Exploring Neuromuscular Electrical Stimulation Intensity Effects on Multifidus Muscle Activity in Adults With Chronic Low Back Pain: An Ultrasound Imaging–Informed Investigation

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ABSTRACT

STUDY DESIGN: Cross-sectional study.

BACKGROUND: Neuromuscular electrical stimulation (NMES) is an effective tool for stimulating multifidus muscle contractions. Ultrasound imaging (USI) is valid and reliable for quantifying multifidus activity represented by percent thickness change from a resting to contracted state. Thus, USI may be used to help determine optimal NMES intensity.

OBJECTIVES: To explore NMES intensity effects on multifidus thickening in adults with chronic low back pain (CLBP).

METHODS: Sixty patients with CLBP participated. L4/5 multifidus ultrasound images were obtained and percent thickness change from a resting to a contracted state was determined at baseline with a limb lift and during NMES application. During NMES, the examiner recorded the intensity, in milliampere, when the multifidus first started to thicken as observed with USI. The examiner also recorded the NMES intensity that resulted in no further multifidus thickening (ie, high-tolerance group) or, in cases where maximal thickening was not observed, the NMES intensity of the submaximal contraction (ie, low-tolerance group). Differences between participants with high versus low NMES tolerance were evaluated.

RESULTS: During NMES, the multifidus began thickening at a higher intensity for the high-tolerance group (n = 39), that is, 34 mA, compared with the low-tolerance group (n = 21), that is, 32 mA ($P = .001$). A greater mean intensity in the high-tolerance group, that is, 62 mA, as compared to 45 mA in the low-tolerance group, resulted in a larger percent thickness change, that is, 30.89% compared to 20.60%, respectively ($P < .001$).

CONCLUSIONS: Results provide clinicians with NMES intensity targets to facilitate multifidus muscle thickening, which provides insight into muscle activity.

KEYWORDS: back muscles, lumbosacral region, spine, ultrasonography

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Introduction

The yearly prevalence of low back pain in the United States is estimated at 15% to 20%, with a lifetime prevalence of more than 60%.[1] Chronic low back pain (CLBP), defined as pain of 3 months or more,[2] is a public health issue given its high prevalence, associated disability, and substantial health care and societal costs.[3,4] Treatment options for CLBP vary from nonoperative management, such as physical rehabilitation and pharmacological management, to surgery.[5]

During physical rehabilitation for CLBP, the erector spinae and multifidi muscles have been identified as important spinal stabilizers to target with exercises.[6,7] Systematic reviews have shown lumbar exercises to be effective for reducing CLBP severity and disability.[8,9] In young, healthy adults, trunk and lower extremity extension exercises result in >50% of a maximal voluntary contraction (MVC) of the posterior spinal stabilizers, that is, 64.9% ± 27.1% and 54.2% ± 22.1%, respectively.[10] Electromyography (EMG) studies of lumbar multifidi activation in patients with CLBP, compared with healthy controls, show lower multifidi muscle activation during exercises and reduced capacity for patients with CLBP to voluntarily recruit the multifidi muscles.[11] To date, in patients with LBP, exercises

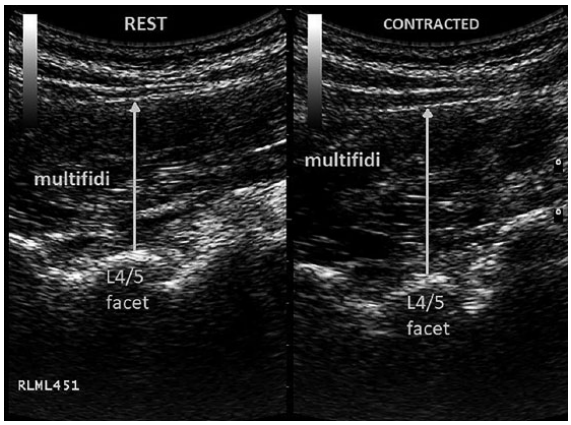


Figure 1. Measurement of L4/5 multifidus.

targeting the lumbar multifidi, with or without biofeedback, have failed to induce immediate changes in multifidi muscle.[12] Active rehabilitation, including exercises targeting the erector spinae and multifidi muscles for 4 to 6 sessions over 12 weeks, has similarly failed to evoke a change in trunk extensor muscle activation per EMG evaluation.[13]

Ultrasound imaging (USI) is highly correlated ($r = 0.79$) with EMG for assessment of low-level multifidi muscle contractions (ie, 19%-34% of an MVC) facilitated with limb lifts while the individual is lying prone.[14] Test-retest reliability has been previously reported for this proxy measure[14,15] of multifidi muscle activity among adults with CLBP using USI.[16] An image of the multifidus muscle is obtained at rest and repeated during a contralateral lower limb lift (Figure 1). Percent thickness change is calculated using the following equation: (contracted thickness obtained during contralateral limb lift − resting thickness)/resting thickness × 100%.[16] Furthermore, USI has been successfully used to provide biofeedback to enhance multifidi muscle thickening in adults without LBP,[17] albeit studies in patient populations are limited.

