Published in final edited form as:
*Clin J Pain*. 2013 April ; 29(4): 334–340. doi:10.1097/AJP.0b013e318267252d.

# WHAT IS THE BEST SURFACE EMG MEASURE OF LUMBAR FLEXION-RELAXATION FOR DISTINGUISHING CHRONIC LOW BACK PAIN PATIENTS FROM PAIN-FREE CONTROLS?

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## Abstract

**Objectives—**Lumbar flexion-relaxation (FR) is a well-known phenomenon that can reliably be seen in normal subjects but not in most chronic low back pain (CLBP) patients. The purpose of this study was to determine which surface electromyographic (SEMG) measures of FR best distinguish CLBP patients from pain-free control subjects. Standing SEMG and lumbar flexion range of motion (ROM) were also evaluated.

**Methods—**A cohort of 218 CLBP patients, who were admitted to a functional restoration program, received a standardized SEMG and ROM assessment during standing trunk flexion and re-extension. An asymptomatic control group of 30 non-patients received an identical assessment. Both groups were compared on eight separate SEMG and three flexion ROM measures.

**Results—**A receiver-operating curve (ROC) analysis was used to determine how well each measure distinguished between the CLBP patients and the pain-free control subjects. All SEMG measures of FR performed acceptably. Between 79% and 82% of patients, and 83% and 100% of controls were correctly classified. Standing SEMG performed less well. Gross flexion ROM was the best single classification measure tested, correctly classifying 88% of patients and 83% of controls. A series of discriminant analyses found that certain combinations of SEMG and ROM performed slightly better than gross ROM alone for correctly classifying the two subject groups.

**Discussion—**Because all SEMG measures of FR performed acceptably, the determination of which SEMG measure of FR is “best” is largely dependent on one’s specific purpose Additionally, ROM measures were found to be important components of the FR assessment.

### Keywords

Flexion-relaxation; chronic low back pain; surface electromyography; maximum voluntary flexion; lumbar range-of-motion

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## INTRODUCTION

Dynamic surface electromyography (SEMG) of the lumbar musculature has been studied extensively in normal and chronic low back pain (CLBP) subjects. A flexion relaxation (FR) phenomenon, in which the lumbar muscles relax completely during maximum voluntary flexion (MVF), is seen in most normal pain-free subjects, but is often absent in CLBP patients.[1–10] FR deficits in low back pain subjects have been found to be associated with pain,[2,11,12] self-reported disability,[1] and fear of pain and re-injury.[13] As a treatment outcome measure, positive treatment changes in FR patterns with chronic low back pain (CLBP) subjects have been shown to be a sign of clinical improvement in self-efficacy beliefs, fear avoidance beliefs,[14] disability self-report, pain, and ROM.[15] Because it is influenced by both psychological and physical factors, and it has been shown to be responsive to treatment, measures of FR are a potentially appealing objective measure of CLBP.[7] Despite the relatively large number of studies that have investigated FR, there is currently no agreement on the best SEMG methodology for assessing this phenomenon.

FR has traditionally been assessed by observing absolute SEMG values as subjects bend into MVF.[8,10,11,16–21] Unfortunately, there are problems with judging the absolute value of an SEMG signal. It is widely recognized that skin resistance between the sensor and the muscle, especially due to adipose tissue, can affect the SEMG reading. Increased adipose acts to buffer the signal, effectively making a muscle look more relaxed than it really is. To correct for the effects of adipose tissue, a SEMG value can be “normalized.” The most common method for normalization involves having the subject produce a maximal voluntary contraction, then judging the muscle activity during a target movement or posture as a percentage of the maximum.[14] In this way, a ratio can be produced (target SEMG reading divided by the maximal SEMG reading times 100 = a percentage). The use of a maximal voluntary contraction with CLBP subjects can be problematic due to pain inhibition and/or insincere effort.[3,5] One way to address the problem of unreliable maximal contractions in pain subjects is to use a standardized sub-maximal contraction in the same aforementioned mathematical formula.

When evaluating FR, a common method for normalizing the SEMG signal, presented in the recent scientific literature, is to compute an FR ratio. Various methods of calculating FR ratios are shown in Table 1. The most popular ratio, utilized separately by Watson[5] and Paquet,[9] is to divide the maximal SEMG values during flexion by the SEMG values during MVF (FRR FLEX/MVF). In this method, the flexion SEMG is essentially used as a sub-maximal contraction, although the mathematical formula used in this ratio does not produce a percentage as in traditional normalization methods. Normal pain-free subjects have been shown to have larger FRR FLEX/MVF scores (indicating larger differences between the flexion SEMG and the MVF SEMG) when compared with CLBP subjects who tend to have smaller FRR FLEX/MVF scores (indicating smaller differences between the flexion SEMG and MVF SEMG).[7,14] Other methods of normalizing the SEMG signal in the evaluation of dynamic lumbar flexion have been proposed or reported sporadically. Haig[22] normalized MVF SEMG to SEMG during standing (FRR STAND/MVF). In separate studies, Ambroz[23] and Mathieu[24] normalized MVF SEMG to SEMG during re-extension (FRR EXT/MVF). Mathieu then determined the presence of FR when MVF SEMG was 10% or less than the SEMG during the re-extension. Sihvonen[3,12] utilized a ratio between the maximum SEMG during the flexion to the maximum SEMG during the re-extension (FRR FLEX/EXT). Compared to pain-free control subjects CLBP patients were found to have a smaller difference in flexion and re-extension SEMG. In addition to SEMG measures of FR, a number of studies have measured standing SEMG in a static posture. In pooling the results of previous studies together, a recent meta-analysis found a relatively large effect size (d =

