Does Motor Control Exercise Restore Normal Morphology of Lumbar Multifidus Muscle in People with Low Back Pain? – A Systematic Review

Sabina M Pinto1
Sweta B Boghra1
Luciana G Macedo2
Yong-Ping Zheng3
Marco YC Pang4
Jason PY Cheung4
Jaro Karppinen5,6
Dino Samartzis7
Arnold YL Wong8

1Department of Rehabilitation Sciences, The Hong Kong Polytechnic University, Hong Kong SAR, China; 2School of Rehabilitation Science, McMaster University, Hamilton, ON, Canada; 3Department of Biomedical Engineering, The Hong Kong Polytechnic University, Hong Kong SAR, China; 4Department of Orthopaedics and Traumatology, The University of Hong Kong, Hong Kong SAR, China; 5Department of Orthopaedics and Traumatology, Helsinki University Hospital, Helsinki, Finland; 6Department of Orthopaedics Surgery, Rush University Medical Center, Chicago, IL, USA

Abstract: Aberrant morphological changes in lumbar multifidus muscle (LMM) are prevalent among patients with low back pain (LBP). Motor control exercise (MCE) aims to improve the activation and coordination of deep trunk muscles (eg, LMM), which may restore normal LMM morphology and reduce LBP. However, its effects on LMM morphology have not been summarized. This review aimed to summarize evidence regarding the (1) effectiveness of MCE in altering LMM morphometry and decreasing LBP; and (2) relations between post-MCE changes in LMM morphometry and LBP/LBP-related disability. Cumulative Index to Nursing and Allied Health Literature, MEDLINE, Cochrane Central Register of Controlled Trials, the Physiotherapy Evidence Database, EMBASE and SPORTDiscus were searched from inception to 30 September 2020 to identify relevant randomized controlled trials. Two reviewers independently screened articles, extracted data, and evaluated risk of bias and quality of evidence. Four hundred and fifty-one participants across 9 trials were included in the review. Very low-quality evidence supported that 36 sessions of MCE were better than general physiotherapy in causing minimal detectable increases in LMM cross-sectional areas of patients with chronic LBP. Very low-quality evidence suggested that MCE was similar to other interventions in increasing resting LMM thickness in patients with chronic LBP. Low-quality evidence substantiated that MCE was significantly better than McKenzie exercise or analgesics in increasing contracted LMM thickness in patients with chronic LBP. Low-quality evidence corroborated that MCE was not significantly better than other exercises in treating people with acute/chronic LBP. Low-quality evidence suggested no relation between post-MCE changes in LMM morphometry and LBP/LBP-related disability. Collectively, while MCE may increase LMM dimensions in patients with chronic LBP, such changes may be unrelated to clinical outcomes. This raises the question regarding the role of LMM in LBP development/progression.

Keywords: imaging, LMM, LBP, morphometry

Introduction

Low back pain (LBP), defined as pain or discomfort between the twelfth ribs and buttocks,1,2 is the leading cause of disability worldwide.3 It affects up to 84% of people at least once in their lifetime. The prevalence of LBP is anticipated to increase with an aging global population.4 Since LBP can lead to tremendous medical burdens and work disability, the overall cost of LBP is expected to increase over time.4 Although LBP is ubiquitous, approximately 85% of LBP cases have...
unclear etiology. Biomechanical research suggests that the occurrence/maintenance of LBP may be related to the suboptimal motor control of deep trunk muscles. Specifically, lumbar multifidus muscle (LMM) is a major paraspinal muscle that provides intersegmental control of the spine and withstands the compressive loading of the lumbar spine. Therefore, structural/functional deficits of LMM may be related to the onset or maintenance of chronic LBP (CLBP).

Compared to asymptomatic individuals, some patients with acute or chronic LBP demonstrate morphometric and/or functional changes in LMM (eg, reduced cross-sectional area (CSA)), increased intramuscular fatty infiltration, decreased resting thickness, and percentage thickness changes during maximum voluntary isometric contraction or contralateral arm lift. However, no significant relation between CSA/fatty infiltration of LMM and LBP has also been reported. Although LMM atrophy may be specific to the location and the side of symptoms, prolonged immobilization may also result in general LMM atrophy. Given the close association between LMM and LBP, one rehabilitation approach is to improve the function and morphology of LMM. Of various physiotherapy interventions, motor control exercise (MCE) is thought to be able to restore LMM morphology and function in patients with LBP. Multiple studies have investigated the effectiveness of MCE in restoring normal LMM morphology or decreasing LBP among patients with CLBP. Some found that MCE increased LMM sizes in these patients. Although a recent Cochrane review found low- to moderate-quality evidence to support MCE in inducing clinically meaningful pain reduction in patients with CLBP as compared to different kinds of controls including sham intervention and education, no review has summarized the effectiveness of MCE in concomitantly restoring LMM morphology and reducing LBP. Further, temporal relations between post-MCE changes in LMM morphology and changes in pain intensity/LBP-related disability among patients with LBP have not been summarized. Therefore, this systematic review aimed to summarize the evidence regarding (1) the effectiveness of MCE in restoring normal LMM morphometry and decreasing LBP; and (2) whether the post-treatment changes in morphology were associated with changes in pain and/or function of patients with LBP.

Methods

Identification and Selection

This review conforms to the Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) guidelines and is registered with PROSPERO (CRD42019120978). A systematic search was conducted in CINAHL, MEDLINE, Cochrane Central Register of Controlled Trials, the Physiotherapy Evidence Database (PEDro), EMBASE and SPORTDiscus from inception to 30 September 2020. Non-English publications were excluded. The search keywords and Medical Subject Headings included were related to LBP, lumbar multifidus, physiotherapy, or rehabilitation (Appendix 1). Studies were included if they: (1) were randomized controlled trials (RCTs); (2) involved people with LBP regardless of chronicity; and (3) compared effects of MCE with another intervention/control group(s) on at least one morphological/morphometric change of LMM (eg, CSA, resting/contracted thickness, percent thickness change during contraction, intramuscular fatty infiltration) (see Appendix 2 for details). Studies involving surgical interventions or cross-sectional comparisons between asymptomatic and symptomatic individuals, review articles, conference proceedings, theses, animal studies and grey literature were excluded. The reference lists of systematic reviews related to LMM morphology/morphometry were reviewed to identify relevant primary studies. The reference lists of the included studies were tracked backward, while forward citation tracing was performed using Web of Science. The corresponding authors of the included studies were contacted to identify additional relevant publications.

Two reviewers (SMP and SBB) independently screened the titles and abstracts based on the selection criteria. Potential full-text articles were retrieved and reviewed. Disagreements in the study inclusion at each stage were resolved by discussion. Any unresolved disagreements were decided by a third reviewer (AW). The inter-rater agreement at each screening stage was analyzed by Kappa coefficients (κ). The agreement was interpreted as none to slight (κ=0.01–0.20), fair (κ=0.21–0.40), moderate (κ=0.41–0.60), good agreement (κ=0.61–0.80), or almost perfect (κ=0.81–1.00).

Data Extraction

The two reviewers independently extracted authors’ names, year of publication, case definition, sample size,
patients’ characteristics, intervention details, outcome measures, measurement methods, attrition rate, and pre- and post-treatment results using a standardized extraction form. The primary outcome measures included LMM morphometry (eg, resting, and contracted LMM thickness, percent thickness change during contraction, volume, CSA, and intramuscular fatty infiltration, etc.) and pain. The LMM morphometric data (eg, CSA, volume, resting thickness, contracted thickness, percent thickness changes) at each lumbar level on both sides were extracted from each included study, whenever possible. Percent thickness change was calculated from \[
\frac{(\text{thickness contracted} - \text{thickness rest})}{\text{thickness rest}} \times 100\%.\]
Greater percent LMM thickness change during contraction as measured by ultrasonography was thought to be an indirect measure of LMM contraction.\(^{36,37}\) The LMM CSA was commonly used to estimate the muscle atrophy/weakness.\(^{22}\) Increased muscle CSA signified muscle hypertrophy.\(^{38,39}\) Secondary outcome measures included correlations between changes in LMM morphology and LBP intensity/LBP-related disability.

### Risk of Bias Assessment

The two reviewers (SMP and SBB) independently assessed the Risk of Bias (RoB) using the Cochrane collaboration RoB Tool (RoB 2.0).\(^{40}\) Any disagreements regarding the scores were resolved by the third reviewer (AW). Each item was scored as low, some concern, or high risk of bias according to the Cochrane handbook descriptions.

### The GRADE Approach

The two authors (SMP and SBB) independently assessed the quality of evidence of the primary outcomes using the GRADE as per GRADE handbook of grading quality of evidence and strength of recommendations. The assessment was based on the study design, risk of bias, inconsistency, indirectness, imprecision, and other considerations.\(^{41}\) The quality of evidence was rated at four levels: high, moderate, low, and very low. GRADE was assessed using [http://gradepro.org](http://gradepro.org).

### Data Synthesis

A meta-analysis was planned to pool relevant data from the included studies. However, given the high clinical heterogeneity among studies (ie, different muscle measurement methods, such as ultrasonography, computerized tomography (CT) or magnetic resonance imaging, and diverse treatments) a qualitative analysis was conducted.

