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Original Articles

# Immediate effects of myofascial release on neuromechanical characteristics in female and male patients with low back pain and healthy controls as assessed by tensiomyography. A controlled matched-pair study

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ABSTRACT

*Background:* Low back pain (LBP) is a major health issue in most industrialised countries. Lumbodorsal fascia has been advocated as a potential source of pain in the lumbopelvic region. Myofascial release constitutes a manual therapeutic approach focussing on the restoration of altered soft tissue function. No previous study has focused on quantifying neuromechanical effects of myofascial release on LBP patients through tensiomyography. The purpose of this study was to quantify immediate neuromechanical alterations of myofascial release on patients with LBP and healthy controls through tensiomyography parameters.
*Methods:* The participants' ($n = 30$) bilateral lumbar erector spinae muscles were assessed via tensiomyography before and after a 6-min myofascial release treatment of the lumbodorsal fascia to evaluate the muscles' mechanical characteristics. Subjects with LBP ($n = 15$) were eligible to partake if they reported having had LBP for most days in the past 12 weeks. Muscle displacement (Dm [mm]), velocity of contraction (Vc [mm/s]), and lateral symmetry (Ls [%]) were assessed through tensiomyography testing.
*Findings:* Statistical analyses revealed a significant increase for velocity of contraction in the right ($p = .021$) and left ($p = .041$) lumbar erector spinae for the subjects with LBP but not for the healthy controls (both $p > .14$).
*Interpretation:* We suggested that myofascial release alters neuromechanical characteristics in subjects with LBP. Tensiomyography may be implemented in clinical settings to monitor intervention effects of the myofascial system, especially the tensiomyography parameter velocity of contraction.

## 1. Introduction

Low back pain (LBP) is a major health issue for both women and men. The lifetime prevalence for the general population in most industrialised countries ranges from 60% to 85% (WHO, 2003), and approximately 10–15% of patients with acute LBP experience a chronic course (Balangué et al., 2012). By definition non-specific or idiopathic LBP is characterised by the absence of a specific spinal pathology and is considered the commonest form of LBP (Airaksinen et al., 2006). Despite considerable research endeavours, the exact causative factors of LBP are not yet understood in detail (Balangué et al., 2012). However, there are indications that the lumbodorsal fascia (LDF) as well as paraspinal muscles embedded in this fascia (e.g. lumbar erector spinae muscles [LES]) are a contributing factor in the pathogenesis and progression of LBP (Goubert et al., 2017; Langevin and Sherman, 2007; Schilder et al., 2014). Panjabi (2006) first proposed microinjuries in lumbar connective tissues may alter the function of embedded mechanoreceptors, and consequently lead to muscle control dysfunction and further biomechanical impairments. Since then, distinct research has approached and developed this hypothesis. Studies suggest that changes in morphological characteristics (Goubert et al., 2017; Langevin et al., 2011) and mechanical behaviour (Langevin et al., 2011; Lo et al., 2019), such as a reduction in shear-strain in subjects with LBP compared with healthy controls (Langevin et al., 2011), may hypothetically be caused by tissue adhesions resulted from previous injury or inflammation (Wilke et al., 2017). Moreover, altered neuromuscular activity and augmented muscle

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recruitment patterns (Hodges and Danneels, 2019; Jubany et al., 2017; Lisiński, 2000) of this multi-layered myofascial junction are associated with LBP.

From the vantage point of the present, it is commonly assumed that fascia is not only essential for balancing and transferring forces among muscles (Schuenke et al., 2012) but functions as a body-wide mechanosensitive signalling network (Langevin, 2006). This in turn makes it a key player in mechanotransduction (Humphrey et al., 2014), allowing cells such as fibroblasts to perceive and react to mechanical stimuli (Cao et al., 2015). Further, the contractility of myofibroblasts might potentially be sufficient to affect musculoskeletal dynamics (Schleip et al., 2019). Moreover, fascia is strongly interlinked with the nervous system through a variety of free nerve endings and mechanoreceptors, making them a strong contributor to proprioception and nociception (Stecco et al., 2007; Tesarz et al., 2011; Yahia et al., 1992). In the light of these aspects – also referred to as fascial neuroplasticity (Schleip, 2003) – the interplay between fascia, skeletal muscle, and the nervous system is increasingly being recognised in scientific exploration with regard to musculoskeletal dysfunction such as LBP syndromes (Langevin and Sherman, 2007; Zullo et al., 2017).

Myofascial release (MFR) is a respected intervention type in manual medicine which was first described in the field of osteopathy (Ajimsha and Shenoy, 2019). This method constitutes a possible therapeutic approach focusing on the restoration of altered soft tissue function and on attaining optimal muscle length by means of elongating or compressing the specific region (Ajimsha et al., 2015). However, despite the widespread use of techniques such as MFR in day-to-day treatment, scientific evidence as well as the mode of action is as yet limited (Ajimsha et al., 2015; Ercole et al., 2010), particularly in terms of objective measurements of potential effects on mechanical characteristics of lumbar myofascial tissues.

Tensiomyography (TMG) represents a special variant of mechanomyography (Macgregor et al., 2018a; Piqueras-Sanchiz et al., 2020) that constitutes an easy-to-handle and non-invasive method to quantify objectively alterations in mechanical features of isolated muscle bellies following MFR therapy. TMG records radial muscle displacement in response to electrical stimuli under static and relaxed conditions (Martín-Rodríguez et al., 2017). This diagnostic procedure has been employed to assess muscle stiffness-orientated characteristics (Martín-San Agustín et al., 2018) as well as contractile capacities of skeletal muscles (Martín-San Agustín et al., 2019). To date, most research on TMG is within the field of sports medicine focusing on limb muscles (Lohr et al., 2019); consequently, little is known about the applicability of this method in clinical populations (Macgregor et al., 2018a) such as patients with LBP.

