PART

I

The Basics of Surface Electromyography

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CHAPTER 1

Introduction

"Electromyography is the study of muscle function through the inquiry of the electrical signal the muscle emanates."[1]

THE HISTORY OF SURFACE ELECTROMYOGRAPHY

The history of surface electromyography (SEMG) has to do with the discovery of electricity and the development of the ability to see through the aid of instruments things that cannot be seen, felt, or touched with the normal senses. It is also the story of the emergence of a new paradigm for assessing and treating the energy of the muscles—a form of "energy medicine," in which the emphasis is on the energy of the body rather than its form. (In this paradigm, form is not unimportant, but it is only of secondary interest.) As is true for all paradigm shifts, many individuals are reluctant to give up their investment in the old paradigm. For example, many practitioners still prefer clinical palpation and observation over measurement of the energy of the muscle, even though each technique may tap into a different domain of information.

The theme of the development of SEMG can be traced back to the mid-1600s, when Francesco Redi[2,3] documented that a highly specialized muscle was the source of the electric ray fish's energy. By 1773, Walsh had been able to demonstrate clearly that the eel's muscle tissue could generate a spark of electricity. It was not until the 1790s that Galvani obtained direct evidence of the relationship between muscle contraction and electricity; he conducted a series of studies that demonstrated that muscle contractions could be evoked by the discharge of static electricity.[4] In 1792, Volta[5] initially agreed; he later concluded that the phenomenon Galvani had seen did not emanate from the tissue itself, but rather was an artifact of the dissimilar metals touching the muscle tissue. Galvani rebutted Volta's criticism and was able to demonstrate the firing of the muscle by contracting it with a severed nerve rather than metal. This finding, however, went unnoticed for four decades because of Volta's popularity. Volta had developed a powerful tool that could be used both to generate electricity and to stimulate muscle. The technique of using electricity to stimulate muscles gained wide attention during the nineteenth century, and some people exploited this novel technique for research purposes. In the 1860s, Duchenne[6] conducted the first systematic study of the dynamics and function of the intact muscle, using electrical stimulation to study muscle function.

It was not until the early 1800s that the galvanometer, a tool for measuring electrical currents and muscle activity, was invented. In 1838, Matteucci used the galvanometer to demonstrate an electrical potential between an excised frog's nerve and its damaged muscle. By 1849, Du Bois-Reymond[7] provided the first evidence of electrical activity in human muscles during voluntary contraction. In his classic experiment, Du Bois-Reymond placed blotting cloth on each of his subject's hands or forearms and immersed them in separate vats of saline solution, while connecting the electrodes to the galvanometer. He noted very minute but very consistent and predictable deflections whenever the subject flexed a hand or an arm. He deduced that the magnitude of the current was diminished by the impedance of the skin. After removing a portion of the subject's skin, Du Bois-Reymond replaced the electrodes and noted a dramatic increase in the magnitude of the signal during wrist flexion.

By the early 1900s, Pratt[8] had begun to demonstrate that the magnitude of the energy associated with muscle contraction was due to the recruitment of individual muscle fibers, rather than the size of the neural impulse. In the 1920s, Gasser and Newcomer[9] used the newly invented cathode ray oscilloscope to show the signals from muscles. This feat won them the Nobel Prize in 1944.

As a result of continuing improvements in EMG instrumentation beginning in the 1930s and continuing through the 1950s, researchers began to use SEMG more widely for the study of normal and abnormal muscle function. During the 1930s, Edmund Jacobson, the father of progressive relaxation, used SEMG extensively to study the effects of imagination and emotion on a variety of muscles.[10] He also used SEMG to study systematically the effects of his relaxation training protocol on muscle activity.[11]

In the 1940s, researchers began to use SEMG to study dynamic movement. For example, Inman and his colleagues conducted a highly regarded study on the movements of the shoulder.[12] In the late 1940s, Price and her colleagues[13] studied clinical populations of back pain patients and noted that the SEMG activation patterns began to migrate away from the site of original injury. Their work was the first documentation of antalgic (painful) postures or protective guarding muscle patterns. Floyd and Silver,[14] in the early 1950s, presented an exceptionally strong study of EMG and the erector spinae muscles. They clearly demonstrated that as a person goes through forward flexion of the trunk, the back muscles shut off as the trunk goes out onto ligamental support.

