techniques designed to promote hamstring flexibility. Within safe limits for your subject, include standing, seated, and supine stretching positions. Within safe limits for your subject, compare “bouncing” motions versus a steady, sustained stretch. Try adding in contract/relax maneuvers or diaphragmatic breathing. Do you think there might be different

responses among subjects with very tight or lengthened hamstrings? Based on your observations, what position and stretch method would you favor for a patient with chronically tight hamstrings and a painful back and hip? Why?

Quantitative Assessment

Clinicians make quantitative assessments most often by documenting microvolt amplitude values, which when recorded properly, serve as indicators of the instantaneous recruitment levels of muscles. In addition, sophisticated SEMG devices are capable of quantifying timing parameters, such as the latency to activation of a muscle, duration of activity, time from onset to peak activity; or precise timing relationships among agonist, antagonist, and synergist muscles. Also, the effects of fatigue can be quantified with frequency spectral analysis – a relatively advanced and less common clinical technique introduced in *optional Laboratory Exercise 6* on page 13. Discussion here is focused on microvolt amplitude procedures of importance to clinicians.

Simple comparisons of microvolt values may be made from one muscle, in the same person, before and after a treatment intervention or (in most clinical situations) across sessions. For example, the number of microvolts recorded from the cervical paraspinal muscles of Mr. Smith in a spontaneous, forward head posture could be compared to the number of microvolts recorded from Mr. Smith's cervical paraspinal muscles following transition to an improved postural alignment. In other words, it is acceptable to compare microvolt values directly if the comparisons are made within muscle site, within subject, and within session.

Direct comparisons of microvolt values are also often made within muscle site and subject but across training sessions. If Mr. Jones was learning to increase activity of his right biceps during attempted elbow flexion and showed a peak recruitment value of 10 microvolts the first week of rehabilitation, 20 microvolts the second week, and 40 microvolts the third week, it might generally be inferred that recruitment

ability is improving. This inference assumes that the original recording set-up is replicated precisely each session – the same SEMG instrument (with the same frequency bandpass and microvolt quantification method), the same electrode type, the same electrode placements, and so forth. Although this type of comparison is routine in clinical rehabilitation, it would likely not be suitable for a controlled research design.

Normalization

From the earlier discussion and laboratory exercises, it should be apparent that "a microvolt is not a microvolt is not a microvolt." For example, 5 microvolts recorded from the wrist extensor group does not have the same meaning as 5 microvolts recorded from the wrist flexor group or 5 microvolts recorded from the gluteus maximus in the same person. And 5 microvolts recorded from the gluteus maximus in one person does not have the same meaning as 5 microvolts recorded from the gluteus maximus of another individual. Further, identical activation of the wrist extensor group in one individual may result in vastly different microvolt scores if SEMG instruments from different manufacturers are compared.

As summarized in earlier sections in this chapter, **Basic Display Options & Recording Principles** and **SEMG, Force, And Fatigue Relationships**, a complex set of factors influences SEMG amplitude measurements. Differences in skin impedance, subcutaneous adipose, muscle geometry and morphology, and unintended variations in electrode set up as well as many other factors confound microvolt comparisons made across recording sites or persons. In addition, manufacturers of SEMG devices vary in their signal amplification and processing methods, which precludes direct comparison of microvolt scores across brands of instruments. SEMG devices are nothing more than sophisticated voltmeters but it is important to recognize that voltage readings are relative to the unique characteristics of each recording set up.

These factors pose a challenge for the clinician who for example, wants to compare the relative recruitment level of Mr. Jones's biceps to that of Mr. Jones's triceps; or wants to compare readings from Mr. Jones's biceps to Mr. Smith's biceps; or wants to compare activation of Mr. Jones's biceps during a standardized task to published database values developed with a different type of SEMG instrument.

The solution to these problems lies in the mathematical process of *normalization*. Using normalization, the microvolt score during the clinical task of interest is converted to a percent of the microvolt value associated with a reference contraction. If comparing homologous muscles and symmetrical movement tasks, the left side can serve as a reference for the right side. Alternatively, the activity level of a muscle during a clinical task can be expressed as a percent of its maximum recruitment level. Once the microvolt scores are normalized, comparisons can be made more effectively across persons, recording sites, sessions, or brands of SEMG devices.

Percent Difference

The following formula is recommended to calculate the left-right percent difference in SEMG amplitude scores recorded during a movement of clinical interest:

$$\% \text{ Difference} = \frac{(\text{higher number of microvolts} - \text{lower number of microvolts})}{(\text{higher number of microvolts})} \times 100$$

In this scheme, the specificity of left versus right scores does not matter. The percent difference between them is derived by subtracting the lower side microvolt score (left or right, whichever it happens to be) from the higher score, dividing by the higher score, and multiplying the result by 100. The microvolt scores might be average values during a movement task or more commonly, peak values recorded during a movement. Ideally, peak values from the left and right would be aver-

aged respectively over 3-5 movement trials and then entered into the formula.

For example, consider a patient with unilateral low back pain who performs standing trunk flexion and then returned to neutral standing. Suppose the SEMG device records a peak amplitude of 40 microvolts from the left lumbar paraspinal muscles during the movement and a peak of 20 microvolts on the right. Using the above formula, we find:

$$\% \text{ Difference} = \frac{(40uV - 20uV)}{40uV} \times 100\% = \frac{20}{40} \times 100\% = .50 \times 100\% = 50\ \% \text{ Asymmetry}$$

A 50% asymmetry score is identified. Intuitively, peak SEMG activity from the lumbar paraspinal muscles might be expected to be roughly symmetrical during flexion/extension. Once the SEMG scores are converted to a percent difference score, the findings can be compared to a standardized database or used to track resolution of asymmetry (hopefully) through a course of a therapy visits.

To take another example, imagine a patient with hyperactivity of the right upper trapezius performing 3 repetitions of bilateral shoulder flexion, moving both arms through an equivalent range of motion arc at equivalent speed. Suppose the SEMG device derives peak SEMG amplitudes from the left and right sides and then averages those respective peak values, so that the average peak from the left side is 10 microvolts and that from the right is 30 microvolts. Using the percent difference formula, we find:

$$\% \text{ Difference} = \frac{(30uV - 10uV)}{30} \times 100\ \% = \frac{20}{30uV} \times 100\% = 0.66 \times 100\% = 66\% \text{ Asymmetry}$$

In this case, there is a 66% average asymmetry score between peak recruitment of the left and right upper trapezius muscles during shoulder flexion.

Note: This calculation is done automatically in the *Symmetry Report* in MyoClinical. In the report it is listed under the bargraphs as *Difference score 1*.

Should you want to select a different formula, left-mouse click on the graph and then right-mouse click to get to the settings.

Percent of Maximal Voluntary Contraction

Sometimes a percent asymmetry score has no clinical meaning, for example with patients with bilateral problems or during the performance of inherently asymmetrical movement tasks. A different normalization procedure can be helpful and also brings intuitive appeal to judgements as to "how hard a muscle is working," relative to its maximal recruitment level. The peak or average microvolt score during a clinical task of interest is divided by the number of microvolts recorded from the same muscle during a maximal effort isometric contraction, and the result multiplied by 100, to yield a *percent of maximal voluntary contraction* (%MVC; also commonly referred to as percent of maximal voluntary isometric contraction, %MVIC). The %MVC normalization formula is:

$$\%MVC = \frac{\text{peak or average number of microvolts during clinical task}}{\text{maximal number of microvolts during isometric manual muscle test}} \times 100\%$$

Clinicians usually use a standard manual muscle test procedure while recording the intensity of maximal voluntary isometric contraction. Three trials of manual muscle testing might be performed and the peak values averaged to generate the denominator for the %MVC normalization equation (some computerized SEMG systems can be programmed to calculate the highest rolling average amplitude, e.g., over a time bin ranging from 100 msec to 2 sec, during maximal effort testing).

Note: In the *Muscle Pattern* protocols in MyoResearch, the program will automatically find the highest consecutive 1 second period obtained during the 2 or 3 maximum attempts, each lasting for 3-5 seconds and use that as 100 % when normalizing any other trials for the same patient.

Take, for example, the case of a patient with right side neck pain that is exacerbated during computer data entry performed for prolonged periods as an occupational task. Suppose it was desirable to evaluate the patient's work to try to identify ergonomic adjustments associated with reduced upper trapezius activity. During a standardized data entry task simulating the patient's existing set up, an average of 20 microvolts is recorded from the right upper trapezius. During three maximal effort contractions of the upper trapezius (best assessed with by applying manual resistance just proximal to the patient's elbow with the shoulder positioned isometrically in 90 degrees of abduction), peak activity is recorded as 95, 100, and 105 microvolts respectively, or 100 microvolts average. Using the %MVC formula we find:

$$\%MVC = \frac{20 \text{ uV data entry}}{100 \text{ uV maximal effort}} \times 100\% = 0.20 \times 100\% = 20 \ \%MVC$$

The patient's upper trapezius is seen to recruit at 20% of its maximal voluntary isometric activity during the data entry task. Next, a different keyboard is substituted, the patient's seat is adjusted, and the monitor raised in height. During the same data entry sequence used earlier, an average of 5 microvolts is recorded from the right upper trapezius. Entering the new value:

$$\%MVC = \frac{5 \text{ uV data entry}}{100 \text{ uV maximal effort}} \times 100\% = 0.05 \times 100\% = 5 \ \%MVC$$

Following the ergonomic interventions, average activity of the right upper trapezius is reduced to 5 %MVC from the 20% MVC produced before. Muscular effort appears lower and it might be assumed that this would be a desirable change for the workplace, associated with lower rates of tension and fatigue. The objective results might be shared with the patient and employer to increase the likelihood of compliance with workstation adjustments.

As was the case with the percent difference method, microvolt scores normalized as a %MVC may be properly compared across subjects. Thus, an experimental study could be constructed wherein %MVC

scores associated with two standardized ergonomic set-ups are averaged across subjects and compared across conditions.

To take a different example, the average %MVC score from a healthy control population might be compared with the average %MVC level derived from a sample of patients with chronic neck or upper extremity pain using an identical ergonomic set up and typing task. In this way, differences in muscular activity between the groups might be found to be associated with chronic pain problems. This information might be incorporated into employer intervention programs to help reduce injury rates.

Other Normalization Methods

Conversion of microvolt measurements to %MVC scores is a popular normalization method used in kinesiological and applied clinical research. However, there are numerous alternative methods used by research investigators. These become necessary when left/right percent symmetry or %MVC procedures are not meaningful. For example, calculation of %MVC scores has no significance if subjects cannot produce a reliable maximal effort - due to pain, neuromuscular disease, or behavioral reasons. In such cases, it might be feasible to normalize the microvolt scores associated with a clinical task of interest as a percent of the microvolt amplitude recorded during with a standardized submaximal contraction.

Suppose it was desirable to conduct a study in which upper trapezius muscle activity is compared during use of two different keyboards, using a standardized typing task, in healthy control subjects and patients with headaches and neck pain. Some of the patients might not be able to produce a reliable MVC microvolt score due to pain responses. To work around this confound, each subject could be asked to abduct his or her arm to 90 degrees, usually a pain-free maneuver. The number of microvolts recorded from the upper trapezius during maintenance of the abduction position could then be used as a reference value. Hence, for each subject, the number of microvolts recorded dur-

ing the typing task would be divided by the microvolt amplitude associated with holding the arm in 90 degrees of abduction, and multiplied by 100 to yield a percentage value. The percent scores could then be averaged across the subjects of each experimental group and compared with each other. This method is nearly identical to the %MVC procedure. The change is that microvolt values associated with a standardized submaximal contraction are substituted for the MVC values in the denominator of the formula.

Normalization can be accomplished using many other submaximal contraction methods and the techniques can be rather complicated and time-consuming, and therefore used more often in experimental studies than clinical applications. Some investigators prefer to normalize SEMG amplitudes recorded during an experimental task as a percent of the microvolt levels associated with production of a 30 or 50 %MVC force level. This method is used with subjects capable of producing a reliable MVC. First, a dynamometer records the maximal force level a subject is able to produce. Fifty percent of that force level is calculated, and the subject is given access to the dynamometer display to voluntarily generate the target force level. The number of microvolts associated with the target force level is then noted. Finally, for each subject, the SEMG amplitude recorded during the experimental task is divided by the SEMG amplitude associated with the target force level. Percentage scores may then be properly averaged across subjects.

During cyclical movement tasks, such as gait or a repetitive series of shoulder flexion movements, the onset of each trial can be marked by an electrical switch or manually placed markers. Successive SEMG tracings may then be overlaid and averaged, to produce an ***ensemble average*** tracing. Each SEMG data point in the ensemble average can be normalized as a percent of the greatest SEMG value recorded during the movement series. Alternatively, each SEMG data point in the ensemble average can be normalized as a percent of the average SEMG amplitude for the whole movement series. Yet another normalization method is to partition the cyclical movement into discrete phases; for example, by averaging SEMG values during shoulder flexion from 0 to

30 degrees, 30 to 60 degrees, 60 to 90 degrees, 90 to 120 degrees, 120 to 150 degrees, and 150 to 180 degrees respectively. The microvolt average during the phase of greatest clinical interest could be divided by the average of a different selected phase.

When the ability to rapidly relax and contract a muscle is of interest, the peak amplitude during movement can be divided by the amplitude recorded during rest. This procedure generates an activity / rest -ratio. With a repetitive movement series such as multiple trials of shoulder flexion, peak scores during flexion would be averaged across trials and then divided by the average of the minimum scores detected during each inter-trial period. The activity / rest -ratio may be useful in quantifying neuromuscular performance in patients with spasticity or perhaps in workers with repetitive strain injuries.

In a similar way, to express the ratio of concentric to eccentric activity, the peak amplitude recorded during the concentric movement phase would be divided by the peak amplitude noted during the eccentric phase. A concentric / eccentric -ratio can be used, for example, to help discriminate certain patients with chronic low back pain from healthy subjects.

If an experimental effect is robust, differences in SEMG scores between experimental and control groups may be statistically significant even without normalization. This is sometimes observed in clinical reports. Commonly though, variability in SEMG scores across subjects is large relative to sample means and discrimination between groups can be difficult. Normalization procedures effectively change the distribution of scores for each group by reducing variability around the group mean, allowing better discrimination of group differences.

These various normalization methods can be confusing and reasonably regarded as one of the more difficult aspects of clinical SEMG. Clinicians should understand the principles of why normalization is important as well as be able to calculate left/right percent asymmetry scores and %MVC scores. The other methods are worth noting because the

clinician will encounter them, and variations on the themes, in experimental reports. A poor normalization method may seriously confound investigative results and clinicians should consider the merits of the author's choice when reading scientific papers. Further, if no normalization method is used (as is sometimes the case), and no difference is found between experimental and control groups, then it is difficult to draw any conclusions from the study. That is, are the findings due to a true lack of experimental effect or rather due to spurious factors that could have been controlled with a normalization procedure? There is no practical way to answer the question without changing the experimental design. In some studies, no reasonable normalization method can be identified due to nature of the clinical problem or inherent limitations of the SEMG recording set up. It is reasonable in these circumstances to expect discussion of the problems and implications by the study authors.

Not much can be done when no practical normalization method is available, except to use as meticulous SEMG technique as is otherwise possible and accept a larger potential margin of error in the results. In summary, normalization methods are not required if comparisons are kept within recording site, subject, and session. Calculation of left/right percent asymmetry and %MVC are not time consuming nor difficult for most clinical applications.

LABORATORY EXERCISE 9: Normalization

The SEMG system you are using possesses powerful software that automatically performs certain normalization functions. For learning purposes though, this exercise will focus on manual calculation of percent asymmetry and percent of maximum voluntary contraction (%MVC). A similar sequence of steps could be performed on a SEMG instrument that only captures and displays the maximal microvolt level produced during a contraction trial (e.g. MyoTrace200 without on-line connection). A calculator will be handy for this exercise.

- Apply electrodes for Channel 1 over the left upper trapezius and those for channel 2 over the right **upper trapezius** (FIGURE 5).
- *(see appendix for system setup if necessary)* Double click on Myo-Clinical icon to open the program. Click on the down arrow under Groups to select *Feedback Monitoring Protocol*. Click on *Next* and *Measure*. Click on *Split* in the top menu bar and then on the yellow *Calibration* button in the top left corner to establish a true baseline.
- Observe the *underlined number* above each bargraph. These numbers keep track of the highest amplitude achieved so far. If the number remains high due to earlier activities performed in the same monitoring screen, refresh the maximum values by pressing *Escape, Measure, Split*.
- Percent asymmetry: Imagine that your subject was a patient with chronic unilateral neck and shoulder pain and you were interested in testing for asymmetrical activation of the upper trapezii.
- Ask the subject to perform 5 repetitions of bilateral simultaneous shoulder flexion. Instruct the subject to move normally with both arms, through a complete and symmetrical range of motion arc at moderate and consistent speed. Use the first 2 repetitions for practice and then:
- Following each of the successive 3 repetitions, ask the subject to pause and write down the maximum SEMG amplitude values for the left and right upper trapezii.
- Following the third repetition, average all the left side values and then average all the right side values.
- Calculate the percent asymmetry using the formula:

$$\%\,\text{Difference} = \frac{(\text{higher number of uV} - \text{lower number of uV})}{(\text{higher number of uV})} \times 100\%$$

- How would you test asymmetry of lumbar paraspinal (FIGURE 30) muscle activation during standing trunk flexion? If time allows, try it (use Channels 3 and 4 if available: you will need your Channels 1 and 2 for upper trapezius set up again).
- % MVC: Imagine that your subject was a patient with chronic unilateral neck and shoulder pain and you were interested in using

SEMG to help make ergonomic adjustments to her work station. For the sake of simplicity, select either the left or right side for the remainder of this exercise and ignore the other side.

- Position the subject's shoulder in 90 degrees of abduction and apply maximal isometric resistance for about 6 seconds just proximal to the elbow. Record the maximal microvolt value detected from the upper trapezius during this activity.
- Repeat three times and note the greatest of the three maximal effort peak values. This greatest value will serve as the denominator for the %MVC calculation.
- TASK 1. Have the subject simulate typing in a slumped, forward head, rounded shoulder posture with elbows abducted and a tense, heavy keystroke style for about one minute. Remember to click on *Store* when the activity starts and *Exit* at the end. Click on *Yes* and use the record viewer screen to obtain average amplitude values for each muscle. (Click anywhere on Channel 1 tracing, then on *Statistics* in the top menu bar. Write down the mean value and click on *OK*. Repeat for Channel 2. Remember to click on *End* when you are done).
- Calculate the %MVC using the formula:

$$\%MVC = \frac{\text{average number of uV during clinical task}}{\text{maximal number of uV during isometric manual muscle test}} \times 100\%$$

- TASK 2. Instruct the subject to simulate typing with a more relaxed keystroke style and as ideal a postural alignment as possible. Follow the software instructions above. Are the %MVC scores different for the two typing conditions?
- Discuss how you could design an experiment and process SEMG data to investigate arm position and upper trapezius activity while using a computer mouse.
- Discuss how you could design an experiment and process SEMG data to investigate the relative activity levels of the erector spinae and gluteus maximus during simple supine bridge movements. Would you expect the bridge movement to require greater activation

of the erector spinae or gluteus maximus? Can you envision how you can use the %MVC method to graduate the intensity of therapeutic exercises. If time allows, perform the %MVC tests for the bridge movement and then see if you can identify ways to modify the task to change the recruitment pattern.

Chapter 2:

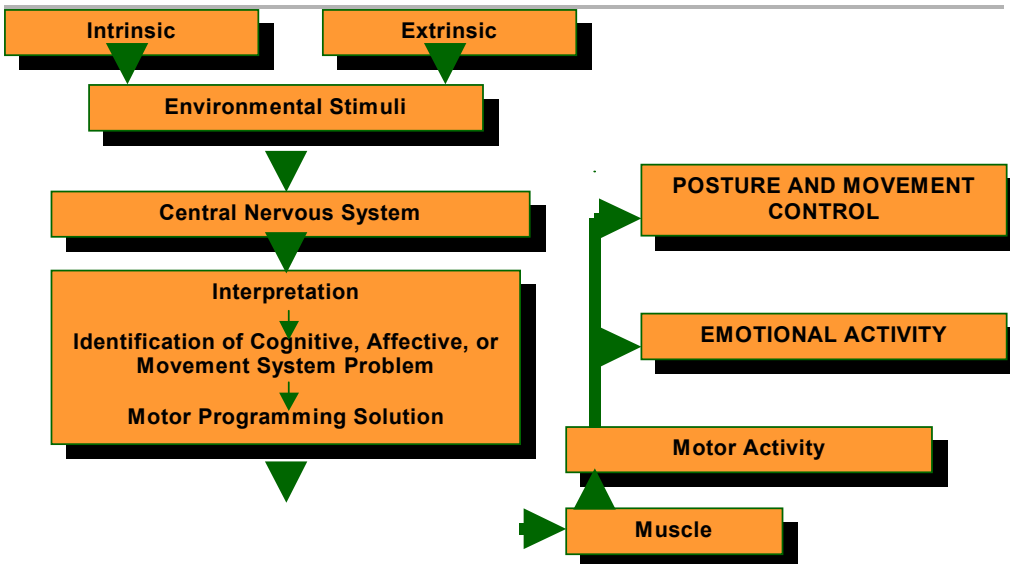
AN OVERVIEW OF SURFACE ELECTROMYOGRAPHY AND MUSCULOSKELETAL DYSFUNCTION

About one third of the adult United States population reports problems related to musculoskeletal dysfunction (Cunningham and Kelsey, 1984), associated with enormous disability as well as social and financial cost. Surface electromyography (SEMG) offers a relatively simple means of monitoring and correcting inappropriate patterns of muscle activity that result in disability due to soft tissue and articular impairments.