Therefore, the purpose of the present study was to examine immediate effects of a single MFR treatment on subjects with LBP and healthy controls utilising TMG. A favourable outcome would open up the possibility for implementing the device as an objective and effective monitoring tool to enhance ideal and individualised therapeutic treatments of the myofascial system. We hypothesised that TMG detects changes in muscle-stiffness-associated and contractile characteristics following an MFR intervention in patients with low back pain.

## 2. Methods

### 2.1. Design

This laboratory-controlled, matched-pairs, repeated-measures design study was conducted from November to December 2016. The implementation was based on recommendations of the *Transparent Reporting of Evaluations with Non-randomised Designs* (TREND) statement (Des Jarlais et al., 2004) and the *Sex and Gender Equity in Research* (SAGER) guidelines (Heidari et al., 2016). The investigation was conducted in accordance with the ethical requirements as laid down in the declaration of Helsinki (as amended in 2008) (Williams, 2008). Beforehand, the study protocol was approved by the university's local ethics committee and was prospectively registered with the DRKS (n. DRKS00011178), the German Clinical Trials Register.

The participants' bilateral LES muscles were assessed via TMG before and after a standardised 6-min MFR treatment of the LDF to evaluate the muscles' mechanical characteristics. The sequence in which the measurements and the intervention were performed (right side first, left side first) was randomised by drawing lots. The room temperature was maintained constant at 23 °C (±1 °C). All subjects were asked to abstain from caffeine intake in the preceding 2 h of the investigation (Pethick et al., 2018), and to avoid fatiguing exercise and/or any additional, specific fascial therapy in the previous 48 h in order to prevent possible confounding. The TMG measurements as well as the MFR interventions were conducted by one qualified osteopath with more than four years of experience with TMG assessments. Additionally, the participants' habitual physical activity (PA) level was recorded and grouped into three categories: sedentary (PA < 1 h per week) – Level 1; moderate (PA 1.5-3 h per week) – Level 2; and high (PA > 3 h per week) – Level 3.

### 2.2. Subjects

Participants aged between 18 and 60 years were recruited as a convenience sample from a local Osteopathic Practice and from a public university. All volunteers were informed about the experimental setup of the study and any potential unpleasantness that might occur during the measurement procedure. All attendees signed an informed consent statement. Subjects with LBP were eligible to partake if they reported having had LBP – between the costal margin and the gluteal fold – for most days in the past 12 weeks (Airaksinen et al., 2006). For both subjects with LBP and healthy controls, exclusion criteria were specific spinal pathologies, nerve root pain, systemic diseases, previous spine surgery, history of malignancy, heart conditions, implanted biomedical device (cardiac pace maker), use of corticosteroids during the past three months, skin alignments, pregnancy, a body mass index (BMI) above 30 $kg/m^2$, and mental disorders (Airaksinen et al., 2006). Further exclusion criteria were an average pain score over the past week of either 0 ("no pain") or above 7 ("severe pain") on a numerical pain rating scale (NPRS; ranging from 0 to 10) for subjects with LBP, and a score above "0" for healthy controls (Airaksinen et al., 2006; Boonstra et al., 2016) (Fig. 1). Eligible participants with LBP were compared with healthy controls and individually matched for age, weight, and sex.

### 2.3. Testing procedure

#### 2.3.1. TMG protocol

The test subjects lay in a prone position on an examination table with arms resting at the side during the conduct of the study. A foam pad was placed proximal to the ankle joint to ensure 5° knee flexion. A digital TMG (TMG-BMC Ltd., Ljubljana, Slovenia) displacement sensor with a spring constant of 0.17 N/mm (GK 40, Panoptik d.o.o., Ljubljana, Slovenia) was placed perpendicularly onto the muscle belly of the LES muscles at the interspace between L3 and L4. Two self-adhesive electrodes (AxelGaard Manufacturing Co. Ltd., Pals Platinum Neuro-Stimulation Electrodes, Model 895,220, 50 × 50 mm) were placed equidistant from the sensor with an inter-electrode distance of 3 cm (Fig. 2). The optimal measurement point (i.e. thickest part of the muscle bulk, around 2 cm lateral to the dorsal midline) was localised via visual orientation and palpation during voluntary and elicited contraction (Lohr et al., 2020). If required, the sensor position was adjusted. Once the optimal measurement point was identified, the position of the sensor and electrodes were marked with a dermatological pen to ensure exact relocation post MFR treatment (Lohr et al., 2018).

A single square wave monophasic 1 ms stimulation pulse was applied utilising an electrical stimulator (TMG—S1, TMG-BMC Ltd., Ljubljana, Slovenia) with an initial stimulation current of 30 mA. In order to obtain the individual maximal twitch response amplitude (i.e. maximal muscle

