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Neuromuscular Electrical Stimulation Training Results in Enhanced Activation of Spinal Stabilizing Muscles During Spinal Loading and Improvements in Pain Ratings

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***Abstract*—Low back pain is associated with dysfunction in recruitment of muscles in the lumbopelvic region. Effective rehabilitation requires preferential activation of deep stabilizing muscle groups yet training these muscles poses challenges in a clinical setting. This study was carried out in order to quantify the response of deep stabilizing muscles (transverses abdominis and deep fibres of multifidus) to a period of training using a novel neuromuscular electrical stimulation (NMES) application in a group of patients with chronic low back pain. Analysis of results revealed clinically and statistically significant improvements in indicators of both muscle groups' performance, as evidenced by ultrasound evaluation of activation during voluntary activity. These improvements were associated with significant improvements in self reported pain levels, suggesting that NMES has an important role to play in CLBP rehabilitation.**

I. INTRODUCTION

Low back pain (LBP) is a very common and disabling condition with significant financial and social costs [1], [2]. Lifetime prevalence is extremely high, with 60-80% of people experiencing LBP and related conditions at least some time in their lives [3]. It all too frequently persists to cause chronic problems for sufferers [4].

The Panjabi spinal stability model proposes that the articular, muscular, and neural systems work together to provide spinal stability by controlling intervertebral movement [5]. Deficiency in any one of these systems could theoretically result in spinal instability. The deep local muscles of the lumbopelvic region which contribute to the stability of the spinal column are implicated in the development of LBP [6]. It has been proposed that atrophy changes affecting the lumbar multifidus (LM) [7] and motor control disturbances affecting the internal oblique (IO) and transversus abdominis (TA) [8, 9, 10] result in segmental instability of the lumbar spine. This in turn may cause or perpetuate CLBP. Corrective exercise programmes addressing atrophy changes in the LM and abdominal muscle motor control disturbances have therefore been proposed as an important component in the management of chronic LBP [11]. Previous research has demonstrated that specific stabilisation exercises (SSE) targeting the local muscles result in improvements in pain and disability, as well as a reduced incidence of recurrence in those with acute and chronic LBP [12, 13]. However, this type of rehabilitation is very labour intensive, requiring extensive instruction and input from the therapist. Furthermore anecdotal evidence suggests that patients frequently have difficulty initiating contractions of the local muscles. As a result effective rehabilitation can be a challenge.

Up to now, Transcutaneous Electrical Nerve Stimulation (TENS) has been the most commonly employed electrical modality in the treatment of CLBP. Though it has been shown to be effective in facilitating short term improvements in pain related disability [14] it is largely a passive intervention and does not target the underlying muscle dysfunction. Neuromuscular Electrical Stimulation (NMES) has been used for many years for strengthening of the superficial abdominal muscle groups [15, 16, 17], primarily with a view to improving physical appearance in a healthy population. To date it has not been widely used to promote active rehabilitation of deep spinal stabilizing muscles such as TA, IO and LM. However, we have recently demonstrated that currently available abdominal muscle stimulation devices can produce an effective contraction of the TA and IO muscles [18]. Therefore, it is possible that NMES could be developed to the extent that it could target TA and LM and be used to overcome the difficulties associated with voluntary activation of these deep spinal stabilizing muscle groups and to facilitate effective rehabilitation of CLBP.

In this paper we will describe a prospective pilot study carried out to investigate the effects of a programme of NMES targeting the local spinal muscles (TA, IO and LM) on measures of local muscle recruitment and pain in a group of subjects with CLBP.

II. METHODS

Participants.

The study population *(n=13; m=7, f=6)* was chosen from volunteer respondents to an advertisement placed in a local newspaper. Inclusion in the study required that participants were aged 20-60 years, complaining of mechanical somatic low back pain (i.e. non inflammatory/ pathological). It was required that current pain be located in the lower lumbar

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region between the L3 level and the gluteal fold, with no pain radiation into the lower limbs. All participants reported chronic pain with a duration of symptoms longer than 6 months and were 'stable' in terms of disability and pain. Written informed consent was obtained from all participants and the study was approved by the local ethics committee.

Table 1. Physical characteristics of study participants.

