Clinical utility of flexion-extension ratio measured by surface electromyography for patients with nonspecific chronic low-back pain

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Abstract

Background: Patients with chronic nonspecific low-back pain (CNSLBP) lack the flexion-relaxation phenomenon in full-trunk bending. This can be quantified by surface electromyography (SEMG) measurement of lumbar erector muscle. The study objective is to explore the clinical utility of the SEMG flexion-extension ratio (FER) in distinguishing patients with CNSLBP from pain-free persons.

Methods: This was a comparative cross-sectional study. We adopted a balanced study design by recruiting 130 participants each for the CNSLBP and control arms. Each participant underwent dynamic SEMG measurement in full-trunk bending, which consisted of standing, flexion, relaxation, and extension. The FER ratio was the ratio of the maximum SEMG in flexion to the maximum SEMG during extension. Receiver-operating characteristic (ROC) analysis was conducted to identify optimal values of the FER and associated sensitivity, specificity, and diagnostic accuracy.

Results: The CNSLBP group and control group were generally comparable in terms of demographics and clinical profile. The CNSLBP group had higher SEMG amplitudes during flexion but lower SEMG during extension. The mean (SD) FER of the CNSLBP group was 0.90 (0.26), which was almost double that of controls 0.47 (0.14). The ROC curve identified an optimal FER cutoff of ≥ 0.692, for which sensitivity and specificity were 76.15% (95% confidence interval [CI], 68.14-82.66) and 98.46% (95%CI, 94.56-99.58). The diagnostic accuracy was 92.1% (95% CI, 88.70-95.54).

Conclusion: The FER derived by lumbar muscle SEMG is able to distinguish patients with CNSLBP from pain-free people with excellent accuracy. This provides good evidence that a customized FER can be used in various clinical scenarios.

Keywords: Chronic disease; Clinical utility; Flexion-extension ratio; Low-back pain; Surface electromyography

1. INTRODUCTION

Low-back pain (LBP) has posed great disease and economic burden worldwide. The lifetime risk of LBP was reported to be as high as 84%.1,2 Most LBP patients are chronic cases suffering from long-term difficulties in daily function and loss of quality of life. Despite the high disease burden, the etiology of LBP in many cases is unclear; thus, the term chronic nonspecific low-back pain (CNSLBP) was coined.3 The clinical assessment of CNSLBP remains a big challenge which has been largely ascribed to the unclear etiology and consequently lack of reliable clinical tools.

Compared with healthy persons, patients with CNSLBP are characterized by the absence or disruption of the flexion-relaxation (FR) phenomenon.4,5 The FR phenomenon refers to electric activities of lumbar muscles during full-trunk bending. Lumbar muscles initially contract but ultimately relax at what appears to be a distinct point in the flexion range of motion (ROM). CNSLBP patients did not show a clear pattern of FR when bending. Alternatively, FR manifested itself in a more complex way.6-9 The FR and its variations among CNSLBP patients are subject to surface electromyography (SEMG) measurement, which is a clinical tool recording electric activities of lumbar muscles in both static and dynamic postures.10

The muscle activities reflected by SEMG have provided quantitative and objective measurements of FR. Studies have shown that SEMG is able to distinguish the FR differences between CNSLBP and pain-free persons in various clinical scenarios.5,11 Several SEMG ratios have been developed to measure FR with an attempt to explore and expand the clinical utility of SEMG in the field of CNSLBP. SEMG-derived FR ratios have been increasingly used to study CNSLBP. Studies have shown that SEMG can identify new CNSLBP patients for early treatment.11,12 SEMG ratios correlated very well with other measures of ROM.6 Some SEMG ratios are very sensitive to patient improvement in their function.13 Baseline SEMG values can predict good recovery in certain groups of CNSLBP.14 Adding FR ratios to ROM measures has improved the accuracy of ROM utility.15

It has been proposed that SEMG holds the promise to be
great clinical measure for CNSLBP. However, current evidence seems to be insufficient to position SEMG in clinical guidelines. Early statements have concluded that SEMG is considered unacceptable as a clinical tool in assessing patients with LBP. However, most SEMG studies may be subject to several drawbacks in study design and patient recruitment. In light of the growing emphasis on evidence-based medicine, more evidence is needed to support the expanded use of SEMG in clinical practice. As such, we conducted this study as an extension of our previous study to further evaluate the flexion-extension ratio (FER) with the dual aim of (1) exploring the utility of SEMG in distinguishing patients with CNSLBP from similar pain-free persons and (2) providing data of sensitivity and specificity of FER for relevant meta-analysis.

2. METHODS

2.1. Study design
This was a comparative cross-sectional study. We adopted a balanced design by recruiting an equal number of patients for the CNSLBP and control arms. The sample size was estimated following the published method. We used the formula based on the specificity, which assumed the value of 0.953 from our previous estimate. The precision was set at 0.05, and the CI was set at 95%. With the above parameters, the total sample size was calculated as 139. To increase the power of this study, we inflated the sample size to 260, with either arm comprising 130 patients. Participants and examiners were not blinded to the CNSLBP status. The study was approved by the Institutional Review Board of the hospital. This work is an investigator-initiated study and was not funded by any institution.

