Lumbopelvic Neuromuscular Training and Injury Rehabilitation: A Systematic Review

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Objective: The aim of this systematic review was to assess the evidence for lumbopelvic neuromuscular training (LNMT) in individuals after musculoskeletal (MSK) injury.

Data Sources: A literature search of PubMed and EMBASE databases was performed for English studies from January 1990 to March 2012. Search terms including and related to trunk, core, stability, injury, and LNMT were used.

Study Selection: All studies directly involving LNMT for MSK injuries were reviewed by 2 authors. These articles were assessed based on the inclusion criteria and if appropriate selected for further analysis. Expert opinion, review articles, and articles involving non-MSK injuries were excluded. Four authors then scored the selected articles for methodological quality. A total of 2312 articles were initially identified. Twenty-nine articles met the inclusion criteria for review and were divided into categories of lower extremity (LE), lumbar, and upper extremity (UE). No trials involving the UE met the inclusion criteria.

Data Extraction: Data including subject demographics (age, height, weight, gender, etc), injury type, intervention type, and outcome measurements were extracted from the relevant articles. A variety of baseline and follow-up scores were extracted including pain levels, patient satisfaction, disability questionnaires, and other functional outcomes.

Data Synthesis: Two out of 3 LE randomized controlled trials (RCTs) and 9/26 lumbar RCTs were rated with high methodological quality based on the scoring system described by van Tulder et al. The average quality score for the LE RCTs was 6.3 (range = 4–9) and for the lumbar RCTs was 5.1 (range = 2–9). The evidence for the effectiveness of the 3 LE studies was rated as conflicting, whereas 24 lumbar studies demonstrated moderate-to-strong evidence. Unfortunately, heterogeneity of populations, interventions, and outcomes precluded a quantitative meta-analysis and specific clinical recommendations.

Conclusions: High-quality evidence is lacking to make specific clinical recommendations for or against the use of LNMT in the rehabilitation of individuals after MSK injury. Based on this review, future research should focus on well-defined, homogeneous populations, interventions specifically addressing neuromuscular activation of the lumbopelvic musculature, patient-specific clinical outcomes, measures of motor control, biomechanics, and return to specific activities.

Key Words: physical therapy, sports rehabilitation programs, lower extremity injuries, soft tissue injuries, back injuries

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INTRODUCTION

Physicians, physical therapists, and athletic trainers commonly prescribe and use techniques targeting what is commonly known as the "core" or "trunk" for the treatment of musculoskeletal (MSK) injuries.[1–8] However, the acceptance of such training has come without a firm body of scientific evidence to support its efficacy and without clear, consistent definitions.[6,9,10] Lack of evidence and inconsistency makes prescribing specific clinical interventions and interpreting outcomes of those interventions difficult. Thus, quantitative evidence in this area can potentially create a very large impact on the practice of rehabilitative medicine and ultimately enhance patient care.

The purpose of this study was to systematically review the evidence for training/rehabilitation programs targeting the core or trunk in individuals after MSK injury to determine if clinical evidence-based recommendations can be made and to provide recommendations for future research. For consistency and clarity, the term lumbopelvic neuromuscular training (LNMT), versus core training or otherwise, will be used as it encompasses the regions of the hips, pelvis, lumbar vertebrae, all articulations adjacent to or connecting these segments, and the muscles that actively cause movement across these articulations. Interventions for nonspecific, mechanical low back pain (LBP) were included in this systematic review because many of these injuries have an etiology based on injury rather than on disease. Further, LNMT interventions

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used in treating those with LBP may be applicable or extendable to treatment of other MSK injuries.

METHODS

Two researchers (M.B., A.C.) independently searched PubMed and EMBASE for articles published in English between January 1990 and March 2012. A search strategy was developed in consultation with a medical librarian and adapted to the databases (Table 1). The research protocol and methods were based on those described and discussed by van Tulder et al,[11] Wright et al,[12] and Moher et al.[13]

The title, abstract, and keywords of the identified studies were examined by the 2 reviewers (M.B., A.C.) to determine whether they met inclusion/exclusion criteria (Table 2). The results were compared at each of the above stages, and differences between reviewers were resolved by consensus. The methodological quality of all eligible studies and levels of evidence (Table 3) were independently examined by 4 reviewers (M.B., A.C., T.B., and D.G.) based on van Tulder et al.[11] Relevant information of the selected studies was extracted by 2 independent reviewers (M.B., A.C.) using predetermined extraction forms. Unfortunately, the diversity among studies in regard to injury (acuity, chronicity, severity, and location), interventions (frequency, intensity, volume, and setting), outcome measures, and methodological quality precluded a quantitative meta-analysis and effect size calculation.

RESULTS

Ultimately, 29 articles meeting the search criteria were accepted in this review (Figure 1). For ease of interpretation, these were divided into the following categories: lower extremity (LE), lumbar, and upper extremity (UE). The methodological quality scores of the randomized controlled trials (RCTs)/controlled clinical trials (CCTs) are shown in Table 4.[11]

TABLE 1. Search Strategy for PubMed

Specific Search	Term Combination	Items Identified
"Body region"	Ankle or foot or knee or hip or "LE" or lumbar or back or shoulder or elbow or wrist or hand or "UE"	497 757
"Lumbopelvic terms"	Trunk or core or lumbopelvic or spine	246 883
"Training characteristic"	Strength or stability or neuromuscular or control or stabilization	1 613 558
"Intervention"	Training or rehabilitation or "physical therapy" or physiotherapy or intervention or exercise	1 006 591
"Injury"	Injury or pain	812 622
Final search	Body region and lumbopelvic terms and training characteristic and intervention and injury	2284

The final search was limited to English text, human subjects, and between dates January 1, 1990, and March 15, 2012, with duplicates being removed. A similar search strategy was employed for EMBASE.