	Mean (SD)
Age (years)	38.9 (9.2)
Height (metres)	1.7 (10.3)
Weight (kg)	75.3 (10.2)
BMI (kg/m^2)	27.0 (2.8)

NMES Intervention.

The electrical stimulation was delivered through a set of 4 hydrogel electrodes located over the lumbar paraspinal regions and the anterolateral abdominal wall. Electrodes were positioned and held in place using a neoprene band that was secured anteriorly using Velcro tabs. The stimulation pulses were generated by a NeuroTech 2010 (a portable research-stimulator; Bio-Medical Research Ltd, Galway, Ireland). The maximum power output was limited to 150mA. It delivered a constant current, symmetrical biphasic waveform. Bi-phasic symmetrical pulses of 480microseconds with an interphase delay of 100 microseconds were employed. These pulses were delivered via two subsets of the electrodes – the abdominal subset and the paraspinal subset at frequencies designed to produce tetanic isometric contractions in the target muscles (20-30Hz). The overall contraction-relaxation cycle was: ramp up 0.5 seconds, contraction 4 seconds, ramp down 0.5 seconds, relaxation 3seconds. Current intensities were individually controllable by the participants. Participants were instructed to use the unit at intensity strong enough to elicit muscle contraction but without any aversive discomfort for between 15 and 30 minutes one to two times a day for 6 weeks. The duration, frequency and intensity of treatment during the intervention period are described in Table 2. Training sessions were initially carried out in the University under the supervision of a Physiotherapist. Following the first 3-5 sessions all subsequent training was carried out in the participants' homes with periodic telephone follow-up to ensure that training was progressing without adverse events.

Table 2. Schedule of NMES training

<table>
<tr><th>Week No.</th><th>Duration</th><th>Frequency</th><th>Intensity</th></tr>
<tr><td>1.</td><td rowspan="4">15 minutes</td><td rowspan="2">Once daily</td><td rowspan="6">Elicits strong muscle contraction without discomfort</td></tr>
<tr><td>2.</td></tr>
<tr><td>3.</td><td rowspan="3">Twice daily</td></tr>
<tr><td>4.</td></tr>
<tr><td>5.</td><td rowspan="2">30 minutes</td></tr>
<tr><td>6.</td></tr>
</table>

Test Procedures.

All participants underwent real time ultrasound imaging (RUSI) to quantify TA and LM activation during functional loading tasks and LM thickness at rest prior to and following the 6-week intervention period. Subjective pain ratings were also recorded at baseline and follow-up using a Visual Analogue Scale (VAS).

Pain Assessment: Participants made a mark on a line corresponding to their level of pain, with the ends of the line being defined as the limits of pain experience (ranging from 'no pain at all' to 'pain as bad as it could be'). The line was measured using a ruler to give a score out of 10. A new, blank score sheet was used each time. The type of VAS used in this study was comparative which gave a measure of pain relief over a 2 week period.

TA and IO activation during loading tasks: The response of the TA and IO to the Anterior Straight Leg Raise (ASLR) loading test was used to assess the automatic recruitment of the deep local lateral abdominal muscles, in a manner which is independent of skill or motivation on the part of the subject [9], during a spinal loading task.

The participant was positioned in supine with the left leg flexed and the right extended, arms resting at the side. A 7Mhz linear ultrasound transducer was placed transversely on the abdomen at the midpoint between the twelfth rib and the iliac crest on the anterior axillary line, with the medial edge approximately 10cm from the midline (Ferreira et al, 2004, Hodges et al, 2003a). The participant was instructed to breathe normally and evenly, with a resting image captured at the end of exhalation [19] using an ultrasound scanner (Logiq 5 Expert, GE Healthcare, UK). They were then instructed to hold the breath at the end of exhalation and raise the right leg to the height of approximately 5 centimetres. Another image was captured at the height of the contraction of the lateral abdominal muscles and stored for offline analysis. This procedure was then repeated on the left side. The stored images were measured using ultrasound image measurement software [20]. The degree of tonic loading in each muscle was evaluated using a standard protocol based on calculation of percentage thickness change in the relevant muscle at the height of the ASLR compared to the resting thickness [9].