2.2. Eligibility criteria
Conforming to the European Guidelines for the Management of CNSLBP, we defined for this study the following inclusion criteria for CNSLBP patients: (1) age 20 to 60 years, (2) primary complaint of low back pain without formal diagnosis of CNSLBP, (3) pain limited to back and lumbar area, (4) pain lasting cumulatively for 6 months during the past year, and (5) supine straight leg raise negative. Exclusion criteria were (1) clinically meaningfull deformities (protrusion > 4mm) shown by computed tomography or magnetic resonance imaging, (2) history of surgeries of the lumbar and back, (3) pain with clear reasons, and (4) severe comorbidities such as cardiovascular diseases prohibiting full-trunk flexion.

2.3. Sample recruitment
Patients and controls were recruited in parallel from the Chirotherapy Clinic of GHAR from August 2012 to May 2014. After recruiting each 10 CNSLBP cases, we invited their colleagues and family to participate as controls. To minimize the effect of spectrum bias, in selecting controls we gave priority to individuals who had reported pain episodes in the past year but were ruled out of CNSLBP diagnosis. The control group was free of pain and limited lumbar flexion at the time of enrollment. Written informed consent was duly obtained for each participant.

2.4. SEMG measurement and flexion extension ratio
We measured SEMG of the erector spinae muscle between L2 and L5. The examination area was carefully prepared by shaving the hair and erasing superficial corneum. These procedures were used to ensure the impedance less than 8KΩ between any two ipsilateral electrodes. Each subject had three electrodes i.e., two recording electrodes and one reference electrode, placed on both sides of the lumbar area. On either side, the two recording electrodes were placed 4cm horizontally from the middle line at the L4 and L5 level, respectively, while the reference electrode was placed 4cm further laterally. Electrodes were disposable Ag-AgCl electrodes filled with solid gel to increase conductivity and with a diameter of 1cm (H93, Arboletd, Germany).

Dynamic SEMGs in carrying out a full-trunk flexion were measured on the day of recruitment. To obtain the best performance of each participant, the examiner briefed each subject and demonstrated full-trunk flexion before actual measurement. Time was also allocated for warm-up exercises. Every subject underwent five trials to capture reliable SEMG signals. A full-trunk flexion consisted of four phases: standing, flexion, relaxation (maximum voluntary flexion), and extension. The SEMG readings for each phase were recorded.

2.5. Statistical analysis
The primary outcome in our study was FER, which is the ratio of the maximum SEMG in flexion to the maximum SEMG during extension. We also investigated other factors relevant to development of CNSLBP following the biopsychosocial model of CNSLBP. The characteristics of the sample were summarized in descriptive statistics and compared between the LBP and control groups. Two-sample t-tests were performed to compare the means of continuous variables, and chi-square test was performed comparing the proportions of each stratum. The SEMGs and FERs for the LBP and control groups were compared to obtain an overall impression of the SEMG profile. The FER distributions were presented graphically with their normality checked by one-sample Kolmogorov-Smirnov (K-S) test. The receiver-operating characteristic curve (ROC) was constructed to evaluate the extent to which the FER ratio discriminates between the CNSLBP patients and asymptomatic individuals. The ROC was also able to identify optimal values of FER where the diagnostic accuracy of FER was maximized. Sensitivity and specificity were computed for the identified optimal FER.

3. RESULTS
As shown in Figure 1, participants in the CNSLBP group and control group were generally comparable. Compared with the control group, the CNSLBP group had a larger proportion of active exercisers (p = 0.035), while it also had a larger proportion of people working in a sedentary manner (p = 0.022). Both groups enrolled people with imaging-detected anatomical abnormalities.

The absolute SEMGs of the two groups were compared in Figure 2. SEMG seemed sensitive to CNSLBP status as significant differences were observed on each individual SEMG measure between the two groups. Compared with asymptomatic subjects, patients with CNSLBP had significantly higher SEMG amplitudes in the position of flexion but lower SEMGs during extension. Consequently, the mean FERs of patients with CNSLBP were almost double that of pain-free controls (0.90 vs 0.47). As theoretically expected, extension SEMG was bigger than flexion SEMG irrespective of CNSLBP status. But for the control group, the dISEMG difference between extension and flexion reached above 30.3μv, which was much higher than...
the maximal difference of 8.7μv for the CNSLBP group.

FER distributions for both the CNSLBP and control groups followed the normal distribution, with insignificant p values of the one-sample K-S test (Fig. 1). However, clearly, the FER of the CNSLBP group shifted toward the higher range compared with the control group. In addition, the CNSLBP group had a wide FER distribution ranging from 0.23 to 1.42, whereas the control group had a range of 0.15 to 0.73.