Neuromuscular electrical stimulation (NMES) can be used to facilitate contraction of the lumbar multifidi in patients with LBP.[18] Recently, Hicks et al[19] established feasibility for using low back NMES as a supplement to trunk muscle exercises in adults with CLBP. In Hicks et al[19] study, NMES intensity was set to a minimum level that resulted in a visible, sustained isometric contraction of the lumbar paraspinal muscles. The intensity was then subsequently increased to each participants "maximal tolerance," with the theoretical objective of electrically activating the multifidi muscles to the highest degree tolerated by the participant.[19] Maximizing muscle activity using NMES in addition to volitional exercises may provide a greater training dose than volitional exercises alone, particularly when muscle activation deficits are present.[20] For example, in the quadriceps muscle postoperatively, for example, following total knee arthroplasty or anterior cruciate ligament reconstruction, where known muscle activation deficits exist,[21,22] greater quadriceps NMES intensities have been correlated with greater postoperative strength gains.[23,24]

When dosing quadriceps NMES, the patient ideally is asked to perform bilateral MVCs against a dynamometer and a visual target is set for the patient to achieve a NMES intensity that results in an electrically facilitated quadriceps contraction of the impaired side that is at least 50% of the MVC of the unimpaired side.[25] Similar dosing of low back NMES in clinical practice is challenging as measurement of MVC is difficult to achieve and MVC-evoked pain in patients with CLBP may lead to an inability or unwillingness to perform maximal exertions.[26] We hypothesized that USI assessment of multifidi muscle percent thickness change, which uses submaximal activation (ie, lower limb lifts) for baseline testing and allows for real-time visualization of muscle thickening during NMES application, would provide a means of measuring and ultimately dosing low back NMES intensity in adults with CLBP. Specifically USI during low back NMES allows the examiner to observe when the multifidus muscle first begins to thicken as NMES intensity is increased (ie, initial multifidus thickening) and the point at which a further increase in NMES intensity results in no further increase in multifidus muscle thickening (ie, maximal electrically induced multifidus thickening). As greater multifidus muscle thickening has been associated with greater muscle activation,[14,15] we hypothesized that individuals who had a high tolerance to low back NMES, that is, who were able to tolerate maximal electrically induced multifidus thickening, would have greater multifidus muscle percent thickness change during low back NMES, when compared with individuals who had a low tolerance to low back NMES, that is, who were not able to tolerate maximal electrically induced multifidus thickening. Furthermore, we hypothesized that maximal electrically induced multifidus thickening would result in multifidus muscle percent thickness change exceeding multifidus muscle percent thickness change achieved during baseline lower limb lifting assessments.

Recognizing all clinicians do not have access to USI for low back NMES dosing, secondary objectives included determining the minimum NMES intensity required to induce initial multifidus thickening, as well as the range of NMES intensities resulting in maximal electrically induced multifidus thickening. Furthermore, given historically low back NMES is dosed to "maximal tolerance," we sought to determine what percentage of patients self-selected a stimulation amplitude resulting in at least initial multifidus muscle thickening per USI, that is, an NMES intensity guaranteeing an electrically elicited contraction (thickening) of the multifidus muscle.

Methods

Study overview and participant recruitment

For this cross-sectional study, patient participants were recruited from July 2016 to August 2017 through the Delaware Physical Therapy Clinic. Patients were considered for inclusion if they were ⩾18 years, had low back pain of ⩾3 months, and

were able to lie on their stomach for ⩾15 minutes. Patients who were pregnant, had a pacemaker, had a spinal fracture(s), or who had received prior low back surgery or low back NMES were excluded. The patient's physical therapist provided a form to patients evaluated for chronic LBP with or without radiculopathy during the enrollment period. Patients who expressed written consent to be contacted were telephoned by the study's examiner who provided a detailed study description and screened participants for eligibility. Patients who were eligible and agreed to participate were scheduled for a single, 30-minute session before or after their subsequent physical therapy appointment. The study was approved by the University's Institutional Review Board for Human Subjects Research (project no. 880375), and all participants signed a written consent form prior to the data collection.