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1.14) in distinguishing between low back pain from control subjects during standing,[7] though some studies found no significant differences.[2,5]

Recently, Alschuler, et al[25] examined the relationship of the aforementioned measures of FR (shown in Table 1), which have been utilized by previous researchers with a number of clinical variables, including self-reported pain ratings, pain-related fear, perceived disability, and manual musculoskeletal tests, such as flexion range of motion (ROM) and supine straight leg raise. They found that the FR ratios that normalized MVF SEMG to either flexion or re-extension SEMG were most associated with the clinical and musculoskeletal characteristics of CLBP. The ratio of MVF to re-extension (FRR EXT/MVF) generally performed the best of all the SEMG measures of FR. It was most highly associated with ROM and was the only SEMG measure to be associated with clinical pain.

The primary purpose of the present study was to determine the most effective lumbar SEMG measure for distinguishing CLBP patients from pain-free control subjects. As with Alschuler's study,[25] we examined four FR ratios, as well as absolute MVF SEMG levels. We also assessed standing SEMG. Because it has been observed that painful muscles often show poor recovery following a contraction,[26,27] standing was measured both before and after recovery from bending. In addition, three different ROM measures (gross, pelvic, and true lumbar) measurements were evaluated. Definitions of SEMG and ROM measures are shown in Table 1. Cut-off points for differentiating between patients and controls on the various measures were determined. Finally, because combinations of different measures have been recommended to help maximize sensitivity/specificity,[7] an analysis of the best combination of the SEMG and ROM measures was performed.

# MATERIALS AND METHODS

## Subjects

A sample of 218 CLBP patients, with compensable occupational lumbar injuries under the Texas Worker's Compensation system, who were enrolled in an interdisciplinary functional restoration rehabilitation program, consented to participate in this study. All patients had demonstrated a minimum of four months of disability since their injuries. They were evaluated at the beginning of treatment with a standard SEMG and ROM assessment protocol. Basic demographic data for are presented in Table 2, along with pre-treatment psychosocial testing of the CLBP patients. As can be seen, the patients demonstrated moderate to high levels of pain intensity, perceived disability, kinesiophobia, and depressive symptoms upon admission to the functional restoration. High levels of psychosocial distress are common among chronically disabled worker's compensation patients, but typically improve significantly following interdisciplinary chronic pain treatment programs.[28–31]

In addition, a group of 30 asymptomatic control group subjects were recruited from among the treatment clinic staff and colleagues. All control subjects had no history of low back pain over the prior year, no prior low back disability, no previous low back surgery, and no evidence of a gross scoliosis curve that might alter myoelectric behaviors. They were measured with the identical SEMG and ROM methodology as the treatment patients.

## Assessment Procedure

A standard methodology was used for electrode placement and SEMG and ROM measurements.[32] The skin was cleaned with alcohol, and silver-silver chloride electrodes from Noromed (1 cm. in diameter and spaced 2 cm. apart) were placed vertically on the left and right erector spinae muscles at L3, approximately 2 cm. from the midline. Patients and control subjects were given standardized instructions for data collection, which have been fully documented elsewhere.[6,15,33] Five SEMG measures were collected: a 10-second standing mean; the maximum SEMG during the flexion movement; approximately 2 seconds of mean SEMG during maximum voluntary flexion; the maximum SEMG during re-extension; and approximately 10 seconds of mean SEMG during standing, following recovery from re-extension. A root mean square (RMS) rectified SEMG signal was monitored and displayed in real time to the experimenter, while being recorded by an SEMG biofeedback system (Procomp Plus, Thought Technology, Montreal, CN). A frequency response of 20–500 Hz, and an averaging factor of .5 seconds for signal smoothing, were used during recording. Microvolt (μV) levels from the left and right side electrodes were averaged to obtain a single mean SEMG μV number. During flexion trials, a physical therapist held inclinometers at the T12 spinous process and at the sacrum, and recorded degrees of flexion ROM using a standard two-inclinometer technique.[34,35] The motion recorded from T12, referred to as “gross motion,” represents the total movement of the six lumbar spine segments, from T12 to S1, combined with movement of the hips. By subtracting hip movement (e.g.. “pelvic motion”), which is measured with the sacral inclinometer, “true lumbar motion,” representing only the six lumbar spine segments, can be determined.