Musculoskeletal Dysfunction and Muscle Imbalance

A *kinematic chain* is a series of linked joint segments that function together during movement. Each joint within a kinematic chain may be capable of motion in several planes of space. By connecting a number of joints, each of which has multiple degrees of freedom, a great many combinations of joint position become possible and a complex situation is created for controlling movement (Bernstein, 1967). Muscles serve to constrain and direct motion of the joint system so that purposeful, goal directed activity can be accomplished.

The central nervous system processes sensory input and then generates a series of efferent commands designed to achieve specific goals, which are executed by muscles **(Flow-chart 1)**. In this sense, muscles enable us to solve problems in our internal and external environments (Higgins, 1991).



FLOW-CHART 1. Motor programs and muscles help to solve environmental problems and serve as vehicles for movement as well as emotional expression.

Motor programs are goal oriented, pre-planned groupings of commands from the central nervous system (CNS) that harmonize the actions of muscles with each other and with the intended goal, and vastly simplify movement control of kinematic chains (Schmidt, 1988).

Motor programs that are selected by the central nervous system must produce a biomechanically efficient pattern of motion along the involved kinematic chain or dysfunction and pain will likely result. By way of analogy, when a door is opened through its range of motion arc, an appropriate level of force is applied at the doorknob and the door swings about an axis located at the hinge pin. The door will not open effectively if too little force is used or may be damaged by excessive force. If force at the doorknob is not applied consistently or alternatively, if the hinge plates are not properly aligned or lose, motion may

be uneven and become something of a struggle. Repeatedly dysfunctional cycles of opening and closing the door may exacerbate loosening and malalignment of the hinge in a dysfunctional spiral, until intervention becomes mandatory.

Of course, biological joints do not have a fixed center of rotation. The center of rotation of biological joints tends to change in location depending on the angle of the associated range of motion arc (Kapandji, 1982). Degenerative joint processes occur when joint motion is produced about a series of instantaneous rotation centers that are located inappropriately (Gertzbein et al., 1985). If the arthrokinematics of a joint are not adequately controlled, articular and periarticular structures will inevitably be subject to aberrant compressive, shear, and tensile loading. Three key factors might be postulated to control the arthrokinematic pattern produced at a joint: the shapes of the joint surfaces, which themselves induce certain rolling and gliding motions; the joint capsule and ligaments, which become taut and restrict displacement of joint surfaces at various planes and degrees of motion; and muscles.

Agonist, antagonist, and synergist muscles function together to control arthrokinematics and produce a desired osteokinematic effect. For example, during flexion of the shoulder, the rotator cuff acts to depress and rotate the head of the humerus in a balanced action with the deltoid, so that the deltoid force does not cause excessive impingement of the subacromial soft tissues. Also during flexion of the shoulder, the upper, middle, and lower portions of the trapezius as well as the lower fibers of the serratus anterior (and other muscles) contract with a set of phased relationships to elevate, abduct, tip and rotate the scapula. Changes in scapular kinematics occur with muscular fatigue (McQuade et al., 1998) and patients with musculoskeletal impairments of the shoulder show faulty scapular kinematics (Babyar, 1996) that can be related to imbalanced muscle action (Ludewig and Cook, 2000). Muscle activity that is not properly coordinated is associated with a wide variety of orthopedic disorders.

Muscle imbalance occurs when the relative stiffness of muscles that participate in concert to execute a specific movement is inappropriately coordinated. Stiffness can be expressed as a ratio of change in force to change in length and it is the comparative stiffness of muscles around a joint that determines joint position during motion (Feldman, 1986). Imbalance in muscle stiffness is presumably a function both of faulty central nervous system motor control and peripheral factors such as inefficient length-tension relationships and passive myofascial compliance (Sahrmann, 2001).

SEMG recordings provide insight into the active component of muscle imbalance and can be linked by clinicians to the results of physical examination. Untoward motor programming may be influenced by nociception, perception, affect, beliefs, metabolic and nutritional issues, segmental and suprasegmental motor reflexes, sympathetically mediated reflexes, and a host of factors related to articular function and periarticular connective tissues. Analysis with SEMG can help clinicians to identify relationships between muscle impairments and other physical and psychological impairments. Classification of impairments with observed functional limitations and disabilities can then be used to drive treatment planning in a thoughtful way (Jette, 1996). The effects of interventions designed to impact on muscle function also can be objectively verified, quantified, and documented with SEMG. In addition, patients can use SEMG feedback to lean more efficient patterns of movement control and transfer those skills to functional contexts.

Historical Perspectives

The modern era of SEMG applications in physical medicine and rehabilitation began perhaps in the late 1950's with the pioneering work of Dr. John Basmajian (Basmajian, 1993). Applications for musculoskeletal pain syndromes gained recognition among clinicians during the

late 1960's and 1970's. Approaches tended to emphasize relaxation based biofeedback in response to emotional stressors and psychophysiologic arousal, although methods were also described for clinical movement assessment and exercise prescription (Basmajian, 1989; Basmajian and De Luca, 1985; Schwartz, 1995).

Over the ensuing decades, interest in uses of SEMG with musculoskeletal pain grew and clinically applied applications became a prominent feature at the meetings of numerous professional societies. Gradually, approaches broadened away from traditional images of relaxation biofeedback and increasingly focused on posture, myofascial dysfunction, and dynamic movement (Cram and Kasman, 1998).

The Situation Today

Emergent themes today involve use of SEMG with functional movement tasks, sophisticated exercise prescription, and a muscle imbalance perspective. Discussion in the community of health care providers who use SEMG extends to many patient populations. These include dysfunction in patients who have sustained acute traumatic injuries, repetitive strain injuries in workers and athletes, and problems in patients with other types of chronic musculoskeletal dysfunction.

SEMG procedures should not be employed solely because a patient has chronic pain, but rather when aberrant muscle activity is suspected as being a primary contributory factor to dysfunction and evaluation with SEMG will affect treatment planning. Feedback training with SEMG may or may not then be appropriate to facilitate motor learning by the patient. The important point is that SEMG should be used to enhance functionally meaningful outcomes that reduce patient disability, in ways that support patient satisfaction, while controlling the financial and social costs of care.

With those objectives in mind SEMG may be considered, for example, with patients with:

- tension-type headache
- temporomandibular pain syndromes
- whiplash injuries
- neck pain associated with repetitive work tasks
- shoulder instabilities
- shoulder impingement syndromes
- peri-scapular pain syndromes
- lateral/medial epicondylalgia
- carpal tunnel syndrome
- post-surgical wrist and hand rehabilitation
- chronic lumbar dysfunction
- delayed rehabilitation after cervical or lumbar surgical fusion or laminectomy
- pelvic floor pain syndromes
- chronic hip dysfunction
- delayed rehabilitation after anterior cruciate ligament repair
- delayed rehabilitation after total knee replacement
- selected patellofemoral pain syndromes

Technological advances enable commercial SEMG units to be miniaturized for recordings of muscle activity during ergonomic assessments at the workplace. Patients can perform functional activities for a protracted time and the resultant SEMG data downloaded for analysis. Portable units are easily incorporated into therapeutic exercise programs in the clinic gym or prescribed for home programs. Commercial systems that incorporate a desktop computer are capable of simultaneous recordings from eight or more channels; sophisticated statistical processing of amplitude, timing and frequency variables; and a plethora of options for patient feedback. Telemetry makes recordings possible during a stunning variety of athletic activities, such as swimming, ski-

ing, horseback riding, and more. Software engineers continue to develop more powerful products while exploiting graphical user interfaces so that operation becomes simpler. Manufacturers and vendors are able to deliver SEMG products to consumers with a cost value that outstrips the pricing of earlier models. Integration of SEMG tracings with digital video systems is now within financial reach of clinicians and other exciting hardware and software developments are in the making.

Assessment Of Patients Using SEMG

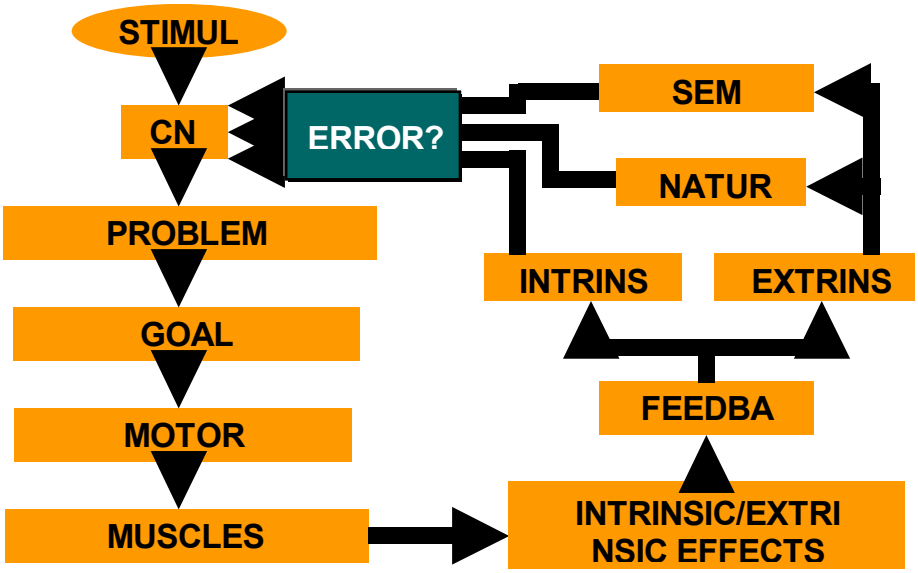
The amplitude of the SEMG signal is usually expressed as some number of microvolts, noted as series of relatively instantaneous measurements, or averaged or integrated over a clinically meaningful period of time. Amplitude analyses are conducted to evaluate the magnitude and timing pattern of muscle activity. Inferences are drawn regarding a muscle's role in effecting a particular posture or movement, and how pathologic processes alter that role. The SEMG activity of a homologous muscle pair or that of an agonist, compared with it's antagonists or synergists, is examined to assess muscle balance. Use of SEMG amplitudes has been described for examination and feedback training with a wide variety of musculoskeletal disorders (Cram and Kasman, 1998; Kasman et al., 1998).

Clinically less common than amplitude analyses, investigation in the frequency domain is performed to study muscular fatigue. SEMG amplitude tracings may be processed to reveal a range of component frequencies, the spectrum of which shifts in a reliable way with fatigue (Basmajian and De Luca, 1985). That is, the frequency spectrum becomes compressed toward slower values due to neuromuscular and metabolic changes associated with high intensity isometric contractions. The shift begins as the contractions are sustained beyond a short time, preceding the actual loss of force, and continues as force declines. This means of fatigue monitoring may have certain advantages over

other measures (Ng, 1997) and successfully discriminates spinal pain patients from control subjects with impressive accuracy (Roy, 1998; Gogia and Sabbahi, 1990). State of the art applications enable frequency analyses to be performed during cyclical dynamic motions (Bonato et al., 2001) and hold promise for clinicians who wish to quantify muscular fatigue directly during the performance of functional tasks. Frequency analyses require specialized equipment and advanced skill even for isometric testing but practical methods are available now in systems designed for clinicians.

SEMG Feedback Training

In addition to clinical and kinesiological evaluations, the SEMG display is often used as a means of feedback for motor learning by patients (Kasman et al., 1998). Muscle cues produced by a SEMG device are far richer than those derived from a subject's intrinsic sensory apparatus. Initially, a patient may have little idea how to change the activity of a muscle that is not under intuitive voluntary control. The patient may not possess a suitable motor programming scheme to achieve the goal (for example, increased activation of one muscle relative to another) and may have difficulty distinguishing correct performance from error (FLOW-CHART 2).



FLOW-CHART 2. Surface electromyographic (SEMG) feedback cues are used to augment intrinsic and naturally occurring extrinsic feedback to form an error detection mechanism during motor learning.

Cues on the SEMG display are obvious and serve as a reference of correctness. Thus the patient becomes able to evaluate various motor strategies for those that meet the goal. Successful strategies are repeated and ineffective strategies are discarded. The patient identifies a progressively smaller subset of effective motor behaviors over time. SEMG feedback is used cognitively to label subtle intrinsic sensations as indicative of changes in muscle activity. Through the repeated association of artificial, extrinsic cues from the SEMG machine with natural kinesthetic sensations, an intrinsic reference of correctness is formed. The learner comes to form mature sensory identification and motor programming schema, and can then achieve the goal independently.

The clinical objectives of feedback training with SEMG for patients with musculoskeletal dysfunction are relatively straightforward.

Patients with muscle ***hyperactivity*** use feedback cues to reduce muscle output. For example, a patient with neck pain and upper trapezius hyperactivity could attend to the SEMG display to help improve posture, self-regulate responses to emotional stressors, or identify ergonomic improvements and motor skills for the workplace. A different patient with headaches and temporomandibular pain might produce chronic masseter and temporalis hyperactivity associated with chronic jaw clenching. Specific SEMG feedback techniques could be used to promote kinesthetic awareness, muscle relaxation, and reduction of para functional behaviors involving the temporomandibular region.

Patients with muscle ***hypo activity*** incorporate SEMG feedback while learning to increase muscle recruitment. For example, a patient might show quadriceps inhibition after knee surgery that delays progress along a standardized clinical pathway. That patient could watch a SEMG display as his or her post-operative exercises are performed. Exercise variants, cognitive strategies, and adjunctive therapeutic agents would be trialed for those that facilitate quadriceps activity. Successful techniques would then be repeated while the patient attempts to raise the SEMG amplitude to match a goal marker on the display, set to progressively higher microvolt values over time.

In addition to training greater and lesser muscle responses as separate objectives, patients may learn to simultaneously increase the activity of a hypo active muscle while decreasing that of a hyperactive muscle. This coordination training takes place between an agonist with it's antagonists or synergists. For example, the patient alluded to previously with neck pain and upper trapezius hyperactivity might also show hypo activity of the lower trapezius. This patient would try to raise the amplitude of the lower trapezius signal, and decrease the amplitude of the upper trapezius signal, during arm elevation maneuvers and simulated functional tasks. Successful training would presumably result in better muscle balance for upward scapular rotation and stabilization, leading to improved biomechanical relationships throughout the neck and shoulder girdle.

Conclusions

A search using "Surface AND Electromyography" on the National Library of Medicine's PubMEd engine demonstrates a clear upward trend in the number of annually based hits for the period of 1985-2001. The trend in research is paralleled by developments in SEMG equipment and clinical procedures. This is not to suggest that clinical applications of SEMG are without controversy. Compelling data supports the use of SEMG feedback training with some musculoskeletal problems but there is an insufficient number of randomized controlled designs to conclusively include or exclude its use for many common disorders (Philadelphia Panel, 2001). Nevertheless, the fundamental validity and reliability of SEMG in movement system and psycho physiological analyses is well accepted (Morrish, 1999: Pullman et al., 2000; Soderberg and Knutson, 2000; Turker, 1993) and recognized in professional practice guidelines (American Physical Therapy Association, 2001). It seems probable that the future will bring new applications of SEMG in performance enhancement in non-injured populations, new developments in forensic medicine, as well as refined approaches to SEMG with musculoskeletal and neuromuscular injuries.

Care providers may choose to make SEMG an integral part of their practice or reserve it's use for occasional investigations of muscle activity and patient training. In any event, SEMG provides a unique means of monitoring muscle activity. Each clinician's repertoire of skills may be broadened by inclusion of SEMG, while patients are provided with powerful opportunities for motor learning. It seems probable that the future will bring new applications of SEMG in performance enhancement in non-injured populations, new developments in forensic medicine, as well as refined approaches to SEMG with a diversity of chronic musculoskeletal disorders.

Succeeding chapters of this manual will focuses on entry-level skills for applications of SEMG with patients. Emphasis is placed on clinical reasoning with SEMG for physical medicine practitioners working with common syndromes. Familiarity with underlying clinical pathol-

ogy and physical examination as well as typical therapeutic procedures (other than those involving SEMG) will be assumed.The greatest weight will be placed on laboratory exercises that illustrate basic SEMG techniques.

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Chapter 3:

REGIONAL APPLICATIONS OF SEMG TO MUSCULOSKELETAL PROBLEMS

This chapter will provide an introduction to clinical applications of surface electromyography (SEMG) for selected musculoskeletal problems. Each section will begin with a brief description of considerations for the beginning practitioner, followed by a case example, and laboratory exercises. The clinical issues that are discussed can be explored in detail through other text resources (Cram and Kasman, 1998; Kasman, Cram and Wolf,1998) as well as numerous review articles and research reports easily identified through literature search.

Temporomandibular region

SEMG has been used in the classic biofeedback arena to promote relaxation of oro-facial muscles associated with tempormandibular dysfunction (TMD) and chronic pain (Cannostraci and Fritz, 1989; Gervitz et al., 1995). These approaches have presumed a cyclical relationship between psychological stress, dysfunctional oral habits such as jaw clenching or bruxism, aberrant biomechanical loading of articular and periarticular structures, and pain (Nicholson et al., 1999). Subjects with chronic TMD demonstrate apparent proprioceptive deficits – they tend to show difficulty discriminating muscle activity states in experimental designs compared with control groups (Flor, 1992; Glaros, 1996). The inference is that some patients with TMD engage in oral behaviors that include chronic hyperactivity of masseter and temporalis muscles with little conscious awareness of their habit. SEMG feedback cues might then be used to assist patients with awareness and resolution of muscle hyperactivity, especially in combination with stress management therapy and orthotic appliances (Hijzen et al., 1986; Turk et al., 1993).

Beyond such traditional psycho physiological applications, SEMG has been used in dental investigations of normal and aberrant neuromuscular relationships around the temporomandibular joints (Angeles-Medina, 2000; Ferrario et al., 1993; Harper et al., 1997; Hellestrand and Hellsing, 1995; Jankelson, 1990; Lafreniere et al., 1997; Lund and Widmer, 1989; Pinho et al., 2000; Yoshida, 1995). The results of frequency analysis of SEMG recordings has demonstrated accelerated fatigue of the masseter in patients with myofascial pain (Gay et al., 1994). Pathomechanical mechanisms underlying nocturnal bruxism have been assessed with SEMG amplitude parameters (Minagi et al., 1998) as have the effects of intraoral appliances and occlusal adjustments (Tsolka et al., 1992; Christensen and Rassouli, 1995). Influences of occlusion and posture on the activity of sternocleidomastoid and upper trapezius muscles have also been reported in patients with mandibular dysfunction (Palazzi, 1996; Zuniga, 1995). Occlusal applications of SEMG are beyond the scope of this manual but facilitation of relaxation and kinesthetic awareness in patients with temporalis and masseter hyperactivity is straightforward.

Case Example

A 42 year old male computer engineer is referred by his dentist with 8 months of progressive bilateral preauricular pain as well as periodic bilateral temporal headache. The patient has a known history of nocturnal bruxism for which he uses a protective night guard and he also believes he clenches his teeth chronically during his daytime hours. Dental and medical histories are otherwise unremarkable. On physical examination, the patient is found to have a forward head posture with apparently hypertrophied masseters as well as wear facets on his teeth, characteristic of bruxism. He opens his mouth to a maximum of 35 millimeters between the teeth with a very modest right deviation of the mandible, with no apparent clicks, pops, or creptius from the temporomandibular joints. There is diffuse tenderness to palpation around the masseter and temporomandibular joint region bilaterally.

Baseline SEMG activity levels from masseter and anterior temporalis sites are elevated in static unsupported sitting and standing relative to expected normative values (Cram and Kasman, 1998) but decrease by about 50% with cueing toward a more erect posture. Activity increases diffusely from baseline levels during visualization of work-related stress imagery and decreases with conscious relaxation.

For treatment, the patient is educated regarding potential relationships between emotional stressors, chronic jaw muscle hyperactivity, and pain. He is referred to a mental health counselor as well as provided with a home audio cassette tape for guided relaxation and kinesthetic awareness, focusing on the head, jaw, and neck. During clinic visits, he is instructed in postural awareness and correction and ergonomic adjustments are simulated for his workstation. SEMG feedback is provided during these activities. He also uses SEMG feedback to assist with deep relaxation of masseter and temporalis muscles and practices conscious discrimination of relaxation versus muscle tension states, at various targeted levels of muscle activation. Instructions are supplied to use an audible timer function on an inexpensive digital wristwatch to signal a pause in activity throughout his daily routine. The patient is asked to monitor posture, gauge jaw muscle activity, and perform a quick relaxation correction if necessary.