Onsite evaluation

Patients provided demographic information and rated their CLBP on a 0- to 10-point scale, where 0 indicated "no pain" and 10 indicated "worst possible pain"; pain at the time of evaluation as well as "best" and "worst" pain in the past 24 hours was recorded. Two self-report measures—the Modified Oswestry Low Back Pain Disability Questionnaire (mOSW) and the Fear-Avoidance Beliefs Questionnaire (FABQ)—were completed as part of the standardized examination. The mOSW quantifies back pain–related disability and has established test-retest reliability in patients with LBP.[27] The FABQ comprised of 2 subscales—physical activity (PA) and work (W), has established test-retest reliability in patients with CLBP, and is recommended for evaluating fear avoidance in patients seeking outpatient services for CLBP.[28] Height and weight were collected and body mass index (BMI) was calculated.

Patients were positioned in prone, over a pillow if needed, to achieve <5° of lumbar extension as assessed with an inclinometer placed at the L4/5 interspinous space. The prone position was maintained for baseline (ie, pre-NMES) testing and during NMES. Right- and left-sided ultrasound images were obtained, with randomization of imaging order, with a MyLab 25 ultrasonography unit (Biosound Esaote Inc., Indianapolis, IN) using brightness mode and a 3.5 to 7.0 MHz curvilinear transducer. Baseline longitudinal images of the L4/5 multifidus bilaterally were obtained at rest and during a contraction facilitated with a contralateral lower limb lift of approximately 5 cm, after 2 practice trials per limb, using the split-screen function, with the transducer oriented longitudinally and angled medially to capture the L4/5 facet and adjacent multifidus; slight counter-pressure of the transducer was applied during contractions (ie, lower limb lifts).[16,29] Measurements of multifidus thickness were taken from the facet joint to the last dark pixel inferior to the fascial line for both resting and contracted images.[16,29] Multifidus muscle percent thickness change was determined for each side (ie, right and left). The side with lesser baseline percent thickness change was imaged during NMES, as previous research of the anterolateral trunk muscles has demonstrated that reduced baseline thickening per USI may allow for greater gains in muscle activity post intervention.[30]

Figure 2. Setup for application of Neuromuscular Electrical Stimulation with ultrasound imaging.

Four, self-adherent, flexible electrodes (2 in × 2 in) were placed over the participant's paraspinal muscles at levels L2 and S1 bilaterally (to allow for ultrasound transducer placement at L4/5 between the electrodes; see Figure 2); 2 splitters were used to attach the single electrical lead to the electrodes. The patient's pelvis was strapped to a plinth table via a mobilization belt crossing the sacrum to limit anterior pelvic tilt during NMES. A portable, clinical electrical stimulator (EMPI 300PV, St. Paul, MN), set to deliver a biphasic pulsatile current, at 50 pulses per second with a symmetrical waveform, and at a pulse duration of 400 μs, was used to deliver paraspinal NMES via a single channel.[19] During initial NMES application, participants were asked to identify when they first felt the electrical stimulation, that is, their sensory threshold, which was recorded in milliampere (mA). The stimulus amplitude was subsequently increased (by holding the intensity button down) to the patient's self-selected "maximal tolerance," hereafter called "self-selected amplitude," which was also recorded in milliampere. Whether USI-visible multifidus thickening was present (ie, observed by the examiner) at the self-selected amplitude was recorded. The examiner, who had 10 years of musculoskeletal USI experience, also simultaneously recorded the intensity in milliampere of initial L4/5 multifidus muscle thickening as visualized with USI and if tolerated by the participant, the intensity at maximal electrically induced multifidus thickening (ie, when a further increase in milliampere did not result in further visible multifidus thickening as observed by the examiner). When participants could not tolerate the NMES intensity resulting in maximal electrically induced multifidus thickening, despite verbal encouragement from the

USI examiner visualizing the multifidus, then the highest intensity tolerated, that is, submaximal electrically induced multifidus thickening, was recorded. Side-by-side, resting and contracted images of L4/5 multifidus (at either maximal electrically induced thickening or submaximal electrically induced thickening) were captured using the split-screen function, and thickness measurements were obtained and percent thickness change was calculated. Pain intensity via verbal report was obtained using a 0- to 10-point scale, where "0" indicated "no pain" and "10" indicated "worst possible pain" for both self-selected and maximum tolerated amplitudes. Participants were subgrouped as high tolerance, that is, tolerated maximal electrically induced multifidus thickening, or low tolerance, that is, tolerated only submaximal electrically induced multifidus thickening.