LM resting thickness and activation during loading tasks: The participant was positioned in prone with both arms resting above the head. A pillow was placed under the lower abdomen to minimise the lumbar lordosis, as well as to standardise joint position for test-retest purposes [21]. The mid point of the L5 spinous process was marked on the skin. This mark provided a visual reference while a 5Mhz curvilinear ultrasound transducer was used to generate a para-saggital view of the LM at the L5 segmental level. The participant was instructed to breathe normally and evenly, with a resting image captured at the end of exhalation [19] on both left and right sides and stored for offline analysis. They were then instructed to hold the breath at the end of exhalation, and with the transducer positioned on the right

side at the L5 segmental level, to raise the contralateral arm to a height of approximately 5 centimetres [22]. An image was captured at the height of the contraction of the LM muscle and stored for offline analysis. This was repeated on the left side. The greatest perpendicular depth from the border of the lumbar fascia with the subcutaneous tissue to the mid point of the articular process was measured on all stored images using ultrasound imaging software. Tonic activation was calculated for each side in a similar manner to that described for the TA and IO muscle groups above.

Data Analysis.

Baseline and follow up values for each of the variables identified in table 3 were identified for each subject. Subsequent to this, treatment and control group mean scores at baseline and follow up were also calculated. Group mean scores prior to the intervention were compared to the equivalent scores at follow-up using dependent 2-sided t-tests with a significance level set at $P<0.05$.

Table 3. Outcome variables used in data analysis

1. VAS Pain Rating
2. Right TA % thickness change on ASLR
3. Left TA % thickness change on ASLR
4. Right IO % thickness change on ASLR
5. Left IO % thickness change on ASLR
6. Right LM resting depth
7. Left LM resting depth
8. Right LM % thickness change on PAR
9. Left LM % thickness change on PAR

Note. ASLR = active straight leg raise; PAR = prone arm raise

III. RESULTS.

All participants completed the test procedures and training sessions without any difficulty or reported adverse events. We observed significant increases in percentage thickness change in left and right TA and IO during the ASLR test at follow-up compared to baseline ($P<0.05$) indicating a positive response to tonic loading following the NMES intervention. There were no significant changes in percentage change in either left or right LM thickness during the PAR test following the intervention period ($P>0.05$), suggesting a neutral response to tonic loading following NMES training. However, we did observe small yet highly significant increases in the resting thickness of both left and right LM following the training period ($P<0.001$). Finally, the observed changes in muscle activation were associated with a highly statistical and clinically significant reduction in self ratings of pain using the 2-week VAS pain rating scale ($P<0.0001$) (Figure 1).

IV. DISCUSSION.

The main finding of this investigation was that repeated stimulation of the abdominal wall can result in improvements in deep stabilizing muscle activation in response to tonic loading. This is associated with significant improvements in pain ratings and suggests that NMES can

Table 4. Baseline and Follow-up Scores

	Baseline	Follow up	Level of significance
Right TA % thickness change on ASLR	24.0(21.45)	34.4(22.3	0.03
Left TA % thickness change on ASLR	17.2(15.7)	26.5(13.3)	0.007
Right IO% thickness change on ASLR	12.8(9.0)	20.0(10.8)	0.001
Left IO % thickness change on ASLR	12.8 (9.0)	20.6(10.4)	0.009
Right LM resting thickness	2.4(0.4)	2.6(0.5)	0.0001
Left LM resting thickness	2.4(0.4)	2.8(0.5)	0.001
Right LM % thickness change on PAR	20.0(13.8)	17.6(10.3)	0.1
Left LM % thickness change on PAR	22.1(7.8)	19.7(9.8)	0.1
VAS Pain Rating	4.6(1.0)	1.9(1.3)	0.0001

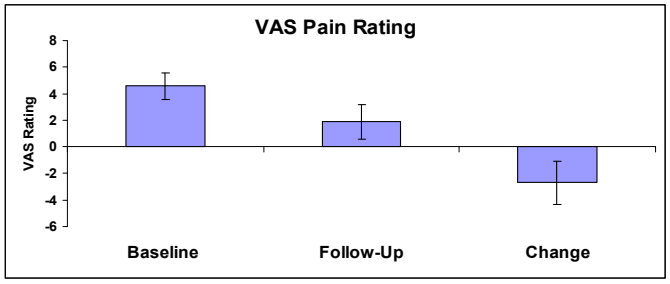

Figure 1. Group mean baseline and follow-up VAS ratings as well as group mean change in VAS rating.

be very effective in CLBP management. We observed an average reduction of 2.7±1.6 in 2-week VAS ratings following NMES training. This represents a reduction of approximately 50% and is equivalent to results observed in outpatient based programmes for CLBP patients that involve behavioural and exercise components [23, 24]. As the intervention in this study was based on self directed home treatment, it is a favorable comparison. Analysis of individual VAS ratings at baseline and follow-up demonstrated that all but one study participant reported a reduction in 2-week pain rating following training. This participant reported no change in pain rating yet subjectively reported being able to perform more activities of daily living at follow-up. This almost global response suggests the presence of a clinically significant treatment effect due to NMES training.