TABLE 2. Study Inclusion and Exclusion Criteria

Inclusion criteria		
	Study type	RCT
		CCT
	Population	Ages: 13–65 y
		Rehabilitation after MSK injury/diagnosis/repair/reconstruction: LBP, tendonopathy, strain, sprain, fracture, diskectomy, etc
	Interventions	Rehabilitation exercises targeting: core, trunk, or "lumbopelvic region"
	Outcomes	Any combination of the following: injury rate, postural control, proprioception, pain, range of motion, swelling, muscle strength, disability questionnaires, return to activity/sport, any component of the International Classification of Functioning, Disability, and Health
Exclusion criteria		
	Study type	Focused on injury prevention, risk assessment, or performance outcomes without injury
	Systemic diseases	Multiple sclerosis, osteoporosis, Guillian–Barre syndrome, etc
	Non-MSK conditions	Scoliosis, pregnancy, neural tube defects, etc
	Neurologic injury	Stroke, spinal cord injury, brain injury, paresis, radiculopathy, etc.
		LBP with neurological inclusion symptoms (eg, stenosis, leg pain, sciatica, radiculopathy)
	Boney surgery	Joint fusions, displaced fractures, joint replacements, etc
	Orthoses/prosthetics	Shoe orthotic

Inclusion/exclusion criteria were assessed at each stage of the systematic review process (Figure 1).

Two out of the 3 articles related to the LE and 9 of the 26 RCT/CCT related to the lumbar region were rated as "high quality."[11] There were no RCT/CCT identified related to the UE. Subjects, interventions, and outcomes were summarized (Tables 5 and 6). Table 7 lists other outcome measures that were used in studies but which results were not summarized in Tables 5 and 6 as they are either not commonly or feasibly performed clinically or not directly related to lumbopelvic neuromuscular control interventions.

Effectiveness of Interventions

Lower Extremity

Three RCTs met the criteria to be included for the LE with an average quality score of 6.3 (range = 4–9). Based on these 3, the evidence for the use of LNMT after LE injury is

TABLE 3. Levels of Evidence[11]

Strong	Consistent findings among multiple high-quality RCTs
Moderate	Consistent findings among multiple low-quality RCTs and/or 1 high-quality RCT
Limited	One low-quality RCT
Conflicting	Inconsistent findings among multiple trials
No evidence	No RCTs

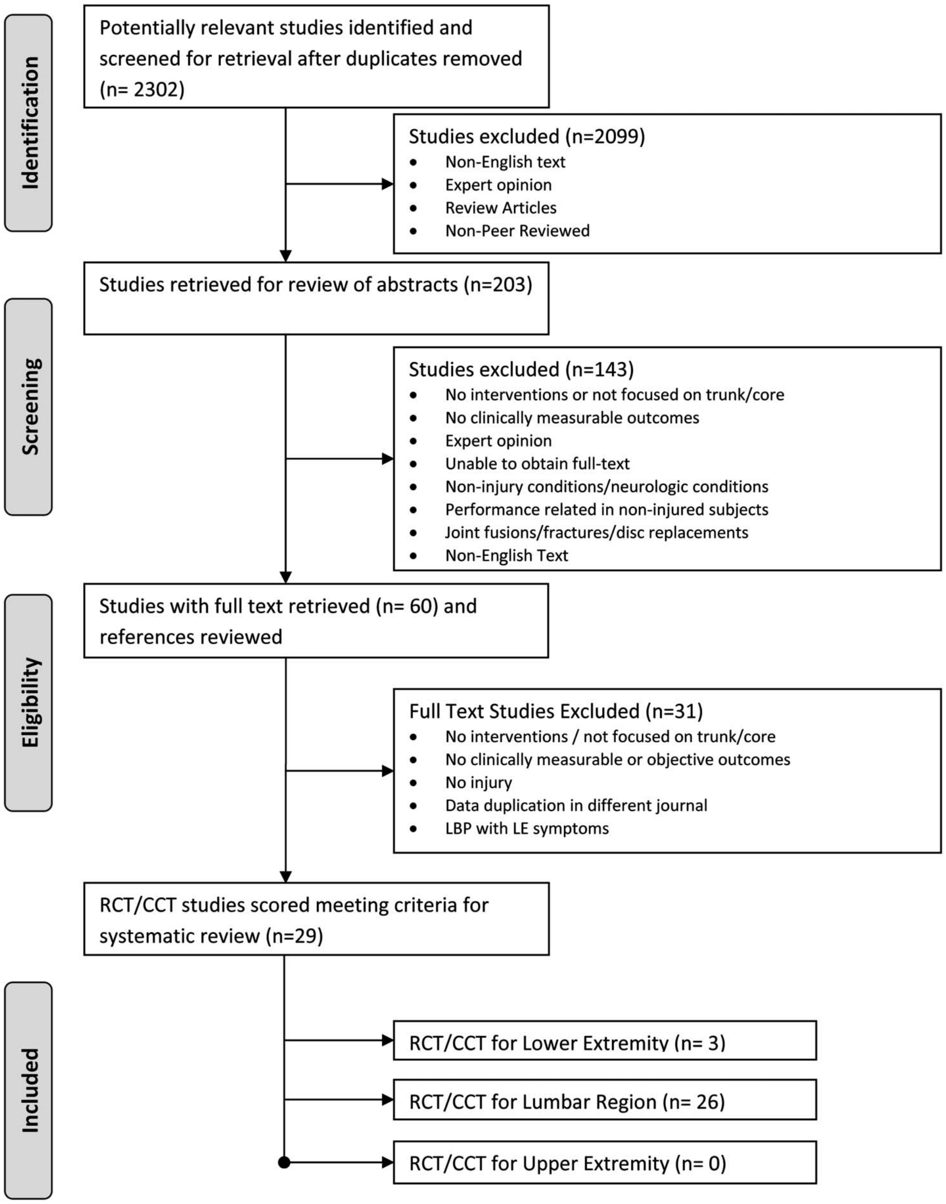

FIGURE 1. Flow diagram of selected studies for systematic review.

conflicting (Table 5). The study populations included those with menisectomies, hamstring strains, and anterior cruciate ligament insufficiency. The number of subjects per group was low, ranging from 11 to 23.