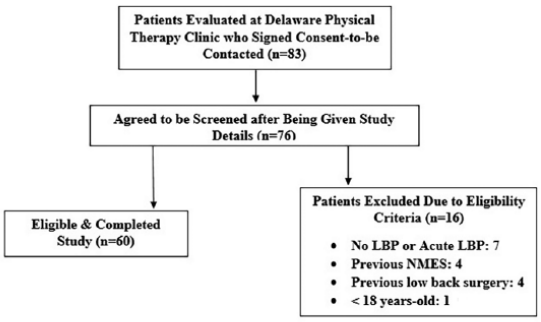
Statistical analysis

All analyses were conducted using IBM SPSS Statistics 24 (Armonk, NY). Participant demographics were calculated for the entire sample and both the NMES high-tolerance and low-tolerance groups. Between-group differences in nominal demographics data were evaluated using the chi-square test of independence, while differences in continuous data were evaluated using *t* tests for parametric data and the Mann-Whitney *U* test for nonparametric data. To test the assumption of normality, the Kolmogorov-Smirnov test was used, while homogeneity of the variances was evaluated with Levene's test ($P \leq .050$). Outliers were removed as necessary to meet parametric testing assumptions. To compare NMES-facilitated multifidus muscle percent thickness change to multifidus percent thickness change obtained at baseline during limb lifting, within-group, paired *t* tests were used. An analysis of covariance (ANCOVA), controlling for age and baseline multifidus percent thickness change (as baseline muscle thickening is known to impact response to interventions),[30] was used to evaluate between-group (high tolerance vs low tolerance) differences in thickening (ie, lesser multifidus muscle percent thickness change at baseline during lower limb lift – lesser multifidus muscle percent thickness change during NMES). Due to the number of comparisons (ie, 15), *P* values of .001 were considered significant to reduce the possibility of a Type I error. Relative differences for sensory threshold, self-selected amplitudes, maximum tolerated amplitudes, and multifidus muscle percent thickness change during NMES were calculated for the low-tolerance group with respect to the high-tolerance group.

Results

Participants

Eighty-three patients with CLBP were contacted, 76 remained interested in participating after being provided study details, and 60 were eligible, enrolled, and completed the study (Figure 3). Descriptive statistics are provided in Table 1. There were no statistically significant between-group differences in demographics



Abbreviations: LBP, Low Back Pain; NMES, Neuromuscular Electrical Stimulation

Figure 3. Participant recruitment.

(all Ps $> .001$), although adults in the low-tolerance group were older ($P = .024$). The sample was predominantly white, had some collegiate education, and had bilateral CLBP symptoms.

Baseline ultrasound measurements

Baseline bilateral multifidi percent thickness changes, including multifidus percent thickness change of the lesser side, is provided in Table 1. Mean baseline L4/5 multifidus percent thickness change was 23.47% (95% confidence interval [CI]: 20.40, 26.54) and 27.45% (95% CI: 23.58, 31.31), for the right and left sides, respectively. The side with less thickening at baseline, that is, the side of interest during subsequent NMES application, had an average percent thickness change of 20.38% (95% CI: 17.77, 22.98). There were no significant between-group differences for any of the pre-NMES USI measures (all Ps $> .025$).

NMES application data

See Table 2 for data obtained during NMES; age is considered as a covariate and adjusted model results are reported. Average sensory threshold was 29% lower in the low-tolerance group as compared with the high-tolerance group and trended toward statistical significance ($P = .004$). Patients in the low-tolerance group had 39% lower self-selected amplitudes than participants in the high-tolerance group, that is, 22 versus 36 mA ($P = .001$); differences in pain at the self-selected amplitude was not significant ($P = .438$). Maximum tolerated amplitudes were 26% lower in the low-tolerance group as compared with the high-tolerance group.

With an average maximal NMES intensity of 62 mA, participants in the high-tolerance group experienced greater multifidus percent thickness change, that is, 30.89%, when compared with participants in the low-tolerance group, who tolerated an average maximum tolerated amplitude of 45 mA resulting in an average multifidus percent thickness change of 20.60%. In relative difference, maximal multifidus percent thickness change was 33% lower in the low-tolerance group when compared with the high-tolerance group.