These interventions seem helpful in the reduction of daytime muscle hyperactivity and the patient shows progressively lower and more stable baseline SEMG activity with improved abilities to discriminate targeted muscle activity levels each clinic session. He becomes increasingly conscious of his nocturnal bruxism but professes not to know how to cease the behavior. A home SEMG trainer is prescribed with a single channel used at a masseter site. The SEMG electrodes are applied just prior to bedtime and the unit remains silent if activity stays below a therapist-programmed threshold amplitude. However, if the SEMG amplitude exceeds the threshold for more than 7 seconds, an audible alarm is triggered to cue the patient to relax (the feedback delay serves to avoid triggering the alarm due to movement artifacts). The patient at first describes the audio feedback as very disruptive of his

sleep but quickly learns to decrease the number of triggering events and relaxation responses seem to become more automated. In addition to this behavioral SEMG feedback approach, he pursues cognitive-behavioral therapy with his mental health practitioner and all symptoms resolve within 8 visits over a 10 week period, with maintenance of success assessed via periodic phone follow-up.

LABORATORY EXERCISE: Temporomandibular Region

- Apply electrodes over the **left and right masseter** sites using Channels 1 and 2 (FIGURE 1). If desired, use Channels 3 and 4 additionally to examine potentially different recruitment patterns from the anterior temporalis muscles (FIGURE 1).
- *(see appendix for setup instructions if needed)*
- Double click on MyoClinical icon. Click on the down arrow under GROUPS and select SYMMETRY PROTOCOLS. Click on NEXT and MEASURE. Click on the yellow CALIBRATION button to establish a true baseline.
- Observe baseline SEMG activity while the subject sits in his or her spontaneous posture. Then cue the subject to lift his or her sternum and enable the head to be passively retracted toward an erect alignment. Contrast this posture with a deliberately exaggerated forward head posture. Do you see changes in muscle activity with changes in posture? SEMG changes may or may not be observed; if not, and you are working with other subject groups, check around the room for a positive response to examine.
- Observe SEMG activity while the subject performs multiple repetitions of jaw opening/closing at modest and consistent speed and through the comfortably available range of motion. Examine for left/right symmetry in amplitude and timing relationships; i.e., could the tracings be relatively overlaid symmetrically or does one side show greater or earlier activation or deactivation or peak activity?
- Observe the subject's mandible while he or she repeats opening/closing and palpate his or her temporomandibular joints. Can you link your visual and manual observations to the muscle activity pat-

terns displayed on the SEMG screen? If dysfunction in the temporomandibular joints seems apparent, can you imagine how it would be prudent to address that issue prior to, or along with, any attempt at SEMG feedback training?

- Instruct the subject to clench powerfully. Note the typically high microvolt value obtained. The amplitude levels reached are often greater than those recorded from larger muscles elsewhere in the body during maximal effort contractions. Speculate why this is the case.
- As an optional activity, ask the subject to chew some food or gum, or bite unilaterally on piece of gauze. Examine if left/right SEMG responses are reciprocally symmetric for left and right side chewing and biting. Observe any differences in master and temporalis activation if both muscles are being monitored.
- Ask the subject to relax his or her jaw muscles as deeply as possible. Instruct the subject to observe the SEMG display and attempt to lower the SEMG amplitudes to the minimum feasible.
- Once activity is as low as possible, cue the subject to attend to intrinsic sensations associated with a relaxed state.
- Click on ESCAPE to exit the measurement screen and BACK to return to the MyoClinical entry screen. Click on the down arrow under Groups and select FEEDBACK MONITOR PROTOCOLS. Click on NEXT and MEASURE.
- Practice *activation recognition training* using the following procedure. Activation recognition training can be performed analogously with most other SEMG recording placements when patients have difficulty consciously recognizing or modulating muscle hyperactivity.
- Instruct the subject to focus on a single master channel, either the left or right per preference or as associated with a symptomatic side.
- Set the white goal marker about 5 microvolts above the subject's baseline activity level. Instruct the subject to clench just enough to bring the masseter activity level up to the goal, attempting to maintain activity just at that level. Although it will not be possible to exactly maintain the goal value and variance should be readily

expected, ask the subject to use the feedback to achieve as steady a response as is feasible while attending to the intrinsic sensations associated with the task. Have the subject attempt to hold the goal level for about 7-10 seconds and rest for 7-10 seconds, repeating successive cycles of the task. Ensure that the subject relaxes muscle activity promptly and completely to baseline levels in between trials.

- As the subject gains proficiency, lower the white goal marker so that it is just barely above the subject's resting baseline, perhaps 1-2 microvolts or even less. Repeat the task described in item (10) above. The new goal should be associated with exquisitely low levels of master activation, with the threshold reached before there is any occlusal contact (that is, assuming the subject has learned to start from a relaxed baseline with the teeth slightly apart).
- Imagine that the subject is a patient with chronic masseter hyperactivity and clenching behaviors. Role play how you would instruct monitor and correct posture, and monitor and reduce jaw muscle activity if indicated such a patient to pause routine activities periodically through the day, monitor and correct posture, and monitor and reduce jaw muscle activity if indicated.

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Cervical region

Historically, the cervical and proximal shoulder girdle region has been among the most frequently studied and clinically treated areas of the body using SEMG. An enormous number of research reports have investigated the role of the upper trapezius as well as other muscles in posture, movement, workstation assessment, and cervical pain (e.g., Basmajian and DeLuca, 1985; Chan et al., 2000; Elert et al. 1998; Enwemeka et al., 1986; Hagberg, 1984; Johnsson, 1982; Kleine et al., 2001; Lannersten and Harms-RIngdahl, 1990; Lowe et al., 2001; Madeleine et al., 1999; Milerad et al., 1991; Rissen et al., 2000; Roe et al., 2001; Roman-Liu et al., 2001; Schuldt et al., 1987; Schuldt et al, 1988; Vasseljen et al., 1995; Vasseljen and Westgaard, 1997; Villanueva et al., 1997). Clinical approaches tend to focus on identifying stress-related trapezius hyperactivity (often also in relation to headache) and elevations in sitting and standing baseline activity (Cram and Kasman, 1998), cervical muscle asymmetries and trigger points (Donaldson and Donaldson, 1990; Donaldson et al, 1994), postural effects (Middaugh et al., 1994), and potential imbalances in activity of the upper trapezius in relation to the lower trapezius (Taylor, 1990).

Patients with neck and shoulder pain who show changes in SEMG activity of the upper trapezius may have abnormal microcirulatory responses to exercise within that muscle (Larsson et al., 1999). In addition, patients with degenerative cervical joint disease can be characterized by SEMG frequency spectral analysis to have decreased resistance to fatigue in cervical muscles (Gogia and Sabahhi, 1994). Surface EMG frequency shift parameters also are linked prospectively with the development of neck and shoulder pain in industrial workers (Lundblad et al., 1998).

As evaluated with sophisticated amplitude analyses, impairments in the frequency and duration of transient relaxation periods during the performance of functional tasks are concurrently and prospectively associ-

ated with pain and disability in certain types of workers (Hansson et al., 2000; Larsson et al., 2000; Sundelin and Hagberg, 1989; Vierested, 1993; Vierested at al., 1993; Vierested et al., 1990; Winkel and Westgaard, 1992). Relaxation following movement is also impaired in patients with whiplash associated disorder (Nederhand, 2000), along with other deviations in SEMG activity and torque responses (Kendall et al., 2001). SEMG is an effective means of studying effects on cervical paraspinal and sternocleidomastoid muscles during rapid head movements produced by experimentally-induced collisions (Brault et al., 2000). Thus, there is a sweeping scope of material involving SEMG applications in the cervical region. A number of intriguing relationships between SEMG patterns and psychological, physiological, biomechanical, and clinical findings have been proposed although definitive treatment regimens must await further research.

Case Example

A 37 year old female graphic designer presented 16 weeks after sustaining a whiplash injury as a driver in a rear end motor vehicle accident. She progressed with prior physical therapy but appeared plateaued in terms of therapeutic progress. The patient complained of persistent right greater than left posterior neck pain, which interfered with driving, work, and recreational activities.

Cervical and shoulder girdle range of motion were within normal limits for age upon physical examination. Standing alignment was noted to be asymmetrical, with the right shoulder girdle appearing to be elevated compared with the left. Manual anterior inter vertebral gliding was provocative of pain from the mid-cervical region to the cervical-thoracic junction. There was diffuse tenderness to palpation of soft tissues around the neck. Neurological screen was negative.

Baseline SEMG activity was elevated in amplitude and variance on the right compared with the left in static sitting. During cervical flexion, there was a 55%, right greater than left, peak amplitude asymmetry from cervical paraspinal recording sites. Despite the fact that excursion of motion was within nor-

mal range, there was an absence of the expected relaxation response seen typically in full flexion. That is, recordings from the paraspinal muscles all along the spine tend to show quiescence as end range flexion is approached in standing. In this case, paraspinal muscle activity continued unabated.

Baseline SEMG activity also appeared elevated on the right compared with the left from the upper trapezius muscles. A 40%, right greater than left, asymmetry was seen in peak amplitude during bilateral, symmetrical arm abduction. Computer typing and mouse work of a type used in the patient's work tasks were simulated. These maneuvers involved periods of movement interspersed with brief periods of non-movement (pausing for creative thought or examination of the computer screen). However, SEMG activity from the right upper trapezius remained increased and relatively unchanged throughout the trial. Activity did not decrease when upper extremity movement stopped. More commonly, a low amplitude gap, or "microrest," would be expected with each transient pause in movement.

The patient was treated with inter vertebral and soft tissue manual techniques and a conditioning exercise program was prescribed. Workstation tasks were simulated and modifications were evaluated with SEMG for their effects on cervical muscle activity. In addition, the patient used SEMG feedback to generally relax muscle activity in sitting and standing, especially on the right. When difficulty was encountered, she was cued to gently shrug the left shoulder so that muscle activity was increased, and then to consciously relax both shoulders together. She then practiced activating and rapidly relaxing cervical paraspinal and upper trapezius muscles, at first with isolated simple movements such as a shoulder shrug and then during functional reaching and work simulation tasks.

A portable SEMG unit was brought to the patient's car in the clinic parking lot to facilitate transfer of skills to a functional environment known to be associated with symptom exacerbation. However, pain and muscle tension continued to be associated with driving and the patient readily admitted to perceptions of emotional stress in relation to her motor vehicle accident. Referral was made to a rehabilitation psychologist. Working together with her care team, the patient composed a list of 15 imaginary driving scenarios,

ranked in order from non-threatening (e.g., sitting in her car in her driveway) to frightening (driving in heavy stop and go traffic with large trucks). She would then used a favored relaxation technique involving diaphragmatic breathing to induce deep relaxation and would begin visualizing the first scenario on her list. If SEMG activity remained low after several minutes, she would progress to the next scenario, and so forth. If SEMG activity increased, she would return to her relaxation technique and resume the imagery sequence once muscle relaxation was re-established. Practice with this systematic desensitization method (without SEMG monitoring) was added to her daily home program. All complaints resolved, SEMG patterns became unremarkable, and functional activities were resumed at pre-accident levels by the 6th clinic session, over a 4 week period.

LABORATORY EXERCISE: Cervical Region

- Apply the electrodes for Channel 1 across the upper cervical region, as superior as possible while staying below the hair line (FIGURE 4).
- *(see appendix for setup instructions)*
- Double click on MyoClinical icon. Click on the down arrow under GROUPS and select FEEDBACK MONITOR PROTOCOLS. Click on NEXT and MEASURE. Click on the yellow CALIBRATION button to establish a true baseline.
- Observe baseline SEMG activity with the posture spontaneously assumed by the subject.
- Ask the subject to assume a deliberately exaggerated forward head posture, maintaining neutral eye level; i.e., upper cervical extension with lower cervical-thoracic flexion. Does the running SEMG amplitude increase? If so, why do you think this occurs?
- Cue the subject to lift his or her sternum so that the head is retracted passively toward an erect alignment and posture approximates the ideal. Does the running SEMG amplitude decrease? If so, why do you think this occurs?

- Imagine that the subject is a patient with chronic headaches and neck pain, who you observe consistently to display a poor, forward head posture. Role-play how you would use SEMG feedback with the patient to demonstrate the effects of different postures on neck muscle activity. Do you think that providing postural instruction while graphically illustrating the effects with the SEMG display might facilitate patient compliance?
- Next, apply the electrodes for Channels 1 & 2 over the left and right cervical paraspinal (CPS) areas at about the C4 level (FIGURE 4). Apply the electrodes for Channels 3 & 4 over the left and right sternocleidomastoid (SCM) muscles (FIGURE 3).
- Click on ESCAPE to exit the measurement screen and BACK to return to the MyoClinical entry screen. Click on STANDARD SETUP FOR 4 CHANNELS under FEEDBACK MONITOR PROTOCOLS. Click on NEXT and MEASURE. Click on the yellow CALIBRATION button to establish a true baseline for all 4 channels.
- Instruct the subject to perform several repetitions of cervical flexion and extension at a moderate and consistent velocity. Look for approximate left/right symmetry and observe the phase of motion associated with peak activity of the CPS and SCM muscles, respectively. Is activity of the CPS muscles quiescent in full flexion? Do the SEMG patterns match your expectations of what you should see? If not, does the subject of a history of cervical injury or are there apparent mobility problems? Calculate the percent difference in left and right peak amplitude values for the movement using the method described in Chapter 1. Aberrant patterns in patients could include marked asymmetry and an absence of a flexion relaxation response in full cervical flexion.
- Instruct the subject to perform several repetitions of cervical side bending and then rotation at a moderate and consistent velocity and including both left and right directions. Consider the actions of the CPS and SCM muscles. Do the SEMG patterns you observe match your expectations? Ask the subject to repeat the rotation movements. You should observe activation of the ipsilateral CPS and contralateral SCM muscles. You should also see approximate ***recip-***

rocal symmetry in peak activity of each homologous muscle pair from left to right movement directions. Aberrant patterns in patients could include marked reciprocal asymmetry or left/right coactivation throughout the motion.

- Apply electrodes over the left and right upper trapezius muscles (using either additional channels or transfer the leads from Channels 3 & 4)
- Perform Laboratory Exercises 6 and 9 if not completed earlier. These exercises use upper trapezius placements to illustrate basic feedback training techniques and data normalization principles.
- Instruct the subject to practice ***discrimination training*** using the following procedure. Discrimination training can be performed analogously with most other SEMG recording placements when patients have difficulty consciously recognizing or modulating muscle hyperactivity.
- Select either the left or right side for practice.
- Set the lower white target bar at 9 microvolts and the upper bar at 11 microvolts. (NOTE: The higher bar may not be visible if you have chosen a small amplitude scale. Click on the up arrow below the bargraph to increase the scaling until you see the upper bar. Drag it down and decrease the amplitude back to where you want it to be).
- Instruct the subject to use a shoulder girdle elevation motion; i.e., shoulder shrug, to increase SEMG amplitude so that it falls within the goal window (for a target muscle other than the upper trapezius, the isolated action of that muscle is used). Have the subject attempt to hold activity within the window, as close to the 10 microvolt level as possible, for about 7-10 seconds and rest for 7-10 seconds, repeating successive cycles of the task. Ensure that the subject relaxes muscle activity promptly and completely to baseline levels in between trials. Although it will not be possible to exactly maintain the goal value and variance should be readily expected, ask the subject to use the feedback to achieve as steady a response as is feasible while attending to the intrinsic sensations associated with the task.
- As the subject gains proficiency, cover the SEMG display or turn the subject away and ask him or her to repeat the task without looking,

saying “now” when he or she thinks the 10 microvolt target is being met. Then give the subject verbal feedback or if using a line tracing display, reveal the screen, so he or she can monitor actual performance.

- Next move the goal markers for a 6 microvolt target, with the goal lines set to 5 and 7 microvolts, respectively. Repeatthe two steps above with the new target value.
- The objective of this procedure is for the subject to internalize the microvolt scale. With an actual patient, you might perform the two steps with target values from 2-10 microvolts in 2 microvolt increments, spending about 3-5 minutes with each goal value and then verbally calling for a random sequence of values, with and without patient access to the feedback display on alternate trials. You might also have the patient practice the same procedure with the other side (typically patients have more difficulty with the task on the symptomatic side and report different subjective sensations with an identical goal value). Advanced patients can then practice simultaneous discrimination of the same or different goal values, with and without feedback.
- Imagine the subject is a patient with chronic neck pain and hyperactivity of the upper trapezius. Role play how you might instruct the patient to pause activity at home and in the work place; for example, once per waking hour, to gauge what muscle activity level is present in the involved upper trapezius (without any SEMG monitoring). The patient might also be instructed to perform a quick postural correction, abbreviated relaxation technique, or stretching technique, completing the sequence in 30-60 seconds.
- Instruct the subject to practice **deactivation training** using the following procedure. Deactivation training can be performed analogously with most other SEMG recording placements when patients have difficulty relaxing muscles - following voluntary activation or episodically during low mechanical demand phases of functional tasks.
- Select either the left or right sides for practice.

- Set the white threshold just above the subject's baseline activity level. Move the blue threshold to the top of the display where it will be out of the way.
- Instruct the subject to shrug his or her shoulder and hold for 3-5 seconds and then relax as quickly as possible so that activity falls rapidly below the white threshold and returns to a stable baseline. This may seem very simple for healthy subjects but can be quite challenging for some patients.
- Ask the subject to perform a simulated functional task, such as imaginary typing or actual handwriting. As the subject performs typing or writing motions, periodically call out, "pause." At each of those points, the subject should cease movement for 1-3 seconds and attempt to bring SEMG activity below the goal marker to a stable, quiescent level.
- With an actual patient, you would carefully evaluate any indicated changes in posture and ergonomic set up prior to performing this task, using the SEMG amplitude to help guide potentially useful interventions. If, for example, the subject types with a faulty forward head posture and shoulders abducted with the elbows elevated, it will not be possible to create "mircrorests" with movement pauses (have the subject try it!).
- Role play how you would instruct a patient to take 3-5 minutes of each hour of a work task, throughout the work day, every day, to consciously produce a mircrorest each 30-60 seconds. Along with suitable ergonomic interventions, the goals is to have microrests produced spontaneously and unconsciously whenever mechanical demands of the task are low. Most functional tasks are not associated with continuous high level muscle recruitment but instead engender cyclical activity patterns or otherwise episodic bursts of activity interspersed with transient rest periods. Can you imagine analyzing a job or sport activity and teaching a patient to recognize and consistently take advantage of microrest opportunities? Often, it is not as difficult as it might sound, being a matter of appropriate mechanical alignment and equipment handling combined with cognitive awareness of the muscle hyperactivity problem, recognition of

muscle activation sensations, and practicing deactivation with SEMG feedback.

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Shoulder girdle region

The principles described for the temporomandibular and cervical regions in previous sections of this manual are also largely applicable to the shoulder girdle. Issues related to postural alignment, conscious recognition of aberrant muscle activity states, and the production of interspersed rest during functional tasks range through the upper quadrant. Electromyographic amplitude and frequency spectral methods (using surface as well as intramuscular fine wire recordings) have been reported extensively in the study of workers and athletes (e.g. Chow et al., 1999; Cook and Kothiyal, 1998; Jensen et al., 1993; Jobe et al., 1984; Larsson et al., 1999; Pink et al., 1992; Pink et al., 1990; Rodroguez et al., 1990; Sundelin, 1993; Winkel and Westgaard, 1992), to address methodological considerations (Elert et al., 2000; Kelly et al., 1996), and also to evaluate various therapeutic exercises for the shoulder in healthy subjects (Ballantyne et al, 1993; Decker et al., 1999; Hintermeister et al., 1998; Malanga et al., 1996; McCann et al., 1993; Moseley et al., 1992; Sullivan and Portney, 1980) and patients with shoulder pain (Roe et al., 2000).

There have also been reports on the use of SEMG feedback training to address posterior and anterior shoulder instability and subluxation (Beall et al., 1987; Reid et al., 1996; Young, 1994). Recently, SEMG techniques have been combined with sophisticated kinematic assessment systems to investigate the effects of scapular muscle fatigue

(McQuade et al., 1998) and scapular muscle imbalance associated with impingement syndrome (Ludewig and Cook, 2000).

It seems apparent from the literature that changes in the relative recruitment levels of scapular muscles occur with fatigue and injury. An assumption that is often anecdotally stated (e.g. Taylor, 1990) but has not been scientifically validated relates to imbalance among the upper trapezius and lower trapezius. Many practitioners believe they see cases of neck and shoulder pain of mixed etiology where the lower trapezius appears hypo active and the upper trapezius is hyperactive during shoulder elevation maneuvers. Clearly there are alterations in scapular kinematics in some patients with painful shoulders that involve excessive vertical displacement of the scapula, and this pattern may be resolved easily with corrective movement feedback cues (Babyer, 1996). Decreased activity from the serratus anterior during swimming and scaption movements has been associated with painful shoulders in experimental designs (Ludewig and Cook, 2000; Scovazzo et al., 1991) but the role of the lower trapezius has not been addressed clearly. Additional study combining surface and intramuscular electromyographic recordings with kinematic measurements are required to resolve lower trapezius issues, which are technically daunting. Nevertheless, it may be recognized that use of SEMG for lower trapezius training is clinically popular and has intuitive appeal. Clinician should also direct attention to the lower fibers of the serratus anterior as a primary site for clinical evaluation.