## Statistical Methods

Eight separate SEMG measures were calculated for statistical analyses. In addition to the SEMG calculations, three flexion ROM measures were recorded, including gross motion, pelvic motion, and true lumbar motion. In all statistical analyses, gross and true lumbar ROM were corrected by eight degrees per fusion level for those patients with lumbar fusions, as has been recommended previously.[6,15,33] The definitions and calculations for all measures are provided in Table 1.

All SEMG and ROM measures were analyzed using a Receiver Operating Characteristic (ROC) analysis. This method compares the values of two groups (patients and controls) on each measure, and constructs a graph of the measures’ performance in classifying the groups for each possible cut-off point. The graph compares the true positive classifications (patient identified as patient) to the false positive classifications (control identified as patient). For each cut-off point, sensitivity and specificity were calculated. Sensitivity is the proportion of patients identified as patients, while specificity is the proportion of controls identified as controls.[36] The cut-off point that maximized both sensitivity and specificity, i.e., where sensitivity and specificity were nearly equal, was chosen as the best cut-off point for differentiating between patients and controls. In addition to sensitivity and specificity, the area under the curve (AUC) can be calculated. The AUC is an overall measure of discrimination; that is, it identifies how accurately the measure can correctly classify patients and controls.[36] Thus, the most useful measure can be identified by comparing the AUC: measures with higher AUC values are better at discriminating between groups.[36] The following guidelines are recommended for interpreting the discrimination performance of a measure from the AUC: excellent discrimination (AUC = .90–1.0); good discrimination (AUC = .80–.90); fair discrimination (AUC = .70–.80); poor discrimination (AUC = .60–.70); and discrimination no better than chance (AUC ≤ .50).[37]

To identify how well the single measures and the various combinations .of measures predicted patient vs. control status, a series of discriminant analyses were performed. The group membership predicted by the discriminant analyses was compared to the actual group membership to determine how well each single measure and combination of measures correctly predicted patients and controls.

## RESULTS

Table 3 shows the ROC results of the SEMG and ROM measures, ranked in descending order of usefulness in differentiating patients and controls, as determined by the AUC. Of the flexion-relaxation ratios, the EXT/MVF (AUC = 0.90) and the FLEX/MVF (AUC = 0.89) had the best results, followed by the FLEX/EXT (AUC = 0.82) and the stand/MVF (AUC = 0.80).

The mean SEMG measures were also compared. The MVF SEMG had good discrimination (AUC = 0.86) and was evaluated in two ways. First, a pre-determined cut-off of 3.5 μV, which has been utilized in previous research[15,33] to correctly classify 100% of control subjects as controls, was used. This cut-off point correctly classified 72% of patients and 100% of control subjects. Next, an optimum cut-off point was identified from the present ROC analysis. This cut-off point, MVF SEMG = 2.4 μV, correctly classified 79% of the patients and 83% of control subjects. In addition, two standing EMG measures were compared: standing pre-flexion and standing post-flexion (e.g., recovery). Both of these measures had poor discrimination (AUC = 0.65 and 0.67, respectively).

Finally, measures of flexion ROM were compared. Gross ROM had the best discrimination (AUC = 0.93), followed by pelvic ROM (AUC = 0.88), and true lumbar ROM (AUC = 0.83). ROM cut-off points established in previous research,[6,15,33]as well as optimum cut-off points identified from the present ROC analysis, were evaluated. For true lumbar ROM, the previously used cut-off point of 50 degrees correctly identified 82% of patients and 60% of controls, whereas the optimum cut-off for true lumbar ROM (49°) correctly classified 76% of the patients and 73% of control subjects. For pelvic ROM, the previously used cut-off point of 45 degrees correctly classified 77% of patients and 83% of control subjects, while the optimal cut-off point derived from the current analysis (49°) correctly classified 82% of patients and 80% of control subjects. For gross ROM, the previously used cut-off point of 110 degrees correctly classified 95% of patients and 60 % of control subjects, whereas the optimal cut-off point derived from the present analysis (97°) correctly classified 88% of patients and 83% of control subjects. In general, all three measures of ROM performed well, and the cut-off points identified in the present analyses were not substantially different from those used in previous studies.

Discriminant analyses were used to examine the predictive utility of both the single SEMG, FR, and ROM measures and the combinations of these measures. The set of measures with the highest classification accuracy was the combination of pelvic ROM and the FRR FLEX/MVF, which correctly classified 83.5% of patients and 96.7% of control subjects, followed by the combination of gross ROM and the FRR FLEX/MVF, which correctly classified 81.1% of patients and 96.7% of control subjects. No combinations of three or four variables exceeded either of these two variable combinations in classification accuracy. However, it should be noted that this represents only a small improvement in classification accuracy over gross ROM alone, which correctly classified 76.6% of patients and 96.7% of controls in the discriminant analysis.