Treatment interventions varied across groups but consistently included "functional" stabilization of the lumbopelvic region. Examples of described interventions included "agility/trunk stabilization,"[41] and "functional training of the trunk, abdominals, and leg."[42] These interventions were often combined with others including patient education, LE strengthening, agility exercises, stretching/flexibility, balance, and proprioception. Frequency, intensity, duration, and volume of the interventions varied across trials. The definition of LNMT also varied across trials and included isolated muscle activation, static holds, and activities incorporating functional movement. The length of outcome follow-up was short and varied from 2 weeks to 4 months. Related outcomes included pain, isokinetic strength testing, agility/hop testing, functional questionnaires, and return to activity. Overall, the outcomes for the subjects were positive.

Lumbar Region

Twenty-six RCT/CCTs related to the lumbar region were found (Table 6). Of the 26 studies, 24 were specific to LBP, whereas the remaining 2 involved postoperative rehabilitation after lumbar diskectomy.[29,38] The average quality score was 5.1 (range = 2–9). Seven studies showed strong evidence, and 17 showed moderate evidence for the effectiveness of LNMT. Conversely, 2 studies were categorized as showing strong evidence for the ineffectiveness of LNMT.[14,17] The number of subjects per group varied from 11 to 156. Further, 2 of the articles (Kuukkanen and Malkia[31,32]) included results from

TABLE 4. Methodological Quality Assessment of RCT/CCTs Based on 11 Validity Criteria Adapted From van Tulder et al[11]

	Quality Criteria[11]											
First Author	**Adequate Randomization**	**Allocation Concealment**	**Prognostic Similarity**	**Subject Blinding**	**Therapist Blinding**	**Assessor Blinding**	**Cointerventions Avoided or Similar**	**Acceptable Compliance**	**Acceptable and Described Dropout Rate (<30%)**	**Similar Outcome Assessment Timing**	**Intention to Treat Analysis**	**"Quality" (# of "Yes" Scores)**
Lumbar region												
Koumantakis et al[14]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	9
Moffett et al[15]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	9
Yeung et al[16]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	9
Harts et al[17]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	N	8
Shirado et al[18]	Y	Y	Y	N	N	Y	Y	?	Y	Y	Y	8
Franca et al[19]	Y	Y	Y	N	N	Y	Y	?	Y	Y	?	7
Jay et al[20]	Y	?	Y	N	N	?	Y	Y	Y	Y	Y	7
Hides et al[21]	Y	?	Y	N	N	Y	?	Y	Y	Y	Y	7
Ahlqwist et al[22]	Y	N	Y	N	N	Y	Y	?	Y	Y	N	6
Bentsen et al[23]	Y	Y	Y	N	N	?	Y	?	N	Y	N	5
Suni et al[24]	Y	N	Y	N	N	N	N	Y	Y	Y	N	5
Mellin et al[25]	Y	?	Y	N	N	N	N	Y	Y	Y	N	5
Mellin et al[26]	Y	?	Y	N	N	N	N	Y	Y	Y	N	5
Mannion et al[27]	Y	?	Y	N	N	?	?	Y	Y	Y	N	5
Mohseni-Bandpei et al[28]	Y	?	Y	N	N	?	Y	?	Y	Y	N	5
Yilmaz et al[29]	Y	N	Y	N	N	?	Y	?	?	Y	N	4
Kofotolis and Kellis[30]	Y	?	Y	N	N	?	Y	?	N	Y	N	4
Kuukkanen and Malkia* [31]	N	N	Y	N	N	?	Y	Y	N	Y	N	4
Kuukkanen and Malkia* [32]	N	N	Y	N	N	?	Y	Y	N	Y	N	4
Norris and Matthews[33]	N	N	Y	N	N	?	Y	Y	N	Y	N	4
Asfour et al[34]	Y	?	Y	N	N	?	Y	?	?	?	N	3
Karimi et al[35]	Y	?	Y	?	N	?	Y	?	N	Y	N	3
Lee et al[36]	Y	?	Y	N	N	?	N	?	?	Y	?	3
Takemasa et al[37]	N	N	N	N	N	N	N	?	Y	Y	N	2
Johannsen et al[38]	Y	?	?	N	N	?	?	?	N	Y	N	2
Harringe et al[39] and Ahlqwist et al[22]	N	N	N	N	N	N	N	Y	N	Y	N	2
LE												
Ericsson et al[40]	Y	Y	Y	N	N	Y	Y	Y	Y	Y	Y	9
Sherry et al[41]	Y	N	Y	?	N	N	Y	Y	Y	Y	N	6
Zatterstrom et al[42]	N	N	Y	N	N	N	N	Y	Y	Y	N	4
UE												
None	—	—	—	—	—	—	—	—	—	—	—	0

At least 50% "yes" scores (6 out of 11 of the criteria) were needed to obtain "high-quality" status.[11]
*Different subsets of results from same RCT reported in 2 different articles.
N, no; Y, yes; ?, do not know/unclear.