Case Example

A 34 year old male construction worker was referred for SEMG assessment 12 weeks after slipping and lurching during heavy overhead work. The patient reported persistent pain along the medial and superior borders of the left scapula despite therapy involving physical modalities, manual techniques, movement re-education and conditioning exercises, medications, and gradated return to work simulations. The patient had returned to light duty, full time work but was unable to return to full duty. No significant medical, bony, articular, or behavioral

problems were identified during prior consultations with family practice, orthopedic, physiatry, physical therapy, and occupational therapy practitioners.

The patient presented with shoulder girdle elevation in standing as well as apparently hypertrophied upper trapezius muscles, clearly visible rhomboid contours, and relatively adducted and inferiorly rotated scapulae, all more so on the left compared with the right sides. Complaints could be reproduced with impingement test maneuvers and repetitive overhead activity as well as palpation of apparent trigger points along the superior/medial border of the left scapula. In addition, mild glenohumeral capsular hypo mobility and shortness of the pectoralis major and minor muscles, latissimus, and upper trapezii were noted. As judged by visual observation of bilateral flexion movements, the scapulae appeared to elevate excessively, adduct slightly, and fail to rotate well in a cephalad direction, all much more on the left compare with the right.

SEMG electrodes applied over the left upper trapezius showed amplitude values increased several hundred percent compared with those of the right side during static sitting and standing. During bilateral simultaneous, symmetrical shoulder flexion, the left upper trapezius recruited with peak and average amplitude values several hundred percent greater than those of the right side. However, corresponding values for the lower trapezius were diminished by several hundred percent on the left compared with right sides. The ratio of peak lower trapezius to upper trapezius activity exceeded 1.5:1 on the right but was less than 0.3 on the left during movement. Upon movement cessation, the right upper trapezius immediately returned to baseline activity levels. However, the left upper trapezius remained active at average levels much greater than the original baseline and with increased volatility. That is, on the left side the post-movement SEMG mean and standard deviation were greater and the ratio of the standard deviation to the mean was disproportionately increased. The same patterns were observed during performance of simulated, symmetrical overhead work activities.

It was hypothesized that faulty motor control of the scapula might be contributing to the patient's problems, including excessive recruitment of the upper trapezius (and perhaps levator scapulae and rhomboids) and insufficient recruitment of the lower trapezius during arm movements. In addition, the patient appeared to maintain chronically increased left upper trapezius activity and had difficulty deactivating the muscle following movement.

SEMG feedback was used to teach the patient to consciously recognize and relax upper trapezius activity during static sitting and standing. He then practiced activating and quickly relaxing the upper trapezius muscles using the techniques described in the previous laboratory exercise section of this manual for the cervical region. Once he succeeded with the task using shoulder shrug movements, he practiced with shoulder flexion, scaption, and abduction through progressively larger movement arcs and at faster speeds, with dumbbells, and simulated overhead work tasks. In addition, the patient was taught to voluntarily increase the activity of the lower trapezius with SEMG feedback. He quickly learned how to accomplish the task using shoulder retraction/depression and then integrated the skill into shoulder flexion, scaption, and abduction motions as well as simulated functional tasks. It was noted that the upper trapezius recruited with dramatically lower SEMG amplitude when he consciously activated the lower trapezius. Over several sessions of SMG feedback training, he became able to dramatically increase the activity of the lower trapezius compared with the upper trapezius with naturally fluid motions and without conscious effort. SEMG activity from the left and right sides took on a symmetrical appearance and he had no difficulty deactivating the left upper trapezius after movement. Scapular movement patterns also became more normal and symmetrical to visual observation. The patient continued with a home exercise program for shoulder flexibility and lower trapezius conditioning and also continued body mechanics and work simulation activities with occupational therapy. All complaints resolved and full duty work was achieved in 6 clinic visits over 6 weeks, with no known problems thereafter.

LABORATORY EXERCISE: Shoulder region

- Set up Channels 1 & 2 to record from the left and right upper trapezius muscles (FIGURE 5). Set up Channels 3 & 4 to record from the left and right lower trapezius muscles (FIGURE 7).
- Double click on MyoClinical icon. Click on the down arrow under GROUPS and select FEEDBACK MONITOR PROTOCOLS. Highlight the STANDARD SETUP FOR 4 CHANNELS. Click on NEXT and MEASURE. Click on the yellow CALIBRATION button to establish a true baseline.
- Instruct the subject to perform 3-5 repetitions each of bilateral, symmetrical flexion, scaption, and abduction through full range of motion and at a modest and consistent speed. Repeat with reciprocal (e.g., first left, then right) movements. Observe the SEMG tracings. You should note the following patterns. Inquire if there is a history of injury and observe the subject's scaplular movement patterns if you observe differences from the desired results.

  - Stable, low amplitude baseline readings from all channels while sitting quietly in a chair.

  - Approximately symmetrical peak activity from the left and right sides for homologous muscle pairs during bilateral movements. Consider calculating the percent difference in left and right peak amplitude values during the flexion movements using the method described in Chapter 1.

  - Approximate reciprocal symmetry for peak activity from the left and right sides of homologous muscle pairs during reciprocal movements.

  - Left/right asymmetry during reciprocal movements. That is, activity from the supper trapezius and lower trapezius should be much greater on the side ipsilateral to the movement and of relatively low amplitude on the contralateral side (as opposed to left/right co-activation).

- Relatively greater peak activity from the lower trapezius sites compared with the upper trapezius sites (this point neglects normalization issues discussed in Chapter 1 but is a commonly accepted, anecdotal standard for these particular recording sites).

- Potentially increased recruitment levels closer to the abduction plane.

- Earlier recruitment of the upper trapezius (relative to its maximum) in the range of motion arc compared with the lower trapezius.

- Practice ***isolation training*** using the following procedure*:*
- Select either the left of right side for practice. Instruct the subject to shrug the shoulder and activate the upper trapezius while maintaining low activity from the lower trapezius as well as contralateral side muscles.
- Instruct the subject to retract and depress the same side scapula so that activity from the corresponding lower trapezius is increased and that of the upper trapezius and contralateral side muscles is maintained at minimal levels.
- Repeat (a) and (b) until the subject can relatively purely isolate the activity of the upper trapezius and lower trapezius.
- Ask the subject repeat shoulder flexion movements while deliberately trying to increase the activity of the lower trapezius compared with the upper trapezius. Note what happens to the peak upper trapezius amplitude if the subject is successful in increasing activity of the lower trapezius.
- As the subject gains proficiency, instruct him or her to continue with a similar recruitment pattern but make the motion as natural and fluid as possible, competing the full range of motion arc at a moderate to higher velocity.
- Select an overhead functional movement to simulate; e.g., reaching or stacking, ball throwing, tennis serve, freestyle swim stroke, and instruct the subject to consciously practice increasing the activity of the lower trapezius compared with the upper trapezius, progressing

from slow deliberate movements to fluid and naturally paced motions.

- Imagine that the subject is a patient with unilateral shoulder pain who is found on examination to have asymmetrically increased activity of the upper trapezius and decreased activity of the lower trapezius during overhead movements. Experiment with therapeutic exercises that might selectively facilitate the lower trapezius compared with the upper trapezius that could be performed in a home program. Try as many different exercises as you can think of and note which produce the best results in this particular subject. Be sure to include lateral shoulder rotation exercises. Do you see value to using SEMG to examine exercise effects in individual patients? Would SEMG seem to be a reasonable research tool to investigate exercises purported to have selective training effects as well as gradate the intensity of such exercises?
- Apply electrodes over the left and right lower fibers of the serratus anterior (FIGURE 11). Utilize additional channels if available or switch the leads for Channels 3 & 4. Repeat steps above but substitute attention to the serratus anterior instead of the lower trapezius. Use scapular depression/protraction motions to initiate isolation training and uptraining for the serratus anterior and analogously work through the same procedures. Keep in mind the following points:
- Gaining conscious control of serratus anterior activity tends to be more difficult than for the lower trapezius.
- Impedance tends to be much higher at the serratus anterior site. Most persons show appreciably lower SEMG amplitudes from the serratus anterior site compared with the upper trapezius site during, for example, shoulder flexion movements. This does not mean that the serratus anterior is less active or weak. Some type of normalization procedure should be performed prior to drawing inferences regarding the relative activity level of different muscles and judgments regarding force production cannot be made (see Chapter 1). There is no apparent clinical standard for a ratio of serratus anterior to upper trapezius activity. Left versus right comparisons, however,

can be made and the percent asymmetry formula described in Chapter 1 may be used for documentation purposes.

- In looking at maximal serratus anterior recruitment during the performance of different exercises, be sure to include classical push-ups as well as variations with end range, deliberate scapular protraction, a push-ups "plus" maneuver, or other modifications. Also include supine shoulder "press" and "press-plus" tasks and anything else you can think of. As time allows, be creative with use of gymnastic balls and resistive exercise equipment. Consider how you might use SEMG to guide exercise prescription if the clinical objective were maximal conditioning of all scapular muscles versus selective facilitation of the serratus anterior. Name some specific sporting activities where you would predict the serratus anterior to be of prime importance. Imagine how you might use SEMG to assess muscle activity patterns during simulated or actual sport performance and SEMG feedback and how SEMG feedback could be provided to enhance athletic training.
- Uptraining the serratus anterior and lower trapezius and downtraining the upper trapezius are procedures that lend themselves well to the purposes of these laboratory exercises. However, this should not be taken to imply that all or most patients with neck and shoulder pain suffer from hyperactivity of the upper trapezius, which is clearly not the case. Each patient should be examined and interventions selected that match the movement system diagnosis.
- Set up two SEMG channels with electrodes applied over the infraspinatus and posterior/middle deltoid on the same side (FIGURES 9,14,15).
- Observe activity from the two channels during lateral shoulder rotation, flexion, scaption, abduction, and extension maneuvers. Do the SEMG tracings meet with your expectations, based on your knowledge of the kinesiological actions of these muscles?
- Instruct the subject try to learn to voluntarily increase the activity of the infraspinatus (disregard the deltoid display for the time being). Imagine that the subject was a patient prone to shoulder instability and the goal is to try to use the infraspinatus (and perhaps adjacent

portions of the rotator cuff, although those are not available for SEMG monitoring) to stabilize the head of the humerus. Begin with lateral shoulder rotation with the arm at the side of the trunk in neutral abduction/adduction. Progress to lateral rotation movements in greater amounts of abduction, culminating in abduction/lateral rotation positions that are associated with provocation of anterior/inferior shoulder instability. Also have the subject practice increasing infraspinatus activity during simulated sports movements. Imagine how you might integrate SEMG feedback with instruction in proper technique and pacing for gym and home exercise programs. Would a simple, portable SEMG device be helpful in these circumstances?

- Ask the subject specifically to increase the activity of the infraspinatus relative to the deltoid, if time allows. Begin isometrically with the arm at the side and progress to reaching movements and simulated functional work or sports activities. Conceptually, could such training be useful for certain patients with impingement syndrome or delayed recovery after rotator cuff repair? Why?

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Low back and Trunk

Clinically relevant electromyographic studies of lumbar muscle activity date to the 1940's (Price, 1948). Early on, it was noted that lumbar muscle activity increases as forward flexion is initiated in standing but then drops to minimal levels as the flexion motion continues, the so-called *flexion relaxation response* (Shirado et al., 1995). This normal response is decreased or absent in some patients with chronic low back pain and muscle dysfunction (Ahern et al., 1988; Triano and Schulz, 1997). The ratio of peak forward flexion amplitude to the amplitude

recorded when full flexion is reached quantitatively discriminates certain patients with chronic low back pain from healthy control subjects (Watson et al., 1997). In addition, some patients with chronic low back dysfunction demonstrate a depressed concentric: eccentric peak SEMG amplitude ratio during standing flexion/ extension. Using this method, the peak SEMG amplitude obtained during concentric lumbar muscle recruitment to extend the trunk to neutral from a flexed position is divided by the peak value recorded while the lumbar muscles fire eccentrically to control forward flexion. The concentric:eccentric ratio has been reported to be significantly depressed in patients with chronic low back pain (mean=1.4±1.0, Ambroz et al., 2000; mean=1.8±0.5 Sihvonen et al., 1991) compared with healthy controls (mean=2.6 ±1.0, Ambroz et al., 2000; mean=3.2 ± 0.8, Sihvonen et al., 1991). Aberrant responses have also been reported during rotation in back pain patients (Wolf et al., 1882). In addition, lumbar SEMG amplitudes have been found to be elevated during static standing in chronic low back pain patients compared with healthy control subjects (Cram and Kasman,1998). Left/right peak amplitude asymmetries greater than about 20% during standing flexion-extension may help differentiate certain back pain patients (Donaldson, 1988). Finally, altered patterns of SEMG activity are associated with intensity of low back pain during pregnancy (SIhvonen et al., 1998).

Despite these findings, there is controversy in earlier literature as to whether lumbar muscle activity is increased or unaffected in patients with low back pain (Sherman and Arena, 1993; Nouwan and Bush, 1984). Mixed experimental results may have resulted from lack of a standardized patient classification system as well as differences in experimental design that underestimated the complexity of movement control of the trunk (Wolf et al, 1989). The preponderance of evidence, though, suggests that whereas many patients with chronic low back pain show typical patterns of lumbar muscle activity in static postures and during standing movements, aberrant SEMG patterns (e.g., absence of a flexion relaxation response, depressed concentric:eccentric ratio, and large left/right asymmetries during standing flexion-extension; markedly elevated postural baseline activity,) are rarely seen

in healthy subjects. Patients with chronic low back and segmental hypermobility as well as radicular symptoms may be most likely to demonstrate abnormal SEMG findings (Sihvonen et al., 1997).

Lifting tasks are often a problem for patients with chronic lumbar dysfunction and they have been studies extensively with SEMG. Investigators have carefully controlled movement variables as well as combined SEMG monitoring with kinematic assessment to study the dynamics of lifting and formulate recommendations for functional lifting techniques (Brown et al., 1994; Minutes et al., 1999; Nielsen et al., 1998; Schulz et al., 1995; Teosinte et al., 1995; Vodkas et al., 1994).

Lumbar as well as abdominal and gluteal SEMG recordings have also been used to assist with biomechanical modeling of other tasks, to analyze therapeutic exercises, and to gradate the intensity of low back exercise prescription (Arokoski et al., 1999; Arokoski et al., 2001; Callaghan, 1998; Fiebert and Keller, 1994; Lavender, 1993; McGill, 1998; Robinson et al., 1994; Shields et al., 1997; Souza et al., 2001; Udermann et al., 1999; Vera-Garcia et al., 2000; Vezina and Hubley-Kozey, 2000). These lines of investigation hold promise toward the development of a sophisticated understanding of neuromuscular control of the trunk, with important implications for the prescription of exercise in injured populations as well as injury prevention in industry. Exciting work in this domain pertains to differentiation of patients with chronic low back pain and spinal instability from healthy control subjects on the basis of motor control responses from rectus abdominis and oblique abdominal muscles (O'Sullivan et al., 1998). Exercises using an abdominal drawing in maneuver, purported to promote trunk stability and selectively facilitate activity of the internal oblique, in fact result in increased SEMG amplitude ratios of internal oblique: rectus abdominis as well as decreased pain and improved function in controlled designs (O'Sullivan et al., 1998; O'Sullivan et al., 1997;).

Another area of SEMG investigation of lumbar dysfunction with impressive results involves frequency spectral analysis. Compression and shift of SEMG frequency components accompany muscle fatigue

and a variety of related techniques have been used to study the effects of resisted isometric trunk extension as well as repeated lifting (Biederman et al., 1991; Dolan et al., 1995; Potvin and Norman, 1993; Roy and Oddsson, 1998; Thompson and Biederman, 1993; Tsuboi et al., 1994; Umezu et al., 1998). SEMG frequency parameters used to quantify fatigue and recovery have discriminated chronic low back pain patients from controls with remarkable accuracy (Klein et al., 1991; Peach and McGill, 1998, Roy et al., 1995; Roy et al., 1990) although very simple methods for clinicians may be less forthcoming (Moffroid et al., 1994)

SEMG feedback training can be combined productively with back muscle strengthening (Asfour et al., 1990). Feedback training with SEMG can also be used to teach patients to lower static levels of lumbar muscle activity (Large and Lamb, 1983) as well as resolve left/right paraspinal muscle asymmetries (Donaldson, 1994). In addition, SEMG techniques have been used to evaluate the effects of manual spinal manipulation on muscle activity (Lehman and McGill, 2001; Lehman et al., 2001).

Behavioral correlates help to predict outcomes with SEMG feedback training (Large, 1985). Maladaptive responses to emotional stressors are linked with lumbar muscle hyperactivity and associated with inability to consciously discriminate muscle activity levels at the low back (Flor et al., 1992a; Flor et al., 1992b). Treatment regimens that incorporate SEMG feedback training (for reduction of lumbar paraspinal muscle hyperactivity) result in lowered levels of lumbar muscle activity as well as reduced pain, less affective distress, and lowered consumption of health care services that persist to at least 24 month follow-up (Flor and Birbaumer, 1993).

In conclusion, SEMG may help in the evaluation of muscle dysfunction in patients with chronic low back pain as well as treatment for those persons who display aberrant patterns of motor activity. Patients with low back pain make up a heterogeneous population and an extraordinarily complex set of kinesiological and psychological factors come into play during the course of daily activities (Geisser et al., 1995).

Both movement system and behavioral variables have been studied with SEMG and appear to be affected by SEMG interventions.

Case Example

A 50 year old male public health educator presented with 3 years of progressive left low back pain, then ranging from 3 to 8 out of a maximum of 10 in pain rating. His symptoms were exacerbated with standing during work presentations as well as household, yard, and sports activity. The patient had multiple MD, chiropractic, and physical therapy consultations.

Moderate multi-level degenerative joint disease was noted with plain films, magnetic resonance imaging, and bone scan. His symptoms had proved refractory to multiple non-steroidal anti-inflammatory drugs, thermal physical agents, inter vertebral mobilization and manipulation, attempted exercise progressions, work pacing, and ergonomic interventions and body mechanics training.

Standing postural alignment was notable for a mild right lateral trunk shift, decreased lumbar lordosis, relative posteriorly tilted pelvis, apparent hypertrophy of lumbar paraspinal and hamstring muscles but seemingly diminished gluteal bulk. He was able to flex his trunk forward with his fingertips reaching the floor and score 5.8 cm with a modified Schoeber's test (reference) for lumbar inter vertebral mobility. However, there was palpable inter vertebral movement at 40 degrees of straight leg raising on the left and 45 degrees on the right, indicative of decreased hamstring flexibility. The gluteus maximus muscles were weak bilaterally, scoring 4+/5 with manual muscle testing. He had difficulty performing an abdominal drawing-in maneuver, wherein the navel was gently retracted in a posterior/superior position, and sustaining that while gently lifting his feet from the plinth in a hooklying position, suggestive of poor oblique and transverse abdomi-

nal muscle control. In contrast, the patient had no difficulty performing multiple sit ups.

Assessed with SEMG, lower lumbar paraspinal muscle activity was elevated and erratic in appearance, left greater than right, in static standing. SEMG amplitudes dropped to symmetric, stable, quiescent values when the patient was instructed to lift his sternum as a postural correction cue. During standing trunk flexion and return, there was an absence of the flexion relaxation response, left greater than right asymmetry in peak amplitude readings by more than 40%, and a ratio of concentric peak amplitude to eccentric peak amplitude of about 1.0 – all aberrant responses. In addition, left and right lumbar paraspinal muscles were coactivated throughout the performance of side bending and rotation maneuvers. Interestingly, when the patient performed a isometric gluteal squeeze in standing, without a visibly apparent shift in pelvic or spinal posture, lumbar muscle activity decreased. Peak gluteal recruitment was diminished on the left compared with the right. Thus, on the painful side, there was increased postural lumbar muscle activity and decreased maximal voluntary gluteal SEMG amplitude. Lastly, the patient exhibited great difficulty with volitional recruitment of oblique abdominal muscles during abdominal drawing in maneuvers. Recruitment of the rectus abdominis, however, was robust during those activities as well as tasks with resisted trunk flexion.

The patient was treated with additional manual inter vertebral and soft tissue mobilization techniques as well as reinforcement of body mechanics training, and therapeutic exercises to promote hamstring flexibility, gluteal power and endurance, oblique abdominal facilitation, and general aerobic conditioning. SEMG feedback was used during the performance of abdominal drawing in maneuvers to promote oblique abdominal recruitment relative to rectus abdominis, beginning in hooklying and then adding alternate foot and upper extremity motions as well as practice in sitting, standing, and during lifting activities and simulated sports and yard work motions. Feedback with SEMG was also used to promote postural correction as well as hamstring relaxation during stretching. Gluteal uptraining was facilitated

with SEMG feedback, first with isometric contractions in standing and progressing to integration with lifting, household, yard and sports activities. The patient was discharged free of pain and performing all desired functional activities after 6 visits completed over a 10 week period. Concomitant with decreased pain and improved function reported by the patient, increases were observed in gluteal and oblique abdominal SEMG amplitudes as well as decreased baseline lumbar paraspinal values, an emergence more and more of a flexion relaxation response, and gain in concentric:eccentric amplitude ratio during standing trunk flexion and return.