Table 1. Descriptive statistics.

NOMINAL VARIABLES (N)	TOTAL (N = 60)	HIGH TOLERANCE (N = 39)	LOW TOLERANCE (N = 21)	*P* VALUE
Sex				.174
Female	35	20	15	
Ethnicity				1.000
Non-Hispanic/Latino	56	36	20	
Race				.203
White	49	32	17	
Asian	8	6	2	
Native American/American Indian	1	1	0	
More than 1 race	2	0	2	
Education level				.188
High school graduate/GED	5	1	4	
Some college	16	11	5	
College graduate	18	11	7	
Some postgraduate	6	4	2	
Completed postgraduate	15	12	3	
LBP location				.083
Bilateral	28	16	12	
Central	8	7	1	
Right	10	9	1	
Left	14	7	7	
Most symptomatic side				.190
Right	25	19	6	
Left	20	10	10	
Indeterminate	15	10	5	
CONTINUOUS VARIABLES	**MEAN (95% CI)**			***P* VALUE**
Age, years[a]	31.0 (24.2, 50.0)	29.0 (22.0, 47.0)	44.0 (31.0, 54.5)	.024
BMI, kg/m^2[a]	25.0 (22.6, 28.5)	25.0 (22.3, 28.5)	25.1 (22.7, 28.4)	.957
Average LBP intensity, 0-10	2.9 (2.5, 3.3)	3.0 (2.5, 3.5)	2.8 (2.0, 3.6)	.657
LBP length of symptoms, years[a]	1.5 (0.5, 3.0)	1.0 (0.5, 2.5)	2.0 (1.0, 5.5)	.090
mOSW, %[a]	14.0 (10.0, 26.0)	14.0 (8.0, 26.0)	22.0 (13.0, 32.0)	.029
FABQ-PA, 0-24	13.2 (11.8, 14.6)	13.2 (11.6, 14.8)	13.2 (10.2, 16.2)	.990
FABQ-W, 0-48[a]	8.0 (0, 13.0)	5.0 (0.0, 10.2)	10.0 (2.5, 20.0)	.023
Baseline right multifidus (%), thickness change (%)	23.47 (20.40, 26.54)	24.11 (20.16, 28.07)	22.28 (17.04, 27.51)	.573
Baseline left multifidus (%), thickness change (%)	27.45 (23.58, 31.31)	28.61 (23.53, 33.68)	25.29 (19.07, 31.50)	.393
Baseline lesser multifidus (%), thickness change (%)	20.38 (17.77, 22.98)	20.87 (17.74, 24.00)	19.46 (14.42, 24.50)	.417

Abbreviations: CI, confidence interval; GED, general education development; BMI, body mass index; LBP, low back pain; mOSW, Modified Oswestry Disability Questionnaire; FABQ-PA, Fear-Avoidance Beliefs Questionnaire-Physical Activity subscale; FABQ-W, Fear-Avoidance Beliefs Questionnaire-Work subscale. Statistical significance ($P \leq .001$).
[a]Data are presented as median (25th, 75th percentile) rather than mean (95% confidence interval).

Table 2. Between-group comparison during NMES application.

	HIGH TOLERANCE (N = 39)	LOW TOLERANCE (N = 21)	*P* VALUE	PARTIAL ETA^2
Sensory threshold, mA	7 (6, 8)	5 (4, 6)	.004	.179
Multifidus initial thickening, mA[a]	34 (31, 37)	32 (28, 36)	**.001**	.232
"Maximal tolerance"				
Self-selected amplitude, mA[b]	36 (32, 40)	22 (16, 28)	**.001**	.229
Pain intensity, 0-10	6.0 (5.2, 6.8)	5.2 (4.1, 6.3)	.438	.029
Maximal or submaximal electrically induced multifidus thickening				
Maximum tolerated amplitude, mA	62 (58, 67)	45 (39, 51)	<**.001**	.288
Pain intensity, 0-10	7.7 (6.9, 8.5)	7.2 (6.1, 8.4)	.805	.008
NMES, lesser side multifidus (%), thickness change (%)	30.89 (26.26, 35.52)	20.60 (14.22, 26.98)	<**.001**	.342

Abbreviations: NMES, neuromuscular electrical stimulation.
Age is considered as a covariate and adjusted model results are reported.
Data are reported as mean (95% confidence interval).
Statistical significance ($P \leq .001$).
[a]Three outliers were removed to meet assumptions for parametric testing.
[b]Four outliers were removed to meet assumptions for parametric testing.