During the late 1950s and the 1960s, George Whatmore,[15] a student of Jacobson, used SEMG to study and treat emotional and functional disorders. His work was summarized in a very unusual book, *The Physiopathology and Treatment of Functional Disorders*,[15] in which he used SEMG to augment the basic progressive relaxation technique he had learned from Jacobson. In addition, he coined the term *dysponesis* to describe "bad" muscle energy patterns that can be observed using SEMG instrumentation.

During the 1960s, the technique of biofeedback was born. Basmajian's[16] work on single motor unit training provided some of the impetus for research on biofeedback (see Figure 1–1). Although this type of training entailed the use of fine-wire electrodes rather than surface electrodes, it clearly demonstrated that EMG feedback could be used to train the neuromuscular system down to its most basic element—the single motor unit. Elmer Green[17] first used SEMG with biofeedback at the Menninger Clinic, where he modified Basmajian's single motor unit training paradigm for general relaxation training. A few years later, Budzynski and colleagues[18] began using SEMG feedback to treat muscle contraction headaches. From there, the biofeedback arena began to expand rapidly.

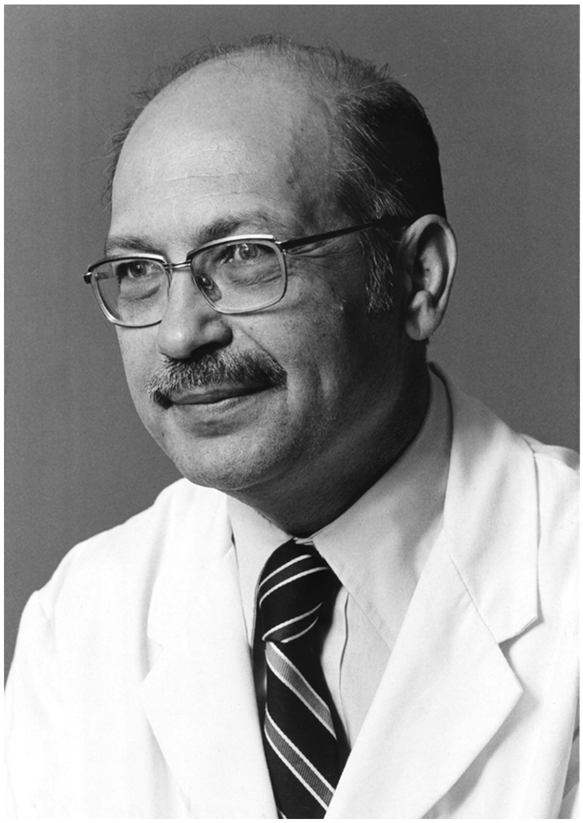

Figure 1–1 John Basmajian, the father of surface electromyography.

Source: Courtesy of Faculty of Health Sciences, McMaster University.

Clinical use of SEMG for the treatment of more specific disorders began in the 1960s. Hardyck and colleagues[19] were among the first practitioners to use SEMG. They used SEMG to teach students not to subvocalize during silent reading, which accelerated students' reading development. Booker and colleagues[20] demonstrated retraining methods for patients with various neuromuscular conditions, and Johnson and Garton[21] used SEMG to assist in the restoration of function of hemiplegic patients. Wolf et al.[22,23] were among the first to use SEMG biofeedback techniques in the assessment and treatment of low-back pain. For a comprehensive review of the history of SEMG and low-back pain through the early 1990s, see the work of Sherman and Arena[24] or an earlier review article by Dolce and Raczynski.[25]

In the early 1980s, Cram and Steger[26] introduced a clinical method for scanning a variety of muscles using a handheld SEMG sensing device; a few years later, Cram and Engstrom[27] presented a normative database of 104 normal subjects, which they used to guide their clinical work. Using the scanning tool, they rapidly sampled the right and left aspects of as many as 15 muscle sites for patients in both the sitting and standing postures. This level of analysis of the postural elements of muscle led to the differentiation of three clinical concepts: (1) site of activity, (2) impact of posture, and (3) degree of symmetry.