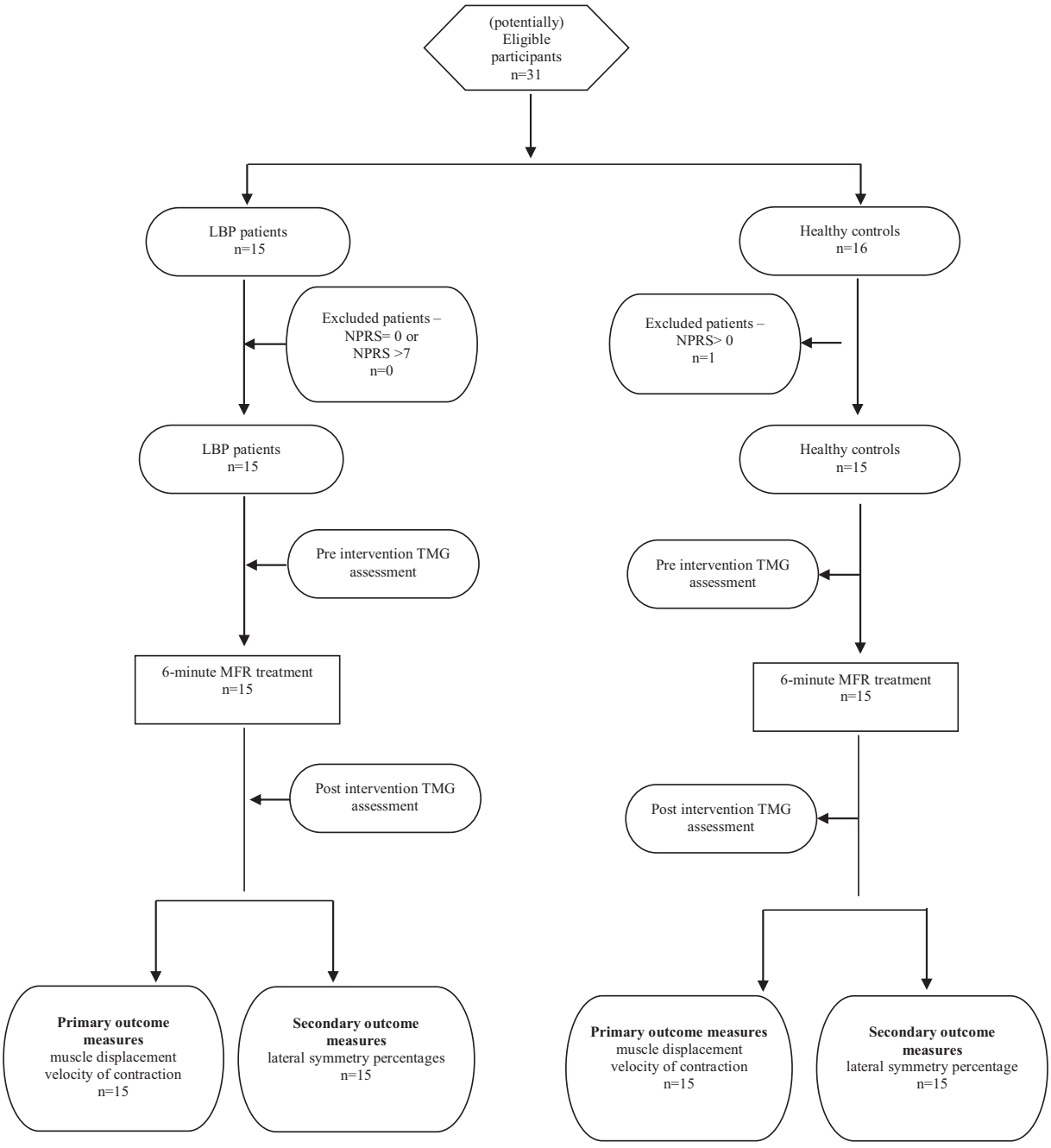


**Fig. 1.** Flow chart of study participants in patients and control group.

displacement) the stimulation current was gradually increased by 10 mA (Piqueras-Sanchiz et al., 2019). Inter-stimulus intervals of ≥10 s were chosen between successive measurements for the avoidance of fatigue and potentiation (Tous-Fajardo et al., 2010). The two highest twitch responses on the displacement graph of each participant were recorded and averaged for subsequent analysis (Tous-Fajardo et al., 2010). The following parameters were extracted: muscle displacement (Dm [mm]), which is defined as the maximal radial deformation during muscle contraction and considered as an indirect indicator for muscle stiffness (Martín-San Agustín et al., 2018), and velocity of contraction (Vc [mm/s]), a relative measure of muscle contraction speed. The latter was calculated as the rate of contraction between 10% and 90% of maximal Dm (Lohr et al., 2018; Macgregor et al., 2018b). Recently, it has been demonstrated that the mentioned parameters were found to be highly reliable as assessed for the LES (Intraclass correlation coefficient [ICC]: 0.81 to 0.99) (Lohr et al., 2018). To evaluate the lateral symmetry (Ls) between the left and right LES in each intervention group, we further extracted the Ls percentages, employing the algorithm implemented in the manufacturer's software (TMG-BMC tensiomyography™). In a recent investigation (Iglesias-Caamaño et al., 2018), the parameter's reliability was deemed excellent (ICC: 0.99).

### 2.4. Intervention

#### 2.4.1. MFR protocol

All participants received a standardised single 6-min MFR treatment (i.e., three minutes on each side) of the LDF following baseline measurement. The subjects remained in prone position as described above. The MFR protocol included two techniques (Arguisuelas et al., 2017; Barnes, 1997) which will be outlined below.

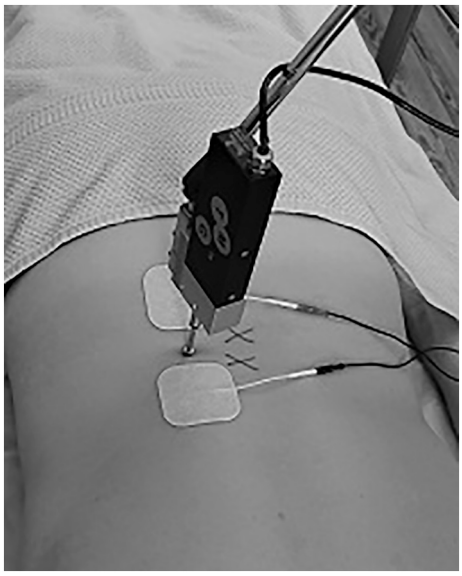

**Fig. 2.** Measurement of the lumbar erector spinae by use of TMG.

*2.4.1.1. Cross-hand MFR to superficial paraspinal myofascial structures.* The practitioner stood beside the participant at the lower chest level, placing crossed hands in an angle of 45° to the horizontal plane on the ipsilateral side (Fig. 3). The caudal hand rested on the lumbosacral region and the cranial hand on the thoracolumbar transition, inducing gentle pressure towards the table and a stretch craniocaudally into the restricted tissue with an intention to release the LF. This technique was conducted for about 90 s on each side.