TABLE 5. Evidence Synthesis for LE RCT/CCTs Categorized Based on the Levels of Evidence[11]

Study (Diagnosis/Condition)	Intervention Groups (n)/ Demographics [Mean (SD)]	Outcomes/Group Differences
Conflicting evidence on effectiveness/ineffectiveness (inconsistent findings among multiple trials)[11,26]		
Ericsson et al[40] (menisectomies)	1. Exercise (functional stability and proprioception) (22), age 45.4 ± 3.2; BMI: 26.1 ± 3.7; sex: 15/7	4 mos (group mean change scores ± SD)
		1-Legged Hop for Distance (cm): G1: [8 ± 10]; G2: [2 ± 7]; difference between groups, $P = 0.040$
	2. Control—no intervention (23); age: 45.9 ± 3.2; BMI: 26.6 ± 2.9; sex: 14/9	*1-Leg Rise* (number): G1: [7 ± 15]; G2: [3 ± 9]; difference between groups, $P = 0.283$
		Square Hop (number): G1: [3 ± 4]; G2: [1 ± 3]; difference between groups, $P = 0.069$
Sherry and Best[41] (hamstring strains)	1. Stretching/hamstring strengthening/ice (11), age: 24.3 ± 12.4; BMI: -; sex: 9/2	*Rehabilitation to Return to Sports* [mean days ± SD]: G1: [33.3 ± 25.9]; G2: [18.8 ± 9.4], ($P = 0.2455$)
	2. Agility/trunk stabilization (13), age: 23.2 ± 11.1; BMI: -; sex: 9/4	*2 wks/1 y Injury Reoccurrence* [injury number (%)]. G1: [6 (54.5%)/7 (70.0%)]; G2: [0 (0%)/1 (7.7%)]; likelihood to reinjury less in G2 vs G1 ($P = 0.00343$/$P = 0.0059$)
		Hop for Height (involved to uninvolved %): G1: [96.1 ± 13.5]; G2: [104.9 ± 16.4]; $P = 0.0637$ between groups
		Hop for Distance: (involved to uninvolved %) NS between groups:G1: [99.4 ± 6.7]; G2: [98.9 ± 6.2]; $P = 0.7943$ between groups
		4 Hop Crossover Test (cm): G1: [99.61 ± 9.3]; G2: [98.0 ± 4.6]; $P = 0.920$ between groups
		40-yd Sprint—second trial (s): G1: [5.9 ± 1.6]; G2: [5.7 ± 0.7]; $P = 0.5181$
Zatterstrom et al[42] (anterior cruciate ligament insufficiency)	1. Quadriceps strengthening (9), age: 27.4 ± -; BMI: -; sex: 4/5	3 mos [Group mean ± SD]
	2. Functional training of trunk, abdominals, and leg (17), age: 23.6 ± -; BMI: -; sex: 10/7	*1-Leg Hop Test (cm):* (NS between groups; $P > 0.05$): Injured: G1: [127 ± 29]; G2: [142 ± 43]; overall increase in both groups; G1 differences present in injured vs uninjured leg; $P < 0.05$
		3 mos: Lysholm Score (NS between groups; $P > 0.05$): G1: [76.4 ± 12.5]; G2: [71.8 ± 12.4]

Functional outcomes related to LNMT are listed when available with results listed as mean ± SD unless noted otherwise. Mean differences and confidence intervals are reported when available. Mean BMI (kg/m^2), age (years ± SD), and sex (m/f) demographics are used to describe the study samples.

BMI, body mass index; G, group; NS, not significant; -, no information provided.

the same RCT but reported different subsets of outcomes in 2 different journals related to the same study.

A variety of different interventions that may be defined as LNMT were used in the studies. These included but were not limited to lumbar stabilization,[14] specific segmental control exercises,[39] integrated back stability program,[33] trunk strengthening,[38] back exercise,[16] and muscle reconditioning.[27] Often, these exercises were combined with other interventions (eg, patient education, aerobic exercise, general exercise, stretching, range of motion, and home exercise). Again, the frequency, intensity, duration, volume, and setting (eg, outpatient clinic, inpatient facility, or home) of the interventions varied across trials.

Outcome measures also varied, most often including pain, disability questionnaires (eg, Oswestry, Roland Morris), trunk strength, trunk endurance, trunk and hip mobility, and return to activity as outcomes. Methodologies for the recording of these measures were inconsistent. In addition, the reporting of results was also inconsistent across trials.

Upper Extremity

No RCT/CCTs were found based on our searches related to LNMT and outcomes in rehabilitation related to the UE. Thus, according to the levels of evidence,[11] there is no evidence to support the use of LNMT in the rehabilitation of UE MSK injury.

DISCUSSION

To our knowledge, no systematic review or meta-analysis has been performed to assess the effectiveness of LNMT in rehabilitation. Our results indicate that overall there is a paucity of high-quality evidence supporting or refuting the use of LNMT and its role in the rehabilitation of individuals after MSK injury. We were unable to calculate effect sizes or perform a meta-analysis based on the heterogeneity of studies and results. Based on this, our conclusions are founded on the quality of RCT/CCTs available.[11]

TABLE 6. Evidence Synthesis for Lumbar Region RCT/CCTs Categorized Based on the Levels of Evidence[11]