Since some included studies did not report within- or between-group treatment effects, secondary-analyses were conducted using Review Manager (RevMan 5.3) to compare within- and between-group differences, as well as the corresponding mean differences (MD) and 95% confidence intervals (CI) in primary outcomes using methods (ie, calculating mean change in each group by subtracting post-intervention mean from baseline mean or calculating mean differences between two groups using post-intervention measurements) recommended in the Cochrane handbook for Systematic Reviews of Intervention.\(^{42}\) To facilitate the comparisons of LMM volume, CSA and pain intensity among studies, the measurement unit in cm\(^3\), cm\(^2\) and cm were converted into mm\(^3\), mm\(^2\) and mm, respectively. Minimal clinically important difference (MCID) for pain, which means the smallest change in pain that a patient considers clinically meaningful, was set at 20mm on visual analogue scale (VAS).\(^{43}\) Minimal detectable change at 95% confidence (MDC\(_{95}\)) was used to indicate the post-treatment change in scores that exceeded the measurement error (ie, true change). For patients with LBP, the MDC\(_{95}\) for LMM CSA, resting and contracted thickness was 100mm\(^2\),\(^{44}\) 3.6mm,\(^{35}\) and 1.8mm,\(^{35}\) respectively. The MDC\(_{95}\) for percent thickness change during contraction was 15.7%.\(^{35}\)

### Results

#### Study Selection

The search yielded 4114 citations. Nine RCTs were included from 41 screened full-text articles (Figure 1). The 2 reviewers demonstrated good agreements in selecting relevant papers at the first (k=0.68) and second stages of screening (k=0.76) (Appendix 3).

#### Characteristics of the Included Studies

The 9 included RCTs were published between 1996 and 2020, involving 451 participants (410 chronic, 41 acute LBP). The mean ages of participants ranged from 31\(^{45}\) to 50.8\(^{46}\) years. The effectiveness of MCE (focusing on the activation of deep trunk muscles in different positions)\(^{2,24,29,30,45–49}\) in restoring normal LMM morphology or decreasing LBP were compared with McKenzie exercise,\(^{29}\) general exercise,\(^{2,30}\) general physiotherapy (eg, transcutaneous electrical nerve stimulation...
(TENS), therapeutic ultrasound therapy, infrared radiation, and traction), massage, high-load lifting exercise, general strengthening plus aerobic exercises and analgesics (Appendix 4). The number of MCE sessions ranged from 12 to 36. Table 1 summarizes the characteristics of these studies. These RCTs had either 3, 4, or 4 treatment arms. Five studies involved a combination of one or two treatments with MCE in at least one arm (eg, MCE plus massage, MCE plus TENS, MCE plus general physiotherapy, MCE plus manual therapy and MCE plus analgesics).

Ultrasonography, CT-scans or magnetic resonance imaging were used to image LMM morphology in the included studies. Most studies measured bilateral CSA, resting thickness, and contracted thickness from ultrasound and magnetic resonance images. Other studies measured CSA from CT images. Although the current study aimed to extract morphometric data from each vertebral level, only one included study reported the CSA of LMM from each of the 5 lumbar levels (L1 to L5). Similarly, only one included study reported the LMM volume of each lumbar level from L1 to L5. Although LMM morphometry on the painful side might differ from non-painful side, most of the included studies did not specify the side of measurements. These studies reported the post-treatment morphometric changes in LMM in terms of percentage or actual dimensions. Given the diverse treatment combinations and LMM morphometry measurement methods in the included studies, the planned meta-analysis was not conducted.

Risk of Bias
Risk of bias assessment for individual trials is presented in Figure 2. Seven studies were considered to have a low risk of bias, while two were deemed to have a high risk of bias.

Effects of MCE on LMM Morphology
The quality of evidence and details of the effectiveness of MCE in restoring normal LMM morphology are presented in Appendix 5 and Table 2, respectively.

Volume of LMM
Only one study with low risk of bias investigated the effects of MCE plus manual therapy on the volume of LMM.

Within-Group Comparisons
Low-quality evidence suggested that 10 sessions of MCE plus manual therapy did not significantly increase the volume of LMM in comparison to general strengthening plus aerobic exercises.

Between-Group Comparisons
Low-quality evidence suggested that 10 sessions of MCE plus manual therapy were not significantly better than...
| Publications       | Case Definition | Age (Mean ± SD); Sample/Sex | Treatment (Frequency, Duration, and Duration/Session) | Outcome Measures | LMM Parameters | Measurement Method | Measurement Time Points |
|--------------------|-----------------|-----------------------------|------------------------------------------------------|------------------|----------------|-------------------|------------------------|
| Akbari et al, 2008 | Chronic LBP >3 months | MCE: 39.6 ± 3.5 yrs; n = 25 GE: 40 ± 3.6 yrs; n = 24 | 8 wks, 2x/wk, 30 mins | Pain VAS | LMM resting thickness (L4-5) | USG | Baseline, 8 wks |
| Berglund et al, 2017 | Chronic LBP >3 months | MCE: 43.3 ± 10.3 yrs; M/F = 13/20 HLL: 42.3 ± 9.8 yrs; M/F = 15/17 | 12 sessions over 2 months. | Pain VAS | LMM resting thickness on both sides of L5 vertebra | USG | Baseline, 2 months |
| Hides et al, 1996 | Acute LBP <3 weeks | MCE + analgesics: 30.9 ± 6.5 yrs; M/F = 8/13. Analgesics: 31 ± 7.9 yrs; M/F = 10/10 | 4 wks and 10 wk | MPQ; pain VAS; daily pain diaries; RMDQ; lumbar ROM; habitual activity levels | LMM CSA (L2 to S1) | USG | Baseline, 1, 2, 3, 4 and 10 wks |
| Hosseini et al, 2013 | Chronic LBP >3 months | MCE: 40.1 ± 10.8 yrs; n = 15 McKenzie: 36.6 ± 8.2 yrs; n = 15 | 6wks, 3x/wk, 60 mins | Pain VAS; FRIQ | Rt & Lt LMM resting and contracted thickness (L4-5) | USG | Baseline, 6 wks |
| Kehinde et al, 2014 | Chronic LBP (unlear definition) | MCE: 45.84 ± 9.95 yrs; n = 31 MCE + TENS: 45.84 ± 9.95 yrs; n = 31 MCE + massage: 44.57 ± 11.82 yrs; n = 30 Analgesics: 50.83 ± 13.03 yrs; n = 30 | 8 wks, 2x/wk | LMM contracted thickness (L4-5) | USG | Baseline, 8 wks |

(Continued)
| Publications            | Case Definition       | Age (Mean ± SD); Sample/Sex                                                                 | Treatment (Frequency, Duration, and Duration/Session)                                                                 | Outcome Measures                                                                                                       | LMM Parameters            | Measurement Method | Measurement Time Points |
|-------------------------|-----------------------|---------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------|---------------------------|--------------------|----------------------|
| Kim and Kim, 2013[17]   | Chronic LBP 3 months  | GPT: 39.6 ± 6.2 yrs; n = 10 GPT + MCE using sling: 39.9 ± 5.8 yrs; n = 10 GPT + MCE using sling + pushups: 40.5 ± 5.4 yrs; n = 10 | 6 wks, 3x/wk, 30 minutes.                                                                                             | ODI, surface electromyographic                                                                                         | LMM CSA on both sides (level was not reported) | CT                | Baseline, 2, 4, and 6 wks |
| Lee et al, 2011[18]     | Chronic LBP (unclear definition) | MCE with a gymnastic ball: 32.7 ± 5.9 yrs; n = 17 GPT: 33.1 ± 5.7 yrs; n = 16                  | 12 wks, 3x/wk, 45 mins                                                                                                 | Pain VAS                                                                                                              | LMM CSA (L4-5)            | CT                | Baseline, 12 wks    |
| Nabavi et al, 2018[2]   | Chronic LBP >12 weeks | MCE + GPT: 40.8 ± 8.2 yrs; n = 20 GE + GPT: 34.1 ± 10.8 yrs; n = 21 Noted: GPT = US, TENS, IRR | 4wks, 3x/wk                                                                                                           | Pain VAS                                                                                                              |                           | USG               | Baseline, 4 wks    |
| Tagliaferri et al, 2020[9] | Chronic LBP >3 months | MCE + Manual therapy: 34.6 ± 7.2 yrs; n = 20 GSA: 34.8 ± 4.9 yrs; n = 20                      | MCE + Manual therapy: 1–3 months, 10 sessions, 30 mins; 4–6 months, 2x30 mins session GSA: 1–3 months, 2x/ wk, 60 mins 4–6 months, 1–2x/ wk, 60 mins, 1–6 months, 3x/wk, 20–40min | Pain VAS, ODI, SF-36, isometric trunk extension, isometric trunk flexion, 1-RM leg press, leg press endurance, peak oxygen consumption | LMM volume (L1-L5)        | MRI               | Baseline, 3 months, and 6 months |

**Abbreviations:** BPS, back performance scale; CSA, cross-sectional area; CT, computed tomography; FRIQ, functional rating index questionnaire; GE, general exercises; GPT, general physiotherapy; GSA, general strengthening and aerobic exercises; HLL, high load lifting; IRR, infrared radiation; LBP, low back pain; LMM, lumbar multifidus muscle; Lt, left; MCE, motor control exercise; M/F, male/female; mins, minutes; MPQ, McGill pain questionnaire; MRI, magnetic resonance imaging; ODI, Oswestry disability index; RMDQ, Roland Morris Disability questionnaire; ROM, range of motion; Rt, right; SF-36, 36-item short-form health survey; US, ultrasound therapy; USG, ultrasonography; VAS, visual analogue scale; wk, weeks; x/wk, times per week; yrs, years; 1-RM, one-repetition maximum.
general strengthening plus aerobic exercises in increasing LMM volume.\textsuperscript{49}

**CSA of LMM**

Three studies\textsuperscript{2,45,49} with low and two\textsuperscript{47,48} with high risk of bias investigated the effects of MCE on LMM CSA.