*2.4.1.2. Connective tissue manipulation – Longitudinal deep strokes of LES muscles.* The practitioner stood beside the participant at the waistline level, facing towards the cranium. The caudal hand rested on the sacrum, inducing slight pressure towards the table (Fig. 4). The intervention started at the lumbosacral transition by applying deep strokes with the cranial hand kept as a loose fist. The strokes were repeated three times in a cephalad direction for approximately 90 s on each side, focusing on the posterior layer of the LF as well as the intermediate (longissimus dorsi) and lateral (iliocostalis lumborum) portion of the ES muscles.

### 2.5. Outcomes

Changes in TMG parameters such as muscle displacement (Dm), velocity of contraction (Vc) were selected as primary outcomes in both groups. Secondary outcome was lateral symmetry (Ls) between the left and right LES in each intervention group. All measurements were performed before and after a standardised 6-min MFR treatment of the LDF.

**Fig. 3.** Cross-hand myofascial release to superficial myofascial structures.

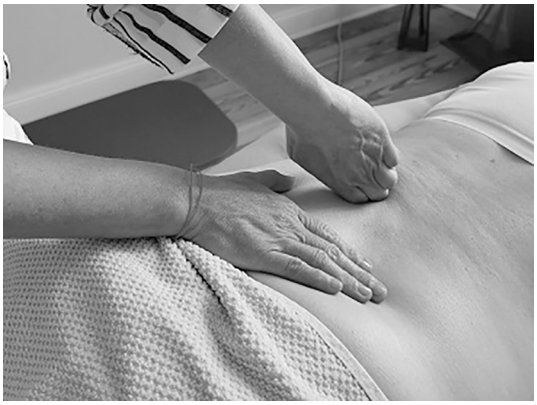

**Fig. 4.** Longitudinal deep strokes of the lumbar erector spinae.

### 2.6. Statistical analyses

To analyse the anthropometric characteristics of the study sample, descriptive statistics (means and standard deviations; relative frequencies for PA level) were calculated for each group and checked for differences using *t*-tests (age, height, weight, BMI) or chi-square tests (PA level). For the TMG variables Dm and Vc (left and right side, pre- and post-intervention) as well as Ls (pre- and post-intervention), means, 95% confidence intervals (CIs), minimum and maximum were calculated. To ensure that the assumptions for the statistical methods employed were met, two preliminary tests were performed, Shapiro-Wilk test to check for normality and Levene's test to check for homogeneity of variances. To investigate the parameters Dm, Vc, and Ls, a three-way analysis of variance (ANOVA) was performed, including the between-subjects factor group subjects with LBP vs. healthy controls), the within-subjects factor time point of measurement (pre vs. post intervention), and the between-subjects factor sex to control for possible interaction with the participants' sex. In the event of a significant interaction effect, simple effects analyses were conducted. Statistical significance was set at $p < .05$, and partial eta-squared ($\eta_p^2$) were calculated as effect sizes of the ANOVA effects. Data analyses were performed using SPSS v. 22.0 (IBM Corp., Armonk, NY, USA).

## 3. Results

### 3.1. Anthropometric characteristics

There were no significant differences between subjects with LBP (7 women and 8 men) and healthy controls (7 women and 8 men) in age (37.5 ± 8.9 vs. 37.3 ± 11.1), height (1.78 ± 0.10 vs. 1.78 ± 0.11), weight (76.6 ± 13.0 vs. 73.9 ± 14.3), BMI (24.4 ± 2.7 vs. 23.0 ± 2.5), and PA level (73% Level 1 / 26% Level 2 vs. 47% Level 1 / 53% Level 2; all $p >$. 131). Significant between-group differences were evaluated for NPRS level ($p < .001$). The mean value on the NPRS scale in the LBP subjects was 4.5 (±1.1), while all healthy control participants reported an NPRS value of 0.

### 3.2. TMG parameters

An overview of the descriptive statistics for Dm, Vc and Ls is provided in Tables 1–3, respectively. Figs. 5–7 illustrate the mean Dm, Vc, and Ls for both time points of measurement, and for both groups. The ANOVAs revealed a significant main effect of time point of measurement for Dm left $F_{(1,26)} = 4.48$, $p = .045$, $\eta_p^2 = 0.15$, but neither for Dm right,

**Table 1**
Descriptive statistics of muscle displacement (Dm) for patients with LBP and healthy controls over the two time points of measurement.