Study (Diagnosis/Condition)	Intervention Groups (n)/ Demographics [Mean (SD)]	Outcomes/ Group Differences
Strong evidence for ineffectiveness (consistent findings among multiple high-quality RCTs)[11,26]		
Koumantakis et al[14] (recurrent LBP)	1. Lumbar stabilization (29), age: 39.2 ± 11.4; BMI: 26.2 ± 4.2; sex: - 2. General exercise (26), age: 35.2 ± 9.7; BMI: 26.4 ± 3.2; sex: -	20 wks [Between group mean difference (95% CI)] *Short Form McGill Pain Questionnaire* (total score): [−1.91 (−5.89 to 2.07)]; $P > 0.05$ *Visual Analog Scale-Pain* (past wk/past mo) [2.62 (−4.58 to 9.82)]; $P > 0.05$/[0.28 (−14.45 to 15.00)]; $P > 0.05$ *Roland Morris Disability Questionnaire* [1.38 (−0.87 to 3.64)]; $P > 0.05$
Harts et al[17] (chronic LBP)	1. High-intensity lumbar extension group* (23), age: 44 (10); BMI: -; sex: 23/0 2. Low-intensity lumbar extension group* (21), age: 42 (10); BMI: -; sex: 21/0 3. Wait list group (21), age: 41 (9); BMI: -; sex: 21/0	0/8/24 wks [Between groups mean difference (95% CI)] *Global Perceived Improvement* (added G3 to intervention = G^) ($P > 0.05$): 0 to 8 wks: [G1 to G2: 17 (−9 to 43); G1 to G3: 39 (14 to 64); G2 to G3: 22 (−4 to 47)]; 0–8 wks: [G^1 to G^2: 13 (−14 to 40)]; 0–24 wks: [G^1 to G^2: −3 (−22 to 16)] *Roland Morris Disability Questionnaire ($P > 0.05$):* 0–8 wks: [G1 to G2: −1.7 (−4.3 to 0.9); G1 to G3: −1.4 (−4.0 to 1.1); G2 to G3: 0.3 (−2.3 to 2.8)]; 0–8 wks: [G^1 to G^2: −0.09 (−3.2 to 1.4)]; 0–24 wks: [G^1 to G^2: 0.9 (−0.7 to 2.4)]
Strong evidence for effectiveness (consistent findings among multiple high-quality RCTs)[11,26]		
Moffett et al[15] (LBP)	1. Exercise therapy with stretching, aerobics, and strengthening exercises of main muscle groups encouraging "normal" movement of spine (89), age: 41.1 ± 9.21; BMI: -; sex: 38/51 2. Control with continued care under physician (98), age: 42.6 ± 8.62; BMI: -; sex: 43/55	6 wks/6 mos/12 mos [Between group mean difference (95% CI)] *Aberdeen Back Pain Scale* ($P \leq 0.05$ all time points except 6 mos): [0.92 (−0.37 to 5.55)]/[2.15 −1.63 to 5.93)]/[4.44 (1.01–7.87)] *Roland Disability Questionnaire* ($P \leq 0.05$ all time points except 6 wks): [0.92 (−0.02 to 1.87)]/[1.35 (0.13–2.57)]/[1.42 (0.29–2.56)] *Euro Quality of Life Health Index* ($P > 0.05$ all time points): [−0.01 (−0.09 to 0.07)]/[−0.01 (0.06–0.04)]/[−0.02 (−0.08 to 0.04)]
Yeung et al[16] (chronic LBP)	1. Back exercise (26), age: 55.6 ± 10.4; BMI: -; sex: 5/21 2. Back exercise with electro-acupuncture (26), age: 50.4 ± 16.3; BMI: -; sex: 4/22	Posttreatment/post 1 mo/post 3 mos [group mean change scores ± SD] *Average Pain* ($P < 0.05$; all time points); power: 69%. G1: [5.12 ± 2.18/5.19 ± 2.47/5.27 ± 2.31]; G2: [3.81 ± 2.10/3.77 ± 2.12/3.46 ± 2.18] *Aberdeen LBP Scale:* ($P < 0.05$; all time points); power: 89%: G1: [30.82 ± 13.03/32.48 ± 15.31/25.82 ± 13.11]; G2: [20.02 ± 10.47/20.36 ± 13.06/19.86 ± 10.12]
Shirado et al[18] (chronic LBP)	1. Trunk muscle strengthening/stretching (103), age: 42.0 (11.16); BMI: 23.0 (2.9); sex: 49/54 2. Nonsteroidal anti-inflammatory drugs (98), age: 42.5 (12.3) BMI: 22.5 (3.7); sex: 40/58	8 wks [Difference of medians of change ratio between groups (95% CI)] *Visual Analog Scale-Pain:* G1 to G2: [no value (−0.20 to 0.06)]; $P = 0.332$ *Roland Morris Disability Questionnaire:* G1 to G2: [no value (−0.33 to 0.00)]; $P = 0.023$ *Japan LBP Evaluation Questionnaire:* G1 to G2: [no value (−0.25 to 0.02)]; $P = 0.021$ *Finger to Floor Distance:* G1 to G2: [no value (−0.10 to 0.00)]; $P = 0.112$

(*continued on next page*)

TABLE 6. (*Continued*) Evidence Synthesis for Lumbar Region RCT/CCTs Categorized Based on the Levels of Evidence[11]

