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Original Article

Correlation between change in pain, disability, and surface electromyography topographic parameters after interferential current treatment in patients with chronic low back pain

Wai Ying Lai, MSc[1, 2], Hongyan Cui, PhD[3], Yong Hu, PhD[1, 3]*

[1] *Department of Orthopedics and Traumatology, Li Ka Shing Faculty of Medicine, The University of Hong Kong: 12 Sandy Bay Road, Pokfulam, Hong Kong*
[2] *Physiotherapy Department, Queen Elizabeth Hospital, Hong Kong*
[3] *Institute of Biomedical Engineering, Chinese Academy of Medical Sciences & Peking Union Medical College, China*

Abstract. [Purpose] Surface electromyography (SEMG) topography is used to objectively assess patients with low back pain (LBP). This study aimed to investigate the correlation between SEMG topographic variables, pain, and disability in patients with chronic LBP (CLBP) after interferential current (IFC) treatment, and to evaluate IFC treatment efficacy using SEMG topography. [Participants and Methods] Twenty nine patients with CLBP were recruited for a 6-week IFC treatment. Pain and disability scores, and the root-mean-square difference (RMSD) of SEMG topographic variables (relative areas [RAs] at flexion and extension) were compared before and after the intervention by repeated measures ANOVA; the correlation between variables was also explored and p-value was set at 0.001. [Results] Significant positive correlations between changes in pain score and the RMSD of RA at flexion (r(29)=0.593), and between changes in pain and disability scores (r(29)=0.426) were observed. All participants showed statistically significant improvements in the RMSD of RA at flexion, pain score, and disability score after IFC treatment. [Conclusion] SEMG topographic variables are closely associated with changes in pain score in patients with CLBP after IFC treatment. The RMSD of RA at flexion can be used as an objective marker in IFC treatment efficacy evaluation.

Key words: Surface electromyography topography, Chronic low back pain, Interferential current

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INTRODUCTION

Globally, chronic low back pain (CLBP) is a debilitating disorder lacking an identifiable etiology[1, 2]. The conservative management of CLBP ranges from exercise therapy[3] to device-based therapy with limited evidence support[4]. Surface electromyography (SEMG) is recognized as an effective and useful tool to evaluate the appropriateness of therapy by providing reliable and unique information on biomechanical and musculoskeletal dysfunction, thereby enhancing the understanding of muscle relaxation, motor control, and proper muscle activation during rehabilitation[5–8]. The large-array SEMG technique has been developed to characterize low back muscle fatigue in patients with low back pain (LBP) that may be induced by low-load and prolonged contractions[5]. To enable the visualization of trunk muscle recruitment patterns in patients with LBP for comparison with those in healthy people, a transcutaneous, time-varying SEMG topography is originated to evaluate global back muscle activities and to monitor the rehabilitation progress[7–11]. A previous study suggested that SEMG topographic

*Corresponding author. Yong Hu (E-mail: yhud@hku.hk)

parameters (relative area [RA] and relative width) during dynamic trunk motion could be used to predict patient response under conservative care[7]. SEMG topography can further identify patient response to functional restoration rehabilitation through a proper prediction/classification model[8]. Meanwhile, the ability of SEMG topography to capture specific back muscle activity while using physiotherapeutic options for LBP, such as electrotherapy, is unknown.

Interferential current (IFC), also known as interferential therapy, has been a popular treatment option for pain relief in patients with CLBP, among physiotherapists[12]. Afferent stimulation from IFC may inhibit the transmission of nociceptive information in the spinal dorsal horn, resulting in analgesia for LBP, according to the gate theory of pain[13–16]. The interference of currents mimics a low frequency stimulation, known as amplitude-modulated frequency (AMF) current, which induces a hypoalgesic effect of lower skin impedance. Further probable mechanisms of IFC antinociceptive action include an activation of the descending inhibitory pathway with a release of endogenous opioids, physiological nerve conduction block, enhanced blood flow, muscle relaxation, and placebo effect[17, 18]. Moreover, IFC is thought to promote segmental analgesia and alter central pain processing in patients with CLBP in a form of peripheral electrical stimulation, although no clear evidence supports this theory[15, 19–21]. Impaired back muscle activity, commonly present in patients with CLBP[22], is thought to be a functional adaptation to pain[7, 23–25]. However, it is unknown whether there are IFC-induced changes in regional motor unit recruitment, and whether these changes, if present, correlate with clinical features of LBP, such as pain score and functional outcomes. Since there is an established relationship between back muscle activity, evaluated in terms of SEMG topographic parameters, and pain intensity in patients with LBP, it is necessary to access the efficacy of SEMG topography in monitoring the response of patients with LBP to IFC treatment.