Table 4 presents the means, standard deviations, and ranges for each SEMG and ROM measure, comparing the CLBP and pain-free control groups. As can be seen, there were significant differences between the two groups on all variables.

## DISCUSSION

A variety of SEMG measures have been used in previous studies to assess FR patterns in both pain-free and CLBP subjects. By using Receiver Operating Characteristics (ROC) and Area Under the Curve (AUC) analyses, the current study evaluated the ability of six different SEMG measures of FR to distinguish between CLBP and pain-free controls subjects. In addition, standing SEMG (both before and after recovery from bending) and three flexion ROM measures (gross, pelvic, and true lumbar) were evaluated. The following guidelines were used to help interpret the results: AUC between 1.0 and .90 suggests excellent discrimination; AUC between .90 and .80 suggests good discrimination; AUC between 0.80 and 0.70 suggests fair discrimination; AUC between 0.70 and 0.60 suggests poor discrimination; and AUC at or less than 0.50 discriminates no better than chance.[37]

As was previously found by Alschuler,[25] who compared the same SEMG measures of FR with clinical and musculoskeletal characteristics associated with CLBP, the present investigation also demonstrated that those FR ratios which normalized MVF SEMG to either flexion SEMG (FRR EXT/MVF; AUC = 0.90) or re-extension (FRR FLEX/MVF; AUC = 0.89) performed the best. The other two FR ratios, FRR FLEX/EXT (AUC = 0.82) and FRR STAND/MVF (AUC = 0.80) were slightly less successful.

Absolute SEMG levels during MVF, with a pre-determined cut-off of 3.5 μV, which has been used in previous research by our group,[15,33] was selected to correctly classify 100% of our control subjects, so that the chances of determining false positives (falsely determining that a CLBP patient had achieved FR) would be minimized. When evaluating absolute SEMG MVF levels with the ROC analysis, 2.4 μV was found to be the best cut-off with our subject pool, correctly classifying 79% of patients and 83% of control subjects. Absolute SEMG at MVF, using both cutoff scores, produced an AUC of 0.86. The two mean standing EMG measures (pre- and post-bending measures) both performed poorly in discriminating between CLBP patients and control subjects (AUC = 0.65 and AUC = 0.67 respectively).

The present study also evaluated the ability of flexion ROM to distinguish between CLBP patients and control subjects. Interestingly, the most successful single measure that was evaluated in this study, including all SEMG measures, was gross trunk flexion ROM (AUC = 0.93). Because SEMG and ROM are frequently used together in FR assessments, and because combinations of different measures have been recommended to help maximize sensitivity/specificity,[7] we also investigated whether combining measures in the present study would increase classification accuracy using discriminant analysis. We identified two combinations of measures with more accurate classification than gross ROM alone for distinguishing between patients and pain-free controls. A combination of pelvic ROM and the FRR FLEX/MVF correctly classified 83.5% of patients and 96.7% of controls, and a combination of gross ROM and the FRR FLEX/MVF correctly classified 81.1% of patients and 96.7% of controls. However, this represents only a small improvement in classification accuracy over gross ROM alone, which correctly classified 76.6% of patients and 96.7% of controls in the discriminant analysis.

Although some of the SEMG measures of FR performed slightly better than others in the present study, they all performed acceptably. The AUC for the FR ratios ranged from 0.80 to 0.90, and the AUC for absolute SEMG at MVF was 0.86. As recommended by Tape,[37] when interpreting AUC results, all of these measures of FR can be considered “good” at discriminating between patients and control subjects. Thus when determining the “best” SEMG measure of FR, one must consider several factors, including what question one hopes to answer and whether one is interested in evaluating group means or individual performance. As stated previously, assessing absolute SEMG values is problematic due to individual subject differences in skin resistance and adipose tissue that act to buffer the SEMG signal. For this reason, FR ratios have been preferred by most clinical researchers in the recent scientific literature. In a recent meta-analysis, FR ratios produced a large effect size ($d = -1.71$) in distinguishing between CLBP patients and control subjects.[7] FR ratios have also been shown to improve within physical therapy[38,39] and multidisciplinary chronic pain management treatment programs,[14] and positive treatment changes in FR ratios have been shown to be associated with clinical improvement in self-efficacy and fear avoidance beliefs.[14]

It should also be noted that, even though FR ratios can presumably correct for problems with adipose buffering, they also offer some clear disadvantages in evaluating individual performance and determining if a “normal” FR pattern has been achieved. Early FR researchers determined the successful achievement of FR by observing “electrical silence” of absolute SEMG levels during MVF. They were interested in whether the lumbar musculature relaxed or not. Alternatively, FR ratios evaluate dynamic aspects of the SEMG pattern during flexion and/or return to standing. FR ratios have generally not provided clinical guidelines for determining whether an individual subject appears to be “normal” or “abnormal,” and FR ratios are not designed to determine that “yes” the subject has demonstrated FR, or “no” the subject has not demonstrated FR. In fact, no previous studies have evaluated individual performance with FR ratios. All have looked at group means. This potentially leaves the clinician lacking guidelines for evaluating an individual patient.