Donaldson and Donaldson[28] took the concept of symmetry and made it dynamic. They studied the degree of symmetrical recruitment during symmetrical and asymmetrical movement patterns in both normal subjects and patients. From this work, they concluded that 20% asymmetry is acceptable during symmetrical movements; levels greater than this are considered pathognomonic. Conversely, asymmetrical movements should bring about asymmetrical recruitment patterns. Donaldson popularized the concept of *cocontractions* as an abnormal finding in asymmetrical movements.

During the 1980s, Will Taylor[29] introduced the concept of measuring synergy patterns in the upper and lower trapezius during abduction. Following the work of Karol Lewit,[30] Taylor noted that myalgias in the upper quarter were commonly associated with postural muscles doing the work of their phasic counterparts. Here, the upper trapezius dominated the stabilizing muscular action associated with abduction to 90 degrees, even though the lower trapezius should have been doing the stabilizing. Thus, Taylor saw the hyperactivity of the upper trapezius as being facilitated by the inhibition of the lower trapezius. Susan Middaugh and colleagues[31] have also clearly delineated the role of a hyperactive upper trapezius in headache and neck and shoulder pain. They concluded that almost all of the dysfunctional patterns in the upper back involve hyperactivity of the upper trapezius.

Scholarly research on SEMG has also flourished. During the early 1960s, Basmajian conceived of an international forum to share information on SEMG, and in 1965 the International Society of Electrophysiological Kinesiology (ISEK) was formed. The organization still exists today, publishing one of the only journals that specifically addresses issues pertaining to SEMG (*The Journal of Electromyography and Kinesiology*). The American and European academic communities (especially the Scandinavian researchers) have provided a strong fundamental basis for understanding EMG in general and SEMG in particular. Space limits the ability to acknowledge the many contributors to this field, but the influence of Carlo DeLuca and his colleagues at the Neuromuscular Research Institute in Boston cannot be overlooked. Much of their work on spectral analysis and muscle fatigue[32] has shed light on the physiology of muscle and methods of measuring it. The work of Scandinavian researchers on tension myalgia in the workplace is very impressive,[33–38] and has clearly added to our understanding of dysfunctions in the workplace. In addition, an excellent summary of the use of SEMG in the occupational setting may be found in a book by Soderberg.[39]

THE ADVANTAGES AND DISADVANTAGES OF SURFACE ELECTROMYOGRAPHY

The use of SEMG has many advantages. Surface EMG recordings provide a safe, easy, and noninvasive method that allows objective quantification of the energy of the muscle. It is not necessary to penetrate the skin and record from single motor units to obtain useful and meaningful information regarding muscles. Rather, one can "see" synergies in the energy patterns that cannot be seen with the naked eye. The technique allows the observer to see the muscle energy at rest and changing continuously over the course of a movement. With the use of multiple sensor arrays, it becomes possible to differentiate how different aspects of muscles do different things. Although palpation skills, muscle testing, and visual observation of posture and movement should never be discarded, they have their limitations. By adding SEMG recording information to the practitioner's fund of knowledge about the muscle function of a particular patient, the practitioner begins to blend valuable information concerning how the nervous system participates in the orchestration of the muscle function. By using SEMG, practitioners may be able to answer the following questions: Is the resting tone congruent with the palpation exam? Do the muscles fire early or late in a recruitment pattern? Does a particular exercise actually activate the muscle it is intended to, or is a substitution pattern present? Does the muscle turn off following a given movement, or does it show irritability following movement?