Therefore, it is aimed to explore the relationship between SEMG topography and clinical parameters in a group of patients with CLBP. Two hypotheses were formulated. First, SEMG topography is associated with subjective pain outcomes and back-related disability in patients with CLBP after IFC treatment. Second, IFC treatment efficacy could be demonstrated by significant improvement in SEMG topography, as well as clinical measures of pain and disability after the intervention.

PARTICIPANTS AND METHODS

The study was a prospective, single-blind, repeated-measures trial. We recruited 31 adult patients with a diagnosis of "LBP", "lumbar spine pain", or "back pain", referred for physiotherapy rehabilitation at the Outpatient Physiotherapy Clinic of Queen Elizabeth Hospital, Hong Kong, and who fulfilled the definition of CLBP (pain involving the region below the ribcage, with no definite physical origins, and symptoms lasting for over 3 months). Patients who presented signs of a serious underlying condition, including major orthopedic, neurological, circulatory, or respiratory conditions; spinal stenosis or radiculopathy; or other specific spinal conditions (such as recent vertebral burst fracture) were excluded. Moreover, patients with a personal or family history of epilepsy, recent or current pregnancies, and a history of abdominal and back surgery were not included. Patients were advised against and agreed not to commence other nonpharmacological therapies during the study period. All participants provided written informed consent before data collection. The Research Ethics Committee (Kowloon Central/Kowloon East) of the Hospital Authority approved this study (REF: KC/KE-15-0132/ER-3).

All data collection and interventions were performed at the aforementioned study site. The patients' age, gender, weight, height, and history of LBP were documented on the first visit. A tailor-made SEMG topography system (YRKJ-G2008; YiRui Technology Co., Ltd., Zhuhai, China) was used to obtain SEMG topography measures during lumbar flexion and extension. Two identical SEMG topography measures were obtained before and immediately after the course of therapy by the same trained physiotherapist. Twenty-one rectangular, silver chloride surface, one-off, self-adhesive electrodes (Tianjin Zhuyou, Tianjin, China) were arranged in 3×7 array along the participant's lower back region (midline on the skin overlying the L3 spinous process) (Fig. 1), which was scraped to remove the dead layer of skin and cleaned with alcohol before the electrodes can be properly applied. Participants were instructed to move their backs forward and backward two times while standing, to ensure consistent testing procedure in each SEMG recording. Participants were asked to perform active lumbar flexion as much as possible, and to maintain the end-range lumbar flexion angle for at least 3 to 4 s before returning to the initial standing position. A bandpass filter of 15–950 Hz was used for SEMG recording, and the sampling rate for SEMG signal acquisition was set at 2,000 Hz.

Self-rated pain scores and disability levels were measured before and after the intervention using the Numeric pain rating scale (NPRS)[26] and Hong Kong version of the Roland–Morris Disability Questionnaire (HKRMDQ)[27] scores, respectively. The NPRS score ranges from 0 (no pain) to 10 (unbearable pain), whereas the HKRMDQ score ranges from 0 (no disability) to 24 (maximum disability). After the baseline SEMG recording, participants underwent IFC application according to a guideline modified from a previous study and based on anecdotal evidence[14] that routine clinical practice followed. Four suction cups were aligned using the vector dipole technique; i.e., four suction cups with soaked sponges were placed in two pairs, with two cups on each side of the lumbar paraspinal muscles (diagonal to each other), and the patient lying prone (Fig. 2). Using an IFC machine (Enraf Nonius Endomed 482 expanded with a Vacotron 460 [NL-3004 GB Rotterdam, The Netherlands]) with lowest intermittent suction force that enabled sufficient electrode contact, the output of the IFC was delivered with a carrier frequency of 4,000 Hz, an AMF of 100 Hz, a frequency variation of 60 Hz, and a ramp slope of 6/6. The current intensity (mA) was adjusted according to the patient's maximal tolerable sensorial threshold. Each treatment session lasted for 20 min. Each patient underwent 12 sessions of IFC therapy, administered twice weekly for 6 weeks by the