Another point of interest is that, despite the problem of adipose buffering, our group has found the absolute mean RMS values during MVF, with the use of an empirically derived SEMG cut-off score ($\leq 3.5$ μV), to be most useful in evaluating individual performance within a clinical setting and determining if and when an individual patient has successfully achieved FR. Using this FR assessment criteria, abnormal pre-treatment FR patterns have been shown to be responsive to functional restoration treatment, so that most patients who are unable to achieve FR pre-treatment demonstrate significant improvement in the ability to achieve FR post-treatment.[6,15,33] Post-treatment success with achieving FR following functional restoration has also been associated with better treatment outcomes, including increased flexion ROM, lower self-reported disability, and decreased visual analog scale (VAS) pain levels, compared to those patients who failed to demonstrate FR post-treatment.[15]

Absolute SEMG values are also the only practical alternative for clinical biofeedback training, in which subjects receive real-time auditory or visual SEMG feedback about the state of contraction of a muscle. The addition of SEMG-assisted stretching (SEMGAS) biofeedback protocol to a standard functional restoration treatment program has been shown to improve success with achieving FR, so that most patients were comparable to a pain free control group post-treatment.[33] In addition, our clinical observation is that, when MVF relaxation is restored, then other aspects of the dynamic flexion and re-extension pattern (i.e., FR ratios) are also normalized. In fact, a recent clinical study determined that positive treatment changes in the FLEX/MVF ratio following a physical therapy treatment program were due to reductions in the MVF SEMG.[38]

There are a few potential limitations to this study. Most obvious is the difference in group size between the patients and controls. Although an a priori power analysis determined that the control group size was adequate to detect medium to large effect sizes, a larger control group would have provided additional power to the analysis. Furthermore, rates of total classification are disproportionately influenced by the larger group, which makes these rates difficult to interpret. Because our groups were of unequal size, we were unable to compare total classification accuracy for the entire sample between the different single measures and the combinations of measures. Two groups of equal size would provide a better estimate of total classification. In addition, the control group was significantly younger than the CLBP patient group.

In conclusion, this study determined that both SEMG measures of FR and flexion ROM measures performed acceptably in discriminating between CLBP patients and control subjects. In our clinical experience, we have found that an FR assessment of SEMG and flexion ROM can provide valuable clinical information about a patient's current functional status, level of movement inhibition, and fear-avoidance beliefs, and serve as an excellent treatment outcome measure.[6,15,33] It is our hope that the cut-off scores for the different SEMG measures of FR and for flexion ROM, determined by the ROC analysis in the present study, can help guide future clinical researchers in determining "normalness" of the FR pattern in individual clinical and normal subjects, and can help guide clinicians in the treatment and restoration of normal FR patterns and ROM in CLBP patients.

## Acknowledgments

Supported in part by grant numbers 2K02 MH01107, 2R01 MH46402, and 2R01 DE10713 from the National Institutes of Health

## REFERENCES

1. Triano JJ, Schultz AB. Correlation of objective measure of trunk motion and muscle function with low-back disability ratings. Spine. 1987; 12:561–565. [PubMed: 2958944]
2. Ahern DK, Follick MJ, Council JR, et al. Comparison of lumbar paravertebral EMG patterns in chronic low back pain patients and non-patient controls. Pain. 1988; 34:153–160. [PubMed: 2971912]
3. Sihvonen T, Partanen J, Hänninen O, et al. Electric behavior of low back muscles during lumbar pelvic rhythm in low back pain patients and healthy controls. Arch Phys Med Rehabil. 1991; 72:1080–1087. [PubMed: 1835833]
4. Shirado O, Ito T, Kaneda K, et al. Flexion-relaxation phenomenon in the back muscles: A comparative study between healthy subjects and patients with chronic low back pain. Am J Phys Med Rehabil. 1995; 74:139–144. [PubMed: 7710729]
5. Watson PJ, Booker CK, Main CJ, et al. Surface electromyography in the identification of chronic low back pain patients: the development of the flexion relaxation ratio. Clin Biomech. 1997; 12:165–171.
6. Neblett R, Mayer TG, Gatchel RJ, et al. Quantifying the Lumbar Flexion–Relaxation Phenomenon: Theory, Normative Data, and Clinical Applications. Spine. 2003; 28:1435–1446. [PubMed: 12838103]
7. Geisser ME, Ranavaya M, Haig AJ, et al. A Meta-Analytic Review of Surface Electromyography Among Persons With Low Back Pain and Normal, Healthy Controls. J Pain. 2005; 6:711–726. [PubMed: 16275595]
8. Floyd WF, Silver PHS. The function of the erector spinae muscles in certain movements and postures in man. J Physiol. 1955; 129:184–203. [PubMed: 13252593]
9. Paquet N, Malouin F, Richards CL. Hip-Spine Movement Interaction and Muscle Activation Patterns During Sagittal Trunk Movements in Low Back Pain Patients. Spine. 1994; 19:596–603. [PubMed: 8184355]
10. Nouwen A, Van Akkerveeken PF, Versloot JM. Patterns of Muscular Activity during Movement in Patients with Chronic Low-back Pain. Spine. 1987; 12:777–782. [PubMed: 2961090]
11. Golding JSR. Electromyography of the Erector Spinae in Low Back Pain. Postgrad Med J. 1952; 28:401–406. [PubMed: 14957661]
12. Sihvonen T, Huttunen M, Makkonen M, et al. Functional changes in back muscle activity correlate with pain intensity and prediction of low back pain during pregnancy. Arch Phys Med Rehabil. 1998; 79:1210–1212. [PubMed: 9779673]
13. Geisser ME, Haig AJ, Wallbom AS, et al. Pain-Related Fear, Lumbar Flexion, and Dynamic EMG Among Persons With Chronic Musculoskeletal Low Back Pain. Clin J Pain. 2004; 20:61–69. [PubMed: 14770044]