LABORATORY EXERCISE: Low back and trunk region

Attach electrodes over the left and right paraspinal muscles at level of about the 4th lumbar vertebrae (FIGURE 30) and left and right gluteus maximus (FIGURE 34).

- Observe baseline responses in standing. SEMG activity should be approximately symmetric from left to right and relatively quiet and stable in magnitude from all sites.
- Instruct the subject, in standing, to perform trunk flexion and return through the person's fully available range of motion. Have the subject take about 2 seconds to flex forward, pause for about 2 seconds in full flexion, and return to neutral standing over 2 seconds. Ask the subject to repeat the motion about 5 times, ignoring the first two repetitions. Instruct the subject to move with a consistent pace across trials. Over the final 3 repetitions, observe for the following normal responses from the lumbar paraspinal muscles:
- Sharp reduction in SEMG amplitude beginning at about 60 degrees of gross trunk flexion and culminating in relative quiescence during the pause at end range flexion – the flexion relaxation response.
- Left/right symmetry of peak amplitude responses within about 20 percent during the flexion and return to neutral motion. To calculate the percent asymmetry, subtract whichever side amplitude value is

lower from the higher value, divide the result by the higher value, and multiply by 100 (Chapter 1).

- A ratio of concentric peak amplitude to eccentric peak amplitude of about 2:1 or greater. To find this value, simply divide the greatest amplitude value during the return to neutral standing by the highest value obtained during the forward flexion motion.
- Ask the subject to place hands on hips and perform trunk extension through the fully available range of motion in standing. Observe for the normal low amplitude response from lumbar muscles. Does quiescence of lumbar muscles meet with your expectations? Which trunk muscles would you expect to be active during this movement?
- Ask the subject to repeat the flexion and extension movements called for in tasks (2) and (3) above. Observe the subject's pattern of hip and lumbar inter vertebral motion recruitment. Subjects who lack a complete flexion relaxation response, generate a relatively lower concentric:eccentric activity ratio, or display activity in true extension typically have a history of low back pain or have limited lumbar mobility. This may be the case even if your subject is able to flex enough so that his or her fingers reach the floor. In this latter situation, hip flexibility may be generous but the lumbar spine appears flattened in curvature. Also observe the subject's static postural alignment and any deviation from the saggital midline during the flexion-extension movements. Left/right asymmetry is commonly accompanied by postural lateral curvature, lateral trunk shift, or asymmetric spinal flexibility.
- Instruct the subject to perform standing trunk side bending to left and right and rotation to left and right, respectively, over several repetitions using a consistent pace. Lumbar paraspinal muscle activity patterns tend to be variable during these motions, especially side bending. Some patients show higher activity from the ipsilateral side muscles, some from the contralateral side muscles, and some from the ipsilateral muscles as side bending is initiated and then from the contralateral side as motion continues to end range and returns to neutral position. In any event, though, at any one point of the motion arc activity from one side should normally dominate over

that from the other side. And whatever is displayed with movement to the left plane should be the approximate mirror image of the pattern displayed with movement to the right. Instead of this reciprocal symmetry, a dysfunctional response would be left/right coactivation throughout movement. Coactivation is often accompanied by relative spinal stiffness but may seen in patients without history of low back pain.

- Practice body mechanics instruction with SEMG feedback:
- Instruct the subject to pick up an object weighing 3-5 lbs. Note any change in baseline activity from lumbar paraspinal muscles after the object is picked up. Then instruct the person to hold the object at arm's length away from the trunk. Is this accompanied by an increase in SEMG amplitude? Why? Would you expect a patient to be more compliant with body mechanics instruction that included holding objects close to the trunk after witnessing the effects at the SEMG display?
- Ask the subject to lower and lift the object to and from the floor, once with what you would consider to be poor body mechanics and again with the ears, shoulders, and hips held in one line and bending the knees. Is there a difference in SEMG amplitude patterns? Is a decrease in SEMG amplitude necessarily to be expected or desirable? Might lumbar paraspinal activity increase if a lordosis, or neutral spine, is better maintained during the lift and could this potentially have a protective effect on articular and periarticular structures?
- Try instructing your subject to lift his or her sternum, if appropriate, and improve standing postural alignment. Is there a decrease in lumbar muscle activity? If so, why do you think this occurs?
- Instruct the subject to perform an isometric gluteal squeeze in standing and try solely to increase gluteal activity from the gluteal SEMG channels while leaving the lumbar amplitudes at baseline. If your subject has difficulty isolating gluteal activity, ask him or her to try it in supine or prone and then return to the standing position.
- Ask the subject to repeat the trunk flexion-extension and lifting-lowering tasks described in tasks (3) and (7) above but this time with

gluteal activation during the movements. Do you observe any changes in lumbar SEMG patterns from before?

- Instruct the subject to perform prone press up exercises, where the trunk is ostensibly lifted passively by the upper extremities with the pelvis remaining in contact with the supporting surface, to move the lumbar spine into extension. Does your subject activate the lumbar muscles during the motion or keep those muscles relaxed. Is the level of lumbar activation different during the movement compared with what you observed as end range extension is maintained for a few seconds? Can your subject use SEMG feedback to keep the lumbar muscles relaxed through the cycle?
- Laboratory Exercise 9: Normalization, Chapter 1, p. 37, asked you to consider how you might design an experiment to gradate the intensity of lumbar paraspinal and gluteal activation during a simple bridge exercise. If you did not perform a SEMG assessment of the bridge maneuver earlier, try it now. For simplicity, focus just on right side responses from the lumbar paraspinal and gluteus maximus muscles. Which muscle would you expect to be activated to a greater intensity? Express the peak amplitude of each muscle's SEMG activity obtained during the bridge as a percent of its maximum amplitude derived during a maximal effort manual muscle test. In fact, which muscle is activated to a greater intensity? Can you instruct the subject to modify the bridge technique to increase gluteal activation relative to lumbar activation?
- Experiment with various exercises that you suspect might facilitate recruitment of gluteus maximus compared with lumbar paraspinal muscles. Be sure to include hip extension/lateral rotation from a hands and knees 4-point position ("fire hydrant"), combined with an abdominal drawing maneuver and cues to maintain neutral spine position.
- If your subject can do so without pain or apparent risk, experiment with various lumbar exercises that might be used to promote strengthening or endurance. Use SEMG to gradate the relative intensity of lumbar activity of the exercises you select.

- Attach electrodes over the left and right rectus abdominis (FIGURE 31), oblique abdominal muscles (external and internal obliques) (FIGURE 31), and specific internal oblique muscles. If you have 8 SEMG channels available, disconnect the gluteal leads but retain the lumbar placements. If you have 4 SEMG channels available, affix all the electrodes but connect leads first to the rectus abdominis and oblique abdominal placements and change the leads, as appropriate, as you proceed through the remaining tasks.
- Instruct the subject to perform the following exercises. Assess the relative activation level of each muscle across exercise conditions. Which exercise is associated with the highest SEMG amplitude for each muscle?
- Partial sit up with knees bent.
- Partial sit up with knees straight.
- Full sit up with knees bent.
- Full sit up with knees straight.
- Diagonal sit up with knees bent (note any particular left/right patterns with the oblique SEMG signals).
- Abdominal drawing in maneuver in hooklying (instruct the subject to gently retract the navel “in and up,” creating a hollow over the abdominal region; to be accompanied by slight posterior pelvic rotation and gentle flattening of the lumbar spine but not a pelvic tilt exercise).
- Sustained abdominal drawing in maneuver in hooklying plus alternate heel raise (“marching in place;” monitor for correct maintenance of the abdominal drawing in maneuver, avoid aggressive pelvic tilt, valsalva maneuver, “pouching out” of the abdomen, or lumbar lordosis). Do not pursue this exercise if the subject is unable to properly sustain the abdominal drawing in maneuver.
- Sustained abdominal drawing in maneuver in hooklying plus alternate heel slide to lower extremity extension and return. Do not pursue this exercise if the subject is unable to properly sustain the abdominal drawing in maneuver.

- Sustained abdominal drawing in maneuver in hooklying plus alternate heel slide along the supporting surface to hip and knee extension, and return. Do not pursue this exercise if the subject is unable to properly sustain the abdominal drawing in maneuver.
- Sustained abdominal drawing in maneuver in hooklying plus alternate heel glide raised a few centimeters up from the supporting surface to hip and knee extension, and return. Do not pursue this exercise if the subject is unable to properly sustain the abdominal drawing in maneuver.
- Sustained abdominal drawing in maneuver in hooklying plus alternate heel glide raised a few centimeters up from the supporting surface to hip and knee extension, and return, combined with contralateral shoulder flexion motions ("dead bug exercise"). Do not pursue this exercise if the subject is unable to properly sustain the abdominal drawing in maneuver.
- Repeat the above series with concomitant maintenance of an isometric pelvic floor ("Kegel's") contraction. Do the abdominal SEMG patterns change with the addition of pelvic floor contraction?
- Any other desired abdominal exercises.

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Hip region

Despite the facts that investigations of hip musculature with EMG date back more than 50 years (Basmajian and De Luca, 1985) and there have been recent kinesiological studies published (e.g., Neumann, 1999; Neumann, 1998), there is a dearth of reports in the clinical realm. In one interesting case series, decreased intramuscular EMG activity from gluteus maximus and gluteus medius muscles as well as aberrant tonic activity from tensor fascia lata, rectus femoris, and adductor longus was identified during gait analysis in patients with osteoarthritis who were to undergo total hip arthoplasty (Long et al., 2993). These findings would seem to be consistent with the clinical theory of Sahrmann (Sahrmann, 2002), who provides a classification and intervention framework for muscle imbalance syndromes around the hip (among other body regions).

Imbalances among the gluteus maximus and hamstring muscles, or gluteus medius and tensor fascia lata, for example may be amenable to SEMG assessment and feedback training. Recordings from the deep lateral rotators of the hip, such as the piriformis, are not feasible with SEMG.

Case Example

A 40 year old male presented with chronic, constant dull aching along the left ischial tuberosity. The patient was active at least 5 days per week with aggressive running or biking on hills, rock climbing, in-line skating, and cross-country skate skiing. Symptoms were clearly exacerbated by sports activity and relieved by rest. He would intermittently experience periods or sharp pain superimposed over his aching by the ischial tuberosity, specifically upon initiating the propulsive phase of movement with a flexed hip during the above-listed sports, especially when moving uphill. These symptoms had come and gone for much of his adult life and he reported having tight hamstrings for as long as he could remember.

Physical examination revealed a healthy appearing, athletic male. Symptoms were unaffected by lumbar screening maneuvers. However, his pain complaint was focally reproduced with maximally resisted left hip extension if the hip was positioned in flexion and even more so with the hip positioned in flexion and the knee in extension. There was mild tenderness to palpation along the hamstring origin at the ischial tuberosity. Hamstring contours and girth were prominent whereas gluteal bulk seemed to be relatively diminished bilaterally. Passive straight leg raising was performed to about 45 degrees on the left and 55 degrees on the right before slight lumbar inter vertebral movement was palpated, and to about 55 degrees on the left and 70 degrees on the right to end range, respectively, with pain on the left.

SEMG recordings were derived from the left and right gluteus maximus and lateral hamstring muscles. Peak activity of the gluteus maximus during manual muscle testing was decreased by 40% on the symptomatic left side whereas the left peak hamstring amplitude, during hamstring manual muscle testing, was 20% greater. The subject then stood in a self-assumed posture with approximately equal weight bearing through his lower extremities (assessed with a scale placed

under each foot). Activity from gluteal and the right lateral hamstring recording sites was minimal. However, the right hamstring site displayed a pattern of continuous and erratic activity. During symmetrical hip extension maneuvers with submaximal resistance in standing, prone, or with simulated sports movements, the left gluteal amplitude was lower than that of the right by 30-45% and hamstring greater by 15-30%. A consistent trend emerged of decreased gluteal activity and increased hamstring amplitude on the left compared with the right sides. It was speculated the patient suffered from a tendonitis-type overuse syndrome at the hamstring attachment to the ischial tuberosity, which was exacerbated chronically by imbalanced muscle action and hamstring overuse combined with a shortened hamstring length. Symptoms became most pronounced during sports with ballistic hamstring contraction in a relatively elongated position.

For treatment, SEMG was used to identify a hamstring stretch position associated with minimal muscle activation (lying supine in a doorway with the with the heel of the affected lower extremity elevated along the door frame). The amplitude of the SEMG signal was used to gauge the degree of lower extremity elevation. When an increase in amplitude was observed, the lower extremity was slightly lowered, a contract-relax maneuver was performed, or the patient used diaphragmatic breathing to relax more fully. The patient had previously practiced stretching his hamstrings in standing by placing the heel of one leg up on the pan of a chair and “bouncing” rhythmically into trunk flexion. This was associated with repetitious, high amplitude peaks of SEMG activity as well as continuous, erratic patterns muscle activity even after the movement was ceased. The patient was instructed to substitute the doorway stretch method for home practice as well as a stretch in a half long sitting position that could be performed on a bench at his workplace periodically through the day, the later of which also compared favorably during SEMG analysis.

On subsequent visits to the clinic, SEMG feedback was used to uptrain recruitment of the left gluteus maximus relative to the lateral hamstrings on the left. The patient began using isometric gluteal contrac-

tions in standing. He used SEMG feedback to experiment with different cognitive strategies to isolate and increase the gluteal signal, a rather non-intuitive task. At first, he was unable to recruit the gluteus maximus without concomitant activation of the hamstrings. The SEMG feedback device was then connected to a standard neuromuscular electrical stimulator (NMES) with stimulation electrodes applied also over the gluteus maximus. The NMES unit delivered current to the gluteus maximus and augmented contraction as voluntary activation was initiated. Over the course of multiple repetitions, this process appeared to facilitate robust gluteal recruitment and more isolated control of that muscle. SEMG feedback was also utilized to identify home exercises that would facilitate isolated gluteal control and the patient used the intrinsic sensations he learned in the clinic to assure correct technique at home.

The patient practiced increasing gluteal activation in progressively larger, faster, and externally loaded movement arcs as he gained success. SEMG feedback was provided during practice on a stationary skier and running treadmill as well as on a slider surface where he could practice skating motions. Symptoms abated after 6 visits during a six week period. Three additional visits were used over four months to ensure progress as he resumed all sports activities to his desired competitive levels.

LABORATORY EXERCISE: Hip region

- Attach electrodes over the right gluteus maximus (FIGURE 34) and lateral hamstrings (FIGURE 36).
- Ask the subject to extend the hip from a prone position with knee flexed versus knee extended. Which knee position is associated with greater hamstring activity? Why? Which knee position is associated with greater gluteal activity? Why?

- Note the relative recruitment levels of the gluteus maximus and hamstrings during the above tasks and compare to results during standing partial squat and sit to stand maneuvers. Remember that inferences regarding strength cannot be made from SEMG recordings and amplitude scores should be normalized before performing quantitative comparisons of recruitment levels across muscle sites. How can you use a normalization procedure to judge quantitatively the relative recruitment level of the gluteus maximus and hamstrings during a partial squat? If time allows, try it.
- Instruct the subject to use SEMG feedback and attempt to facilitate recruitment of the gluteus maximus relative to the hamstrings, beginning with supine or prone isometric contractions, progressing to standing isometric contractions, and then open and closed chain hip extension and functional tasks. The subject may find selective facilitation of the gluteus maximus relative to the hamstrings to be a challenging task and might require several sessions with SEMG feedback prior to success.
- Experiment with different exercises to identify an activity that seems intrinsically to facilitate gluteus maximus recruitment compared with the hamstrings. Try as many different positions and facilitation techniques as you can think of. Any particular exercise that achieves the goal would be desirable for inclusion in a home exercise program.
- Apply electrodes over the right gluteus medius (FIGURE 33) and tensor fascia lata (FIGURE 33).
- Ask the subject to stand unilaterally on the right lower extremity and flex the left hip as well as abduct the right hip. Then instruct the subject to stand unilaterally on the left lower extremity. Note the relative recruitment level of each muscle across activities. Remember that inferences regarding strength cannot be made from SEMG recordings and amplitude scores should be normalized before performing quantitative comparisons of recruitment levels across muscle sites. How can you use a normalization procedure to judge quantitatively the relative recruitment level of the gluteus medius

and tensor fascia lata during maintenance of left unilateral stance? If time allows, try it.

- Instruct the subject to use SEMG feedback and attempt to facilitate recruitment of the gluteus medius relative to the tensor fascia lata. Begin with the subject positioned in prone with the left hip in flexion and performing abduction/lateral rotation motions. Progress to side-lying hip abduction with lateral rotation. Then ask the subject to continue in standing using hip extension/lateral rotation motions and advance to unilateral stance and step up/down maneuvers. The subject may find selective facilitation of the gluteus medius relative to the tensor fascia lata to be a challenging task and might require several sessions with SEMG feedback prior to success.
- Experiment with different exercises to identify an activity that seems intrinsically to facilitate gluteus medius recruitment compared with the tensor fascia lata. Try as many different positions and facilitation techniques as you can think of. Any particular exercise that achieves the goal would be desirable for a home exercise program.

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Knee region

A large volume of literature relates to clinical SEMG studies of knee musculature. Investigations pertain principally to one of three areas: general knee rehabilitation, muscle function following anterior cruciate ligament injury, and patellofemoral dysfunction.

Early studies found SEMG feedback plus exercise superior to exercise alone for patients with osteoarthritis, post-menisectomy, and post-arthroscopy (King et al, 1984; Levitt et al., 1995;, Lucca and Recciuti, 1983; Spreneger et al., 1979). With these patient populations, SEMG can be used to document left/right differences as well as the rehabilitative course of post-operative or non-operative care. Exercise variants can be examined for those that have the optimal effect and incorporated into home programs. SEMG feedback can also be combined with routine exercise protocols to enhance motivation, muscle recruitment, and exercise technique.

Injuries to the anterior cruciate ligament result in altered patterns of muscle activity about the knee (Branch et al., 1989; Ciccotti et al., 1994; Tibone et al., 1986). SEMG feedback combined with exercise has been used to ameliorate post-surgical inhibition and promote recovery of torque production in a manner superior to exercise alone or exercise plus cutaneous electrical stimulation (Draper, 1990; Draper and Ballard, 1991). Patients with unrepaired tears of the anterior cruciate ligament spontaneously show increased hamstring and hamstring:quadriceps SEMG activity during stance (Bulgheroni et al., 1977). Increased hamstring activation might biomechanically support the intrinsic arthrokinematic role of the anterior cruciate ligament and training for increased hamstring:quadriceps coactivation has been suggested in a case report (Maitland et al., 1999). In an analogous way, SEMG feedback has been recommended to train the magnitude and timing of the medial gastrocnemius during treadmill walking in patients with anterior cruciate deficiencies and lower functional ability, in a manner that matches spontaneous SEMG patterns displayed by patients with unrepaired tears of the anterior cruciate ligament who

report higher life function (Sinkjaer and Arendt-Nielsen, 1991). More recently, SEMG frequency analysis has been used to generate recommendations for strengthening versus endurance training in patients following operative repair of anterior cruciate ligament tears (McHugh et al., 2001).

Imbalanced action of the vastus medialis oblique compared with the vastus lateralis has long been assumed by clinicians to play a role in excessive lateral tracking of the patella and patellofemoral pain. This postulate seems reasonable on the basis of anatomical and kinesiological considerations and numerous investigators have sought to resolve the issue. Some authors have reported a decreased ratio of vastus medialis oblique amplitude relative to that of the vastus lateralis, or other measures of vastus medialis oblique insufficiency, in knees with patellofemoral dysfunction (Kasman, 1998). Others experimenters have found a nonselective depression of vastus medialsis oblique and vastus lateralis amplitude variables. Yet other investigators have failed to find any difference in recorded muscle activity between healthy control and patellofemoral knees. Consistently, healthy control subjects show normalized vastus medialis oblique: vastus lateralis amplitude ratios of about 1.0 ± 0.4 but the functional significance of that point, if any, is not clear. Certainly, there is no systematic evidence that dysfunction of the vastus medialis oblique is linked to patellofemoral dysfunction in the majority of studied subjects (Powers, 1998).

The situation is clouded, however, by lack of a standardized patient classification system, limitations in SEMG amplitude normalization methods, and differences in experimental design. It may be that the activity of the vastus medialis oblique is largely irrelevant to the development and maintenance of patellofemoral dysfunction. Alternatively, dysfunction of the vastus medialis oblique may be an important factor in a subclass of patients or when combined with other etiological factors. SEMG frequency analysis may help elucidate whether the vastus medialis oblique and vastus lateralis muscles display similar or different fatigue characteristics in patients with patellofemoral pain versus healthy controls (Callaghan et al., 2001). In addition, the activity of the

vastus medialis longus muscle may prove to be more significant than clinically presumed and greater vastus medialis longus; vastus lateralis SEMG amplitude ratios have been associated with (not necessary causal to) increased lateral patellar glide (Powers, 2000). Clinicians should not assume the vastus medialis oblique to be a problem and should avoid feedback training protocols for uptraining the vastus medialis oblique, unless a deficit is demonstrated convincingly during SEMG examination.