| | | | t0 | | | t1 | | |
|---|---|---|---|---|---|---|---|---|
| Group | Variables | Sex | Mean ± SD (CI) | Min | Max | Mean ± SD (CI) | Min | Max |
| LBP subjects ($n$ = 15; 7F) | Dm (mm) L | F | 2.36 ± 1.32 (1.13–3.56) | 0.19 | 3.98 | 2.74 ± 1.44 (1.40–4.07) | 0.51 | 4.02 |
| | | M | 5.01 ± 2.45 (2.96–7.05) | 1.36 | 8.65 | 5.47 ± 2.83 (1.97–11.19) | 1.97 | 11.2 |
| | | Total | 3.77 ± 2.27 (2.46–5.09) | 0.19 | 8.65 | 4.19 ± 0.68 (2.74–5.65) | 0.51 | 11.2 |
| | Dm (mm) R | F | 2.69 ± 1.50 (0.95–3.13) | 0.14 | 3.82 | 3.23 ± 1.47 (0.88–3.85) | 0.12 | 4.24 |
| | | M | 4.51 ± 2.46 (2.45–6.57) | 1.85 | 9.07 | 4.77 ± 1.27 (3.05–6.48) | 2.12 | 8.59 |
| | | Total | 3.36 ± 2.29 (2.09–4.63) | 0.14 | 9.07 | 3.65 ± 2.19 (2.44–4.85) | 0.12 | 8.59 |
| Healthy controls (n = 15; 7F) | Dm (mm) L | F | 3.44 ± 1.6 (1.98–4.90) | 1.34 | 5.29 | 3.47 ± 1.24 (2.32–4.62) | 1.7 | 4.82 |
| | | M | 4.9 ± 1.3 (3.78–6.01) | 3.08 | 6.92 | 5.10 ± 1.29 (4.03–6.18) | 3.57 | 6.81 |
| | | Total | 4.21 ± 1.59 (3.34–5.10 | 1.34 | 6.92 | 4.34 ± 1.48 (3.52–5.16) | 1.7 | 6.81 |
| | Dm (mm) R | F | 3.35 ± 1.57 (1.90–4.80) | 1.34 | 5.5 | 3.23 ± 1.47 (1.87–4.60) | 1.65 | 5.42 |
| | | M | 4.88 ± 1.49 (3.61–6.13) | 1.79 | 6.95 | 4.77 ± 1.27 (3.71–5.83) | 2.78 | 6.6 |
| | | Total | 4.18 ± 1.67 (3.24–5.09) | 1.34 | 6.95 | 4.05 ± 1.54 (3.20–4.90) | 1.65 | 5.42 |

Abbreviations: CI, Confidence interval; Dm, muscle displacement; F, female; L, left; M, male; Max, maximum; Min, minimum; R, right; SD, standard deviation; t0, pre-measurement; t1, post-measurement.

**Table 2**
Descriptive statistics of velocity of contraction (Vc) for patients with LBP and healthy controls over the two time points of measurement.

| | | | t0 | | | t1 | | |
|---|---|---|---|---|---|---|---|---|
| Group | Variables | Sex | Mean ± SD (CI) | Min | Max | Mean ± SD (CI) | Min | Max |
| LBP subjects (n = 15; 7F) | Vc (mm/s) L | F | 95.02 ± 63.69 (36.11–153.93) | 6.82 | 197 | 118.57 ± 93.53 (57.53–179.61) | 18.72 | 195.2 |
| | | M | 236.51 ± 99.25 (153.54–319.49) | 77.6 | 365 | 224.25 ± 66.76 (151.83–360.71) | 90.26 | 504.1 |
| | | Total | 170.48 ± 109.56 (109.81–231.15) | 6.82 | 365 | 192.01 ± 121.35 (124.81–259.21) | 18.72 | 504.1 |
| | Vc (mm/s) R | F | 80.36 ± 48.96 (35.08–125.63) | 8.31 | 122.2 | 101.33 ± 69.14 (37.38–165.28) | 7.76 | 195.8 |
| | | M | 185.08 ± 90.03 (110.87–259.30) | 81.32 | 357.8 | 204.41 ± 75.15 (141.58–267.23) | 102.7 | 339.2 |
| | | Total | 136.31 ± 88.84 (87.01–185.41) | 8.31 | 357.8 | 156.30 ± 87.78 (107.69–204.92) | 7.76 | 339.2 |
| Healthy controls (n = 15; 7F) | Vc (mm/s) L | F | 163.02 ± 80.87 (88.63–237.80) | 71.8 | 268.2 | 150.87 ± 78.83 (77.97–223.78) | 49.36 | 249.4 |
| | | M | 229.10 ± 58.97 (179.79–278.40) | 151.4 | 313.5 | 224.25 ± 66.76 (168.44–280.06) | 129.8 | 333.4 |
| | | Total | 198.26 ± 75.54 (156.42–240.09) | 71.8 | 313.5 | 190.01 ± 79.55 (145.96–234.06) | 49.36 | 333.4 |
| | Vc (mm/s) R | F | 149.43 ± 76.45 (78.72–220.13) | 58.68 | 236.4 | 141.12 ± 71.93 (74.60–207.65) | 64.93 | 242.4 |
| | | M | 224.49 ± 90.53 (148.81–300.17) | 107.6 | 376.8 | 208.09 ± 82.56 (139.06–277.11) | 109.4 | 358.5 |
| | | Total | 198.46 ± 90.03 (139.60–239.32) | 58.68 | 376.8 | 176.84 ± 82.59 (131.10–222.57) | 64.93 | 358.5 |

Abbreviations: CI, confidence interval; F, female; L, left; M, male; Max, maximum; Min, minimum; R, right; SD, standard deviation; t0, pre-measurement; t1, post-measurement; Vc, velocity of contraction.