Study (Diagnosis/Condition)	Intervention Groups (n)/ Demographics [Mean (SD)]	Outcomes/ Group Differences
Franca et al[19] (chronic LBP)	1. Segmental stabilization (15), age: 42.07 (8.15); BMI: 26.40 (4.47); sex: 4/11 2. Superficial strengthening (15), age: 41.73 (6.42); BMI: 26.92 (3.64); sex: 4/11	6 wks [Group mean gain (difference) ± SD] *Visual Analog Scale-Pain:* G1: 5.8 ± 1.61; G2: 3.6 ± 1.56 ($P < 0.001$; between groups) *McGill Pain Questionnaire (Sensory):* G1: 31.8 ± 6.6; G2: 8.9 ± 5.05 ($P < 0.001$; between groups) *Oswestry:* G1: 15.26 ± 3.43; G2: 8.86 ± 2.82 ($P < 0.001$; between groups) *Transverse Abdominuc Activation Capacity (mm Hg):* G1: 4.66 ± 2.22; G2: −0.40 ± 1.60 ($P < 0.001$; between groups)
Jay et al[20] (neck/shoulder/LBP)	1. Kettlebell training (20), age: 44 (8); BMI: 24 (3); sex: 3/17 2. Control (20),·age: 43 (10); BMI: 22 (2); sex: 3/17	8 wks [Between groups mean change score difference (95% CI)] *Visual Analog Scale-Pain:* neck/shoulder: [−2.1 (−3.7 to −0.4)]; $P = 0.02$; LBP: [−1.4 (−2.7 to −0.02)]; $P = 0.05$ *Strength (N·m):* back extension: [18.3 (8.6–28.0)]; $P = 0.0005$; trunk flexion: [8.3 (−6.5 to 23.0)]; $P = 0.26$; shoulder elevation: [−0.6 (−6.2 to 5.0)]; $P = 0.84$
Hides et al[21] (LBP)	1. Specific stabilization exercises (20), age: 31 ± 7; BMI: -; sex: 7/13 2. Control (standard medical management) (19), age: 31 ± 8; BMI: -; sex: 9/10	*Risk of Recurrent Episodes of LBP (95% CI) 1/2 to 3 y:* G1: 0.33 (0.16–0.68)/0.37 (0.17–0.81); G2: 4.12 (1.43–11.88)/3.35 (1.33–8.44) *Number of Recurrent Episodes of LBP (mean* ± SD*) 1/2 to 3 y:* G1: 2.8 ± 2/4.6 ± 6.7; G2: 4.2 ± 3.4/5 ± 3.8; G1: 30% vs G2: 84% ($P < 0.001$) recurrence at 1 y
Ahlqwist et al[22] (LBP)	1. Individualized physical therapy and exercise (23), age: 15± -; BMI: -; sex: 8/15 2. Self-training standardized back exercise program (22), age: 13± -; BMI: -; sex: 6/16	12 wks [Difference: after treatment-before treatment] *Visual Analog Scale-Pain:* G1: −3.63; G2: −3.33, $P > 0.05$ between groups
Moderate evidence for effectiveness (consistent findings among multiple low-quality RCTs and/or 1 high-quality RCT)[11,26]		
Bentsen et al[23] (chronic LBP)	1. Dynamic strength back exercises @ fitness center + home training for 3 mos, then home training only for 9 mos (41), age: 57 (born in 1933); BMI: -; sex: 0/41 2. Home training daily for 12 mos (33), age: 57 (born in 1933); BMI: -; sex: 0/33	*Million Questionnaire of Disability Subjective Index*—3/12 mos: Significant improvement at 3 and 12 mos (G1 and 2); no difference between groups (no values given) *Use of Analgesics (*no values given); no difference at any time point
Suni et al[24] (LBP)	1. LNMT exercises of the trunk and counseling (52), age: 46.6 ± 5.8; BMI: 27.1 ± 3.7; sex: 54/0 2. Control - not specified (54), age: 46.9 ± 5.3; BMI: 27.4 ± 3.7; sex: 54/0	12 mos [Between group mean ratios (95% CI)] *Pain in last week (VAS):* [12 mos: [0.61 (0.38–0.97)]; $P = 0.032$ *Pain in last 2 mos:* [12 mos: [0.61 (0.47–1.00)]; $P = 0.052$ *Pain and Disability Index:* [12 mos: [0.86 (0.57–1.29)]; $P = 0.46$ *Oswestry Disability Index:* [12 mos: [0.98 (0.79–1.23)]; $P = 0.88$
Mellin et al[25] (chronic LBP)	1. Inpatient exercise (156)† 2. Outpatient exercise (148) 3. No intervention (152) [overall subject demographics not divided into groups: $n = 456$; 58% male, 35–54 y];†	3 mos [Group mean change scores ± SD] *Pain (VAS; $P < 0.05$; G1 vs G2 and G1 vs G3):* G1: [−55.0 ± 85.2]/G2: [−33.2 ± 79.6]/G3: [−16.2 ± 75.2] *LBP Disability Index ($P < 0.05$; G1 vs G2 and G1 vs G3):* G1: [−3.0 ± 7.9]/G2: [−2.7 ± 6.9]/G3: [−0.3 ± 8.6] *Index of Physical Measurements (lumbar mobility, hip mobility, and trunk strength)* ($P < 0.05$; G1 vs G2 and G1 vs G3): G1: [3.7 ± 5.6]/G2: [0.8 ± 4.8]/G3: [1.2 ± 5.5]

TABLE 6. (*Continued*) Evidence Synthesis for Lumbar Region RCT/CCTs Categorized Based on the Levels of Evidence[11]