The deep abdominal stabilizer, TA exhibited significant improvements in the thickness change in response to ASLR after NMES training on both sides. This suggests that TA is able to provide a greater contribution to spinal stability following NMES training. This improvement in tonic activation of TA following training was associated with a concurrent improvement in percentage thickness change in IO in response to ASLR. This suggests that a co-contraction between the TA and IO is more likely following training. Whittaker [19] has reported that such a co-activation is an

optimum recruitment pattern of the deep local abdominal muscles during spinal loading tasks.

We also observed a significant increase in the group mean resting depth of LM (at the L5 level) at follow up on both right and left sides. This suggests an increase in muscle bulk or hypertrophy effect due to training. This is clinically significant when considering that significant atrophy has been identified at the lowest two lumbar levels in subjects with CLBP with the greatest asymmetry seen at L5 in those with unilateral pain [25]. Reversal of this atrophy is associated with reduced recurrence of LBP at long term follow up [26]. Therefore, it is reasonable to relate the observed increases in LM depth in this study to the concurrent decrease in pain complaints. Further, one could postulate that the observed LM hypertrophy will serve to protect subjects from recurrence of their symptoms.

We observed moderate, yet non-significant, decreases in the extent to which LM thickened during PAR on both sides. This is an interesting finding and would appear to be contrary to the observed increases in LM resting depth at first glance. A possible explanation may be the anatomical constraints being placed on the muscle. The LM is bordered medially by the spinous process, inferiorly by the lamina and laterally by fascia and the longissimus pars lumborum muscle. As such the only direction for muscle expansion is in a lateral direction. With a significant increase in resting depth having been observed, it is possible that these anatomical constraints may place some directional limitations on expansion of the muscle during active contraction thereby limiting the extent of thickness change observed. In a validation study using comparative EMG analysis, Kiesel [22] observed a linear relationship between increases in muscle activity and muscle thickness at low levels of EMG activity (approximately 20% of maximum voluntary contraction). Thereafter the relationship becomes curvilinear. One of the reasons for these findings could be the aforementioned anatomical constraints placed on the muscle. The consequence is that further increases in muscle activity may not be reflected by further increases in muscle thickness, and may even decrease in some instances where a significant hypertrophy effect has taken place. This finding warrants further attention in future studies.

There are limitations in the present research that must be taken into account when interpreting the clinical significance of our findings. We have not included a control group in this investigation. We did obtain data from a small number of subjects who were subjected to passive TENS therapy over the same period of time and observed a definite trend towards improved findings in our subjects who underwent active NMES training. However, there were not enough subjects in the TENS group in order to perform a valid comparison. We did not standardize the current intensity across all study participants, nor did we standardize the strength of contraction beyond asking each participant to reach a level where a strong perceptible contraction was observed without discomfort. We did this in an effort to replicate the relatively uncontrolled conditions under which this protocol is likely to be used in clinical practice. In addition, we are only reporting findings from the beginning and end of a training programme – a real analysis of the value of NMES training for spinal stability will have to wait until we have carried out a long term follow up at 3, 6 and 12 months. We would contend that the gains observed in this investigation might provide patients with an opportunity to engage in more active rehabilitation and restore normal motor programming to prevent recurrence. However, this hypothesis has yet to be tested.

Nonetheless, the results in this investigation, though preliminary, are very encouraging. We have observed a consistent pattern of improvements in measures of TA, IO and LM in a small group of patients with CLBP who were subjected to a programme of NMES training. These improvements in size and activation of the local spinal stabilizers were associated with concurrent and consistent decreases in pain ratings. We now need to perform larger controlled trials with long term follow-up of study subjects in order to confirm these promising initial findings.

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