Baseline versus NMES conditions

High-tolerance group participants experienced a significant increase in multifidus percent thickness change with NMES, that is, 32.36% (95% CI: 27.05, 37.67) compared to 20.87% (95% CI: 17.74, 24.00) during lower limb lifting at baseline ($P < .001$); low-tolerance group participants had similar multifidus percent thickness change with NMES, that is, 17.88% (95% CI: 10.99, 24.76) compared to 19.46% (95% CI: 14.42, 24.50) with baseline lower limb lifting ($P = .573$). Controlling for *age and baseline multifidus activity*, participants in the high-tolerance group had significantly greater ($P < .001$; partial eta$^2 = .288$) increases in thickening, that is, 10.70% (95% CI: 6.16, 15.23), as compared with participants in the low-tolerance group, that is, –0.11% (95% CI: –6.35, 6.13), when comparing change in multifidus percent thickness change from baseline to during NMES.

Initial and maximal multifidus thickening intensities

Based on 95% CIs, the minimal NMES intensity required to induce initial multifidus thickening as observed with USI was 28 mA (Table 2). In some participants, however, initial multifidus thickening did not occur until 37 mA. Amplitudes of 58 to 67 mA using the selected electrode configuration, stimulator, and parameters were sufficient to induce maximal thickening as observed with USI in all who could tolerate such intensities. Only 48% (n = 29) of patients had a self-selected amplitude resulting in at least initial multifidus thickening, that is, electrically activated multifidus muscle thickening.

Discussion

Our study is among the first to evaluate low back NMES tolerance in a group of patients with CLBP who were novices to NMES treatment. Low back NMES applied to L2 through S1, delivered with an EMPI 300PV clinical electrical stimulator, set to deliver a biphasic pulsatile current at 50 pulses per second with a symmetrical waveform and a pulse duration of 400 μs facilitated multifidus muscle activity in an outpatient physical therapy patient sample with CLBP. This electrical stimulator has been previously used in clinical research.[19,24] Sixty-five percent of patients had high tolerance to low back NMES, ultimately tolerating an intensity resulting in maximal electrically induced multifidus muscle thickening. Individuals with low tolerance to low back NMES experienced 33% less multifidus muscle thickening during electrical stimulation than participants with high tolerance to NMES. For participants able to tolerate high NMES intensities, NMES-elicited multifidus muscle percent thickness change was significantly greater than percent thickness change obtained with lower limb lifting. Thus, NMES, for those who can tolerate high intensities, may provide a means of eliciting multifidus muscle percent thickness change exceeding percent thickness change achieved with exercises utilizing unloaded lower limb lifts. For participants with low tolerance to NMES, using the selected electrode configuration, stimulator, and parameters, intensities that were 26% less than the high tolerance group resulted in submaximal electrically induced multifidus muscle percent thickness change per USI, but resulted in overall multifidus percent thickness change similar to that obtained during an unloaded lower limb lift. Thus, data suggest that even at lower intensities, low back NMES may be beneficial for facilitating multifidus muscle percent thickness change.

When USI is unavailable for direct multifidus muscle visualization enabling therapist and patient feedback, to ensure multifidus muscle thickening, intensities of ⩾37 mA are recommended at the above-mentioned NMES parameters with the trialed (or similarly capable) device; if the goal is to ensure maximal electrically induced multifidus thickening, then intensities of 58 to 67 mA may be necessary. Less than 50% of participants self-selected amplitudes resulting in visible multifidus thickening per USI; therefore, dosing guided only by requesting the patient to identify their "maximal tolerance" may result in subtherapeutic levels of low back NMES when the goal is to facilitate electrically induced multifidus muscle thickening.

The intensity of NMES may be a critical parameter to consider when the therapeutic goal is to elicit and improve multifidus muscle activity in adults with CLBP. Using USI, we found that high-intensity low back NMES was able to elicit multifidus muscle percent thickness change (a proxy for muscle activity),[14,15] exceeding percent thickness change achieved with an unloaded lower limb lift. While there has been little research on low back NMES, high-intensity NMES as an adjunct treatment to address quadriceps muscle activation and strength impairments has been previously studied. For example, Stevens-Lapsley et al[24] administered quadriceps NMES for 15 contractions (2 sessions per day, 6-7 days/week) at each patient's self-selected amplitude using the EMPI 300PV clinical stimulator and the following NMES parameters: symmetrical waveform at 50 pulses per second, 250 μs pulse duration, on-time of 15 seconds (including 3 second ramp), and off-time of 45 seconds. They found that higher NMES intensities were associated with greater improvements in quadriceps muscle activation and strength 3.5 weeks post total knee arthroplasty.[24] Future research may evaluate whether repetitive high-intensity low back NMES results in greater USI-evaluated multifidus muscle percent thickness change, EMG-evaluated multifidus muscle activation, and/or paraspinal muscle strength gains, when compared with low-intensity NMES. This preliminary study supports further longitudinal evaluation of the impact of low back NMES intensity on impairment-based outcomes.