The tracings and numerical printouts associated with SEMG provide information to clinicians and researchers alike regarding mechanisms of muscle function and dysfunction; they also suggest methods to improve treatment approaches. The objective tracings and data from SEMG recordings allow clinicians to communicate with one another and to insurance carriers about their findings. In the Western world, such objective findings are considered essential. Finally, the biological information obtained via SEMG methods can be fed back to the patient, providing a basis for neuromuscular reeducation and for self-regulation. Such information can fine-tune the response of the patient's nervous system to the therapist's verbal instructions. When the therapist asks the patient to relax the muscle between movements, the patient can actually see whether he or she has "let go" of the recruitment pattern or if it is necessary to "let go" again. As the patient learns to recruit a particular muscle, the initial attempts may be compared to the current attempts. This type of information provides feedback and motivation for the patient's therapeutic efforts. It may also become an important source to demonstrate to third-party payers that the prescribed treatment is having the desired effect.

The weakness of SEMG is inherent in the anatomy we study, the instruments we use to study it, and the methods or procedures we choose to use. It is important that clinicians acknowledge and understand these limitations. One key limitation is our ability to monitor only a few muscle sites. The neuromuscular system is very rich and complex, and to reduce it to one or two channels of SEMG information is very limiting. At a minimum, a four-channel SEMG instrument allows one to study the right and left aspects of two opposing groups. At this level, the information becomes much more meaningful and practical. Scanning multiple sets of muscles in their resting state may help the practitioner to decide which regions of the musculature might be of further interest. Another possible shortcoming of SEMG recordings has to do with muscle substitution patterns. The neuromuscular system may express the same movement using different muscle groups. When this occurs, the naive practitioner may believe that SEMG recordings are either inconsistent or unreliable. Thus, it is important for practitioners to understand the "normal" case, so that they can interpret recordings with greater confidence. To that end, this book contains an atlas of tracings for many movement patterns (see Part III).

Another difficulty with SEMG is the possibility of "cross-talk," a phenomenon where energy from one muscle group travels over into the recording field of another muscle group. When this happens, problems may arise in the specificity of SEMG recordings. It may make it difficult or even impossible to isolate the SEMG recordings from a specific muscle. Some electrode placement sites have greater specificity than others. The electrode atlas grades the electrode sites according to their specificity. Three grades are used: general, quasi-specific, and specific. An additional limitation to SEMG is that, to date, there are only a few published guides to electrode placement[35,40–42] and two video presentations.[43,44] Unfortunately, none of these guides has become the standard. Thus, an upper trapezius recording from one clinic or study may not represent the same energy pattern recorded in another clinic because of differences in electrode placement. The atlas in this volume should be complete and comprehensive enough to encourage a more standardized method for SEMG electrode placement. Use of a standardized method strengthens the interpretation of SEMG recordings at a given muscle site.

The practitioner should remember that SEMG is not a measure of force, nor is it a measure of strength, or of the amount of effort given, or of muscle resting length. It is simply a measure of the electrical activity given off by the muscle. Practitioners must be cautious about how they interpret the SEMG findings, being careful not to overinterpret them. For example, under normal circumstances, one should not compare the SEMG amplitudes recorded from one muscle (e.g., upper trapezius) with that of another muscle (e.g., lower trapezius). Differences in the SEMG amplitudes during dynamic procedures may simply be due to differences in the amount of muscle mass present for each muscle, rather than to differences in how hard the muscles are working. To compare across muscle groups, one must normalize the SEMG data first (see Chapter 3). For example, clinicians might normalize the activity of the upper trapezius to lower trapezius as a ratio, or they might reference muscle groups to a maximum voluntary isometric contraction (MVIC) and work with the percentage of MVIC.

A final shortcoming is that SEMG electrodes are not totally unobtrusive. The electrodes and leads can potentially encumber a movement pattern or make the patient feel self-conscious about a posture or movement. Thus, the SEMG recordings may not perfectly reflect the customary patterns of use for the patient. Practitioners are encouraged to have several different kinds of electrodes on hand so that they can choose the correct type of electrode for the muscle and movement pattern they wish to study.

Readers are encouraged to keep the previously discussed strengths and limitations of SEMG in mind as they read this book. By learning what SEMG can and cannot do, clinicians will be able to serve their patients better.

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