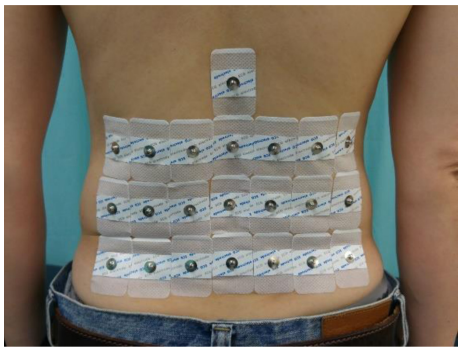

Fig. 1. Surface electromyography electrode placement.

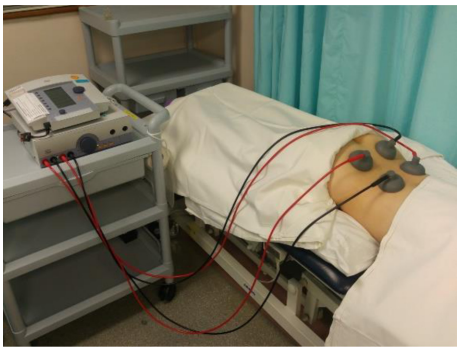

Fig. 2. Application of interferential current.

same registered physiotherapist. Detailed descriptions of the study were not disclosed to participants to avoid priming them. Weekly telephone calls were made to remind participants to adhere to the aforementioned advice.

The time-varying SEMG topography extracted and produced 50 frames for analysis that presented muscle activity change during lumbar flexion to extension, and the topographic parameter, RA, was derived from the equation below[7]:

$$Relative\ Area\ (RA) = \frac{High\ activity\ area_{60\%}}{Total\ topography\ area}$$

The acquired SEMG signals were processed and the root-mean-square (RMS) value of the amplified data was defined as multiplying the raw data by 2000 times, and the observation window used to calculate the RMS value was 400 ms. Muscle activity during the phases of flexion and extension was extracted for the root-mean-square difference (RMSD) analysis of SEMG topographic parameters (RAs in flexion and extension) using the following equation, with reference to data of a heathy population reported in a previous study[7]

$$RMSD = \sqrt{\frac{\sum_{i=0}^{i=N}(b_i - a_i)^2}{N}}$$

where a_i is the mean value of normal data (reference data), b_i is the RMS of individual patient data (compared data), and N is the sampling number.

Pearson's correlation coefficient was used to evaluate the difference between the RMSD of RA at flexion, RMSD of RA at extension, and all subjective measures (NPRS and HKRMDQ scores). One-way repeated-measures analysis of variance (ANOVA) was used to examine within-group differences in the RMSD of SEMG parameters, pain scale scores, and disability outcome at baseline and after the intervention. All statistical analyses were performed using SPSS for Windows version 23.0 (IBM Corp., Armonk, NY, USA). Bonferroni correction was applied to allow for multiple comparisons, and $p<0.001$ was considered to be statistically significant.

RESULTS

Two of the 31 patients recruited dropped out from the study (one patient failed to complete the 12-session therapy, and another failed to return for the treatment and follow-up assessment). In total, 29 patients who fulfilled the eligibility criteria and completed the therapy were included for analysis. The baseline demographic characteristics are presented in Table 1. The mean age and body mass index of the included participants were 51.28 ± 14.3 years and 22.41 ± 2.6 kg/m^2, respectively. More females (76.7%) were engaged in this study, and approximately 80% of participants had LBP evolving for more than 2 years.