Importantly, we have established that high-intensity low back NMES, while pain-provoking, can be tolerated by most of the patients when verbal encouragement informed by USI-visualized multifidus thickening is given. The high intensities among adults with CLBP who tolerated maximal electrically induced multifidus thickening in our study, that is, 58 to 67 mA, were similar to low back NMES intensities, that is, 58.34 ± 12.97 mA, tolerated by patients with lumbar degenerative kyphosis in a study by Kim et al.[18] Kim et al[18] used a similar 4-electrode configuration for low back NMES, but a different portable stimulator (CMMX-001A; Cybermedic Corp., Republic of Korea) that delivered a constant current and symmetrical biphasic waveform (biphasic symmetrical pulses of 200 μs [ie, 400 μs]; interpulse delay of 100 μs) with a frequency of 50 Hz.

Nevertheless, even with verbal encouragement informed by USI feedback, we report that there is a subset of adults with CLBP (eg, the low-tolerance group) who cannot tolerate higher NMES intensities. Maximal tolerable amplitudes in the low-tolerance group were, on average, 26% less than in the high-tolerance group. Given BMI was not significantly different between groups, decreased tolerance to NMES in the low-tolerance group was likely not related to the amount of subcutaneous fat in the paraspinal region (ie, distance between electrodes and multifidi muscle). Low NMES tolerance, however, may be secondary to heightened pain sensitivity as exemplified by "maximal tolerance" data. For example, pain ratings, that is, 4.1-6.3 out of 10, in the low-tolerance group at significantly lower self-selected NMES intensities were similar to pain ratings, that is, 5.2-6.8 out of 10, reported at higher self-selected NMES intensities in the high-tolerance group ($P = .438$).

Clinicians may be able to improve stimulation tolerance for patients with low tolerance by modifying parameters. For example, if the individual feels the onset of the peak current is too quick, increasing the ramp time may allow the individual to prepare for the stimulation. Conversely, for those who dread the rise to the peak amplitude, reducing the ramp up time may decrease their perceived discomfort. Some patients may benefit from distraction such as relaxation techniques, while others may prefer knowing exactly when to expect the contraction, which may be achieved with the use of a timer. Clinically, adjustments addressing perceived threat may reduce patient complaints; however, the impact on associated tolerance levels must be investigated.

Another potential explanation for lower tolerance to NMES application may be reduced by sensory thresholds in the paraspinal region. Independent of age,[31] individuals classified into the low-tolerance group perceived NMES at 29% lower amplitudes than those in the high-tolerance group, although this was not statistically significant ($P = .004$). This may suggest heightened sensitivity of the low back region in participants with low tolerance to high-intensity NMES. Reduced sensory thresholds may also help to explain why participants with low tolerance to NMES self-selected maximal tolerated amplitudes that were significantly lower than their peers with high tolerance to NMES. Further exploration of sensory thresholds in adults with CLBP may be informative.

There have been several studies evaluating percent thickness change from resting to a contracted state using USI.[16,18,29] Prior USI studies have reported L4/5 multifidus percent thickness changes of 20.3% ± 6.0% in younger adults and 21.4% ± 9.0% in older adults without CLBP,[16] using similar methodology; results are comparable to our adults with CLBP, who had baseline multifidus percent thickness changes of 17% to 23%. Participants in our study were receiving physical therapy at the time of data collections, so treatments administered prior to the data collection might have restored any multifidus thickening deficits present at the initiation of

physical therapy. Nevertheless, for the high-tolerance NMES group, there was significantly greater multifidus muscle percent thickness change obtained during NMES than during the lower limb lifting task administered at baseline, suggesting high-intensity NMES may have the potential to elicit multifidus percent thickness changes exceeding those achieved with volitional exercises alone.

