EVALUATING FUNCTION/IMPAIRMENT OF LOW BACK PAIN USING SEMG

Recent advances in the use of surface electromyography (SEMG) have proved useful in the evaluation of movement, gait, postural, and functional disturbances in low back pain patients.

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Electrodiagnostic evaluations, with one type being electromyography (EMG), are commonly performed in diagnosing nerve and muscle pain disorders. Conventional EMG assessment is usually referred to as “needle EMG,” where a fine concentric or monopolar needle electrode is inserted into a particular muscle. Quantitative analyses are then conducted on needle insertion-generated activity, as well as motor unit action potential waveforms. Another less intrusive form of EMG evaluation is surface EMG (SEMG). Rather than inserting needles, which many patients complain of as being painful and too invasive, electrodes are placed on the skin using simple adhesive collars and overlying the muscle(s) being studied. One drawback of SEMG, as compared to needle EMG, is that only superficial muscle activity can be recorded. Nevertheless, as will be reviewed, SEMG has been found to be useful in evaluating movement, gait, postural, and functional disturbances.

In this present article, we will focus on the use of SEMG in evaluating the degree of physical impairment in low back pain (LBP). Indeed, whenever one evaluates painful spinal disorders such as LBP—especially in workers’ compensation or personal injury populations—as recently reviewed by Gatchel, Ricard et al, the degree of potential physical impairment needs to be considered for employment/injury compensation issues. Impairment refers to the alteration of a person’s usual health status due to anatomic or pathophysiologic abnormalities. For back pain, it is frequently evaluated by measuring strength, lifting capacity, range-of-motion, aerobic capacity, as well as measures of human performance. A traditional problem, though, has been the lack of universal agreement about what measure(s) should be used in impairment evaluations. The American Medical Association identified only range-of-motion in earlier versions of its Guides to the Evaluation of Permanent Impairment, but it is no longer included in the most recent 6th Edition. There are growing annual costs associated with the diagnoses and care of musculoskeletal disorders such as LBP, amounting to tens of billions of dollars in the United States alone. In fact, in a most recent survey of expenditures among adults with back and neck problems, Martin et al reported a 65% increase (adjusted for inflation) of expenditures from 1997 to 2005, which was a more rapid increase than overall health expenditures. Thus, there is a great need to develop valid measures to objectively quantify physical function in patients with these disorders. Such objective measures would aid in assessing both physical impairment needed to address compensation issues, as well as use in determining a therapeutic endpoint following treatment.

At the outset, it should also be kept in mind that a traditional problem faced by evaluators attempting to objectively measure musculoskeletal disorders such as LBP—where there is often primarily soft tissue involvement—is that psychosocial factors frequently influence the experience/reporting of pain. Some examples of such psychosocial factors are neuromuscular inhibition due to fear-avoidance of movement, secondary gain, etc. Nevertheless, there is still an urgent need for the ability to quantify physical function with appropriate validity criteria in place, in order to help evaluate both impairment and a therapeutic endpoint following treatment. SEMG may fill this need.
The use of SEMG to evaluate and treat LBP has made significant advances over the past few decades. As noted earlier—unlike traditional electromyography, which uses fine-wire needles inserted into muscles to measure their electrical activity directly—SEMG involves the placement of gel-filled electrodes onto the skin to measure the sum of the action potentials generated by the muscles underlying the electrode. Skin is usually prepped with alcohol to remove surface oil and to ensure good contact between the skin and the electrode. The signal detected by the electrode is proportional to the force and contraction intensity of the muscle. There have been three main types of SEMG evaluations for LBP. The first is static measurement, where the isometric activity of the paraspinal muscles is measured in a fixed position. The second is dynamic measurement, where muscle activity is measured during motion. Dynamic movements typically utilize exercises or stretches with maximal or submaximal muscular contractions. The third approach combines static and dynamic measurement. An example of this is the measurement of the flexion-relaxation phenomenon. Measurements are taken at rest in the standing position, during the motion of forward flexion, at rest during full flexion, and during the extension phase of the movement as the patient returns to the standing position. These measurements are combined into ratios to determine the presence or absence of flexion-relaxation.