Numerous exercises have been purported by clinicians to selectively facilitate recruitment of the vastus medialis oblique. These have been evaluated exhaustively and with little controversy (for review, see Callaghan and Oldaham, 1996; Kasman, 1998; Laprade et al., 1998; Powers, 1998; Zakaria et al., 1997). There is no apparent evidence of selective effects on the vastus medialis oblique with quadriceps set, terminal knee extension, straight leg raise, or various combinations and variants of those exercises, including lateral hip rotation as well as tibial rotation. Activity ratios of the vastus medialis oblique:vastus lateralis have tended to be reported at higher values during closed chain compared with open chain activities. It has been suggested that hip adduction combined with resisted knee extension might have a facilitory effect on the vastus medialis oblique in the closed chain (Hodges and Richardson, 1993) but methodological limitations preclude a robust conclusion.

Patellofemoral taping according to the method of McCommell (McConnell, 1986) has become widely used by clinicians. Although patellofemoral taping appears consistently to be associated with decreased pain and some studies have identified alteration in SEMG activity from the vastus muscles (Gilread et al., 1998; Werner et al., 1993), other investigations have failed to report SEMG changes (Cerny, 1995; Salsich et al., 2002).

Lastly, it has been demonstrated that healthy subjects as well as patients with patellofemoral pain can learn to increase the activity of the vastus medialis oblique relative to the vastus lateralis and this has been associ-

ated with decreased pain, increased function, and improved patellar alignment assessed radiographically (Ingersoll and Knight, 1991; Leveau and Rogers, 1980; Wise et al., 1984). However, additional, better controlled designs with matched subjects as well as use of standardized exercise dosages across experimental groups and systematic functional assessments are needed to assess the true value of SEMG feedback training.

Case Example

A 39 year old female high school teacher presented with right retropatellar and infrapatellar pain and knee stiffness 8 months following surgical repair of a traumatic anterior cruciate ligament tear. In addition the patient had a manipulation under anesthesia 6 months after surgery in an attempt to restore range of motion for impairment due to capsular fibrosis. The patient's problems had proved refractory to extensive use of physical modalities, manual mobilization, therapeutic exercise, and attempted functional activity progression. She was normally active with elite modern dance, aerobics class teaching, gym exercise, and outdoors activities. The patient was unable to work, manage household activity normally, or engage in typical recreational activity due to her impairments.

Physical examination revealed knee effusion and quadriceps atrophy apparent to observation and confirmed by girth measurements as well as decreased calf girth. Passive range of motion was restricted to minus 5 to 160 degrees. There was markedly decreased passive medial-lateral patellar glide. A 55% torque deficit was noted at 60 degrees per second during isokinetic testing. Shortness of the rectus femoris and ilio psoas was also noted. Gait was markedly dysfunctional with decreased right weight bearing during stance, decreased right push off and a medial heel whip, decreased right step length, decreased right knee and ankle motion throughout the cycle as well as decreased arm swing and asym-

metrical trunk motion, and overall, a slow and dysrhythmic cadence as well as multiple verbal pain behaviors and facial grimacing.

SEMG electrodes were applied over the VMO and VL muscles. During maximal effort quad setting in long sitting, peak activity from the right VMO was decreased by 80% compared with the left side whereas the VL deficit was 40% on the involved side. During partial squat maneuvers, VMO:VL ratios of peak amplitude scores showed values of 0.3-0.4 on the right and 0.7 on the left. Normalizing the partial squat scores to 100% of maximal voluntary contraction (MVC) levels obtained in sitting resulted in VMO:VL ratios of 0.8 on the right and 0.7 on the left. The dramatic shift in right/left VMO:VL ratios when normalized to seated MVC levels illustrates the importance of selecting an appropriate normalization procedure (Chapter 1). That is, if muscle activity is aberrant during the normalizing reference contraction and during the clinical assessment task in the same way, a deficit that is in fact present may be masked. In this case, the patient could not produce an unaffected MVC contraction to use for normalization and percent asymmetry or non-normalized VMO:VL ratios are more relevant.

SEMG feedback was used during treatment to reduce guarding and promote quadriceps relaxation during knee flexion stretches. In addition, the patient used SEMG feedback cues to increase VMO and VL activity in general, and the VMO relative to the VL in particular, while performing therapeutic exercises. SEMG feedback was then integrated with gait, dance, sports, and other functional activities. Training began three times per week and tapered in frequency over 16 weeks as absolute levels of VMO and VL recruitment and VMO:VL ratios became more symmetric on the right side compared with the left.

Feedback training with SEMG was but one part of a comprehensive intervention plan, which also behavioral support, included ultrasound, manual patellar mobilization, manually assisted range of motion stretching, practicing weight acceptance with dual scales, gait training, exercise prescription with a daily quota system and functional activity progression, and a rigorous home program. At discharge, range of

motion of the right knee was 0 to 135 degrees and painless, gait was normal, and she had made a full return to all desired activities of daily living.

Many of the modalities, manual therapy techniques, and therapeutic exercises used as interventions were similar to those trialed in prior courses of physical therapy. The addition of SEMG feedback and its integration with exercise and functional activity retraining seemed to make the difference. SEMG feedback appeared to give the patient a sense of control and facilitated self-efficacy during the therapeutic course. Presumably, motor control impairments rendered prior exercises and attempted functional activity progressions ineffective and contributed to faulty biomechanical relationships and pain. SEMG feedback may then have aided in the resolution of motor impairments that enabled the other interventions to achieve the desired effects in promoting strength, range of motion, and functional gains.

LABORATORY EXERCISE: Knee

- Attach electrodes over the right rectus femoris (RF, FIGURE 39), vastus medialis oblique (VMO, FIGURE 41), and vastuls lateralis (VL, FIGURE 40).
- Record peak amplitude values for each muscle during maximal voluntary contraction (MVC). Use a resisted straight leg raise (with the untested leg flexed in a half hooklying position) for the RF and resisted knee extension in sitting for the VMO and VL together.
- Ask the subject to perform the following activities. For each movement and muscle, convert the peak amplitude recorded during the task to a percent MVC (for each muscle, divide the peak amplitude recorded during the movement by the MVC amplitude obtained in the task above). Using the percent MVC values, assess the comparative recruitment levels of each muscle during each of the exercises. Do any of the exercises seem to selectively facilitate recruitment of any particular muscle?

- Quadriceps set in supine.
- Straight leg raise.
- Straight leg raise plus quadriceps set.
- Straight leg raise plus hip lateral rotation.
- Straight leg raise plus resisted hip adduction (what potential confound might exist with the surface VMO recordings and how might it be overcome?).
- Terminal knee extension in supine.
- Seated knee extension.
- Seated knee extension plus ankle dorsiflexion.
- Seated knee extension plus tibial medial and lateral rotation.
- Partial squat.
- Partial squat with recorded lower extremity positioned in lateral hip rotation.
- Partial squat with resisted hip adduction; e.g., squat while squeezing a firm pillow between the thighs (what potential confound might exist with the surface VMO recordings and how might it be overcome?)
- Lunge.
- Step up.
- Step down.
- Any other desired activity.
- To get a sense of the challenge, instruct the subject to use SEMG feedback and attempt to increase the activity of the VMO compared with the VL. Note that the subject will no doubt find this to be a difficult task and likely would require numerous sessions prior to success.

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Chapter 4:

AN OVERVIEW OF SURFACE ELECTROMYOGRAPHY AND NEUROMUSCULAR DISORDERS

Surface electromyography (EMG) has been an approach used in rehabilitation for well over 30 years. The fundamental notion is that by placing electrodes or sensors over appropriate muscles, the clinician can guide treatment by showing patients how their muscles are behaving while at the same time, engaging a neuromuscular reeducation technique.

Surface EMG has the added benefit of providing a ***quantitative value*** assigned to the amount of EMG that has been processed per unit of time. Clinicians can determine that time interval, and its numerical value results from converting the "wavy" lines we call analog signals or muscle potentials, into an "integral" of EMG/time. Last, it is possible to "***train***" patients to increase or decrease their EMG output by conditioning or **"*shaping*"** their responses. This approach involves the use of a target, also called a threshold, goal, or level detector that is placed on the screen in the form of a horizontal line and can be moved upward or downward. The objective is to train the patient to increase or decrease the muscle response and move the goal in the appropriate direction. This approach is one way in which we help patients to increase or decrease their muscle activity by using the visual cues (sometimes with audio cues as well when patient responses change in relationship to the goal line). This form of training has often been referred to as ***EMG biofeedback***.

An important part of any surface EMG display, whether in guiding patient activation of muscle or in a biofeedback mode, is making sure that the muscle signal representations actually appear on the screen rather than appearing to be to small or far too large, thus "**saturating**" the screen. The controls over this display are governed by changing the amplification or "**gain**", sometimes also called the "**sensitivity**" of the display. This topic is covered elsewhere in this syllabus. The important point here is that both the clinician and the patient should be able to see the signal adequately.

For the purpose of this portion of the syllabus, we define patients with neuromuscular disorders as those who have sustained insult, whether by trauma or disease, to the central or peripheral nervous systems. Such patients might include children with cerebral palsy, individuals who have sustained a stroke, traumatic brain injury, spinal cord injury, peripheral nerve injury or a host of other diagnoses.

Contemporary use of surface EMG with neurological patients

It could be argued that most therapists depend upon their hands and manual skills to make decisions about patient responsiveness to treatment. Most clinicians treating a variety of patients might share this perception. Furthermore, it takes time to identify and target the muscles of interest, place electrodes on these muscles, and "set up" or interface the patient to the machine. In reality, however, little time is needed to accomplish these tasks. With little training, the time for set up is often less than 2 minutes! The **advantages to using surface EMG** include:

- bringing muscle activity levels to the awareness of the patient and the clinician
- recognizing the patient's ability to activate muscles even when a response to palpation is not sensed
- guiding treatment through observation of muscle changes
- quantifying muscle activity.

The last of these advantages is particularly relevant in today's "health care market" because it is possible to relate these changes in quantity to functional measures in an effort the bridge the gap between physiological behavior and functional capability. These relationships are being demanded with greater frequency by individuals in position to make decisions about reimbursement.

So what should a clinician interested in using surface EMG consider in establishing and justifying its usage? First, reality dictates that time per session and number of reimbursable treatments per patient are becoming more constrained. This situation supports the notion that a form of "on-line" monitoring might be beneficial to facilitating appropriate responses and improvement. More important, most clinicians today realize that this constrained environment implies that most time should be spent in treating patients within a functional, task-oriented manner.

Therefore, the **fundamental principle** for the application of surface EMG to patients with neuromuscular disorders (for example, stroke, spinal cord injury, traumatic brain injury, multiple sclerosis, Parkinson's disease, peripheral neuropathy) is that **weak muscles need to be recruited to gain function**. Secondarily, muscles that appear to be hyperactive should be inhibited (de-recruited). With respect to the upper extremity, the clinician might choose to think in terms of reaching, grasping, manipulating and releasing objects, because these motions characterize function use of the limb. There are differences in how this principle is applied to patients with different diagnoses, but essentially, this is the goal. For example, the deleterious effects of fatigue might be more significant in the treatment of a patient recovering from a peripheral nerve injury than from a patient with stroke.

The **guiding concept for applying these principles**, then, would be specified in the treatment of upper and lower extremities.

In the **upper extremity**, we would tend to think about activation of musculature that would lead to isolated shoulder flexion and controlled extension of the elbow wrist and digital joints. A secondary goal would be relaxation of muscles that have elevated "tone" and for whom co-activation might impair functional motion. These muscles might include those that elevate and adduct the shoulder and flex the distal joints.

In the **lower extremity**, we would think about activation of muscles that are accessible to surface EMG and serve to flex the thigh and leg and lead to controlled dorsiflexion and eversion of the ankle joint. Secondarily, we would want to relax those muscles that yield exaggerated extension of the hip, thigh and ankle (plantar flexion and inversion).

Given that our treatment times are limited, emphasizing the primary principles are essential to reacquiring maximal function. We now know from many studies (REFS) that even when hyperactive muscles, those with increased tone, are down-trained, they remain co-activated (co-contract) when neuromuscular patients attempt functional tasks, such as reaching or walking. Thus for example, after down-training the biceps brachii and up-training the triceps brachii during an elbow extension, there will be a co-contraction when the patient extends the elbow while reaching and not viewing the muscle activity. The issue, ultimately, is if the patient can overcome the co-activation by more effectively recruiting the target muscle, triceps brachii, in this case.

Patients with neuromuscular disorders who have exaggerated "tone" will **not succeed** when this modality is applied in the context of surface EMG monitoring or biofeedback training unless at least two important criteria are met: (1) the tone is first reduced by pharmacological blocking agents; and (2) pain or joint contractures do not prevail. Patients may improve their movement capabilities, but without control over these two important symptoms, muscle monitoring as a retraining tool will not yield functional improvement, where **function** is defined as:

the ability to manipulate the environment (**upper extremity**) or to walk independently or safely with minimal assistance or guidance (**lower extremity**).

So, in summary, muscle monitoring can be used to help patients with neurological disorders improve. This improvement is predicated upon a strategy that first demands that patients recruit weak muscles and secondly relax hyperactive muscles. Last, it must be stated that the **guiding rule** for assessing the success of using this approach hinges upon the patients ability to produce the correct response in the **absence** of provision of muscle information and for the clinician to use the equipment correctly to provide optimal visualization of responses for the benefit of the patient and the clinician.

Contra indications

For whom would surface EMG monitoring be inappropriate among patients with neuromuscular deficits? Certainly patients with **receptive aphasia** or **profound sensory loss** will not benefit. As noted previously, if increased tone has resulted in joint deformities or pain, this approach will not be helpful unless these problems can be corrected with some degree of persistence in the correction. Patients with **limb neglect**, **reluctance to engage in the therapy** or with **secondary gain issues** (for example, obvious use of the disability to manipulate family members) may not benefit. Individuals with evidence of **profound cognitive deficits** or **dementia** will probably be inappropriate as would children or adults to **fear the instrumentation** (rarely an issue).

Chapter 5:

REGIONAL APPLICATIONS TO PATIENTS WITH NEURO-MUSCULAR CONDITIONS

This chapter provides treatment strategies for upper and lower extremities patients with neuromuscular disorders. **The first** portion of each section describes electrode placements and treatment approach for the joint of the extremity being discussed. Variations in the strategy are specified for different diagnoses when relevant. Pictural representations are provided also. **The second** portion provides a case scenario for which leading questions are asked and then answered. The second portion is designed for readers who have had clinical experience.

Anterior neck region

While not considered a part of the upper extremity, there are times when these muscles might be monitored. One such common occurrence is for **spasmodic torticollis** (**wry neck**).

General goal: This is a situation where the prevailing goal is reduction of hyperactivity.

The only muscle to be recruited is the **sternomastoid** muscle (FIGURE 2) to the side to which the head is turning. The opposite sternomastoid and the **upper trapezius** (FIGURE 5) of the side to which the head is turning should be down-trained. Occasionally the **anterior scalene** (FIGURE 3) muscles can be observed to be tight and should also be down-trained. This tightness can be noted if range of motion into cervical spine extension appears tight or limited.

The recording site for the sternomastoid muscle is along its anterior portion to avoid pick up of a carotid arterial pulse more posteriorly. The upper trapezius (as in the case of shoulder forward flexion retraining, *see below*) can be monitored with closely spaced electrodes along its anterior border as well. The anterior scalene muscles can be identified superior to the most medial aspect of the clavicle.

Patients are first trained in static (sitting or standing) postures by attempting to keep sternomastoid activity low (below threshold level) as the head is turned to the side opposite to this muscle. The same is true for the upper trapezius on the side to which the head is rotating. This training is subsequently added to dynamic (walking or walking in place) behaviors. Generally, patients are much more able to succeed in the former task than in the latter one. The treatment objective is to gradually raise the sensitivity of the amplification scales so that even small amounts of activity can be kept to a minimum. Visual imagery or relaxation exercises can accompany this training.

Clinical Case:

AB is a 24 year old man who had noticed gradual head rotation to right that got worse during walking and working activities. He denies history of trauma to the torso, limb or neck regions. He claims that he first noted this activity 3 weeks after breaking up with his fiancée. Your examination also reveals bilateral limitations in cervical extension and jaw opening.

Questions:

1. Which sternomastoid muscle would be monitored?

2. Which upper trapezius would be down-trained?

3. Would other muscle monitoring be considered and if so, which muscles and why?

Answers:

1. Both sternomastoid muscles would be monitored with the left one down-trained and the right one up-trained.

2. The right upper trapezius would be down-trained.

3. Bilateral anterior scalene muscles could be monitored and trained to be relaxed. In addition, the masseter could be monitored bilaterally for excessive activity. This muscle is accessible for recording at the angle of the mandible. (see Chapter 3 on Musculoskeletal Problems).

It should be noted that spasmodic torticollis might be of psychogenic or neurogenic origin. In this case, the history is suggestive of the former and could be ascertained through a detailed history. In such cases, behavioral counseling may be appropriate.

Upper extremity: general goal

Start with all movements within a confined "working space" so that objects that might be targeted for end of reach or grasp do not demand maximal lengthening of flexor muscles. Gradually increase the distance between the patient and the object to be reached or manipulated. The fundamental strategy is **to first recruit target muscles engaged in the activity and secondarily reduce activity among those muscles having enhanced, "tone".**

1. Shoulder

Forward shoulder flexion is a fundamental requirement for successful manual exploration of working space. The muscle to be targeted is the **anterior deltoid** (FIGURE 13). This muscle can be palpated through a contraction against resistance and active electrodes can be aligned longitudinally. The supraspinatus is NOT selected because it is "roofed" by the anterior fibers of the **upper trapezius**, from where electrodes can be closely spaced along its anterior border at mid-belly. The primary goal is to up-train (increase) the output from the anterior deltoid.

However, if movement into shoulder flexion is restricted because of limitations in scapular rotation, efforts to recruit the **serratus anterior** should be considered since this muscle is important for scapular abduction and upward rotation. This muscle can be accessed through closely spaced electrodes located just midline to the inferior border of the scapula (FIGURES 10, 11). This placement is important because misalignment or increased inter-electrode distances can lead to volume conducted pickup of latissimus dorsi or intercostals muscles.

Other important aspects of shoulder movement to improve the areas from which the extremity can retrieve are external rotation of the humerus at the shoulder joint and abduction. In both cases, the goal is to increase EMG output from the **infraspinatus** (FIGURE 9) and **middle deltoid** (FIGURE 14) muscles, respectively. The infraspinatus muscle can be identified in isolation from the middle trapezius at a level below the spine of the scapula and from half way to the lateral border of the scapula. The middle deltoid muscle is found by asking the patient to abduct the arm against resistance, outlining the contour of the entire deltoid and isolating the middle fibers in a line that drops inferiorly from the acromion shelf to the mid muscle.

Are there other muscles that should be considered for EMG monitoring? Recalling that a secondary objective is to reduce activity in hyperactive muscles, limitations in active motion toward shoulder abduction and external rotation might be caused by a "tight" or hyperactive **pec-**

toralis major muscle (FIGURE 12). Electrodes could be placed along the anterior axillary fold, away from the chest wall.

In summary, the general goal for improving active mobility of the shoulder joint among patients with neuromuscular disorders, **irrespective of diagnosis**, is to up-train muscles into shoulder flexion, abduction and external rotation, while minimize over-activity in shoulder elevation, adduction and internal rotation. In many cases, it may be necessary to promote scapular rotation as a precursor to enhancing motion at the shoulder. In examining patients, it is important to note the degree of synergy at this joint. Excessive flexion, adduction and internal rotation to the point where passive movement away from this pattern cannot be made without considerable effort on the clinician's part might suggest changes in viscoelastic properties of the joint and/or muscle that make use of muscle monitoring as a primary source of training self-defeating.

Clinical Case:

Mrs. T is a 65 year old woman who sustained a left middle cerebral artery infarct 3 months prior to referral. Her cognition is intact and her speech is comprehensible after 6 weeks of speech therapy. She appears well–motivated and has excellent family/caregiver support. Sensation is intact and there is visible movement out of synergy. Initiation of finger and wrist extension, though limited can be observed. Your initial goal is to improve shoulder mobility since Mrs. T notes that "I think my hand is coming back, but my shoulder feels tight".

Your examination reveals that Mrs. T can initiate movement in all directions but fatigues, particularly in efforts to abduct her arm and "reach out in that direction". How can surface EMG be used to foster improvement at her shoulder joint?

Questions:

1. Which muscles might be reasonable to up-train to help achieve the goal of increased motion at the shoulder to explore her "space" more effectively?

2. Does the scapular region require retraining and should SEMG be used in the process?

3. Is there need to "down-train" any muscles as a secondary treatment strategy?

Answers:

1. To gather more abduction in her reach one should consider up-training the middle deltoid (abduction) and infraspinatus.

2. Perhaps, one would need to observe the degree of scapular rotation Mrs. T can initiate to determine how "tight" she is in this region and if monitoring the serratus would be favorable.

3. Perhaps. If her shoulder abduction-external rotation is restricted by tightness in her pectoralis major, it would be worthwhile to monitor pectoralis major and down-train that muscle.