14. Watson PJ, Booker CK, Main CJ. Evidence for the Role of Psychological Factors in Abnormal Paraspinal Activity in Patients with Chronic Low Back Pain. J Musculoskelet Pain. 1997; 5:41–56.

15. Mayer TG, Neblett R, Brede E, et al. The quantified lumbar flexion-relaxation phenomenon (QLFRP) is an excellent measurement of improvement in a functional restoration program. Spine. 2009; 34:2458–2465. [PubMed: 19789467]

16. Kippers V, Parker AW. Posture related to myoelectric silence of erector spinae during trunk flexion. Spine. 1984; 9:740–745. [PubMed: 6505844]

17. Donisch EW, Basmajian JV. Electromyography of deep back muscles in man. Am J Anat. 1972; 133:25–36. [PubMed: 5008883]

18. Morris JM, Benner G, Lucas DB. An electromyographic study of the intrinsic muscles of the back in man. J Anat. 1962; 4:509–520. [PubMed: 17105132]

19. Portnoy H, Morin F. Electromyographic Study of Postural Muscles in Various Positions and Movements. Am J Physiol. 1956; 186:122–126. [PubMed: 13354766]

20. Tanii K, Masuda T. A kinesiologic study of erectors spinae activity during trunk flexion and extension. Ergonomics. 1985; 28:883–893. [PubMed: 4029113]

21. Lehman GJ, McGill SM. The importance of normalization in the interpretation of surface electromyography: A proof of principle. J Manipulative Physiol Ther. 1999; 22:444–446. [PubMed: 10519560]

22. Haig AJ, Weismann G, Haugh LD, et al. Prospective Evidence for Change in Paraspinal Muscle Activity after Herniated Nucleus Pulposus. Spine. 1993; 18:926–929. [PubMed: 8316896]

23. Ambroz C, Scott A, Ambroz A, et al. Chronic Low Back Pain Assessment Using Surface Electromyography. J Occup Environ Med. 2000; 42:660–669. [PubMed: 10874660]

24. Mathieu PA, Fortin M. EMG and kinematics of normal subjects performing trunk flexion/ extensions freely in space. J Electromyogr Kinesiol. 2000; 10:197–209. [PubMed: 10818341]

25. Alschuler KN, Neblett R, Wiggert E, et al. Flexion-relaxation and Clinical Features Associated With Chronic Low Back Pain: A Comparison of Different Methods of Quantifying Flexion-relaxation. Clin J Pain. 2009; 25:760–766. [PubMed: 19851155]

26. Cram, JR.; Kasman, GS. Dynamic assessment. In: Criswell, E., editor. Cram's introduction to surface electromyography, 2nd edition. Sudbury, MA: Jones and Bartlett Publishers; 2011. p. 123-140.

27. Neblett R. Active SEMG training strategies for chronic musculoskeletal pain: part 1. Biofeedback. 2002; 30:28–31.

28. McGeary DD, Mayer TG, Gatchel RJ. High Pain Ratings Predict Treatment Failure in Chronic Occupational Musculoskeletal Disorders. J Bone Joint Surg. 2006; 88-A

29. Anagnostis C, Mayer TG, Gatchel RJ, et al. The Million Visual Analog Scale: Its Utility for Predicting Tertiary Rehabilitation Outcomes. Spine. 2003; 28:1050–1060.