The first use of EMG as a diagnostic tool was in the 1940s, although this was needle EMG rather than SEMG. Researchers found that trigger points (small areas of contracted tissue) displayed higher levels of electrical activity when compared to the surrounding tissue. Price et al subsequently found that back pain patients had more incidence of abnormally high and low SEMG activity and more right-left asymmetry during movement. This was thought to be the result of abnormal protecive posture and ischemia to the unused muscles. Other researchers found that chronic LBP patients showed lower levels of paraspinal muscle activity during movement. This was thought to result from disuse or deconditioning of the spinal muscle groups due to fear of increased pain. Still others found increased levels of EMG activity when standing, particularly when standing for long periods. The results, though, were not consistently replicated by other researchers. These early studies contained several methodological flaws which may have affected the validity of the results. For example, most of the studies failed to report the length of time patients had been experiencing back pain, and some even failed to distinguish between acute and chronic back pain. The studies were also handicapped by technical difficulties involving the recording equipment and the electrodes. In addition, studies varied widely in the "gain" or amplification power settings used for recording signal amplitudes, making the different studies difficult to compare.

More recently, several EMG patterns have been hypothesized to be associated with chronic LBP. Lofland et al found increased resting SEMG activity in the paraspinal muscles and was able to correctly classify patients and controls when combined with a physical symptoms checklist.

Asymmetry. Some researchers have noted an asymmetry between the right and left erector spinae muscle groups and have proposed that this asymmetry causes a postural abnormality that contributes to the development of chronic LBP. For example, Cram and Steger reported that left-to-right asymmetry in paraspinal SEMG activity could distinguish between chronic LBP patients and headache patients. However, Lariivre et al were unable to replicate this finding. The Flexion-Relaxation Phenomenon (FRP). The FRP may be the most common measurement taken with SEMG. First described in the 1970s, FRP occurs in people without LBP when bending forward at the waist with the knees straight. SEMG shows increases in erector spinae muscle activity during forward flexion until approximately a 70 degree angle is reached. Then, the erector spinae muscles relax, and the torso is suspended by the posterior ligaments and fascia. The FRP has been found not to occur in chronic LBP patients who continue to have high levels of EMG activity even in the fully flexed position. Watson et al demonstrated that the presence of vertebral muscles in chronic LBP patients in response to psychological stress, but did not find this pattern in chronic pain patients without LBP.
or absence of the FRP could reliably differentiate chronic LBP patients from controls.\textsuperscript{16}

In spite of all the research reviewed above, though, there are still differing opinions concerning the utility of SEMG in differentiating between LBP patients and normals.\textsuperscript{1,2} Most recently, a meta-analysis that reviewed 44 studies evaluating SEMG measures with chronic LBP patients was conducted by Geisser and colleagues. They concluded that the results were quite equivocal and recommended that “Further research is needed to determine the combination of measures that are cost-effective, reliable, valid and discriminate with a high degree of accuracy between healthy persons and those with LBP.”\textsuperscript{14} Thus, these earlier results indicated that the potential utility of SEMG recordings (which are safe, non-invasive and potentially objective measures of muscle functioning/impairment in LBP) was not yet realized.

The Comprehensive Muscular Activity Profile (CMAP)
The CMAP was developed with significant technological advances (Medical Technologies Unlimited, 2008) in direct response to the American Association of Electrodiagnostic Medicine’s (AAEM) questioning of the potential viability of SEMG as an assessment tool. This most recent attempt to achieve the above realization of an objective and reliable SEMG measure of muscle function/impairment in the lumbar spine incorporates significant technological advances as delineated in Table 1. The features and benefits of the CMAP system expand its availability and applicability of its utilization for bilateral testing, as well as sports and pediatric medicine usage. On rare occasions (on the order of 1%), needle studies may be necessary but such testing converts a non-invasive test into an invasive one, restricts the number and location of the electrodes (biosensors) required, and renders the test static rather than dynamic. These drawbacks of needle EMG, in turn, prevents the testing of compensatory muscle activity, which is crucial in the diagnosis of chronic neuro-muscular diseases.