Study (Diagnosis/Condition)	Intervention Groups (n)/ Demographics [Mean (SD)]	Outcomes/ Group Differences
Mellin et al[26] (chronic or recurrent LBP)	1. Inpatient exercise + refresher course 2. Outpatient exercise + refresher course 3. No intervention (Subjects per group not specified; no demographics listed, n = 476)	1.5 y/22 mos/2.5 y [Group mean change scores ± SD] *Trunk Strength* ($P < 0.05$; G1 vs 2 at 22 mos/2.5 y): Women: G1: [1.7 ± 2.7/2.6 ± 2.9/2.3 ± 2.6]/ G2: [0.5 ± 2.5/1.1 ± 2.4/0.6 ± 2.4]/ G3: [1.4 ± 3.2/? ± ?)/1.6 ± 2.5] *Index of Physical Measurements:* Men: ($P < 0.05$ at 2.5 y; G1 vs G2 and G1 vs G3): G1: [1.7 ± 5.6/3.7 ± 6.2/3.5 ± 6.5]/G2: [0.7 ± 5.6/2.1 ± 6.6/1.3 ± 6.7]/G3: [1.5 ± 5.4/?±?/0.4 ± 6.1]; Women: ($P < 0.05$ at 22 mos; G1 vs G2): G1:[1.2 ± 7.4/4.7 ± 8.0/3.5 ± 7.6]/G2: [−0.9 ± 5.9/1.4 ± 6.8/1.0 ± 6.7]/G3: [1.1 ± 7.5/? ± ?/2.8 ± 7.6]
Mohseni-Bandpei et al[28] (nonspecific LBP)	1. Pelvic floor muscle (PFM) exercises (10), age: 34.71 (5.03); BMI: 23.89 (2.48); sex: 0/10 2. Traditional physiotherapy treatment for LBP (10), age: 34.91 (6.29); BMI: 24.05 (2.27); sex: 0/10	8/12 wks [Between groups mean change score difference (95% CI)] *Visual Analog Scale-Pain:* 8 wks: [0.11 (−1.16 to 0.94)]; $P = 0.829$/12 wks: [−0.07 (−1.03 to 0.82)]; $P = 0.41$ *Oswestry Disability Index (%):* 8 wks: [0.60 (−13.69 to 14.89)]; $P = 0.931$/12 wks: [0.44 (−11.21 to 10.53)]; $P = 0.72$ *PFM Strength (water centimeter):* 8 wks: [−46.48 (−58.15 to −34.80)]; $P = 0.000$/12 wks: [−31.05 (−44.12 to −18.37)]; $P = 0.000$ *PFM Endurance (s):* 8 wks: [−29.04 (−41.13 to −16.94)]; $P = 0.000$/12 wks: [−16.19 (−24.01 to −8.29)]; $P = 0.000$
Yilmaz et al[29] (lumbar microdiscectomy)	1. Dynamic lumbar stabilization exercises (14), age: 46.0 ± 9.8; BMI: -; sex: 8/6 2. Home exercise program (14), age: 41.0 ± 8.9; BMI: -; sex: 6/8 3. No exercise (14), age: 42.8 ± 11.4; BMI: -; sex: 8/6	3 mos [Group mean change scores ± SD] *Pain—VAS ($P < 0.05$; G1 vs G2 and G3; G2 vs G3):* G1: [3.14 ± 0.66]/G2: [1.71 ± 1.68]/ G3[0.21 ± 1.12] *Modified Oswestry Index ($P < 0.05$ G1 vs G2 and G3; G2 vs G3):* G1: [13.36 ± 5.05]/G2: [7.79 ± 5.34]/G3: [3.14 ± 3.63] *Progressive Isoinertial Lifting Evaluation of Back (kg) ($P < 0.05$; G1 vs G2 and G3):* G1: [5.18 ± 2.68]/ G2: [1.79 ± 2.06]/G3: [0.18 ± 0.67]
Kofotolis et al[30] (chronic LBP)	1. Rhythmic stabilization training (28), age: 40.6 ± 6.4; BMI: 25.2 ± 1.0; sex: 0/28 2. Isotonic exercises (28), age: 41.8 ± 7.7; BMI: 24.8 ± 1.7; sex: 0/28 3. No exercise (30), age: 42.1 ± 8.4; BMI: 24.3 ± 0.7; sex: 0/30	8 wks [Group mean ± SD] *Borg Back Pain Intensity Scale ($P < 0.05$; pre vs 8 wks for each group):* G1: 1.1 ± 0.2/G2: 1.3 ± 0.4/G3: 1.4 ± 0.3 *Oswestry LBP Disability Questionnaire ($P < 0.05$; G1 and G2 vs G3):* G1: 10.0 ± 0.8/G2: 10.6 ± 0.9/G3: 14.0 ± 2.1 *Trunk Endurance: flexion (s) ($P < 0.05$; G1 and G2 vs G3):* No values provided (G1: increase 23.6%/G2: increase 26.4%) *Trunk Endurance: extension (s) ($P < 0.05$; G1 and G2 vs G3:* No values provided (G1: increase 41.6%/ G2: increase 69.5%)

(*continued on next page*)

TABLE 6. (*Continued*) Evidence Synthesis for Lumbar Region RCT/CCTs Categorized Based on the Levels of Evidence[11]

Study (Diagnosis/Condition)	Intervention Groups (n)/ Demographics [Mean (SD)]	Outcomes/ Group Differences
Kuukkanen and Malkia[31] (subacute LBP)	1. Intensive training (29) (including trunk exercises), age: -; BMI: -; sex: 11/18 2. Home exercise (29), age: -; BMI: -; sex: 15/14 3. Control (28) (no training), age: -; BMI: -; sex: 13/15	Baseline/12 mos [group mean ± SD] (paper also presents 3 mos and 6 mos) *Borg Back Pain Index (P < 0.05, 12 mos vs baseline G1,G2; NS for G3):* G1: 2.5 ± 1.3/1.5 ± 1.4; G2: 1.9 ± 1.5/1.0 ± 1.3; G3: 1.8 ± 1.7/1.3 ± 1.8, NS between groups at baseline, NS between G1,G2 at any time point *Oswestry Index (P < 0.05, 12 mos vs baseline G1,G2; NS for G3):* G1: 17 ± 5.8/10 ± 4.6; G2: 17 ± 9.5/ 6 ± 5.2; G3: 14 ± 8.7/10 ± 9.5; NS between groups at baseline, NS between G1,G2 at any time point *Back Extensor Strength (N; P < 0.05, 12 mos vs baseline G1,G2; NS for G3):* G1: 693 ± 219/827 ± 296; G2: 675 ± 278/779 ± 285; G3: 797 ± 319/ 836 ± 262; NS between groups at baseline, NS between G1,G2 at any time point
Kuukkanen et al[32] (subacute LBP)	1. Intensive training (29) (including trunk exercises), age: -; BMI: -; sex: 11/18 2. Home exercise (29), age: -; BMI: -; sex: 15/14 3. Control (28) (no training), age: -; BMI: -; sex: 13/15	12 mos (no values given) *Psychomotor Speed Tests* (faster in asymptomatic vs symptomatic, $P < 0.05$) *Movement Time* (increase in all groups; $P = 0.001–0.04$) *Total Response Time* (decreased in all groups; $P = 0.001–0.02$) *Vertical Jump (flight time)* (increase in all groups; $P > 0.001–0.04$; between groups, $P > 0.05$)
Norris and Matthews[33] (chronic LBP)	1. Integrated back stability program (27), age: 37.5 ± 9.5; BMI: -; sex: 12/15 2. Back care advice (32), age: 36.9 ± 8.5; BMI: -; sex: 16/16	6 wks [Effect Size (95% CI)], *P* value for between group comparisons *Short Form McGill Pain Questionnaire:* Section 1: [−1.21 (−1.75 to −.063)], $P < 0.001$; Section 2: [−0.85 (−1.37 to −.03)], $P = 0.178$; Section 3: [−1.76 (−2.34 to −1.14)], $P < 0.001$ *Roland and Morris Disability Questionnaire (P < 0.05):* [−4.38 (−5.25 to −3.39)], $P = 0.001$ *Patient Satisfaction:* 89% of subjects considered acceptable
Asfour et al[34] (chronic LBP)	1. EMG biofeedback for back extensors (13), age: 43.27 (12.73); BMI: -; sex: 6/9 2. Control (19), age: 46.53 (17.62); BMI: -; sex: 7/8	0/2 wks [mean ± SD] *Visual Analog Scale-Pain:* G1: 6.07 ± 2.94/4.73 ± 2.58 (NS within); G2: 5.6 ± 2.35/5.6 ± 2.44 (NS within) [no *P* values given] *Back Extensor Strength (N):* G1: 224.86 ± 209.19/ 408.20 ± 231.67 ($P < 0.01$ within); G2: 284.22 ± 141.82/331.66 ± 199.67 (NS within) [no *P* values given]
Lee et al[36] (LBP)	1. Standard LBP protocol + core stability exercises (13), age: 50.4 (9.1); BMI: -; sex: 8/5 2. Control [standard LBP protocol] (19), age: 46.6 (9.1); BMI: -; sex: 9/10	*Million Pain Interference Visual Analog Scale*—4 wks: reduced in both groups; no difference between groups (no values)
Karimi et al[35] (chronic LBP)	1. Concise supervised stability training (20), age: 25.94 ± 5.7; BMI: -; sex: - 2. Electrotherapy (18) (ultrasound, TENS, infraRed), age: 28.11 ± 6.21; BMI: -; sex: -	Baseline/10 d [mean ± SD] (stability index scores pre–post intervention; limits of support also evaluated) *Biodex Balance System Double Leg Eyes Closed Overall Stability Index* ($P < 0.05$, no between group comparisons): G1: OSI 9.78 ± 1.87/8.22 ± 2.27; G2: OSI 11.30 ± 1.94/9.52 ± 2.61 (NS) *Biodex Balance System Double Leg Eyes Closed A/P Stability Index* ($P < 0.05$, no between group comparisons): G1: 7.19 ± 1.67/5.80 ± 1.93; G2: 7.84 ± 1.66/ 6.17 ± 1.88