**Within-Group Comparisons**

Very low- to low-quality evidence substantiated that 12 sessions or more MCE with or without adjunct treatments (e.g., resistance training, TENS, massage, manual therapy) significantly increased CSA of LMM at multiple lumbar levels.\textsuperscript{2,45,47–49} Similarly, there was very low- to low-quality evidence that 36 sessions of MCE caused post-treatment increases in LMM CSA by 121 mm\textsuperscript{2}, which exceeded MDC\textsubscript{95}\textsuperscript{48} (Table 2).

**Between-Group Comparisons**

Low-quality evidence supported that MCE along with analgesics induced significantly greater increases in LMM CSA than analgesic alone among patients with acute LBP.\textsuperscript{45} Likewise, there was very low-quality evidence that 18 or more sessions of MCE or MCE plus general physiotherapy caused significantly greater increases in LMM CSA than general physiotherapy alone in patients with CLBP.\textsuperscript{47,48} However, only 36 sessions of MCE plus general physiotherapy exceeded MDC\textsubscript{95} (by 120 mm\textsuperscript{2}) than general physiotherapy in patients with CLBP (Table 2).\textsuperscript{48} However, there was low-quality evidence that 12 sessions of MCE plus general physiotherapy/MCE plus manual therapy were not significantly different from 12 sessions of general exercise plus general physiotherapy/general strengthening plus aerobic exercises in altering LMM CSA.\textsuperscript{2,49}

**Resting LMM Thickness**

Four studies\textsuperscript{2,24,29,30} examined changes in the resting LMM thickness at the L4-5 level among patients with...
### Table 2 Effect of Motor Control Exercise on the Morphometry of Lumbar Multifidus Muscle

| Publications            | Interventions                  | Durations                                      | Within-Group Change in Morphology                                                                 | Between-Group Differences (MD (95% CI) s)                                      |
|-------------------------|--------------------------------|------------------------------------------------|---------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| **LMM volume**          |                                |                                                |                                                                                                                                                         |                                                                                 |
| Tagliaferri et al, 2020 | Gp1: MCE + manual therapy      | Gp1: 3 months: 10 sessions, 30 mins.           | Changes from baseline to 3 months (L1-L5 volume)                                                  | Between-group analysis (Gp2-Gp1)                                               |
|                         | Gp2: GSC                       | 4–6 months                                    | Gp1 mean changes (95% CI): at 3 months = −200 mm³ (−700 to 300 mm³), \( p = 0.477 \)              | At 3 months                                                                    |
|                         | MRI – L1-L5                     | 2x/wk, 30 mins.                               | Gp2 mean changes (95% CI): at 3 months = 400 mm³ (−100 to 1000 mm³), \( p = 0.102 \)           | MD (95% CI) = 600 mm³ (−100 to 1400 mm³), \( p = 0.096 \)                      |
|                         |                                | Gp2: 3 months: 2x/wk, 60 mins                 | No significant increase in LMM volume from L1-L5 in both the groups at 3 months                   | At 6 months                                                                    |
|                         |                                | 4–6 months                                    | Changes from baseline to 6 months (L1-L5 volume)                                                 | MD (95% CI) = 600 mm³ (−100 to 1400 mm³), \( p = 0.116 \)                     |
|                         |                                | 1–2x/wk, 60 mins                              | Gp1 mean changes (95% CI): at 6 months = 200 mm³ (−300 to 700 mm³), \( p = 0.463 \)             | No significant between-group differences in LMM volume at 3 and 6 months.      |
|                         |                                | 6 months: 3x/wk, 20–40min                     | Gp2 mean changes (95% CI): at 6 months = 800 mm³ (300 to 1300 mm³), \( p = 0.003 \)           |                                                                                 |
|                         |                                |                                                | Only Grp 2 demonstrated significant increases in LMM volume from L1-L5 at 6 months.             |                                                                                 |
| **LMM CSA**             |                                |                                                |                                                                                                                                                         |                                                                                 |
| Hides et al, 1996       | Gp1: MCE + drugs                | 4 wks and 10wks                               | The difference between the sides at the most affected vertebral level was expressed as a percentage of CSA for the unaffected side at that level.            | Significantly greater post-treatment increases in LMM CSA on the painful side in Gp1 than Gp2 at 4th weekFU \( p = 0.0001 \) |
|                         | Gp2: Drugs only                 |                                                | Gp1: at 4th wk = 0.71 ± 2.49%, at 10th wk = 0.24 ± 3.29%                                         | Since percentage changes in CSA were reported, MDC⁹⁵ could not be used for comparisons. |
|                         | USG – L2-S1                     |                                                | Gp2: at 4th wk = 16.84 ± 9.26%; at 10th wk = 14.02 ± 6.31%                                      |                                                                                 |
|                         |                                |                                                | Since percentage changes in CSA were reported, MDC⁹⁵ could not be used for comparisons.           |                                                                                 |
| Study | Group 1 | Group 2 | Group 3 | Change from baseline to 6 wks | Change from baseline to 12 wks | Change from baseline to 4 wks |
|-------|---------|---------|---------|-------------------------------|-------------------------------|-------------------------------|
| Kim and Kim 2013<sup>47</sup> | Gp1: GPT | Gp2: MCE using sling + GPT | Gp3: MCE using sling + GPT + pushups | 6 wks, 3x/wk, 30 mins | Gp1 mean change: Rt LMM = −0.2 ± 0.5mm², Lt LMM = 0.2 ± 0.5mm² (p > 0.05) | Gp1 mean change at L4-L5 = 121.0 ± 43.0mm², (p < 0.05) |
| | | Axial CT scan - L4-L5 | | | Gp2 mean change: L4-L5 = 3.3 ± 18.3mm², (p > 0.05) | Gp1 mean change (95% CI): Rt LMM CSA = 0.4mm² (0.2 to 0.6mm²) (p = 0.01); Lt LMM CSA = 0.5mm² (0.2 to 0.8mm²) (p = 0.01) |
| | | | | | Significant increase in LMM CSA in Gp2 and Gp3 | Gp2 mean change (95% CI): Rt LMM CSA = 0.3mm² (0.0 to 0.6mm²) (p = 0.081); Lt LMM CSA = 0.2mm² (0.1 to 0.5mm²) (p = 0.045). |
| | | | | | Changes in all groups did not exceed MDC<sub>95</sub> | Changes in both groups were smaller than MDC<sub>95</sub> |
| Lee et al. 2011<sup>48</sup> | Gp1: MCE on a gymnastic ball | Gp2: GPT | | 12 wks, 3 d/wk, 45 mins | | Reported between-group analysis: (p < 0.05) |
| | | Axial CT scan - L4-5 | | | Gp1 mean change at L4-L5 = 121.0 ± 43.0mm², (p < 0.05) | Secondary analysis, MD (95% CI) |
| Nabavi et al. 2018<sup>2</sup> | Gp1: MCE + GPT | Gp2: GE + GPT | | 4wks, 3x/wk | | Gp1 minus Gp2 = 120mm² (100-140mm²), (p > 0.05) |
| | | USG - L5 | | | Gp1 mean change: (95% CI): Rt LMM CSA = 0.4mm² (0.2 to 0.6mm²) (p = 0.01); Lt LMM CSA = 0.1mm² (0.0 to 0.2mm²) (p = 0.01) | Gp1 had a greater effect than Gp2, which exceeded MDC<sub>95</sub> |

*Post-treatment LMM CSA in Gp2 > Gp3; Rt (p < 0.001), Lt (p < 0.01). Secondary analysis, MD (95% CI) |

*Reported between-group analysis: (p < 0.05) |

*Secondary analysis, MD (95% CI) |

*Reported between-group analysis.*
### Table 2 (Continued).