ROC curve
The ROC curve in Figure 2 identified FER ≥ 0.692 as the optimal cutoff point, at which the sensitivity and specificity of the FER to distinguish CNSLBP subjects from pain-free controls were 76.15% (95%CI, 68.14–82.66) and 98.8% (95%CI, 94.56–99.58), respectively. The diagnostic accuracy (area under curve) was 92.1% (95%CI, 88.70–95.54), suggesting that FER was an excellent diagnostic tool according to established standard.22

4. DISCUSSION
Our study evaluated one specific SEMG measure for FR phenomenon and found that FER is able to differentiate new patients with CNSLBP from comparable pain-free people with excellent accuracy (92.1%).22 The sensitivity and specificity of FER corresponding to the FER cutoff of 0.692 are considered satisfactory for the purpose of clinical diagnosis in the outpatient setting. Our results provide good evidence to support the use of SEMG ratios in clinical practice.

Several studies have evaluated FER in different populations of LBP with or without comparison to pain-free controls.4,23,24 This study found consistent results with previous studies. LBP patients tend to have lower absolute SEMG values in reextension, as reported by Shirado et al24; CNSLBP tend to relate patients to higher FER.23 Although the present sample was totally...
different from that of our previous study,11 the findings were similar to the prior results. The changes in cutoff FER (0.680 vs 0.692), sensitivity (78.1% vs 76.15%), and specificity (95.30% vs 98.46%) all fall below 3.5%. This further substantiates the clinical utility of FER in CNSLBP management.

The FER seemed to work better in Chinese patients, as the FER in our sample achieved a sensitivity of 76.15% and a specificity of 98.46%, which was higher than the previously reported sensitivity of 74% and specificity of 77% in a western population.23 Accordingly, the diagnostic accuracy was 92.1%, which is greater than the 82% previously reported. In our study, FER also outperformed the best FR ratio identified by that same study.23 In addition, we found much bigger values for the FER group of our sample derived a mean FER of 0.9, which was twice as much as the 0.44 reported.25 Similarly, the mean FER for our control group was 0.47, which was almost double that of 0.26 for the western sample.23 Given the heterogeneity of CNSLBP patients, and many physical as well as psychological factors involved in pain manifestation, it is understandable that FER performance varies by study population and research setting.

The between-study variation of FER performance had both clinical and research implications. For clinical purposes, probably a range of FER rather than a single or fixed value should be proposed considering real-life clinical complexity. For research purposes, this may render comparisons of absolute FER across different study populations less informative or meaningful. On the other hand, the FER pattern when comparing CNSLBP patients with controls was quite consistent. Therefore, the idea of comparative design in SEMG studies on CNSLBP is reinforced. As scientific evidence accumulated over time, this may call for an updated systematic review based on meta-analysis to reevaluate SEMG and give informed recommendations.

Applying the FER in various clinical settings may entail adjustment of the FER threshold. As displayed in Figure 1, the FER for CNSLBP had a wider distribution, which covered a big proportion (88%) of healthy controls. The cutoff value of FER could be set at 0.8 or higher to accurately diagnose a Chinese patient with CNSLBP based on FER alone. For screening purposes, it is feasible to adjust the FER value downward to increase the sensitivity. The ROC curve (Figure 2) illustrated that the discrimination ability of the FER is one-directional along the observed range. As for other clinical purposes, such as evaluating the treatment outcome, different FER values have been used to make the most of this SEMG measure. At the present time, there is no golden standard based on FR ratios to confirm the presence or absence of the FR phenomenon. Further exploration in this regard would make great sense.

SEMG is a noninvasive measurement that can quantify electrical signals of lumbar muscles in both static and dynamic posture.10 In essence, SEMG has been proposed as an objective clinical marker of muscle activity, providing valuable information for clinical judgment. Thus, not surprisingly, SEMG has gained popularity in the medical community.15 However, there are still debates about its clinical utility and value of evidence. Some studies have produced mixed results.26 Shortcomings of SEMG research and SEMG ratios have been discussed in reviews.17,27 However, many unsettled issues may be addressed with a balanced design and rather large sample size. As informed by this literature, our study was designed as a comparative study with an equal number of patients in the two arms. The sample size was inflated to gain sufficient power. Plus, controls were selected from family members, colleagues, and friends of the index patient. All of these measures will increase the comparability between the two groups and enhance the validity of our results.

We acknowledge the limitations of the study when applying our findings in clinical practice. We did not compare the FER with other FR-related SEMG indices. Thus, we are not in the position to recommend the FER relative to other SEMG ratios. However, this may not affect the value of our study for providing scientific evidence, because FR ratios independently reflect different aspects of muscle movement.4 We did not correlate FER measures with ROM measures such as lumbar movement or hip movement. This may weaken the persuasive power of the results. Because the gold standard for CNSLBP diagnosis has not been established,28,29 our study did not use one. Although it is common research practice in the field, it may in itself cause a methodological flaw as a diagnostic study design. Lastly, participants in the CNSLBP and control group are heterogeneous in our study. This could be a source of instability when extrapolating the sensitivity and specificity of FER in other specific populations.

In conclusion, our study found that FER derived by SEMG of the lumbar muscles is able to distinguish patients with CNSLBP from pain-free individuals with excellent accuracy. This information about the FER, whether used alone or complementary to other clinical measures, would be valuable in various clinical scenarios of CNSLBP, such as patient screen-
ing, diagnosis, or assessment of rehabilitation therapy. Therefore, SEMG may serve as an effective and inexpensive tool in CNSLBP management.

REFERENCES