The CMAP is an FDA-approved system that not only evaluates both lumbar range-of-motion and lifting capacity, but can also detect whether the effort put forth by the patient is maximum (full) or submaximal (faking). Through the use of SEMG signals derived from single muscles or muscle groups, the CMAP can provide an objective quantification of physical function. As noted earlier, psychosocial factors—such as fear avoidance and secondary gain—can interfere with true measures of range-of-motion and lifting capacity.\textsuperscript{16} Having the ability to objectively determine functional capacity under maximum effort is essential for adequate diagnosis and treatment of musculoskeletal injuries. As a first step in addressing this issue, the following basic question was addressed: Can the CMAP accurately document whether a subject is exerting appropriate muscular effort during range-of-motion and lifting testing or is submaximal effort being exerted? To answer this question, a recent randomized controlled study was conducted to assess the ability of the CMAP to accurately determine whether maximum effort was put forth by normal individuals.\textsuperscript{17} In this study, participants undergoing range-of-motion and lifting capacity assessments were randomly assigned to one of two groups: those given instructions to give either maximum effort, or those given instructions to “fake” and give submaximal effort on each task. For the maximum effort group, the following are excerpts from the instructions that were given:

“The major purpose of this study is to evaluate a new measure of muscle activity while you are bending your back. You will be asked to bend forward, backward and sideways while this muscle activity is being recorded on a computer... This measurement method is going to be used in the future with people who have hurt their backs at work... However, before it can be used, we need to get baseline data from people with healthy backs, such as yours, to compare against. Therefore, I want you to bend as much as you can when instructed, so that we have a good measure of maximum bending from someone as healthy as you...”

In contrast, excerpts of the almost identical instructions given to the group encouraged to “fake” or produce submaximal effort were as follows:

“The major purpose of this study is to evaluate a new measure of muscle activity while you are bending your back... Sometimes, people want to “fake” being hurt in order to get out of work. To do this, they will not bend their backs as far as they can so that they will appear to be having problems with their backs. What I want you to do is imagine that you want the therapist to think that you have a bad

### Table 1. The Significant Technological Advances of the CMAP

- **High Signal To Noise Ratio.** CMAP offers a signal to noise ratio (S/N) of 125 to 1, whereas the best previous attempts topped out at 40 to 1. Simply put, an am radio S/N ratio is approximately 60 to 1 at best, while a CD/DVD audio has 105-112 to 1 at best. The strength of the signal (data) relative to noise (artifact) allows for a pure, powerful, clear signal that can, for the first time, be subject to expert, reproducible, automated and human analysis. This eliminates intra-reader variability and allows for pattern recognition and comparison against a knowledge base. Furthermore, the intensity of the signal (amplitude and area under the curve) can be absolutely derived. This is vital to analysis of the type and force of a contraction.

- **Elimination Of Interference Patterns.** Motion artifact is reduced by proprietary cables individually run straight to the handmade custom circuit board. This eliminates “cross talk” interference. Special contacts/leads and algorithms are used to remove 60 cycle interference patterns from true voluntary or involuntary muscle firing. Aerospace components, with their inherent low specification variances, complete the advancements made to mitigate interference.

- **High Frequency Range.** CMAP’s SEMG frequency range is capable of up to 500 Hz. This is an enhancement to the 400 Hz standard. Ninety-nine per cent of the medically important frequencies fall below 300 Hz, well within the range of a high quality SEMG.
Thus, the utility of the CMAP system goes far beyond the general capabilities of standard equipment used to measure functional capacity. The CMAP is unique in that it can objectively identify maximum and submaximal effort being put forth. The importance of this capacity stems from the economical factors associated with musculoskeletal injuries. Oftentimes, monetary issues can influence the perceived degree of injury, especially with workers’ compensation claims. The ability to objectively verify not only the functionality of patients, but also their intent, is essential in determining the appropriate diagnosis and treatment protocol. The use of SEMG with the CMAP system allows for the necessary objectivity needed to fully evaluate patients with musculoskeletal injuries.