| Publications          | Interventions     | Durations | Within-Group Change in Morphology                                                                 | Between-Group Differences (MD (95% CI) s)                                                                 |
|-----------------------|-------------------|-----------|-----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Tagliaferri et al. 2020<sup>19</sup> | Gp1: MCE + manual therapy Gp2: GSA MRI – L1-L5 | Gp1: 3 months: 10 sessions, 30 mins | Changes from baseline to 3 months at different levels  
Gp1 mean changes (95% CI): L1 = −10.2 mm² (−18.8 to −1.6 mm²), (p = 0.019); L2 = −10.0 mm² (−21.3 to 1.0 mm²), (p = 0.052); L3 = −9.1 mm² (−37.0 to 18.8 mm²), (p = 0.521); L4 = −13.9 mm² (−47.3 to 19.6 mm²), (p = 0.416); L5 = −3.0 mm² (−29.7 to 23.9 mm²), (p = 0.831))  
Gp2 mean changes (95% CI): L1 = 9.7 mm² (−2.3 to 21.6 mm²), (p = 0.112); L2 = 12.2 mm² (−8.6 to 33.0 mm²), (p = 0.251); L3 = 9.9 mm² (−9.6 to 29.5 mm²), (p = 0.318); L4 = 23.7 mm² (−6.1 to 53.5 mm²), (p = 0.119); L5 = 37.7 mm² (11.2 to 64.2 mm²), (p = 0.005)  
Significant increase in LMM size at L1 at 3 months in Gp1.  
Significant increase in LMM size was noted at L1 and L5 at 3 months in Gp2 compared to Gp1.  
At 6 months  
Gp1 mean changes (95% CI): L1 = −2.8 mm² (−11.6 to 6.0 mm²), (p = 0.529); L2 = −9.0 mm² (−20.0 to 2.0 mm²), (p = 0.109); L3 = 0.0 mm² (−28.6 to 28.6 mm²), (p = 0.999); L4 = −5.8 mm² (−40.1 to 28.5 mm²), (p = 0.741); L5 = 13.0 mm² (−14.5 to 40.4 mm²), (p = 0.355)  
Gp2 mean changes (95% CI): L1 = 6.5 mm² (−5.5 to 18.5 mm²), (p = 0.287); L2 = 3.8 mm² (−17.0 to 24.6 mm²), (p = 0.721); L3 = 26.3 mm² (6.7 to 45.8 mm²), (p = 0.008); L4 = 37.8 mm² (8.0 to 67.6 mm²), (p = 0.013); L5 = 46.0 mm² (19.5 to 72.5 mm²), (p = 0.001)  
Significant increase in LMM size at L3, L4 and L5 at 6 months in Gp2 only  
Changes in both groups did not exceed MDC<sub>95</sub> at 3 and 6 mon ths.  
Significant increase in LMM size was noted at L1 and L5 at 3 months in Gp2 compared to Gp1.  
At 6 months  
L1 = 9.3 mm² (−5.7 to 24.4 mm²), (p = 0.225)  
L2 = 13.2 mm² (−1.1 to 37.4 mm²), (p = 0.287)  
L3 = 26.3 mm² (−7.8 to 60.4 mm²), (p = 0.130)  
L4 = 43.6 mm² (−1.7 to 88.9 mm²), (p = 0.059)  
L5 = 33.0 mm² (−5.1 to 71.2 mm²), (p = 0.090)  
No significant between-group differences in LMM size from L1 to L5 at 6 months were noted. | Between group differences at different levels  
At 3 months  
L1 = 19.9 mm² (5.0 to 34.8 mm²), (p = 0.009)  
L2 = 23.1 mm² (−0.8 to 47.1 mm²), (p = 0.058)  
L3 = 19.1 mm² (−14.5 to 52.8 mm²), (p = 0.266)  
L4 = 37.6 mm² (−7.1 to 82.3 mm²), (p = 0.099)  
L5 = 40.6 mm² (2.9 to 78.3 mm²), (p = 0.035)  
Significant increase in LMM size was noted at L1 and L5 at 3 months in Gp2 compared to Gp1.  
At 6 months  
L1 = 9.3 mm² (−5.7 to 24.4 mm²), (p = 0.225)  
L2 = 13.2 mm² (−1.1 to 37.4 mm²), (p = 0.287)  
L3 = 26.3 mm² (−7.8 to 60.4 mm²), (p = 0.130)  
L4 = 43.6 mm² (−1.7 to 88.9 mm²), (p = 0.059)  
L5 = 33.0 mm² (−5.1 to 71.2 mm²), (p = 0.090)  
No significant between-group differences in LMM size from L1 to L5 at 6 months were noted. |

### Resting thickness

| Publications          | Interventions | Durations | Within-Group Change in Morphology                                                                 | Between-Group Differences (MD (95% CI) s) |
|-----------------------|---------------|-----------|-----------------------------------------------------------------------------------------------------|------------------------------------------|
| Akbari et al. 2008<sup>20</sup> | Gp1: MCE Gp2: GE USG - L4-5 | 8 wks, 2x wk, 30 mins | Changes from baseline to 3 months at different levels  
Gp1 mean ± SD: pre = 8.6 ± 2.4 mm; post = 9.7 ± 2.5 mm (p < 0.01)  
Gp2 mean ± SD: pre = 8.8 ± 1.5 mm; post = 9.3 ± 1.6 mm (p < 0.01)  
Significant increase in resting LMM thickness in both the groups were noted.  
Secondary analysis (post minus pre)  
Gp1 = 1.1 mm (−0.3 to 2.5 mm), (p = 0.11)  
Gp2 = 0.5 mm (−0.4 to 1.4 mm), (p = 0.26)  
Changes in both groups did not exceed MDC<sub>95</sub> | Between-group analysis data was not reported.  
Secondary analysis  
Gp1 minus Gp2 = 0.4 mm (−0.8 to 1.6 mm) (p = 0.61)  
No significant between-group difference was noted.  
Between-group difference was smaller than MDC<sub>95</sub> |
| Study                        | Group 1 | Group 2 | Method | Baseline (6 wks) | Post (6 wks) | % Change | p Value |
|------------------------------|---------|---------|--------|------------------|--------------|----------|---------|
| Berglund et al., 2017        | Gp1: MCE | Gp2: HLL | USG - LS | 12 sessions over 2 months | Larger side: pre = 2.7 ± 0.4mm; post = 2.7 ± 0.5mm; % change = 0.4 ± 18.0% | Smaller side: pre = 2.5 ± 0.4mm; post = 2.6 ± 0.5mm; % change = 8.0 ± 20.9% | \( p = 0.001 \) |
|                              | Gp1 mean ± SD: | Gp2 mean ± SD: | Larger side: pre = 2.6 ± 0.5mm; post = 2.7 ± 0.6mm; % change = 1.7 ± 14.1% | Smaller side: pre = 2.4 ± 0.5mm; post = 2.7 ± 0.5mm; % change = 11.2 ± 18.1% | Increases in LMM thickness on the smaller side > the larger side in both groups |
| Hosseinifar et al., 2013     | Gp1: MCE | Gp2: McKenzie exercise | USG - L4-5 | 6wks, 3x/wk, 60 mins | Larger side: pre = 30.0 ± 2.9mm; post = 31.5 ± 4.8mm | Smaller side: pre = 30.8 ± 4.6mm; post = 32.6 ± 4.8mm | \( p < 0.05 \) |
|                              | Gp1 mean ± SD: | Gp2 mean ± SD: | Larger side: pre = 29.4 ± 5.9mm; post = 31.1 ± 5.7mm | Smaller side: pre = 29.7 ± 5.5mm; post = 31.1 ± 5.0mm | Significant increases in resting Rt and Lt LMM thickness in Gp1 and Gp2 |
| Nabavi et al., 2018          | Gp1: MCE + GPT | Gp2: GE + GPT | USG - L5 | 4 wks, 3x/wk | Change from baseline to 4 wks | Gp1 mean changes (95% CI): | Gp2 mean changes (95% CI): |
|                              | Gp1 mean changes (95% CI): | Gp2 mean changes (95% CI): | Rt LMM = 1.5mm (1.1 to 2.1mm) (p = 0.01); Lt LMM = 1.5mm (0.9 to 2.4mm) (p = 0.01) | Rt LMM = 1.8mm (1.0 to 2.2mm) (p = 0.01); Lt LMM = 1.7mm (0.8 to 2.5mm) (p = 0.01) | Significant increase in bilateral resting LMM thickness in both the groups |

**Contracted thickness**

*Continued*
Table 2 (Continued).