Pearson correlation analysis indicated a significant positive association between a change in the NPRS score and a change in the RMSD of RA at flexion ($r(29)=0.593$, $p=0.001$), and between a change in the NPRS score and a change in the HKRMDQ score ($r(29)=0.426$, $p=0.021$). A change in the RMSD of RA at extension did not significantly correlate with a change in RMSD of RA at flexion and other clinical outcome measures ($p>0.05$). Table 2 illustrates pairwise comparisons of SEMG topographic data and self-reported outcomes at baseline and after intervention using repeated measures ANOVA with a Greenhouse-Geisser correction. The ANOVA indicated statistically significant changes in the RMSD of RA at flexion [$F(1, 27)=41.62$, $p<0.001$], NPRS score [$F(1, 27)=256.5$, $p<0.001$], and HKRMDQ score [$F(1, 27)=65.5$, $p<0.001$] after intervention. It is found that no statistically significant change in the RMSD of RA at extension [$F(1, 27)=0.78$, $p=0.385$].

Table 1. Baseline demographic characteristics of participants who completed the study

Variables	All (N=29)
Age, years	51.3 ± 14.3
Weight, kg	60.4 ± 7.0
Gender (male/female) (%)	5/24 (20.8)
Height, m	1.64 ± 0.05
Body mass index, kg/m^2	22.4 ± 2.6
Pain duration, years	7.07 ± 5.3
Pain lasting	
≤24 months (%)	6 (20.7)
>24 months (%)	23 (79.3)

Data are presented as mean ± standard deviation, except gender that is presented as number (male-to-female ratio) and pain presented as months (ratio of participants).

Table 2. Comparison between SEMG topographic variables and clinical outcomes before and after intervention

Variable	Baseline	Post-intervention	p-value
RMSD of RA at flexion	0.264 ± 0.10	0.182 ± 0.07 *	<0.001
RMSD of RA at extension	0.417 ± 0.09	0.400 ± 0.09	0.385
NPRS score	6.03 ± 1.7	2.93 ± 1.8 *	<0.001
HKRMDQ score	10.34 ± 4.7	6.62 ± 4.6 *	<0.001

Data are presented as mean ± standard deviation.
*Statistical significance set at p<0.001.
NPRS: Numeric pain rating scale; HKRMDQ: Hong Kong version of the Roland-Morris Disability Questionnaire; RMSD: root-mean-square difference; RA: relative area.

DISCUSSION

The current study showed a correlation between a change in the RMSD of RA at flexion and the change in patient self-rated pain level after IFC treatment. Values of the RMSD of RA at flexion were consistently lower in proportion to the clinical outcomes of LBP after IFC treatment, although there were no significant correlations between SEMG topographic parameters and back-related disability scores. These findings highlighted the clinical utility of SEMG topography in evaluating the treatment effect of IFC in patients with CLBP.

The pathophysiology of CLBP is complex, and the relationship between pain, back-related disability, and musculoskeletal status has undergone numerous investigations using lumbar paraspinal muscle SEMG[28–34]. Dynamic SEMG is a reliable and repeatable method for monitoring lumbar muscle activity change during LBP rehabilitation[5, 7] by recording the flexion-relaxation ratio[9], electric activity in terms of microvolts, and median frequency[32]. The relationship between muscle activity, pain, and disability showed ambiguous results in patients with LBP[35–37]. The current study results showed a positive correlation between a change in the RMSD of RA at flexion and a change in self-rated pain, echoing previously reported findings of a relationship between muscle activity and pain[30, 36]. Moreover, we demonstrated that SEMG topography not only has a prognostic value in determining patient response to rehabilitation[7, 8], but also an ability to estimate treatment effect.

However, the RMSD of RA at extension reportedly has a low clinical practicability; there are several possible reasons for the insignificant variance in the clinical practicalities of the RMSDs of RA at flexion and extension. First, the RMSD of RA at flexion is more sensitive to muscular change than that at extension, as the reduction of SEMG signals at near-maximal flexion and the beginning of extension is associated with the passive structures of the back[9]. Spinal stability is maintained by passive mechanical properties of the global torque-producing muscles, instead of optimal lumbar paraspinal muscle coordination[38]. Second, the relatively high baseline value of the RMSD of RA at extension that persisted after the intervention may indicate a persistent overactivation of deconditioned lumbar paraspinal muscles in patients with CLBP[39]. Lastly, the paraspinal muscle reflexes elicited in trunk extension may reduce the gamma motor-neuron drive, and hence muscle spindle excitability[40]. Therefore, the amplitude of SEMG signals during dynamic contractions, especially during the extension phase, may be inadequate to estimate changes. No value of the RMSD of RA at extension was lowered after IFC treatment; thus, further research is needed to explore the potential use of the RMSD of RA at extension in LBP assessment.