**SEMG Biofeedback And LBP**

Another area in which SEMG has been extremely useful is in the biofeedback treatment of chronic LBP patients. Flor and Birbaumer showed that SEMG biofeedback relaxation training successfully decreased chronic LBP to a greater extent than either a control group or a sham condition in which patients were given false SEMG feedback. Neblett has developed an SEMG-assisted stretching protocol that can normalize the flexion-relaxation phenomenon (FRP) in chronic LBP patients and can reduce pain and improve socioeconomic outcomes in conjunction with an interdisciplinary rehabilitation program. This was stimulated by an earlier study by Neblett et al which demonstrated that, while chronic LBP patients demonstrate an absence of a normal FRP response, such a deficit can be corrected with treatment. Indeed, a recent study demonstrated that, at the beginning of a functional restoration program, the majority of patients failed to demonstrate either a normal FRP or range-of-motion (ROM). However, after the rehabilitation program during which they received SEMG training, the majority of patients did show normal FRP and ROM. These improvements were also accompanied by concurrent improvements in self-reported pain and disability. Such results are quite promising in demonstrating that SEMG training can be a useful tool in objectively identifying deficits and then producing improvements in function of chronic LBP patients.

**Standardization of SEMG In LBP Patients**

It should also be kept in mind that for any SEMG protocol, the standardization of SEMG methodology and functional tests should be carefully adhered to in order to enhance the usefulness of SEMG to identify deficits and improvements in function in chronic LBP patients. Standardization in electrode orientation and location can be improved by using a linear array electrode to determine the muscles motor point and fiber direction. After determining the motor point and muscle fiber direction, the surface electrodes are placed between the motor point and the tendon in the direction of the muscle fibers. Careful adherence to these procedures has been shown to improve SEMG reliability. Refinements in functional tests, such as the Flexion-Relaxation test, may also improve accuracy of SEMG in identifying deficits and improvements in function in chronic LBP patients. The amplitude and frequency of the SEMG signal is affected by the type of contraction (isometric, concentric, eccentric) and speed of movement. The Flexion-Relaxation test employs all three types of contractions: isometric at the start and in the full flexion phase; eccentric during trunk flexion; and concentric during trunk extension. Whenever possible, the speed of movement should be standardized to improve the predictive quality of the SEMG signal. This would require adjustments in the time taken to complete the flexion and extension phases of the motion for subjects with different ranges of motion. Finally, the predictive quality of the SEMG signal could be improved by standardizing procedures used to normalize the SEMG amplitude (the earlier discussed CMAP protocol certainly does this).
As just reviewed, there have been significant recent advances in the use of SEMG with LBP patients in both the assessment and treatment arenas. The RCT study by Gatchel and colleagues clearly demonstrated that the CMAP system is a potentially useful method for evaluating lumbar range-of-motion and lifting capacity, while also documenting subject effort during these performance tasks. This is a significant advance because past research on the use of SEMG measures has been quite mixed in terms of their validity to discriminate, with a high degree of accuracy, between healthy persons and those with LBP. This is likely due to the fact that psychosocial factors (e.g., fear-avoidance of movement, secondary gain, etc.) often influence the experience and reporting of pain. Therefore, it is vitally essential to have a method to monitor whether subjects are exerting maximum effort during purposeful muscle activity. Data from the Gatchel et al study revealed the ability to do just that. In contrast, past research attempts to monitor subject effort on human performance tests for impairment evaluations have not been successful.

Obviously, additional clinical research is needed to further address this important issue by evaluating a patient group with LBP. Finally, the use of SEMG biofeedback as an adjunct to a more comprehensive interdisciplinary pain management program for chronic LBP has been shown to have great promise.

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