| Publications          | Interventions | Durations       | Within-Group Change in Morphology                                           | Between-Group Differences (MD (95% CI) s)                      |
|-----------------------|---------------|-----------------|-----------------------------------------------------------------------------|---------------------------------------------------------------|
| Hosseinifar et al, 2013 | Gp1: MCE      | 6wks, 3x/ wk    | Gp1 mean ± SD: Rt LMM pre = 36.3 ± 4.0mm, post = 37.8 ± 4.7mm; Lt LMM pre = 37.1 ± 3.9mm, post = 39.9 ± 4.4mm (p < 0.05) | Between-group analysis was not reported                       |
|                       | Gp2: McKenzie  | 60mins          | Gp2 mean ± SD: Rt LMM pre = 35.0 ± 6.2mm, post = 36.3 ± 5.2mm; Lt LMM pre = 36.6 ± 5.3mm, post = 37.4 ± 4.9 mm (p > 0.05)     | Secondary analysis (Gp1 minus Gp2)                            |
|                       | exercises     |                 | Significant increase in contracted Lt LMM thickness in Gp1 only            | Rt LMM = 1.5mm (~2.1 to 5.1mm), (p = 0.41)                    |
|                       | USG - L4-5    |                 | Secondary analysis (post minus pre)                                        | Lt LMM = 2.5mm (~0.8 to 5.8mm), (p = 0.14)                    |
|                       |               |                 | Gp1: Rt LMM = 1.5mm (~1.6 to 4.6), (p = 0.35); Lt LMM = 2.8mm (~0.2 to 5.8), (p = 0.07) | No significant between-group difference was noted.            |
|                       |               |                 | Gp2: Rt LMM = 1.3mm (~2.8 to 5.4), (p = 0.53); Lt LMM = 0.8mm (~2.9 to 4.5), (p = 0.67) | Between-group difference in the changes of Lt LMM exceeded MDC<sub>95</sub> |

| Kehinde et al, 2014   | Gp1: MCE      | 8 wks, 2x/ wk   | Gp1 mean ± SD: pre = 2.7 ± 0.7mm, post = 3.2 ± 0.7mm (p = 0.01)            | Between-group analysis was not reported                       |
|                       | Gp2: MCE +    |                 | Gp2 mean ± SD: pre = 2.8 ± 0.5mm, post = 3.3 ± 0.5mm (p = 0.01)            | Secondary analysis                                           |
|                       | TENS.         |                 | Gp3 mean ± SD: pre = 2.7 ± 0.6mm, post = 3.0 ± 0.5mm (p = 0.01)            | Gp1 minus Gp2 = 0.2mm (~0.1 to 0.5mm), (p = 0.20)            |
|                       | Gp3: MCE +    |                 | Gp4 mean ± SD: pre = 2.9 ± 0.6mm, post = 3.0 ± 0.5mm (p = 1.00)            | Gp1 minus Gp4 = 0.2mm (~0.1 to 0.5mm), (p = 0.20)            |
|                       | massage.      |                 | Significant increase in contracted LMM thickness at L4-L5 at 8 wk in Gps1, 2 and 3 only | Gp1 minus Gp3 = 0.1mm (~0.4 to 0.2mm), (p = 0.52)            |
|                       | Gp4: Analgesics|                 | Secondary analysis (post minus pre)                                        | Gp2 minus Gp3 = 0.3mm (0.1 to 0.6mm), (p = 0.02)            |
|                       | USG - L4-5    |                 | Gp1 = 0.5mm (0.2 to 0.9mm), (p = 0.005)                                   | Gp2 minus Gp4 = 0.3mm (0.1 to 0.6mm), (p = 0.02)            |
|                       |               |                 | Gp2 = 0.5mm (0.3 to 0.8mm), (p < 0.0001)                                   | Gp3 minus Gp4 = 0.0mm (~0.3 to 0.3mm), (p = 1.00)            |
|                       |               |                 | Gp3 = 0.3mm (0.0 to 0.6mm), (p = 0.04)                                     | Significant increase in contracted LMM thickness was noted in Gp2 compared to Gp1, Gp3 and Gp4 | Gp4 minus Gp4 = 0.1mm (~0.2 to 0.4mm), (p = 0.48) |
|                       |               |                 | Gp4 = 0.1mm (~0.2 to 0.4mm), (p = 0.48)                                     | Between-group differences were smaller than MDC<sub>95</sub>  |

Note: The bold values indicate that the changes exceeded MDC<sub>95</sub>.  
Abbreviations: CSA, cross-sectional area; CT, computed tomography; d/wk, days per week; FU, follow up; GE, general exercises; Gp, group; GPT, general physiotherapy; GFT, general physiotherapy; GSA, general strengthening and aerobic exercises; HLL, high load lifting; IRR, infrared radiation; LMM, lumbar multifidus muscle; Lt, left; MCE, motor control exercises; MD (95% CI), mean difference (95% confidence intervals); MDC<sub>95</sub>, minimal detectable change at 95% confidence interval; mins, minutes; MRI, magnetic resonance imaging; Rt, right; SD, standard deviation; TENS, transcutaneous electrical nerve stimulation; US, therapeutic ultrasound therapy; USG, ultrasonography; wk, week.
CLBP. The treatments ranged from 2 to 3 days/week, with 30–60 minutes each for 4 to 8 weeks. All four studies demonstrated a low risk of bias.\textsuperscript{2,24,29,30}

**Within-Group Comparisons**

Very low- to low-quality evidence suggested that 12 to 18 sessions of MCE with/without adjunct treatment, general exercises, high-load lifting, McKenzie exercise, or general exercises plus general physiotherapy significantly increased resting LMM thickness.\textsuperscript{2,24,29,30} Although these post-MCE increases in the resting LMM thickness ranged from 1.1mm to 1.8mm, they did not exceed MDC\textsubscript{95}.\textsuperscript{2,29,30} (Table 2).

**Between-Group Comparisons**

There was very low- to low-quality evidence that 12 to 18 sessions of MCE or MCE plus general physiotherapy were not significantly better than other treatments (eg, general exercises,\textsuperscript{30} high load lifting exercise,\textsuperscript{24} McKenzie exercise,\textsuperscript{29} general exercise plus physiotherapy,\textsuperscript{2} in increasing LMM resting thickness (Table 2).

**Contracted LMM Thickness**

Two studies with low risk of bias\textsuperscript{29,46} evaluated the effects of 16 to 18 sessions of MCE on the contracted thickness of LMM at the L4-5 level in patients with CLBP.

**Within-Group Comparisons**

Low-quality evidence suggested that MCE with/without adjunct treatment significantly increased the contracted thickness of LMM ranging from 0.3mm to 2.8mm.\textsuperscript{29,46} However, only 18 sessions of MCE caused significant increases in contracted thickness of left LMM that exceeded MDC\textsubscript{95} (Table 2).\textsuperscript{29}

**Between-Group Comparisons**

There was low-quality evidence that MCE was comparable to McKenzie exercise in increasing LMM contracted thickness.\textsuperscript{29} Low-quality evidence suggested that although MCE plus TENS caused significantly greater increases in contracted LMM thickness than MCE plus massage or analgesic alone, the differences did not exceed MDC\textsubscript{95} (Table 2).\textsuperscript{46}

**Effects of MCE on Percent LMM Thickness Changes During Contraction and LMM Fatty Infiltration**

Despite the comprehensive search, no RCT investigated the effects of intervention on percent LMM thickness changes during contraction or LMM fatty infiltration.

**Effects of MCE on LBP Intensity of the Included Studies**

Of the 9 included RCTs, 7 trials reported post-treatment decreases in LBP intensity (Table 3). Seven included studies\textsuperscript{2,24,29,30,45,48,49} used VAS to measure LBP intensity, which comprises a 10cm straight line with the two endpoints indicating no pain (0cm) and maximum pain (10cm), respectively.\textsuperscript{51}

**Within-Group Comparisons**

There was very low- to low-quality evidence that 4 to 24 weeks of MCE,\textsuperscript{29} McKenzie exercise,\textsuperscript{29} general exercises,\textsuperscript{30} high-load lifting exercises,\textsuperscript{24} MCE plus manual therapy,\textsuperscript{49} general strengthening plus aerobic exercises,\textsuperscript{49} and general physiotherapy\textsuperscript{2,48} significantly decreased pain. The average pain reduction following MCE alone ranged from 2.8mm to 18.5mm on VAS, which were smaller than MCID.\textsuperscript{24,29,30} There was very low- to low-quality evidence that combining MCE or general exercises with general physiotherapy,\textsuperscript{2} MCE on a gymnastic ball or general physiotherapy alone\textsuperscript{48} significantly reduced CLBP intensity by 33mm to 46mm on VAS, which exceeded the MCID for pain using VAS (>20mm) (Table 3).\textsuperscript{43} Similarly, low-quality evidence supported that MCE with analgesics and nonsteroidal anti-inflammatory drugs significantly reduced acute LBP, although the extent of pain reduction was not reported.\textsuperscript{45}

**Between-Group Comparisons**

There was low-quality evidence that MCE alone caused significantly greater CLBP reduction than general exercise alone,\textsuperscript{30} or McKenzie exercise alone.\textsuperscript{29} However, there was no evidence that MCE with or without adjunct treatments was significantly better than high load lift exercise,\textsuperscript{24} general physiotherapy,\textsuperscript{48} general strengthening plus aerobic exercises,\textsuperscript{49} general exercise plus general physiotherapy,\textsuperscript{2} or drug alone\textsuperscript{45} in reducing acute or chronic LBP. Given the high clinical heterogeneity among studies, meta-analysis was not conducted.