Central sensitization associated with cortical and subcortical reorganization is proposed as the mechanism of CLBP development[19, 41]. Based on our results, the peripheral electrical stimulation of IFC served as an effective neurostimulation intervention for CLBP treatment, indicated by an improvement in all subjective measures and the RMSD of RA at flexion.

Applying IFC alone in clinical practice is unlikely to produce favorable results, and a review suggested that IFC treatment works more effectively as a cointervention with other treatment modalities for musculoskeletal pain relief[18]. Our results confirmed that the sole application of IFC treatment produced an interim analgesic effect by influencing the excitability of motor neuron pools and blocking neurotransmission over the underlying area. The peripheral electrical stimulation of different frequency and wavelength can be quantitatively ascertained using SEMG topography in terms of the RMSD of RA at flexion. A previous study showed that electrotherapeutic massage has limited effects on muscle fatigue, as demonstrated using SEMG and blood flow assessment[42]. Therefore, our results should be interpreted with caution, as normalization in the RMSD of RA at flexion may not only result from the alternating modulated frequency, but also from the intermittent cutaneous massage effect of the applied IFC. A high degree of adherence to IFC treatment, as seen in the present study wherein only two patients dropped out, may also be required to achieve substantial SEMG topographic alterations secondary to pain modulation. Future research is required to examine changes in SEMG topographic parameters after administering an IFC treatment of different duration, frequency, intensity, swing patterns, electrode placement, and current modes, as well as to establish the optimal IFC parameters required in the management of patients with LBP.

No consensus has been reached regarding a cost-effective therapy for patients with CLBP. IFC is a common electrophysical modality used for pain alleviation, although the mechanism of action of IFC remains an enigma. It is found that a reduction in back pain and disability scores after a short-term treatment course of IFC, which was consistent with other study findings[18, 43]. Previous studies reported a relationship between muscle activity and perceived disability[44], as well as a significant correlation between disability and fear avoidance[45, 46].

Our study has some limitations. First, an insignificant association between SEMG topographic parameters and HKRMDQ scores was found, suggesting that a functional alleviation of CLBP after IFC treatment could not be measured using SEMG topography alone. A combination of functional and psychological variables that can differentiate between treatments may be more appropriate in the assessment of patients undergoing rehabilitation for CLBP. Second, the positive impact of IFC treatment should also be carefully considered, as this study did not include a control group. Third, therapist blinding was impossible for intervention application; moreover, the relatively high proportion of female participants in our study may affect result generalizability. Fourth, the effect of alternating electrode position and electrode contact may be non-negligible, and may contribute to the insignificant SEMG difference detected between trunk flexion and extension. Hence, it is necessary to minimize the presence of artefacts by establishing standardized procedures and using advanced apparatuses before the clinical application of SEMG topography for IFC treatment effect assessment.

In conclusion, this study demonstrated a positive correlation of the RMSD of RA at flexion with self-rated pain. A smaller RMSD of RA at flexion was associated with a lower self-rated pain in patients with CLBP after a 6-week IFC treatment course. SEMG topography can reflect IFC treatment efficacy by quantifying the RMSD of RA at flexion. Large-scale, high-quality, randomized clinical trials are needed to validate the efficacy of SEMG topography in detecting the therapeutic effects of other physical therapy techniques for patients with CLBP.

Authors' contributions

Concept/idea/research design: Y. Hu; Writing: W.Y. Lai, Y. Hu; Data collection and analysis: W.Y. Lai; Algorithm development and data analysis: H. Cui; Fund procurement: Y. Hu, H. Cui; All authors approved the final manuscript.

Funding and conflict of interest

The authors declared no competing interests.

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