30. Vlaeyen JWS, Kole-Snijders AMJ, Boeren RGB, et al. Fear of movement/(re)injury in chronic low back pain and its relation to behavioral performance. Pain. 1995; 62:363–372. [PubMed: 8657437]

31. Wesley AL, Gatchel RJ, Garofalo JP, et al. Toward More Accurate Use of the Beck Depression Inventory with Chronic Back Pain Patients. Clin J Pain. 1999; 15:117–121. [PubMed: 10382925]

32. Cram, JR.; Kasman, GS. Electrodes and site selection strategies. In: Criswell, E., editor. Cram's introduction to surface electromyography, 2nd edition. Sudbury, MA: Jones and Bartlett Publishers; 2011. p. 65-73.

33. Neblett R, Mayer TG, Brede E, et al. Correcting Abnormal Flexion-relaxation in Chronic Lumbar Pain: Responsiveness to a New Biofeedback Training Protocol. Clin J Pain. 2010; 26:403–409. [PubMed: 20473047]

34. Mayer TG, Tencer AF, Kristoferson S, et al. Use of Noninvasive Techniques for Quantification of Spinal Range-of-Motion in Normal Subjects and Chronic Low-Back Dysfunction Patients. Spine. 1984; 9:588–595. [PubMed: 6238424]

35. Keeley J, Mayer TG, Cox R, et al. Quantification of Lumbar Function: Part 5: Reliability of Range-of-Motion Measures in the Sagittal Plane and an In Vivo Torso Rotation Measurement Technique. Spine. 1986; 11:31–35. [PubMed: 2939567]

36. Fawcett T. An introduction to ROC analysis. Pattern Recognit Lett. 2006; 27:861–874.

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37. Tape TG. Interpreting diagnostic tests. 2010 [University of Nebraska medical center web site]. Available at: http://gim.unmc.edu/dxtests/roc3.htm.
38. Marshall P, Murphy B. Changes in the Flexion Relaxation Response Following an Exercise Intervention. Spine. 2006; 31:E877–E883. [PubMed: 17077724]
39. Marshall PW, Murphy BA. Muscle Activation Changes After Exercise Rehabilitation for Chronic Low Back Pain. Arch Phys Med Rehabil. 2008; 89:1305–1313. [PubMed: 18586132]
40. Mayer T, Tabor J, Bovasso E, et al. Physical Progress and Residual Impairment Quantification After Functional Restoration|Part I: Lumbar Mobility. Spine. 1994; 19:389–394. [PubMed: 8178224]

## Table 1

Definitions and Calculations of Flexion-Relaxation Ratios, Absolute Surface EMG Measures, and Flexion Range-of-Motion Measures

| MEASURE | DEFINITON AND METHOD OF CALCULATION |
|---|---|
| **Flexion-Relaxation Ratios** | |
| FRR STAND/MVF | Mean standing SEMG values prior to flexion are divided by the mean SEMG during maximum voluntary flexion.[25] |
| FRR FLEX/MVF | Maximum SEMG values during flexion are divided by the mean SEMG during maximum voluntary flexion.[5,9] |
| FRR EXT/MVF | Maximum SEMG values during re-extension are divided by the mean SEMG during maximum voluntary flexion.[23,24] |
| FRR FLEX/EXT | Maximum SEMG values during flexion are divided by the maximum SEMG values during re-extension.[3,12] |
| **Absolute SEMG (μV)** | |
| MVF SEMG | Mean absolute RMS SEMG levels during maximum voluntary flexion.[15,33] |
| Standing SEMG | Mean absolute RMS SEMG levels during standing, prior to bending.[7] |
| Standing Recovery SEMG | Mean absolute RMS SEMG levels during standing, following bending.[26] |
| **Flexion Range-of-Motion** | |
| Gross ROM | Degrees of trunk motion at maximum voluntary flexion, measured by inclinometer at T12.[40] |
| Pelvic ROM | Degrees of pelvic motion at maximum voluntary flexion, measured by inclinometer at S1.[40] |
| True ROM | Degrees of true lumbar motion at maximum voluntary flexion (Gross ROM - Pelvic ROM).[40] |

## Table 2

Demographic Characteristics of Subject Cohort

| Value | Patients N= 218 | Controls N = 30 | Significance |
|---|---|---|---|
| Age mean (SD) | 46.8 (9.5) | 37.6 (9.3) | p < .001 |
| Gender (% male) | 140 (64.2%) | 17 (56.7%) | NS |
| Race (%) | | | NS |
| Caucasian | 124 (57%) | 24 (80%) | |
| African-American | 49 (23%) | 3 (10%) | |
| Hispanic | 24 (11%) | 2 (6.7%) | |
| Asian | 2 (1%) | 1 (3.3%) | |
| Other | 4 (2%) | 0 (0%) | |
| Time from injury to program admission in months (mean/SD) | 28.4 (34.7) | n/a | |
| Pre-rehab Lumbar fusions n (%) | 57 (25.8%) | n/a | |
| Working at admission n (%) | 17 (8.5%) | n/a | |
| Pain Intensity VAS mean (SD) *range* | 7.1 (1.6) *2–10* | n/a | |
| Million visual analog disability scale[29] mean (SD) *range* | 106.3 (17.6) *27–146* | n/a | |
| Tampa Scale for Kinesiophobia[30] mean (SD) *range* | 33.8 (7.2) *15–49* | n/a | |
| Beck depression inventory[31] mean (SD) *range* | 22.9 (12.2) *2–80* | n/a | |