**Temporal Relations Between Changes in LMM Morphology and Changes in LBP Intensity or LBP-Related Disability**

Only two included RCTs with low risk of bias investigated the correlations between changes in LMM morphology and the corresponding changes in LBP intensity among patients with acute (n=41)\textsuperscript{45} or CLBP (n=65).\textsuperscript{24} There was no evidence that post-treatment increases in LMM resting
### Table 3 Effect of Motor Control Exercise on Low Back Pain

| Publications          | Interventions                     | Pain Measures | Within-Group Change in Pain | Between-Group Differences (MD (95% CI) s) |
|-----------------------|-----------------------------------|---------------|-----------------------------|-----------------------------------------|
| Akbari et al, 2008    | Gp1: MCE                          | VAS (mm)      | Gp1 mean ± SD: pre = 7.3 ± 1.0mm, post = 2.5 ± 1.2mm, (p = 0.0001) | Between-group analysis data was not reported. Reported p value (p = 0.015) |
|                       | Gp2: GE                            |               | Gp2 mean ± SD: pre = 8 ± 1.2mm, post = 4 ± 1.5mm, (p = 0.0001) | Secondary analysis                      |
|                       |                                    |               | Secondary analysis (pre minus post) |                          |
|                       |                                    |               | Gp1 = 4.8mm (4.19 to 5.41mm), (p < 0.00001) | Gp1 minus Gp2 = −1.5mm (−2.26 to 0.74mm) (p = 0.0001) |
|                       |                                    |               | Gp2 = 4mm (3.23 to 4.77mm), (p < 0.00001) | Gp1 showed significantly larger decreases in LBP than Gp2 |
|                       |                                    |               | Significant post-treatment reduction in LBP in Gp1 and Gp2. | Between-group difference was smaller than MCID |
|                       |                                    |               | Changes for both groups were smaller than MCID |                          |
| Berglund et al, 2017  | Gp1: MCE                          | VAS (mm)      | Gp1 mean ± SD: pre = 48.7 ± 27.0mm, mean change ± SD at 2 months: −18.5 ± 26.7mm, (p value was not reported) | Between-group analysis data was not reported. Reported p value (p = 0.95) |
|                       | Gp2: High load lift exercise       |               | Gp2 mean ± SD: pre = 41.3 ± 23.8mm, mean change ± SD at 2 months: −19.0 ± 25.5mm, (p value was not reported) | Secondary analysis                      |
|                       |                                    |               | Significant post-treatment reduction in LBP in Gp1 and Gp2. | Gp1 minus Gp2 = 0.5mm (−12.71 to 13.71mm) (p = 0.94) |
|                       |                                    |               | Changes for both groups were smaller than MCID | No significant post-treatment differences between Gp1 and Gp2 |
| Hides et al, 1996     | Gp1: MCE plus drugs                | VAS (mm)      | Significant decreases in pain intensity in both groups. (Values were not reported) | No significant difference between the two groups from 1 to 4 weeks (p = 0.96) |
|                       | (analgesics + nonsteroidal anti-inflammatory) |               |                             | LBP assessment at 10th wk was not reported. |
|                       | Gp2: Drugs                         |               |                             |                          |
| Hosseinifar et al, 2013 | Gp1: MCE                          | VAS (mm)      | Gp1 mean ± SD: pre = 4.3 ± 1.6mm, post = 1.5 ± 1.4mm, (p < 0.05) | Between-group analysis data was not reported. Reported p value (p < 0.05) |
|                       | Gp2: McKenzie exercise              |               | Gp2 mean ± SD: pre = 4.4 ± 2.0mm, post = 2.7 ± 1.4mm, (p < 0.05) | Secondary analysis                      |
|                       |                                    |               | Secondary analysis (pre minus post) |                          |
|                       |                                    |               | Gp1 = 2.8mm (1.72 to 3.88mm), (p < 0.00001) | Gp1 minus Gp2 = −1.20mm (−2.20 to −0.20mm) (p = 0.02) |
|                       |                                    |               | Gp2 = 1.7mm (0.46 to 2.94mm), (p < 0.00001) | Gp1 showed significantly larger decreases in LBP than Gp2. |
|                       |                                    |               | Significant post-treatment reduction in LBP in Gp1 and Gp2. | Between-group difference was smaller than MDC95 |
|                       |                                    |               | Changes for both groups were smaller than MCID |                          |
| Study                          | Group 1 | Group 2 | VAS (mm) | Note |
|-------------------------------|---------|---------|----------|------|
| Lee et al, 2011               | MCE on a gymnastic ball | GPT | Gp1: mean ± SD: pre = 59 mm ± 19 mm, post at 12th wk = 13 ± 11 mm, (p < 0.05)  
Gp2: mean ± SD: pre = 56 mm ± 20 mm, post at 12th wk = 21 ± 15 mm, (p < 0.05)  
Secondary analysis (pre minus post)  
Gp1 = 46 mm (45.56 to 56.44 mm), (p < 0.00001)  
Gp2 = 35 mm (22.75 to 47.25 mm), (p < 0.00001)  
Significant post-treatment reduction in LBP in Gp1 and Gp2  
Within-group changes in both groups exceeded MCID | Between-group analysis was not reported  
Secondary analysis  
Gp1 minus Gp2 = -8 mm (-17.02 to 1.02 mm) (p = 0.08)  
No significant difference between Gp1 and Gp2 at the 12th wk  
Between-group difference was smaller than MCID |
| Nabavi et al, 2018            | MCE plus GPT | GE plus GPT | Gp1 MD (95% CI): 33 mm (22 to 43 mm), post-treatment decreases in LBP (p = 0.01)  
Gp2 MD (95% CI): 35 mm (22 to 41 mm), post-treatment decreases in LBP (p = 0.01)  
Significant post-treatment reduction in LBP in Gp1 and Gp2  
Within-group changes in both groups exceeded MCID | Between-group differences: (p = 0.82)  
Gp2 minus Gp1 = 2.0 mm (0.2 to 3.4 mm) (p = 0.82)  
No significant difference between Gp1 and Gp2  
Between-group difference was smaller than MCID |
| Tagliaferri et al, 2020       | MCE + manual therapy | GSA | Gp1: Significant decrease in LBP at 6 (p < 0.05), 8 (p < 0.05), 10 (p < 0.001), 12 (p < 0.001), 14 (p < 0.001), 16 (p < 0.001), 18 (p < 0.01), 20 (p < 0.001), 22 (p < 0.001), and 24 (p < 0.001) weeks.  
Gp2: Significant decrease in LBP at (p < 0.05), 8 (p < 0.05), 10 (p < 0.05), 12 (p < 0.01), 18 (p < 0.01), 20 (p < 0.05), 22 (p < 0.05), 24 (p < 0.01).  
Significant post-treatment reduction in LBP at 6 months in both Gp1 (p < 0.001) and Gp2 (p = 0.008) | Gp1 was better than Gp2 in decreasing LBP at 14 and 16 weeks (p = 0.003)  
No significant difference between Gp1 and Gp2 at 6 months |

**Note:** The bold values indicate the within-group changes exceeded minimal clinical important difference.

**Abbreviations:** 95% CI, 95% confidence interval; FLU, follow-up; GE, general exercises; Gp, group; GPT, general physiotherapy; GSA, general strengthening and aerobic exercises; HLL, High load lifting; LBP, low back pain; MCE, motor control exercise; MCID, minimal clinical important difference; mins, minutes; mm, millimeter; SD, standard deviation; VAS, visual analogue scale; wk, week.
thickness\textsuperscript{24} or CSA\textsuperscript{45} were related to LBP reduction (Table 4). Likewise, no evidence suggested that post-treatment increases in LMM CSA were related to changes in Roland Morris Disability Index scores in patients with acute LBP\textsuperscript{45} (Table 4).

**Protocol Deviations from PROSPERO Registration**

Although the original protocol planned to summarize evidence regarding the effectiveness of various physiotherapy interventions in restoring normal LMM morphology and reducing pain in patients with LBP, the search yielded diverse treatments. Since the initial review question was too broad and MCE was the most commonly studied LBP treatment, we narrowed it down to a more specific research objective. Therefore, the current review focused on the effectiveness of MCE in restoring normal LMM morphology and decreasing pain in people with low back pain.

**Discussion**

This is the first systematic review to summarize the evidence regarding the effects of MCE on LMM morphology, LBP, and the correlations between changes in LMM morphology and LBP intensity or LBP-related disability. Our findings suggest that MCE may be little or no better than other interventions in changing LMM morphology or decreasing pain intensity. Similarly, there is no correlation between changes in LMM morphology and LBP or LBP-related disability.

The weak effects of post-MCE changes in LMM morphology (eg, thickness or CSA) may be related to insufficient exercise dosages (ie, frequency, intensity, type, and duration of MCE). Sokunbi Oluwaleke et al found that thrice weekly MCE for 6 weeks caused significantly greater increases in LMM CSA than once weekly MCE.\textsuperscript{52} Exercise-induced skeletal muscle hypertrophy usually occurs after exercising for at least 6-weeks.\textsuperscript{53} Previous research has shown that muscle strengthening at 2–3 sessions per week yielded significantly greater CSAs of quadriceps and elbow flexors than exercising once-weekly.\textsuperscript{54}

Our findings suggest that the number of treatment sessions rather than exercise types might elicit post-treatment LMM morphological changes. However, there was conflicting evidence regarding whether these post-treatment changes in CSA exceeded the measurement error. Future studies should investigate the dose–response relationship between MCE intervention frequency/duration/intensity and the corresponding changes in LMM morphometry at different lumbar levels to determine optimal treatment dosage.

Interestingly, MCE\textsuperscript{29,45} and high-load lifting exercises\textsuperscript{24} appear to selectively increase the resting thickness\textsuperscript{24} and contracted thickness\textsuperscript{29,24} of LMM on the painful side to reduce asymmetry, which is not uncommon among patients with acute\textsuperscript{12}/chronic LBP.\textsuperscript{14,50} However,
since most of the studies had small sample sizes and short-treatment durations, future large-scale prospective studies with longer follow-ups are warranted to determine the long-term effect of MCE or high-load lifting exercises on restoring LMM symmetry among patients with acute/chronic LBP and to identify the mechanisms underlying the selective muscle hypertrophy.