In patients with LBP, exercises targeting the lumbar multifidi muscles (eg, prone contralateral lower limb lifts) in isolation have not been shown to improve multifidi muscle percent thickness changes, as assessed with USI.[12] Similarly, Arokoski et al[32] reported multifidus activation, as evaluated with EMG, did not significantly change after generic trunk exercise. Arokoski et al[32] suggested that lumbar multifidus muscles should be specifically targeted to improve muscle function. Baek et al[33] reported that specific deep lumbar stabilizing exercises are labor and time intensive, requiring extensive therapist instruction and motivated patients. Furthermore, Bilgin et al[34] showed that unloaded, specific stabilizing exercises alone did not enhance multifidus activation over a 6-week period. We have demonstrated that NMES application can be used to enhance immediate lumbar multifidus muscle percent thickness change (a proxy for muscle activation)[14,15] and that high-intensity NMES can facilitate multifidus muscle percent thickness changes exceeding those evoked with unloaded lower limb exercises. Future work may elucidate whether high-intensity NMES, as an adjunct to trunk muscle exercises, enhances multifidus muscle activity over time, as exercise interventions alone have failed to alter multifidus muscle function.

Our results suggest that low back NMES application, even with lower intensities, is sufficient to elicit multifidus muscle percent thickness changes approximating percent thickness changes during prone lower limb lifting exercises. Consequently, for patients unable to perform limb lifts to facilitate multifidus thickening (due to deconditioning, pain, etc), low back NMES application may be at a minimum a surrogate for active exercises and at best outperform them. This suggests that there is the potential for low back NMES to be used to preserve and/or restore multifidus muscle function in patient populations where active exercise is not possible.

Study Limitations

The generalizability of the results may be limited to adults with CLBP who have similar clinical presentations. Intensity findings, in milliampere, are contingent on the selected stimulation device, parameters, and electrode configuration (including the use of splitters), while relative differences may be used when comparing these results to findings of future studies using varying methodology. As USI is operator dependent, the use of an experienced USI examiner may have enhanced measurement precision, although this was not formally evaluated. To minimize participant burden and given that only a single image could be taken during NMES application, a single set of baseline images, that is, rest and contracted, of L4/5 was obtained; prior studies have taken up to 3 sets of images for assessment of multifidus muscle thickening.[16,29] While application of the NMES from initial thickening to acquisition of the image was <20 seconds, it is possible that muscle fatigue could have occurred, negatively impacting contracted thicknesses. Furthermore, given the cross-sectional design of this study, we are unable to determine the long-term benefits of low back NMES on multifidus muscle percent thickness change.

In summary, during low back NMES, when intensity is increased to the patient's self-selected amplitude, most of the patients may not select an intensity sufficient to create USI-visible multifidus muscle thickening. The USI can be used as a form of feedback to educate patients regarding multifidus muscle thickening. Specifically, the patient can be informed that although it may feel like an NMES intensity that would elicit multifidus muscle thickening, multifidus muscle thickening is not yet occurring. Tolerance of higher NMES intensities may elicit multifidus muscle percent thickness change exceeding percent thickness change obtained with prone, unloaded lower limb lifting. With low tolerance to NMES, multifidus muscle percent thickness changes are significantly lower and similar to those obtained with unloaded lower limb lifting. For clinicians without USI who have access to an EMPI 300PV clinical stimulator (or stimulator with similar parameter capabilities), study amplitude data may assist with dosing NMES intensity by providing target minimums for patients with CLBP when the goal is to facilitate multifidus muscle thickening. Future work may evaluate the benefit of low back NMES dosed at high versus low intensities as an intervention for CLBP; of particular interest may be evaluating changes in multifidus muscle percent thickness change pre NMES and post NMES and the relationships between multifidus muscle changes and improvements in clinical impairments, such as activation of the multifidus muscle, strength of the paraspinal muscles, and low back pain.

Clinical Messages

- Dosing low back neuromuscular electrical stimulation intensity to the patient's self-selected amplitude may not result in multifidus thickening.
- Per ultrasound imaging, lower stimulation intensities may elicit multifidus muscle thickening changes equivalent to changes found with lower limb lifting exercises, while higher intensities may induce changes exceeding those obtained with limb lifting.

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Author Contributions

Conceived and designed the experiments: JMS, GEH. Analyzed the data: JMS, RTP, AMA. Wrote the first draft of the manuscript: DCC, AMA. Contributed to the writing of the manuscript, developing structure and arguments for paper: JMS, RTP, TJM, GEH. Made critical revisions: JMS, RTP, TJM. All authors reviewed and approved the final submitted manuscript. Approved final proof: JMS.

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