**Table 3**
Descriptive statistics of lateral symmetry (Ls) for patients with LBP and healthy controls over the two time points of measurement.

| | | | t0 | | | t1 | | |
|---|---|---|---|---|---|---|---|---|
| Group | Variables | Sex | Mean ± SD (CI) | Min | Max | Mean ± SD (CI) | Min | Max |
| LBP subjects (n = 15; 7F) | Ls % | F | 72.1 ± 14.1 (59.1–85.2) | 45.0 | 91.0 | 74.6 ± 19.1 (57.2–92.2) | 47.0 | 96.0 |
| | | M | 82.0 ± 8.1 (75.2–88.8) | 67.0 | 93.0 | 88.1 ± 4.0 (84.9–91.4) | 82.0 | 93.0 |
| | | Total | 77.4 ± 12.0 (70.8–84.0) | 45.0 | 93.0 | 81.8 ± 12.0 (73.7–89.9) | 47.0 | 96.0 |
| Healthy controls (n = 15; 7F) | Ls % | F | 84.9 ± 7.2 (78.2–91.6) | 73.0 | 94.0 | 86.1 ± 10.0 (76.9–95.4) | 69.0 | 96.0 |
| | | M | 88.5 ± 6.7 (83.0–94.1) | 78.0 | 95.0 | 83.7 ± 8.9 (76.2–91.1) | 71.0 | 94.0 |
| | | Total | 86.8 ± 7.0 (83.0–93.0) | 73.0 | 95.0 | 84.8 ± 9.2 (79.7–89.9) | 69.0 | 96.0 |

Abbreviations: CI, confidence interval; F, female; Ls, lateral symmetry; M, male; Max, maximum; Min, minimum; SD, standard deviation; t0, pre-measurement; t1, post-measurement.

Vc nor for Ls (all $p > .442$, $\eta_p^2 < 0.03$), as well as a significant main effect of sex for Dm and Vc right and left (all $p < .005$, all $\eta_p^2 > 0.28$), but not for Ls ($p = .076$, $\eta_p^2 = 0.12$). There was no main effect of group in any of the variables examined (Dm: all $p > .307$, all $\eta_p^2 < 0.04$; Vc: all $p > .181$, all $\eta_p^2 < 0.01$; Ls: $p = .058$, $\eta_p^2 = 0.13$). A statistically significant interaction effect between group and time point of measurement with large effect sizes was found for Vc in the right ($F_{(1,26)} = 7.92$, $p = .009$, $\eta_p^2 = 0.23$) and left LES ($F_{(1,26)} = 4.48$, $p = .044$, $\eta_p^2 = 0.15$), but neither for Dm (right: $F_{(1,26)} = 3.17$, $p = .087$, $\eta_p^2 = 0.11$; left: $F = 3.18$, $p = .252$, $\eta_p^2 = 0.05$), nor for Ls ($F_{(1,26)} = 2.47$, $p = .128$, $\eta_p^2 = 0.09$). To break down the significant interaction effect for the Vc measures, simple effects analyses were performed comparing pre vs. post measurement within each experimental group. These revealed a significant increase over time in Vc for the subjects with LBP (right: difference between estimated marginal means = 20.15, 95% CI = 3.36, 36.93, $F_{(1,26)} = 6.09$, $p = .021$, $\eta_p{}^2 = 0.19$; left: differences between estimated marginal means = 21.65, 95% CI = 0.94, 42,36, $F_{(1,26)} = 4.62$, $p = .041$, $\eta_p^2 = 0.15$), but not for the healthy controls, both $F < 2.29$, both $p > .14$. None of the interactions with the factor sex (group * sex, time point of measurement * sex, group * time point of measurement * sex) reached statistical significance (all $F < 2.82$, all $p > .11$).

## 4. Discussion

To our knowledge, this is the first study that assessed the effects of MFR in subjects with LBP by TMG through a controlled matched-pair design. A healthy control group was used for comparison. The most important findings of our research were that a single MFR treatment had an impact on neuromechanical characteristics of LES muscles, especially in participants with LBP. This was evident particularly from the bilateral

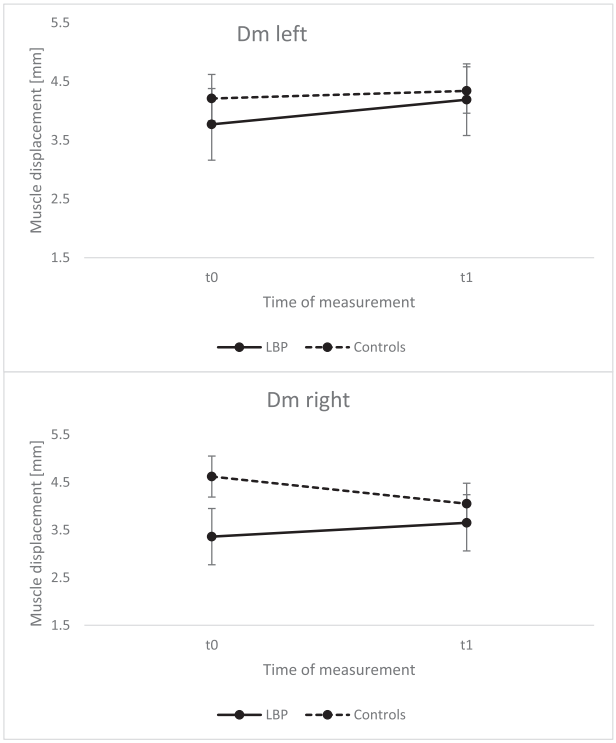


**Fig. 5.** The mean muscle displacement (Dm) on the left LES (top) and right LES (bottom) over the two measurment points (pre vs. post) for both groups. Error bars correspond to the standard error.