The current review found low-quality evidence that there were no clinically important differences between MCE and other physiotherapy interventions in reducing CLBP. Our finding concurred with a prior meta-analysis\(^5\) and a Cochrane review,\(^3\) which revealed low- to high-quality evidence that MCE and other interventions had comparable effects on reducing non-specific LBP. However, these findings contradict another meta-analysis of eight studies, which concluded that MCE was more effective than general exercises in decreasing pain in patients with CLBP.\(^6\) The disparity might be ascribed to the differences in measurement scales used in studies to measure pain intensity, treatment duration and dosages, criteria used for exercise progression, and follow-up periods. The discrepancy in results might also be attributed to less patients (n=603) involved in Gomes-Neto et al’s meta-analysis\(^6\) as compared to that of Smith et al\(^5\) (n=2258).

The current review found no evidence to support a significant correlation between changes in LMM morphology and changes in LBP or LBP-related disability.\(^24,45\) These findings differed from that of cohort studies, which found that patients with improved LBP displayed improved LMM morphometry (eg, increased percent thickness change during contraction).\(^57,58\) The discrepancy may be due to the fact that many prior studies only evaluated the immediate post-treatment changes in LMM morphology and LBP intensity without long-term follow-ups. It is plausible that post-treatment morphological changes may be transient or may take time to develop. Future RCTs should clarify the association between temporal changes in LMM morphometry and the corresponding changes in LBP/LBP-related disability at different follow-up time points.

Additionally, while multiple factors may affect the clinical outcomes of patients with CLBP (eg, depression, anxiety, fear avoidance, catastrophizing and sleep),\(^59–61\) all included RCTs in the current review did not adjust for these confounders in their analyses, which might have affected the reported temporal relations. Future studies should conduct path analyses to determine if LMM morphometry may mediate or moderate LBP intensity/LBP-related disability after considering other potential confounders. The findings may help refine assessments and treatments for patients with LBP and concomitant aberrant LMM morphology.

Multiple factors may affect the measured LMM morphometry. First, since LMM thickness is a 2-dimensional measurement, changes in resting/contracted thickness as measured by ultrasonography can be affected by multiple factors (eg, the tightness of surrounding tissues, line of force, etc.).\(^52\) Therefore, LMM CSA measurements may be better to reveal morphometric changes. Second, LMM morphology as measured by ultrasonography is user dependent. The assessors’ experiences may affect the measured results. Unfortunately, all included RCTs did not report the test–retest reliability of their LMM measurements. Although the current review used previously reported MDC\(_{95}\) to determine whether the reported LMM morphometric changes exceed measurement errors, the actual measurement error in each study might differ. Third, changes in LMM CSA as measured on CT scans are not directly related to muscle function, although bigger CSAs are thought to be associated with greater muscle strength. Future studies should evaluate the effects of MCE on LMM function (eg, electromyographic activity) in addition to morphology.

**Strengths and Limitations**

This review had several strengths. Comprehensive literature searches in 6 databases, standardized screening, data extraction, and methodological quality assessments of the studies were performed to ensure proper extraction and evaluation of data. The study protocol was registered with PROSPERO, while the reporting of the review followed the PRISMA guideline to ensure credibility and comprehensiveness of data. Further, since this review only included RCTs, our conclusion was drawn based on studies with the highest level of evidence.

Our review had some limitations. First, given the heterogeneity of outcome measures, exercise intensity, and underreporting of the side of LMM morphology in the included studies, no meta-analysis was conducted. Future studies should standardize the reporting/definition of LMM morphology and interventions to enable meta-analyses. Second, the sample sizes of the RCTs were small, ranging from 30\(^29,47\) to 122,\(^46\) which might have limited the statistical power. Future research should estimate the sample size based on the effect sizes of existing studies to ensure sufficient power to detect post-treatment
changes in LMM morphology. Third, only RCTs published in English were included. Future systematic reviews should include non-English publications to improve the generalizability of findings. Fourth, the mean age of participants in the RCTs ranged from 30.9 to 50.8 years. Our findings may not be generalized to younger/older patients with LBP.

Conclusions
There is preliminary evidence that MCE may change LMM morphology, although it may be dose dependent. Specifically, 36 or more sessions of MCE may increase LMM CSA in patients with CLBP. However, existing evidence does not support that MCE is more effective than other exercises in treating acute/chronic LBP. That said, future research is warranted to determine the effects of MCE on segmental or global morphometry (including intramuscular fatty infiltration) of LMM and clinical outcomes, as well as to quantify the causal relationships between changes in LMM morphology and LBP/LBP-related disability.

Author Contributions
All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agreed to be accountable for all aspects of the work.

Disclosure
This work was funded by Early Career Scheme (251018/17M). The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The content of the manuscript has not been published or submitted for publication elsewhere. There are no financial or other relationships that has a direct financial interest in any matter included in this manuscript. Jaro Karppinen reports personal fees from Pfizer, outside the submitted work. The authors report no other potential conflicts of interest for this work.

References
1. Koes B, Van Tulder M, Thomas S. Diagnosis and treatment of low back pain. *BMJ*. 2006;332(7555):1430–1434. doi:10.1136/bmj.332.7555.1430
2. Nabavi M, Mohseni Bandpei MA, Mosallanezhad Z, Rahgozar M, Jaberzadeh S. The effect of 2 different exercise programs on pain intensity and muscle dimensions in patients with chronic low back pain: a randomized controlled trial. *J Manipulative Physiol Ther*. 2018;41(2):102–110. doi:10.1016/j.jmpt.2017.03.011
3. Vos T, Abajobir AA, Abate KH, et al. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet*. 2017;390(10100):1211–1259. doi:10.1016/s0140-6736(17)32154-2
4. Hartvigsen J, Hancock MJ, Kongsted A, et al. What low back pain is and why we need to pay attention. *Lancet*. 2018;391(10137):2356–2367. doi:10.1016/s0140-6736(18)30480-x
5. Refshauge KM, Maher CG. Low back pain investigations and prognosis: a review. *Br J Sports Med*. 2006;40(6):494-498. doi:10.1136/bjsm.2004.016659
6. Hodges PW, Richardson CA. Inefficient muscular stabilization of the lumbar spine associated with low back pain. A motor control evaluation of transversus abdominis. *Spine*. 1996;21(22):2640–2650. doi:10.1097/00007632-199611150-00014
7. Freeman MD, Woodham MA, Woodham AW. The role of the lumbar multifidus in chronic low back pain: a review. *PM R*. 2010;2(2):142–146; quiz 141 p following 167. doi:10.1016/j.pmrj.2009.11.006
8. Panjabi MM. The stabilizing system of the spine. Part II. Neutral zone and instability hypothesis. *J Spinal Disord*. 1992;5(4):390–397. doi:10.1097/00008709-199206000-00003
9. Moseley GL, Hodges PW, Gandevia SC. Deep and superficial fibers of the lumbar multifidus muscle are differentially active during voluntary arm movements. *Spine*. 2002;27(2):E29–E36. doi:10.1097/00007632-200201150-00013
10. Belavy DL, Armbrrecht G, Richardson CA, Felsenberg D, Hides JA. Muscle atrophy and changes in spinal morphology: is the lumbar spine vulnerable after prolonged bed-rest? *Spine*. 2011;36(2):137–145. doi:10.1097/BRS.0b013e3181ce93e8
11. Danneels LA, Vanderstraeten GG, Cambier DC, Witvrouw EE, De Cuyper HJ, Danneels L. CT imaging of trunk muscles in chronic low back pain patients and healthy control subjects. *Eur Spine J*. 2000;9(4):266–272. doi:10.1007/s005860000190
12. Hides J, Gilmore C, Stanton W, Bohlscheid E. Multifidus size and symmetry among chronic LBP and healthy asymptomatic subjects. *Man Ther*. 2008;13(1):43–49. doi:10.1016/j.math.2006.07.017
13. Kamarz M, Kiresi D, Oguz H, Emlik D, Levendoglu F. CT measurement of trunk muscle areas in patients with chronic low back pain. *Diagn Interv Radiol*. 2007;13(3):144.
14. Parkkola R, Rytkoski U, Kormano M. Magnetic resonance imaging of the discs and trunk muscles in patients with chronic low back pain and healthy control subjects. *Spine*. 1993;18(7):830–836. doi:10.1097/00007632-199306000-00004
15. Gildea JE, Hides JA, Hodges PW. Size and symmetry of trunk muscles in ballet dancers with and without low back pain. *J Orthop Sports Phys Ther*. 2013;43(8):525–533. doi:10.2519/jospt.2013.4523
16. Teichtahl AJ, Urquhart DM, Wang Y, et al. Fat infiltration of paraspinal muscles is associated with low back pain, disability, and structural abnormalities in community-based adults. *Spine J*. 2015;15(7):1593–1601. doi:10.1016/j.spinee.2015.03.039
17. Mengiardi B, Schmid MR, Boos N, et al. Fat content of lumbar paraspinal muscles in patients with chronic low back pain and in asymptomatic volunteers: quantification with MR spectroscopy. *Radiology*. 2006;240(3):786–792. doi:10.1148/radiol.2403050820
18. Kjaer P, Bendix T, Sorensen JS, Korsholm L, Leboeuf-Yde C. Are MRI-defined fat infiltrations in the multifidus muscles associated with low back pain? *BMC Med*. 2007;5(2). doi:10.1186/1741-7015-5-2
19. Zhang S, Xu Y, Han X, Wu W, Tang Y, Wang C. Functional and morphological changes in the deep lumbar multifidus using electromyography and ultrasound. *Sci Rep*. 2018;8(1):6539. doi:10.1038/s41598-018-24550-5
20. Sweeney N, O’Sullivan C, Kelly G. Multifidus muscle size and percentage thickness changes among patients with unilateral chronic low back pain (CLBP) and healthy controls in prone and standing. *Man Ther.* 2014;19(3):433–439. doi:10.1016/j.math.2014.04.009