**Table 3**

Receiver Operating Characteristic (ROC) Analyses of Surface EMG and Flexion ROM Measures with Chronic Low Back Pain and Pain-Free Control Subjects.

| Measure | Cut-off scores between CLBP and control subjects | Area Under Curve | Sensitivity (% of patients correctly classified as patients) | Specificity (% of controls correctly classified as controls) |
|---|---|---|---|---|
| **Flexion-Relaxation Ratios** | | | | |
| EXT/MVF | ≤ 5.6 | 0.90 | 0.82 | 0.83 |
| FLEX/MVF | ≥ 9.5 | 0.89 | 0.83 | 0.80 |
| FLEX/EXT | ≤ 0.55 | 0.82 | 0.74 | 0.77 |
| STAND/MVF | ≥ 1.29 | 0.80 | 0.72 | 0.70 |
| **Absolute SEMG (μV)** | | | | |
| *MVF SEMG | ≤ 3.5 * | 0.86 | 0.72 | 1.00 |
| MVF SEMG | ≤ 2.4 | 0.86 | 0.79 | 0.83 |
| Standing SEMG pre-flexion | ≤ 4.8 | 0.65 | 0.62 | 0.67 |
| Standing SEMG post flexion (e.g. Recovery) | ≤ 6.7 | 0.67 | 0.60 | 0.60 |
| **Flexion Range of Motion (degrees)** | | | | |
| *Gross ROM | ≥110 * | 0.93 | 0.95 | 0.60 |
| Gross ROM | ≥97 | 0.93 | 0.88 | 0.83 |
| *Pelvic ROM | ≥ 45 * | 0.88 | 0.77 | 0.83 |
| Pelvic ROM | ≥49 | 0.88 | 0.82 | 0.80 |
| *True lumbar ROM | ≥ 50 * | 0.83 | 0.82 | 0.60 |
| True lumbar ROM | ≥ 49 | 0.83 | 0.76 | 0.73 |

MVF = maximum voluntary flexion, EXT = extension, FLEX = flexion

*Cut-off scores used in previous research[15,33]

## Table 4

A comparison of surface EMG and flexion ROM measures between chronic low back pain and pain-free control subjects

| Measure | CLBP Subjects (N= 218) | Control Subjects (N= 30) | significance |
|---|---|---|---|
| **Flexion-Relaxation Ratios** | | | |
| EXT/MVF (mean, SD) *Range* | 38.7 (28.7) *1.6–91.9* | 3.9 (2.4) *1.3–13.2* | <0.001 |
| FLEX/MVF (mean, SD) *Range* | 5.2 (6.8) *0.9–40.6* | 15.1 (7.7) *5.1–38.5* | <0.001 |
| FLEX/EXT (mean, SD) *Range* | 0.70 (0.20) *0.3–1.4* | 0.47 (0.15) *0.2–0.9* | <0.001 |
| STAND/MVF (mean, SD) *Range* | 1.5 (2.3) *0.1–15.3* | 2.6 (1.6) *0.9–6.0* | 0.007 |
| **Absolute SEMG (μV)** | | | |
| MVF SEMG (mean, SD) *Range* | 12.2 (9.7) *0.8–44.6* | 2.0 (0.6) *0.8–3.4* | <0.001 |
| FR achieved (μV ≤3.5)* (n, %) | 29% (n = 63) | 100% (n = 30) | <0.001 |
| Pre-flexion (mean, SD) *Range* | 7.0 (4.6) *1.2–26.0* | 4.9 (3.3) *1.8–16.8* | 0.014 |
| Post-flexion/Recovery (mean, SD) *Range* | 9.4 (5.7) *1.4–28.9* | 6.6 (4.8) *1.4–21.4* | 0.011 |
| **Flexion Range of Motion (degrees)** | | | |
| Gross ROM (mean, SD) *Range* | 71.7 (24.2) *10–143* | 110 (11.7) *77–130* | <0.001 |
| Pelvic ROM (mean, SD) *Range* | 32.6 (16.7) *2–92* | 6 (10) *36–75* | <0.001 |
| True lumbar ROM (mean, SD) *Range* | 39.1 (12.9) *3–65* | 53.9 (8.2) *38–70* | <0.001 |

MVF = maximum voluntary flexion, EXT = re-extension, FLEX = flexion

*Cut-off score used in previous research[15,33]