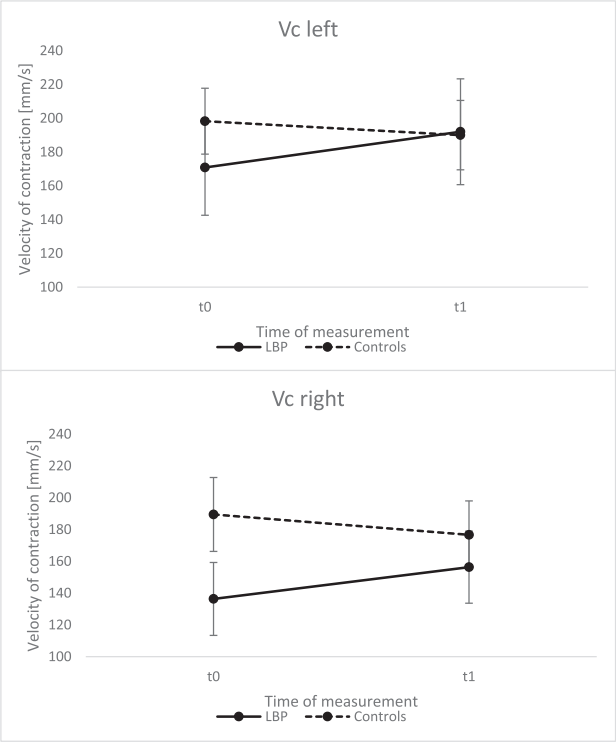


**Fig. 6.** The mean velocity of contraction (Vc) on the left LES (top) and the right LES (bottom) over the two measurement points (pre vs.post) for both groups. Error bars correspond to the standard error.

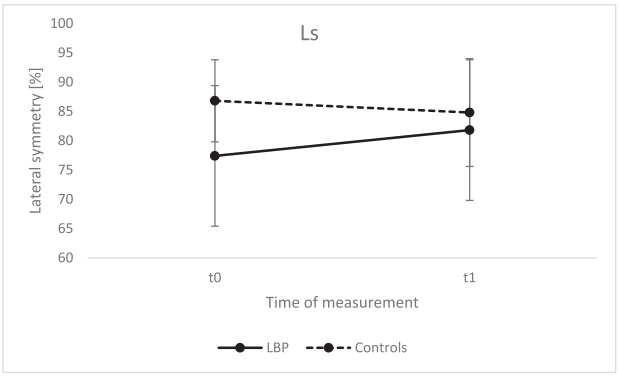


**Fig. 7.** The mean lateral symmetry (Ls) over the two measurement points (pre vs. post) for both groups. Error bars correspond to the standard error.

significant increase in the TMG-derived parameter Vc from pre- to post-measurement ($p \leq .041$), whereas the symptom-free controls were uninfluenced by the intervention. Regarding muscle displacement, an indirect measure of muscle stiffness, there was a significant increase over time ($p = .045$) in Dm left within both groups, whereas Ls remained statistically unaltered.

The immediate responsiveness on muscle contractile dynamics (i.e., increased Vc) following MFR in the LBP group may have been mediated by several interconnected pathways. For instance, an accumulation of hyaluronan between the layers of deep fascia and the underlying epimysium has been associated with non-specific pain syndromes (Stecco et al., 2016). This may alter the tissue's density, and consequently, comprise the entire lumbar myofascial structures (Stecco et al., 2011). Considering the fact that muscle spindles, including their corpuscles, are closely interlinked to peri-and epimysial fasciae (Boyd-Clark et al., 2002), a rigid environment potentially inhibits their activation (Stecco et al., 2016) which may consequently lead to altered muscle function (Stecco et al., 2013). It is known that the physical-chemical characteristics of hyaluronan can be modified by pressure (Stecco et al., 2011) or temperature (Matteini et al., 2009). Recently, Fidut-Wrońska et al. (2019) observed a significant increase in temperature following a single 3-min fascial manipulation® (Stecco and Day, 2010). Considering these aspects, it seems plausible that pressure applied during MFR, which may have been accompanied by an increased temperature in myofascial tissues, has altered hyaluronan viscosity, and, in turn, enhanced the sliding ability between myofascial tissue layers. As a consequence, improved fluid dynamics and more compliant tissue viscoelastic behaviour might have had an impact on the mechanoreceptors' sensitivity in that zone, such as muscle spindles (Stecco et al., 2013). An improved motoneuronal activation arises then, resulting in increased Vc.

In terms of the spatial parameter Dm, our findings were less consistent. The results revealed an increase over time within both groups in the left LES, suggestive of reduced muscle stiffness following MFR application independent of LBP. By contrast, the situation on the contralateral side was quite different. Here, while none of the effects reached significance, the interaction between group and time point of measurement was at least marginally significant ($p = .087$) with a medium effect size ($\eta_p^2 = 0.11$), based on minimal changes in Dm pointing in opposite directions for the two groups (t0 vs. t1: LBP 3.36 vs. 3.65, controls 4.18 vs. 4.05; cf. Table 1 and Fig. 5). Taken together, the results for the parameter Dm may demonstrate a tendency towards a positive effect of MFR on muscular stiffness for LBP patients, while the effect in healthy subjects remains unclear. However, this still needs to be investigated with a larger sample.

Recent investigations have provided strong support for the hypothesis that restricted myofascial tissue with an increased density and/or thickness as well as alterations in the cross-sectional area (CSA) are often