21. Kiesel KB, Underwood FB, Mattacola CG, Nitz AJ, Malone TR. A comparison of select truncus muscle thickness change between subjects with low back pain classified in the treatment-based classification system and asymptomatic controls. *J Orthop Sports Phys Ther.* 2007;37(10):598–607. doi:10.2519/jospt.2007.2574

22. Paalanne N, Niinimaki J, Karppinen J, et al. Assessment of association between low back pain and paraspinous muscle atrophy using opposed-phase magnetic resonance imaging: a population-based study among young adults. *Spine.* 2011;36(23):1961–1968. doi:10.1097/BRS.0b013e3181f6f890

23. Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine.* 1994;19(2):165–172. doi:10.1097/00007632-199401010-00009

24. Berglund L, Aasa B, Michaelson P, Aasa U. Effects of low-load motor control exercises and a high-load lifting exercise on lumbar multifidus thickness: a randomized controlled trial. *Spine.* 2017;42(15):E876–E882. doi:10.1097/BRS.0000000000001989

25. Chung S, Lee J, Yoon J. Effects of stabilization exercise using a ball on multifidus cross-sectional area in patients with chronic low back pain. *J Sports Sci Med.* 2013;12(3):533.

26. Sipaviceni S, Kliziene I, Pozeriene J, Zaicenkoviene K. Effects of a twelve-week program of lumbar-stabilization exercises on multifidus muscles, isokinetic peak torque and pain for women with chronic low back pain. *J Pain Relief.* 2017;37(01):01. doi:10.4172/2167-0846.1000039

27. Huang Q, Li D, Yokotsuka N, et al. The intervention effects of stabilization and McKenzie exercises on transverse abdominis muscle on lumbar multifidus muscle wasting ipsilateral to symptoms in patients with low back pain. *Spine.* 2011;36(23):1961–1968. doi:10.1097/BRS.0b013e3181f6f890

28. Paalanne N, Niinimaki J, Karpinnen J, et al. Assessment of association between low back pain and paraspinous muscle atrophy using opposed-phase magnetic resonance imaging: a population-based study among young adults. *Spine.* 2011;36(23):1961–1968. doi:10.1097/BRS.0b013e3181f6f890

29. Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine.* 1994;19(2):165–172. doi:10.1097/00007632-199401010-00009

30. Chung S, Lee J, Yoon J. Effects of stabilization exercise using a ball on multifidus cross-sectional area in patients with chronic low back pain. *J Sports Sci Med.* 2013;12(3):533.

31. Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH. Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine.* 1994;19(2):165–172. doi:10.1097/00007632-199401010-00009

32. Saragiotto BT, Maher CG, Yamato TP, et al. Motor control exercise versus general exercise on lumbar local stabilizing muscles for nonspecific low back pain: a Cochrane review. *J Clin Med.* 2014;35(3):186–191. doi:10.1136/bmjmed-2017-110668

33. McHugh ML. Interrater reliability: the kappa statistic. *J Sports Sci Med.* 2010;9(6):1726. doi:10.3390/jcm9061726

34. Tagliaferri SD, Miller CT, Ford JJ, et al. Randomized trial of general strength and conditioning versus motor control and manual therapy for chronic low back pain on physical and self-report outcomes. *J Clin Med.* 2020;9(6):1726. doi:10.3390/jcm9061726

35. Wilson A, Hides JA, Blizard L, et al. Measuring ultrasound images of abdominal and lumbar multifidus muscles in older adults: a reliability study. *Man Ther.* 2016;23:114–119. doi:10.1016/j.math.2016.01.004

36. Hides JA, Richardson CA, Jull GA. Multifidus muscle recovery is not automatic after resolution of acute, first-episode low back pain. *Spine.* 1996;21(23):2763–2769. doi:10.1097/00007632-199612100-00011

37. Akodu A, Akinbo S, Odebiyi D. Effect of stabilization exercise on lumbar multifidus muscle thickness in patients with non-specific chronic low back pain. *Iran Rehabil J.* 2014;12(2):6–10.

38. Kim G-Y, Kim S-H. Effects of push-ups plus sling exercise on muscle activation and cross-sectional area of the multifidus muscle in patients with low back pain. *J Phys Ther Sci.* 2013;25(12):1575–1578. doi:10.1589/jpts.25.1575

39. Lee W, Lee Y, Gong W. The effect of lumbar strengthening exercise on pain and the cross-sectional area change of lumbar muscles. *J Phys Ther Sci.* 2011;23(2):209–212. doi:10.1589/jpts.23.209

40. Tagliaferri SD, Miller CT, Ford JJ, et al. Randomized trial of general strength and conditioning versus motor control and manual therapy for chronic low back pain on physical and self-report outcomes. *J Clin Med.* 2020;9(6):1726. doi:10.3390/jcm9061726

41. Wallwork TL, Stanton WR, Freke M, Hides JA. The effect of chronic low back pain on size and contraction of the lumbar multifidus muscle. *Man Ther.* 2009;14(5):496–500. doi:10.1016/j.math.2008.09.006

42. Haefeli M, Elfering A. Pain assessment. *Eur Spine J.* 2006;15(Suppl 1):S17–S24. doi:10.1007/s00586-005-1044-x

43. Sokumbi Oluwaleke WP, Moore A. A randomised controlled trial comparing the effects of frequency of application of spinal stabilisation exercises on multifidus cross sectional area (MFCSA) in participants with chronic low back pain. *Physiother Singapore.* 2008;11(2):9–16.

44. Staron R, Karapondo D, Kraemer W, et al. Skeletal muscle adaptations during early phase of heavy-resistance training in men and women. *J Appl Physiol.* 1994;76(3):1247–1255. doi:10.1152/jappl.1994.76.3.1247

45. Mangine GT, Hoffman JR, Gonzalez AM, et al. The effect of training volume and intensity on improvements in muscular strength and size in resistance-trained men. *Physiol Rep.* 2015;3(8):e12472. doi:10.14814/phy2.12472
55. Smith BE, Littlewood C, May S. An update of stabilisation exercises for low back pain: a systematic review with meta-analysis. BMC Musculoskelet Disord. 2014;15(1):416. doi:10.1186/1471-2474-15-416

56. Gomes-Neto M, Lopes JM, Conceicao CS, et al. Stabilization exercise compared to general exercises or manual therapy for the management of low back pain: a systematic review and meta-analysis. Phys Ther Sport. 2017;23:136–142. doi:10.1016/j.ptsp.2016.08.004

57. Wong AY, Parent EC, Funabashi M, Kawchuk GN. Do changes in transversus abdominis and lumbar multifidus during conservative treatment explain changes in clinical outcomes related to nonspecific low back pain? A systematic review. J Pain. 2014;15(4):377 e371–335. doi:10.1016/j.jpain.2013.10.008

58. Wong AY, Parent EC, Dhillon SS, Prasad N, Kawchuk GN. Do participants with low back pain who respond to spinal manipulative therapy differ biomechanically from nonresponders, untreated controls or asymptomatic controls? Spine. 2015;40(17):1329–1337. doi:10.1097/BRS.0000000000000981

59. Sribastav SS, Peiheng H, Jun L, et al. Interplay among pain intensity, sleep disturbance and emotion in patients with non-specific low back pain. PeerJ. 2017;5:e3282. doi:10.7717/peerj.3282

60. Wertli MM, Burgstaller JM, Weiser S, Steurer J, Kofmehl R, Held U. Influence of catastrophizing on treatment outcome in patients with nonspecific low back pain: a systematic review. Spine. 2014;39(3):263–273. doi:10.1097/BRS.000000000000110

61. Werneke MW, Hart DL, George SZ, Stratford PW, Matheson JW, Reyes A. Clinical outcomes for patients classified by fear-avoidance beliefs and centralization phenomenon. Arch Phys Med Rehabil. 2009;90(5):768–777. doi:10.1016/j.apmr.2008.11.008

62. Sions JM, Velasco TO, Teyhen DS, Hicks GE. Ultrasound imaging: intraexaminer and interexaminer reliability for multifidus muscle thickness assessment in adults aged 60 to 85 years versus younger adults. J Orthop Sports Phys Ther. 2014;44(6):425–434. doi:10.2519/jospt.2014.4584