2. Elbow

A fundamental issue in using SEMG monitoring to facilitate reach is the recruitment of elbow extensors and the reduction of activity in elbow flexors during that effort. Elbow extensor muscles that could be considered are the triceps brachii and anconeus. That portion of the triceps brachii most amenable to reliable EMG pick-up is the **lateral**

head of triceps brachii (FIGURE 17). The reasons for this observation are as follows: Placements over the medial head run the risk of contamination for either the coracobrachialis or the biceps brachii. The long head proceeds along the midline of the posterior arm. If a patient has a sizeable amount of subcutaneous fat, then signals generated from this part of the muscle can be attenuated. The lateral head of triceps brachii becomes a good candidate because of its relative isolation from arm flexor muscles. By resisting a contraction of the triceps into extension that lateral head can be identified below the inferior contour of the deltoid muscle. Placement of closely spaced electrodes (1 cm or less) just below and lateral to this deltoid fold should approximate midway along the arm between the posterior inferior acromion above and the olecranon below.

The **biceps brachii** (FIGURE 18) can be monitored to reduce EMG activity at its mid-point along the anterior arm. This position will capture both heads of the biceps. Use of closely spaced electrodes (approximately 1 cm inter-electrode distance) will minimize volume conducted pick-up from the triceps brachii.

One assumes that training for elbow extension will occur after training of the shoulder region. This triceps recruitment should be done with the intended reach target moved progressively further away from the patient. This procedure places more stretch on the biceps and may lead to reflex inhibition of the triceps. By successively training with greater demands upon shoulder flexion and elbow extension, it is hoped that the patient will more effectively recruit the triceps with minimal co-activation of the elbow flexor muscles.

While this training approach is relevant to virtually all neuromuscular pathologies in which an imbalance exists between these muscles, it should be noted that there may be times when the predominant “tone” is in elbow extensor rather than flexor muscles. Under those circumstances the training strategies are totally reversed.

In ***summary***, the goal in working with elbow musculature is to foster further extension while minimizing co-activation of elbow flexion. This approach generally means up-training of the triceps brachii and down-training of the biceps brachii. There are times when this strategy may have to be reversed based upon the prevalence of an upper extremity extension synergy. The medial and long heads of triceps brachii may not be as easily isolated as the lateral head. Training should proceed with increasing demands upon more elbow extension and shoulder flexion. This approach is appropriate for most patients with upper extremity neuromuscular disorders. Exceptions may include peripheral neuropathies and demyelinating diseases, such as multiple sclerosis, where intense training may enhance fatigue and yield a paradoxical adverse effect on neuromuscular control.

Clinical Case:

JT is a 16 year old male who sustained a focal head injury one year prior to this referral. He presents with sufficient cognition to follow instructions, a desire to improve upper extremity function in his dominant right upper extremity and an excellent support mechanism at home. He has active finger and wrist extension but postures his right elbow in flexion. He has recently been given Bo Toxin injections to his elbow flexor muscles. This procedure yielded substantially greater voluntary elbow extension. You now wish to use surface EMG in conjunction with your preferred neuromuscular re-education techniques to enhance elbow extension.

Questions

1. Is monitoring of the brachialis for further reduction of flexor activity appropriate?

2. What is the best training strategy for recruitment of elbow extension?

3. Does this patient need to be reevaluated periodically from an surface electromyographic perspective?

Answers

1. Monitoring of the brachialis muscles is probably not a preferred method of treatment. This muscle lies beneath the biceps brachii and cannot be monitored in isolation. One would have some difficulty ascertaining the degree to which improvement (down-training) was related to the biceps and/or the brachialis response.

2. Monitoring of the lateral head of triceps brachii starting at a high sensitivity setting and progressing to lower sensitivity with the addition of resistance and greater demand on the amount of active extension necessary to reach a target or hold an object. Electrode placement would be along the lateral border of the posterior arm below the inferior border of the deltoid muscle.

3. Yes. Because the effectiveness of the block will wear off in a matter of a few months, it is prudent to determine the extent to which the return of "tone" or "tightness" to the biceps brachii might influence activation of the triceps and overall function, i.e., the relationship between triceps EMG activation and functional measures.

3. Forearm: pronation/supination

The prospects for isolated EMG recordings from the **pronator teres** (FIGURE 21) or pronator quadratus are meager. This fact is precipitated by the reality that while the pronator teres is the most laterally placed of the forearm flexor mass, even closely placed electrodes arranged longitudinally along the direction of the muscle fibers may yield volume conducted pick up from the adjacent flexor carpi radialis. This latter muscle can be hyperactive during efforts at pronation thus lending confusion as to whether the recording is generated from the pronation

effort or the wrist flexion associated with it. One way to deal with this problem is to up-train pronator teres and wrist or finger extensor muscles concurrently as the patient attempts to achieve pronation with wrist/finger extension. The pronator quadratus can be monitored just proximal to the wrist joint with closely spaced active electrodes oriented longitudinally across the forearm. Because the pronator quadratus is located very deeply, concurrent activation of wrist or finger flexors during efforts at isolated pronation may lead to inappropriate elevated levels of EMG generated by muscles other than that targeted for training.

The primary muscle for supination is the supinator. This muscle wraps around the head of the radius and is difficult to access with surface electromyography. While claims have been made to record from this muscle through electrodes placed less than 1 cm apart on the dorsum of the wrist just next to the proximal posterior ulna bone, these recordings are less than ideal. The opportunity to record activity from the biceps brachii rather than the supinator for supination is confounded by the inability to differentiate the desired motion (forearm supination) from an undesired one (elbow flexion).

In summary, isolated pronation and supination of the forearm using electromyography is most difficult. Because of the prospects for contamination of EMG from other muscles, some clinicians have resorted to the use of position feedback devices rather than electromyographic feedback to monitor these forearm rotational movements.

4. Wrist: flexion/extension

Isolation of muscles to examine these movements is not nearly as complex as with pronation and supination motions. Successful electrode placements hinge on knowing the anatomy and particularly the relative location of tendons associated with several of these muscles. **Brachioradialis** (FIGURE 20) is a muscle that forms the most dorsal and lateral

of the dorsolateral group. It is easily palpated and recordings can be made through closely spaced electrodes directly overlying the proximal portion of the muscle just distal to the elbow joint. The muscle, however, acts to flex the forearm rather than having a profound effect upon the wrist. In this manner, it is a reasonable muscle to monitor and train for forearm flexion but not for action at the wrist joint.

On the other hand, the two muscles, immediately to the dorsum of brachioradialis, the **extensor carpi radialis longus and brevis** (FIGURE 22) act to extend and radially deviate (abduct) the wrist. Electrodes closely spaced (less than 2 cm inter-electrode distance) at virtually the same location as the brachioradialis electrodes (2 cm distal to the elbow crease) can depict wrist extension nicely and in isolation. To record from extensor carpi ulnaris, requires that the clinician place electrodes adjacent to one another at mid forearm slightly dorsum to the ulnar bone.

The **flexor carpi radialis** (FIGURE 23) is located in a line along the volar surface of the forearm between the medial epicondyle of the humerus and the capitate carpal bone approximately 6 cms from the elbow joint. Placing electrodes close together (less than 2 cm inter-electrode distance) helps to assure isolated recordings from this muscle.

Training strategies presume that increased tone in wrist flexor muscles prevails and that there is a need to enhance output from the wrist extensor muscles. Up-training the output from the extensor carpi radialis muscles and secondarily reducing output from the wrist flexors accomplish this goal. Proximal placements of closely spaced electrodes assure minimal contamination from activity generated in finger musculature.

In summary, muscles governing wrist flexion and extension are relatively easy to isolate. The goal of wrist extension is common to most patients with neuromuscular disorders. Again, care must be exercised not to overuse these muscles if they are becoming reinnervated following peripheral nerve lesions or neuropathies.

Clinical Case:

RR is a 21 year old women who sustained a high cervical spinal cord compression after falling off a horse. There appears to be some indication of sparing at the C6-8 region as reflected in the development of some volitional wrist extension. You wish to assess this possibility and build upon it without further enhancing what appears to be some persistent "tone" in her wrist flexors. At this point, it appears worthwhile to explore the use of surface EMG to assist this patient.

Questions

1. What is a primary treatment strategy with SEMG?

2. Should you try to use SEMG approaches to build upon wrist extension and controlled supination?

3. Is monitoring wrist flexion necessary?

Answers

1. Increase output from extensor carpi radialis starting at high gain or sensitivity and low threshold and progressing with requirements for greater output. Much verbal encouragement and reward is appropriate with each gain, since the accompanying "new" movement will encourage the patient to try even harder.

2. Supination will be difficult since the primary muscle will be the biceps brachii that might already be overused. The status of the elbow flexors would possibility would first have to be assessed. If activity was profound or the muscle group overused, one would be reluctant to work on supination this way.

3. Yes. The clinician does not know the status of the wrist flexors until they are examined electromyographically. One clue is if the patient

tends to posture herself in wrist flexion. This observation would at least suggest that there is a need to work on extension and determine later if down-training of wrist flexor activity is necessary.

Fingers: Flexion and Extension

The principles underlying monitoring of these muscles (**extensor digitorum communis** (FIGURE 24), and **flexor digitorum superficialis** (FIGURE 25) are very similar to those discussed for the wrist flexor and extensor muscles, except the placements are more distal to afford pick up of the fleshy fibers of these muscles at locations where the muscles acting on the wrist joint have already become tendinous. Placement for the extensor digitorum communis is at the midpoint on the dorsum of the forearm in longitudinal alignment with the direction of the muscle, three-quarters down its length and separated by not more than 1 cm. The flexor digitorum superficialis muscle placement is on the volar surface of the forearm aligned longitudinally proximal to the wrist and on either side of the tendon of palmaris longus using a similar inter-electrode distance. At this point the muscle is isolated from wrist flexor muscles. The flexor digitorum profoundus cannot be accurately monitored with surface electrodes.

With respect to finger extension, the **extensor indicis proprius** lies deep to the common finger extensor and is not accessible with SEMG electrode placements. However, a reasonable surrogate muscle that performs a comparable function is the **first dorsal interosseous** muscle (FIGURE 26) to which very closely spaced electrodes can be placed. In passing, it should be mentioned that electrodes placed between the metacarpal bones on the dorsum of the hand (**dorsal interossei**) or in the palm (**ventral interossei**) may monitor finger abduction and adduction, respectively. These placements are suspect, however, since so many other muscles can influence the recording sites. For example, any hand movements involving closure or exaggerated finger extension

along with separation of electrode to skin contact because of sweating can easily invalidate these recordings.

Inevitably controlled finger extension is important for any manual behavior. Among patients with weak finger extension and enhanced tone in finger flexor muscles, recruitment of the former is mandatory to achieve meaningful function. Up-training of finger extensor muscles must be undertaken first with less demand placed on the patient, for example, working toward retrieval of objects close to the body and subsequently with objects moved further away. This latter task imposes more control requirements on the patient's flexor muscles, which are now more lengthened.

Again, there are few situations in which this training strategy is not relevant to patients with neurological diagnoses. Clinicians should be cautious when applying this approach to patients who have periodic uncontrolled finger extensor movements, especially if the patient is unaware that such activity is occurring. This situation is sometimes seen in stroke patients, for example, who have regained some distal hand movement but also have dyskinesia (unaware of joint position sense). In such circumstances the effort is made to use the visual feedback of the SEMG output as a substitute for inaccurate appreciation of movement.

In ***summary***, finger flexor and extensor EMG can be isolated from one another. It is not possible to accurate record from the deep finger flexor muscle. Training should be geared toward the recruitment of finger extensor muscle activity. As with training strategies that preceded targeting the fingers, there is a need to integrate the recruitment of the digits in reaching tasks with the recruitment of other muscles monitored more proximally. Monitoring finger abduction and adduction is more difficult and there may be times when the strategy to recruit finger extensors should be tempered with controlled activity with finger flexors.

Clinical Case:

LT is a 45 year old woman who has a 15 year history of multiple sclerosis. Her recurrent episodes are getting progressively worse. She has heard about electromyographic monitoring and has gotten permission from her HMO for 5 sessions of this approach because, as a home maker, she believes that this approach might improve her ability to cook and feed herself. She comes to your clinic for evaluation of neuromuscular status and implementation of a program to evaluate her capabilities and improve her hand function. Muscle tests reveal a general performance of 3-4+/5 for most muscle groups bilaterally. There is marked atrophy of her hand intrinsics and weakness in her grip and hand opening, right worse than left. LT is right handed. You have decided to perform muscle training during feeding tasks.

Questions:

1.Which muscle should be monitored?

2.What should the goal be?

3.Should other muscle groups be assessed?

Answers:

1. Certainly finger flexor and extensor muscle activity should be explored.

2. The goal should be to find a balance of co-activation in this patient so that she will be able to grip utensils consistently without dropping them. This balance can only be ascertained by recording the activity from both muscle groups while a utensil is being held and during the feeding task itself. For example, recognizing that either fatigue or "dropping" a utensil is preceded by reduced finger extensor activity,

might lead to a training protocol to increase extensor output during graded contractions against resistance (strengthening exercise).

3. One might also want to monitor wrist extensor (preferably) or flexor (secondarily) activity to see if muscle output here drops more precipitously than with digital muscles.

The Thumb (Pollux)

Perhaps the cornerstone to upper extremity function is the thumb. Yet while this digit has such profound cortical representation, its surface area makes recording activity difficult. The **extensor pollicis longus** (FIGURE 27) can be accessed by electrodes that are juxtaposed in line with the tendon and directly over the dorsum of the joint. At this point the last fleshy fibers of this muscle may still be responsive to recordings. The most superficial portion of the thenar muscle group contains the **abductor pollicis brevis** (FIGURE 28). Small, closely spaced electrodes positioned over dry skin may permit recording during efforts to open the hand. Recruitment of these two muscles concurrently may be advisable when using two channels of muscle activity. Trying to uptrain these muscles while performing reaching tasks is reasonable as long as movement artifact is not created by contact of the thenar electrode with the object, thus yielding transient but erroneously elevated EMG responses. It may also be of interest to record from one or both of these muscles while emphasizing total extension of elbow wrist and fingers. One difficulty in this procedure, is the possibility of recording from the adjacent flexor pollicis brevis, a muscle whose activation would usually be contrary to the goal of hand opening. Thus electrodes placed over the abductor must be small and almost touching one another.

In ***summary***, the long extensor and the small abductor of the thumb can be co-activated or engaged independently as part of a strategy to facilitate hand opening. It is important that changes in EMG from these

muscles, much like in recording from muscles governing other digits, be related to functional return as measured by tasks now completed or time to complete tasks.

Clinical Case

ST, a 60 year old man, sustained a right brain CVA following an infarct one month previously. A residual deficit can be seen in hyperextension of the dominant left first CMC and MP joints and flexion of the interphalangeal joint. The patient also suffers from apparent neglect of the limb. You are asked to retrain the hand to make it more functional. The patient appears cooperative but disoriented about why he is there.

Questions:

1. Is treatment appropriate using surface EMG?

2. If not what other options might one consider?

Answers:

1. Treatment is probably inappropriate since the patient is unaware of the problem (remember contra indications to use of surface EMG with neuromuscular patients). Even efforts to increase long thumb extensor output might not be retained.

2. A more aggressive manual therapy to see if this thumb imbalance might not be overcome would be appropriate. The use of muscle monitoring could be considered at a later time.

Lower extremity: general goal

Use of SEMG in the treatment of patients with neuromuscular disorders is designed to facilitate independent ambulation or the reduced but safe dependency on fewer assistive devices. Training goals are aimed at improving support on the impaired lower extremity, and promoting comparable hip flexion, knee extension and ankle dorsiflexion/eversion during the appropriate phases of the gait cycle. As with the upper extremity, a reasonable approach within the context to time limitations for individual and total treatments is to facilitate (promote) activity in target muscles and secondarily, to reduce activity in hyperactive muscles.

1. Weight shifting / weight bearing

Weight bearing on an impaired lower limb is essential for successful ambulation. Often patients with neuromuscular deficits are reluctant to bear weight during the stance phase and often reduce the length of stance on that limb. Weight shifting onto the more impaired lower extremity with a goal of increasing single limb support (even without stepping) is important to enhance patient confidence. One activity is to monitor extensor muscles to foster this goal. Muscles that can be monitored include: **gluteus maximus** (FIGURE 34), **gluteus medius** (FIGURE 33), **vastus medialis oblique** (VMO, FIGURES 40, 41) or a broader placement on the **quadriceps femoris** (FIGURE 38). In each case the goal is to increase muscle output. The gluteus maximus placement is either posterior directly below the iliac crest on an imaginary line midway between the greater trochanter and lower sacrum or, alternatively just above the gluteal fold. Inter-electrode distances should not exceed 2 cm. A wider inter-electrode placement might result in volume-conducted recordings from neighboring muscles. Often excessive subcutaneous fat might obscure the pickup from the muscle to the overlying electrode site. The placement for gluteus medius is vertically oriented

line connecting the two. The electrodes are placed longitudinally along that line, less than 2 cm apart. If the active electrodes are placed so that the lie closer to the iliac crest than to the trochanter, the possibility of recording volume conducted activity from the gluteus maximus is reduced. The VMO is found near the medial aspect of the superior border of the patella with active electrodes closely spaced (1 cm inter-electrode distance) and oriented in the direction of the fibers (medial thigh to superior medial patella). The placement for quadriceps femoris is more general with electrodes oriented along the central portion of the quadriceps in line with the middle of the patella at mid femur and 2-3 cm apart. While this placement does afford a non-specific representation of the quadriceps, the possibility of recording from other neighboring muscles (e.g., sartorius or adductor mass) does exist. This situation can be improved by narrowing the inter-electrode distance.

The training strategy is to recruit these muscles during progressively increasing weight bearing. This activity can be reinforced with mirror feedback to assure alignment of the pelvis and/or minimization of hyperextension of the knee joint (recurvatum). One inherent danger in this approach is over-engaging the quadriceps mechanism. If weight bearing does lead to a locking of the knee that cannot be easily overcome by the patient, then there is a need to find a balance between activation of the quadriceps and co-activity in the hamstrings. There are two approaches to monitoring this muscle group. One is to place electrodes longitudinally about 5 cm above the lateral posterior need joint and not more than 2 cm apart so that the primary recording is from the **biceps femoris** (FIGURE 36). An alternative is to engage the entire **hamstrings** (FIGURE 35) by placing electrodes about 5 cm above the posterior knee joint but across the muscles thus attempting to pick up the semitendinosis (medially) and biceps femoris (laterally). While broader in scope, the latter placement runs the risk of volume conducted pick up of the adductor mass, particularly the adductor magnus.

To prevent recurvatum, a reasonable training strategy with EMG monitoring is to train the patient to co-activate the VMO and the hamstrings

without allowing the knee to fully extend. This strategy is beneficial when the patient has difficulty unlocking the extended knee and is a necessary approach prior to initiating walking. After all, if the patient cannot successfully unlock the knee then initiating gait will be difficult.

Clinical Case:

MS is a 17-year old boy who was born with cerebral palsy and is referred for ambulation training following muscle lengthening procedures performed on his hip adductor, hamstring and triceps surae tendons. He has always walked with Loftstrand crutches and the goal is to reduce dependence on assistive devices to the extent possible. You wish to determine his standing balance and lower extremity positioning. Clearly he favors his right lower extremity. You wish to employ EMG monitoring in helping you to improve independent standing balance and gait initiation.

Questions:

1. Which muscles would you consider monitoring and why?

2. If hamstring muscles were chosen, what would the orientation of the electrodes be?

3. What is the training strategy you will employ?

Answers:

1. Quadriceps (close placement to avoid possible pick up from hyperactive adductors) hamstrings and, if pelvic control appeared compromised, gluteus medius.

2. A longitudinal placement along the biceps femoris to minimize volume conduction from the adductors.

3. The goal would be to increase output from all these muscles to the point where the patient can stand independently for at least 15 seconds (to demonstrate reasonable control over his lower extremity in standing posture (NOTE: imbalance may be due to poor control over or weak erector spinae musculature, which would need to be assessed as well. If the patient cannot unlock his knee, it may be necessary to co-activate lateral hamstrings and quadriceps to minimize full knee extension in standing.

2. Gait initiation: hip flexion

After a patient has demonstrated the ability to stand on the more impaired leg, the ability to release this stand through gait initiation is important. The first effort is directed toward hip flexion. Fundamentally there are two muscle groups that can be considered. The **sartorius** (FIGURE 32) is the more easily accessed. This muscle can be palpated just below the anterior superior iliac spine where it is already fleshy. To move more inferiorly along its medial extent as it crosses the thigh could result in pick up from the quadriceps, even if the recommended less than 2 cm inter-electrode distance placement is followed. Just superior to the upper fibers of sartorius in the first quarter of its extent lies the floor of the femoral triangle, which contains the iliacus muscle. While the iliacus and the psoas major muscles combine to form the primary mover for hip flexion, the iliopsoas, accurate recordings from this muscle free from contamination of pick-up from the adductors or quadriceps (rectus femoris) is questionable. The **adductor mass** (FIGURE 37) lies medial to the sartorius and within that zone and an imaginary line running down the inner thigh from the pubic symphysis to the medial knee joint line. Closely placed electrodes in this region will afford good recordings from the adductor group (adductor longus and brevis and some of adductor magnus). Awareness of adductor activity can be ascertained by observing the direction of the thigh during forward projection of the femur. If there is evidence of motion of the femur toward

the thigh (as is often seen in “adductor spasticity”), there may be a need to down-train adductor activity during the swing phase of gait.