a concomitant in unspecific LBP syndromes (Ercole et al., 2010; Fortin and Macedo, 2013; Langevin et al., 2009; Langevin et al., 2011). Furthermore, it has been postulated that an increase in the spatial parameter Dm is indicative of reduced muscle stiffness and muscle atrophy (Ditroilo et al., 2011; Šimunič et al., 2019). Calvo-Lobo et al. (2017) examined alterations in LES mechanical properties utilising TMG between myofascial trigger points and control points in LBP subjects assessed on the LES. The authors observed moderate positive correlations ($p = .047$, $T_B = 0.045$) between Dm and pressure pain threshold. One possible explanation for the lack of more marked Dm effects in the current study might be attributed to the heterogeneity in the selected LBP subjects. There is a growing body of research suggesting variations in lumbar muscle structure between different LBP populations. The underlying mechanisms are dependent, inter alia, on the continuation of the pain complaints (Hodges and Danneels, 2019). The findings of Goubert et al. (2017) indicate that alterations in muscle structure are more prominent in continuous chronic LBP compared to recurrent LBP. In the current study, we did not further subdivide or classify the LBP group. As such, it stands to reason that structural alterations (e.g., increased density and/or muscle atrophy), which are more extensive in a chronic phase (Hodges and Danneels, 2019), were not readily evident in the LBP group as we included subacute patients with LBP with a pain duration of down to 3 months (Qaseem et al., 2017). Apart from this, it can be conjectured that multiple MFR treatments over a longer period (i.e., dose-dependent effect) as well as the time point of measurement (e.g., immediate vs. 30-min post-intervention) could lead to larger impacts on muscle mechanical characteristics. This assumption is supported by an investigation of Macgregor et al. (2018b). Differences between groups (rest vs. foam rolling [FR]) in Dm were obvious only on the third day of a 3-min FR in healthy participants. Moreover, the authors observed a progressive increase in Dm post-treatment – compared to baseline, Dm was increased by 15% immediately after FR and by 19% 30 min after FR. This observation supports the hypothesis that impacts on myofascial mechanical characteristics (e.g., stiffness) following (Self-) MFR may appear with a certain delay (Behm and Wilke, 2019), which seems to be associated with prolonged alterations in tissue hydration status following myofascial interventions (Schleip et al., 2012). Thus, further investigations are required taking potential effects of MFR on the stiffness related variable Dm over the short and long term into account.

Since previous studies found associations between paraspinal muscle asymmetry and LBP (Chon et al., 2017; Fortin and Macedo, 2013), another focus was set on the analysis of the participants' muscles' lateral symmetry. This was done by utilising the algorithm implemented in the TMG software. Although statistically non-significant, the initial data indicate small group differences which can be regarded as a descriptive trend ($p = .058$) with a medium effect size ($\eta_p{}^2$ 0.13) towards higher symmetry values in the controls averaged across the time point of measurements (85.8%) compared to the LBP subjects (79.6%). To substantiate the relevance of this difference, a value above 80% – as shown in the controls – has been recommended as an acceptable level of Ls (Atikovic et al., 2015; García-García, 2015). However, it should be mentioned that these data were predominantly assessed on the lower and/or upper extremity in younger participants, and that to date there seems to be no straightforward criterion to determine the participants' asymmetry utilising the implemented TMG algorithm (García-García et al., 2019). Thus, there is a necessity to examine further population-based data to substantiate this preliminary tendency of Ls in LBP subjects, in particular to permit a more profound evaluation and interpretation of the results.

As might be expected, the analyses revealed significant sex-based differences in Vc and Dm (all $p < .005$). These findings are in line with a recent investigation showing lower mean values in women compared with men (Dm $p < .001$; Vc $p < .001$) as assessed in the LES of asymptomatic participants (Lohr et al., 2020). This appears reasonable considering the fact that, in general, the percentage of type I fibre area in the LES in women is higher than in men (Mannion, 1999; Thorstensson and Carlson, 1987), with lower trunk muscle density reflecting larger content of intra-muscular adipose tissue (Johannesdottir et al., 2018; Urrutia et al., 2018). In contrast, men exhibit bigger muscle fibres and larger CSA (Johannesdottir et al., 2018), accompanied by greater LES thickness (Lim, 2013), characterised by higher force-generating capacity (Jones et al., 2008) – resulting in higher Vc and Dm in men (Lohr et al., 2020). Nevertheless, the current data showed no interactions with the factor sex. Interestingly, recent studies observed sex-mediated differences following (self-) MFR, however, regarding range of motion. Within a comprehensive systematic review it was outlined that the application of tool-assisted MFR may be less effective on range of motion in men (Wilke et al., 2020). However, currently, with a minimum amount of data, one can only speculate about possible underlying mechanisms. Further work is necessary, especially for a targeted implementation of optimal therapeutic/exercise regimes for both women and men.

To summarise, the present study was able to show significant immediate effects in neuromechanical characteristics of the LES muscles in patients with LBP following a single MFR intervention. These acute alterations were successfully detected by use of TMG. The acute post-interventional adaptations were particularly evident in the variable Vc. Future endeavours should aim to explore potential effects of MFR on the instrument's variables over the short and long term.

Several limitations are associated with the study. One limitation relates to the modest sample size investigated. Future investigations would benefit from larger sample sizes, especially considering the observed descriptive tendency towards a positive effect of MFR on stiffness related characteristics. A further restriction refers to the fact that only immediate effects on muscle mechanical characteristics were considered. Therefore, no conclusions can be drawn regarding the short and long-term effectiveness of MFR on the instrument's variables. Furthermore, although both groups did not differ in terms of anthropometric characteristics (i.e., height, weight, BMI), it cannot be ruled out that unassessed differences in subcutaneous thickness (Calvo-Lobo et al., 2018) and/or the muscle's CSA may have impacted the results. Finally, bias must be admitted due to a lack of blinding of the evaluator and therapist which may exaggerate outcomes and may undermine generalizability.

## 5. Conclusion

This is the first study showing that a single MFR intervention alters neuromechanical features of the LES in patients with LBP by using TMG. Such changes may enhance the restoration of myofascial function and improve muscle efficiency. These immediate muscle mechanical adaptations were particularly evident in the TMG-derived measure Vc – a variable associated with muscle contraction speed. Although the analyses of TMG Dm – an indirect measure of muscle stiffness and Ls – the muscles' lateral symmetry – revealed no significant effects, a trend towards group differences emerged. These initial findings encourage further research into the applicability of TMG as a non-invasive assessment tool to monitor rehabilitation procedures.

## Declaration of Competing Interest

None.

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