Clinical Case:

RR sustained a gunshot wound that resulted in a paraparesis at the L4 level. He has improved in his standing balance with use of orthotics and now is undergoing gait training. His attending physician has asked if gait training is feasible and if there are mechanisms to assist RR in promoting his understanding of how to begin walking. A referral has come to you to address this issue.

Questions

1. Is there an easy way to gain some insight into this possibility?

2. How might you use SEMG to begin the evaluation/treatment process?

Answers

1. This case is not easy because there are so many factors to assess before one can determine the feasibility and practicality of moving forward using SEMG. However, we know that hip flexion is a necessary prerequisite to walking. We will assume that RR can stand in his orthotics.

2. After first palpating the sartorius to confirm that activity might be present (even if the results from manual muscle testing yield a trace or poor grade), activity can be assessed with surface EMG either in a gravity-eliminated position or in standing. In the latter case, gentle resistance can engage the sartorius and the patient attempts to build upon the activity as he attempts to raise the limb from the floor. This activity can first be attempted in standing with repeated leg lifts and then during ambulation where emphasis is placed on increasing EMG output during the initiation of swing to foot clearance.

3. Gait: knee flexion

Monitoring of quadriceps and hamstrings has already been discussed. Here we are concerned about the patient's ability to recruit hamstrings during the toe off to mid-stance phases of gait. The goal is to engage the hamstrings by starting with muscle monitoring either across the hamstrings (see above: *Lower Extremity, 1 Weight shifting / weight bearing*) or longitudinally along the biceps femoris if activation of the adductor muscles is suspected. The patient attempts to increase muscle output as the hamstrings contract to raise the leg against gravity. If the output is insufficient to cause movement, the activity can be repeated in a side-lying (gravity eliminate) position before advancing to standing. If a patient cannot generate sufficient hamstring activity in this position to move the leg posteriorly, then the explanation may be twofold: either (1) the muscle group is too weak to allow movement in which case resistive exercise may be necessary or the approach might be abandoned; or (2) the quadriceps are co-contracting in which case this muscle group must be down-trained while the hamstrings are being up-trained (sometimes called "differential training"). If the latter approach results in movement, then the procedure can be repeated in standing.

Clinical Case:

LD is a 55-year old patient with Parkinson's disease who apparently has a rigid pattern of walking with an extended lower extremity but in isolation can easily demonstrate knee flexion (sitting posture or side-lying). The question is can he be trained to effectively flex his knee during the swing phase of gait to "break up" his apparent extensor synergy. The patient is cooperative and willing to try new approaches. He has excellent support and encouragement from family members at home.

Questions

1. What fundamental training strategy can be employed using SEMG?

2. Is there an alternative approach that can be attempted?

Answer

1. Starting in a sitting position, monitor hamstrings at high gain (sensitivity) to see if the patient can generate hamstring activity with knee flexion. This effort should be progressed to a standing (stationary) position and then to ambulation.

2. If the strategy used above does not work, then attempts to initiate flexion at the hip by monitoring sartorius activity toward hip flexion might result in either relaxation of the knee extensors or ease in recruiting knee flexors. So this task may be progressed to activate sartorius and hamstrings concurrently. Last, it may be necessary to attempt to relax quadriceps at the same time hamstrings are being recruited (differential training).

4. Gait: ankle control

A primary concern regarding ankle control for all patients with neuromuscular deficits characterized by increased extensor tone at the ankle joint is the ability to flex (dorsiflex) the ankle joint while demonstration controlled inversion and eversion of the subtalar and inter-tarsal joints. Failure to do so can result in extending onto an inverted foot thus risking damage to joints or ligaments. The fundamental strategy is to recruit the **tibialis anterior** muscle (FIGURE 42) or, more generally, the anterior compartment (including tibialis anterior and extensor digitorum longus) using a more generalized placement. Because inversion of the ankle accompanies ankle dorsiflexion, it is important to control for this occurrence. The most reasonable approach would be to engage the peroneal muscles in the lateral compartment of the leg. However, the lateral intramuscular septum that separates the posterior and lateral compartments is thin and allows for volume-conducted pick-up from the triceps surae, which may co-contract as the anterior muscles are

recruited. Thus, a reasonable muscle to recruit instead of the peroneus longus or brevis is the **extensor digitorum brevis** (FIGURE 44). This relatively obscure muscle sits on the dorsolateral aspect of the foot and is responsible for extending the proximal joints of the four toes. However, this movement is difficult to accomplish without also everting the ankle (Try it on yourself!). Therefore up-training the extensor digitorum brevis in concert with the tibialis anterior is a logical approach to gaining controlled ankle flexion during the swing phase of gait. There may be times when it is necessary to down-train the ankle extensor muscles, for example the **medial or lateral gastrocnemius** (FIGURE 43). Even when efforts are made to relax this muscle at rest or during the swing phase, it will co-contract with the anterior leg muscles in the absence of feedback. It is best to encourage the patient to overcome this co-activation. Often the ability to do so with the resultant gain being active dorsiflexion beyond a neutral position may be the determining factor regarding whether use of an orthotic assist will be needed. Remember, our general rule here is to recruit (train) muscles in the same direction. Often up-training is a far easier task for patients to achieve than down-training!

Clinical Case:

RG is a 57-year old man who sustained a right middle cerebral infarct 4 months prior to referral. He has compromised sensation in this left lower extremity but control over his hip and knee joints. His ankle joint appears "strange" because he cannot feel it but is able to initial dorsiflexion and inversion when he looks at it. You are being asked to evaluate this patient and you are considering use of muscle monitoring to do so.

Questions

1. What primary training strategies might you consider?

2. What secondary training strategies would you consider if the primary ones did not work?

3. Are there special circumstances or precautions needed in this case?

4. How would you assess and report “functional” gains?

Answers

1. Primary: up-train the anterior compartment of his left leg. If inversion persists as active range of motion into dorsiflexion is achieved, consider monitoring the extensor digitorum brevis (EDB). The patient may not be able to wear his shoe while engaged in that task. Training of the EDB will require starting at a very high gain (sensitivity) and working toward a lower gain, thus making the patient work harder to generate muscle activity seen as a signal on the monitor. The most difficult aspect of this training involves the patient’s ability to control the contraction (eccentrically) in his anterior muscles as his foot approaches the floor – holding during approaching heel contact.

2. Secondary: down-train the gastroc-soleus complex through monitoring of the medial or lateral gastrocnemius muscles.

3. Yes. This patient essentially presents with a dyskinetic foot. He will need to be trained to incorporate visual guidance with his awareness of correct responses through EMG monitoring.

4. Functional improvement can be assessed through recording active range of motion in static posture or during the swing phase of gait; relating these changes to peak or averaged EMG; recording changes in walking speed and/or distance; and noting changes in use of assistive devices.

The Physical Interface: Electrodes and Skin Preparation

Skin should always be prepared by applying an alcohol wipe (preferably with an abraded surface, such as a gauze pad) vigorously and briskly until a mild erythema is observed. This approach will remove oils and dead skin while also reducing the resistance between the signal source (the muscle beneath) and the electrode recording surface (above). Generally, electrodes are "disposable" and come pre-gelled, that is, a conducting medium is embedded over the recording surface of the electrode.

While much has been written about the "exact placement" of electrodes with respect to such factors as the end plate distribution across and through the muscle, the thickness of the muscle, and the orientation of muscle fibers, the fact is that muscle fiber orientation end plate zone alignment may change throughout the course of the muscle. Therefore, knowledge of the muscle anatomy, particular the depth, location of muscle bellies, and the general location of where within the muscles the tendons or insertions are located become important. Many clinicians appear "confused" and even intimidated about the need to retain this knowledge. The fact remains, however, that most clinicians know where muscles lie, can identify their "bellies" and can access the approximate locations of tendinous components of muscles through anatomy atlases. All that is required is to recognize that an ***electrode pair is merely a substitution for the palpating finger!***

General rules

There are general rules that clinicians must recall when applying surface electromyography. These are few and not very difficult.

Inter-electrode distances: The closer a pair of recording electrodes, the more specific the "pick-up area". Wider inter-electrode distances are employed for non-specific monitoring, as occurs when attempting general relaxation of a hyperactive muscle group or recruitment of a group of muscles what have become re-innervated after a peripheral nerve lesion or recovery from other peripheral neuropathies or prolonged immobilization.

Muscle depth: Muscles that lie beneath other muscles cannot be easily recorded with surface EMG. Surface electromyography does just that – record from predominantly surface muscles. Thus it is foolhardy to believe that one can record from the supraspinatus when the muscle of

overlain by the upper trapezius or the rhomboids when that muscle is covered by the middle trapezius. If the clinician cannot control for the activation of the more superficial muscle, there is little reason to believe that one is accurately "picking up" a deeper muscle. Thus, knowledge of the anatomy becomes important.

Electrode placements: Placement of electrodes becomes an important consideration when attempting to isolate muscle groups. To aid in successfully placing electrodes, clinicians should consult muscle atlases. For example, knowing where a muscle becomes tendinous is important in distinguishing muscle groups. For example, the **flexor digitorum superficialis** (FIGURE 25) becomes superficial just proximal to the wrist joint where the last fleshy fibers attach to the tendons transmitted beneath the carpal tunnel. Electrodes placed longitudinally here will allow maximal isolation of finger flexors from wrist flexors that can be more easily recorded from distal to the medial epicondyle of the humerus. The same principle holds for distinguishing the common finger extensor muscle from the radial wrist extensors. Close examination of the course of the **extensor pollicis longus** (FIGURE 27) will reveal that its last fleshy fibers attach obliquely to the muscle tendon just above the wrist joint, so closely spaced electrodes oriented toward the thumb and placed on the dorsum of the wrist can capture its muscle activity. Similarly, recalling that the **sartorius** muscle (FIGURE 32) originates as a muscle mass beneath the anterior superior iliac spine would allow closely spaced electrode placements at that point without major concern about contaminated pick-up by the neighboring rectus femoris. Hence the sartorius could be monitored for hip flexion. Conversely, it would be naïve to believe that the prime mover for hip flexion, the iliopsoas, could be monitored in relative isolation as a hip flexor because of its depth.

Recording stability: Electrodes should be secure and afford little movement during static or dynamic activities. This consideration includes trying not to touch electrodes while managing the patient. Similarly leads coming from the patient and going to the amplification stage of the machine should be stabilized and free from "drag" or excessive movement.

NOTE: The following section provides illustrations for some of the most common electrode placements. In some of the pictures the black ground electrode is located at the recording site. This method should only be used for single channel recordings. For multichannel recordings with Noraxon systems the common **ground electrode should always be placed on a bony prominence**, such as C7 vertebrae, iliac crest or tibialis (for examples, see FIGURES 4, 31, 44).

ORIENTATION: FIGURES 1, 2, 31-34 AND 37 are left side. All other figures are right side.

Fig 1. MASSETER, TEMPORALIS, FRONTALIS

Fig 2. STERNOMASTOID

Fig 3. ANTERIOR SCALENE

Fig 4. CERVICAL PARASPINALS

Fig 5. UPPER TRAPEZIUS

Fig 6. MIDDLE TRAPEZIUS

Fig 7. LOWER TRAPEZIUS

Fig 8. LEVATOR SCAPULAE

Fig 9. INFRASPINATUS

Fig 10. SERRATUS ANTERIOR (upper fibers)

Fig 11. SERRATUS ANTERIOR (lower fibers)

Fig 12. PECTORALIS MAJOR

Fig 13. ANTERIOR DELTOID

Fig 14. MIDDLE DELTOID

Fig 15. POSTERIOR DELTOID

Fig 16. TRICEPS BRACHII LONG HEAD

Fig 17. TRICEPS BRACHII LATERAL HEAD

Fig 18. BICEPS BRACHII

Fig 19. WIDE vs. NARROW PLACEMENT

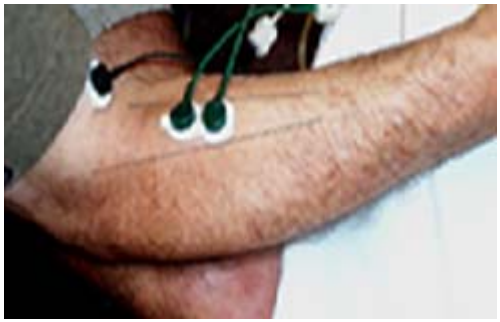

Fig 20. BRACHIORADIALIS

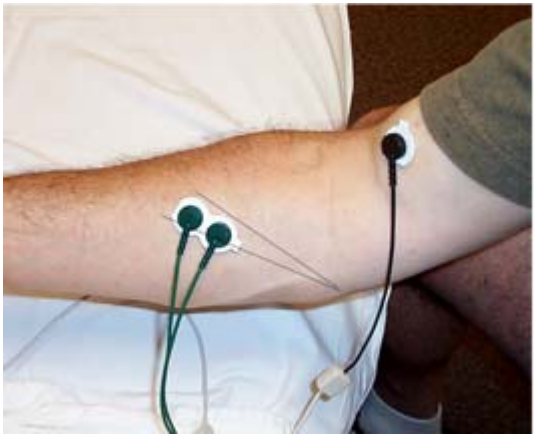

Fig 21. PRONATOR TERES

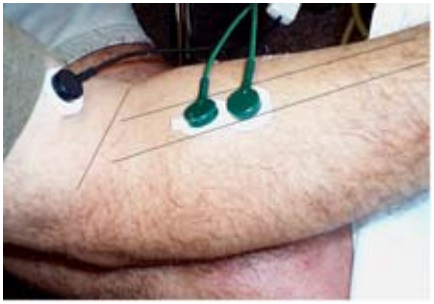

Fig 22. EXT.CARPI RADIALIS LONGUS

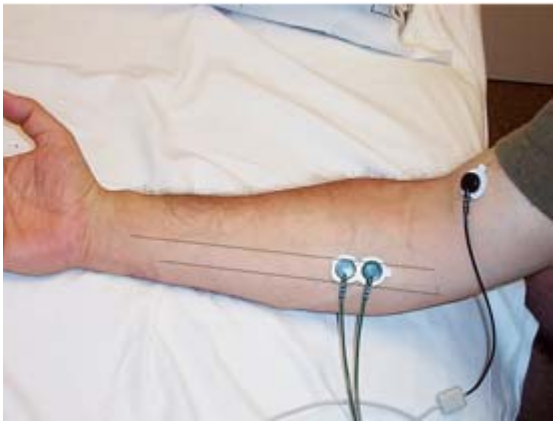

Fig 23. FLEXOR CARPI RADIALIS

Fig 24. EXTENSOR DIGITORUM COMMUNIS

Fig 25. FLEXOR DIGITORUM SUPERFICIALIS

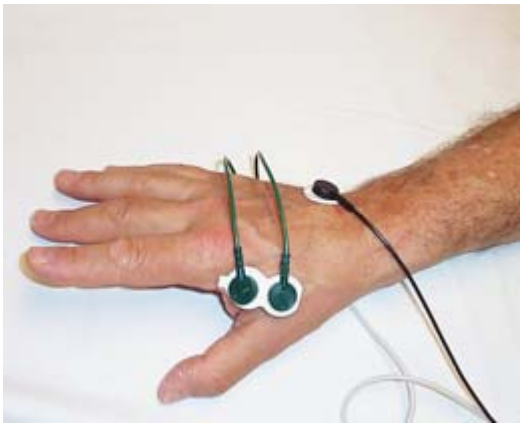

Fig 26. FIRST DORSAL INTEROSSEOUS

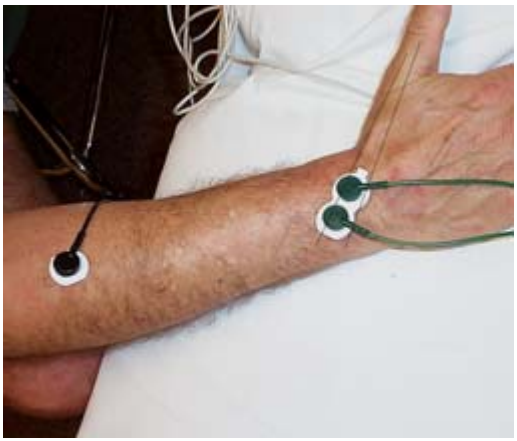

Fig 27. EXTENSOR POLLICIS LONGUS

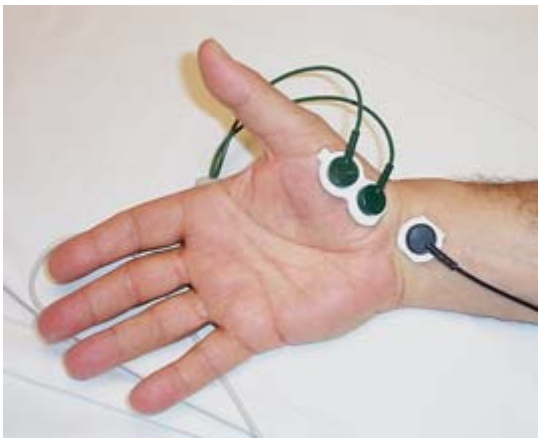

Fig 28. ABDUCTOR POLLICIS BREVIS

Fig 29. THORASIC PARASPINALS

Fig 30. PARASPINAL MULTIFIDUS

Fig 31. RECTUS ABDOMINIS, EXT.OBLIQUES

Fig 32. SARTORIUS

Fig 33. TENSOR FASCIA LATAE, GLUT. MEDIUS

Fig 34. GLUTEUS MAXIMUS (upper & lower fibers)

Fig 35. HAMSTRINGS (wide)

Fig 36. MED.HAMSTRINGS, BICEPS FEMORIS

Fig 37. ADDUCTOR MASS

Fig 38. QUADRICEPS FEMORIS (wide)

Fig 39. RECTUS FEMORIS

Fig 40. VAST. LATERALIS, VAST. MED. OBLIQUE

Fig 41. VASTUS MEDIALIS OBLIQUE

Fig 42. ANTERIOR TIBIALIS

Fig 43. MEDIAL GASTROCNEMIUS

Fig 44. EXTENSOR DIGITORUM BREVIS

Setting up the system

- Turn on the EMG system and the computer.
- *MyoSystem1200, MyoSystem2000 and TeleMyo*: Check to make sure that the interface cable is plugged into the rear panel of the EMG system and securely attached to the A/D (analog to digital converter) card. The card is located in one of the PCMCIA slots in the side panels of a laptop computer or in the rear panel of a desktop computer. *TeleMyo* users need to also make sure that the red error light in the front panel of the receiver goes off when both units are on. If the error light stays on, check the antenna cable connections and turn the orange knob in the rear panel of the receiver to either direction until you find the correct carrier frequency and the error light goes off.
- *MyoSystem1400, MyoTrace200+* : Check to make sure that the USB (universal serial bus) cable is plugged into the rear panel of the EMG system and one of the USB ports in your computer. You may need to open or slide a lid to find the port. It is marked with a three prong USB symbol. *MyoTrace200+* users need to also check that the MyoTrace200+ unit is connected to the front panel of the isolated A/D system.
- Double-click on the *MyoClinical* icon to open the program. (If you can not find the icon, go to Start, Programs, Noraxon, MyoResearch, MyoClinical or find the program in Windows Explorer C:\Programs\Noraxon\MR2.02\macro.exe.)
- If the program is being opened for the first time, you will need to enter the serial number (in format *mcxxxxxxcm*) from the cover of your installation diskette. If you can not locate the password call Noraxon at 1-800-364-8985.
- Click on the *down arrow* under Groups and select *Coordination* protocol.
- Click on *Next* and then on *Database*.
- Click on *Setup* in the top menu bar and select *A/D setup*.
- Verify that the hardware settings match your system:

All MyoSystem models and MyoTrace200+ should use the Myosystem setting.

TeleMyo users should use the US TeleMyo setting.

A/D setting should be set to *USB*, *Driverlinx* (for AI-12 Keithley card) or *CIO* (Computer Boards) depending on which device you have.

Other settings can remain as is (calibration 30, filling mode checked).

- Click on *OK* and then on *Exit* button on the right.
- Click on *New Patient*, *Add Patient*, type in a *name* and click *OK*.
- You are ready to start a measurement.
- **NOTE:** It will not be necessary to check the hardware settings next time. You can skip the *Database* part and go directly to *New Patient*.

Recording vs. monitoring

- Before going to the measurement screen, type in a file name such as Lab 4. (You can return to this screen from the measurement screen with *Escape* key in your keyboard). In the measurement screen, after *Calibration* click on *Store* to start and *Exit* to end a recording. Click on *Yes* to save it. MyoClinical will automatically display the recording in the RecordViewer window. Click anywhere on the screen to see the corresponding EMG amplitude in the bar at the bottom of the screen. *(See Laboratory Exercise 3 on page 7 for available display features).*
- Be sure to click on *End* when you want to go back to the measuring screen. (Clicking on Continue will take you to the analysis page which is not required for most of the laboratory exercises. If you accidentally do it, click on continue again and click on No if prompted.) To view a previous recording click on *Database*, highlight the file name in the records column and click on *View*.