TABLE 6. (*Continued*) Evidence Synthesis for Lumbar Region RCT/CCTs Categorized Based on the Levels of Evidence[11]

Study (Diagnosis/Condition)	Intervention Groups (n)/ Demographics [Mean (SD)]	Outcomes/ Group Differences
Takemasa et al[37] (LBP with/without organic lesions)	1. Trunk muscle exercises + LBP + organic lesions (41), age: 34.9 ± 11.3; BMI: (male) 23.0 ± 3.2; (female) 22.1 ± 2.8; sex: 23/18	1–6 mos (pre–post exercise) [Group mean ± SD]
	2. Trunk muscle exercises + LBP − organic lesions (31), age: 32.4 ± 10.2; BMI: (male) 22.2 ± 2.9; (female) 22.3 ± 2.6; sex: 17/14	*VAS (G1 and 2 improved (P < 0.01); NS between groups):* G1: 4.1 ± 2.0/2.4 ± 1.7; G2: 4.4 ± 1.9/ 1.4 ± 1.4; G3: 5.1 ± 1.2/4.3 ± 1.8
	3. Control—No LBP (not specified) (126), age: 30± -; BMI: -; sex: -	*Japanese Orthopedic Association Score* (G2 > G1 ($P < 0.05$)): G1: 23.1 ± 2.6/25.5 ± 2.8; G2: 23.9 ± 1.3/27.1 ± 1.3; G3: 22.7 ± 2.3/23.9 ± 2
Harringe et al[39] (LBP in female gymnasts)	1. Specific segmental control exercises (33) [15 with LBP (G1-LBP); 15 with no LBP]; age: 13 [range, 11–15]; BMI: 17.6 [range, 15.1–21.5]; sex: 0/33	3 mos
	2. Education/advice (18) [4 with LBP (G2-LBP); 8 with no LBP]; age: 14 [range, 12–16]; BMI: 19.3 [range, 16–23.1]; sex: 0/18	*Back Pain—Borg Scale:* G1 and G2 different at baseline (age/weight/BMI, and training): Less days with pain ($P = 0.005$) G1-LBP vs G2-LBP [no values]; NS ($P > 0.05$) max pain intensity G1-LBP vs G2-LBP [no values]; NS ($P > 0.05$) median pain intensity G1-LBP vs G2-LBP [no values]
Johannsen et al[38] (lumbar diskectomy)	1. Supervised trunk strengthening (11), age, 39 [range, 24–55]; BMI: 19.3 [range, 16–23.1]; sex: 7/4	3 mos/6 mos [median ± 12.5 percentiles]
	2. Unsupervised home trunk training (16), age: 36 [range, 24–57]; BMI: 19.3 [range, 16–23.1]; sex: 12/4	*Back Pain—5 point box scale* between groups ($P > 0.05$): G1: 2.8 (1.8–4.8)/2.8 (1.8–4.2); G2: 2.4 (1.7–4.2)/2.5 (1.8–5.8)
		Disability (impaired activities out of 12) between groups ($P > 0.05$): G1: 0 (0–2)/0 (0–3); G2: 0 (0–2)/0 (0–2)
		Patient Self-assessment between groups ($P > 0.05$): G1: 1.1 (0.7–1.9)/1.0 (0.6–1.5); G2: 1.2 (0.7–2.0)/1.3 (0.7–2.9)
Mannion et al[27] (chronic LBP)	1. Active physiotherapy	Pre to postintervention-3 mos [mean ± SD]; *P* value
	2. Muscle reconditioning on training devices 3. Low impact aerobics (132/148 subjects, group allocation not reported) [mean age (y) of all subjects: 45.0 (10.0); 57% female]	*Isometric Back Muscle Fatigability* (Biering-Sorensen test): Increase times for all groups [123 ± 57–145 ± 72]; $P = 0.0001$: G1: 111 ± 51; G2: 123 ± 63; G3: 137 ± 56; $P = 0.37$

Functional outcomes related to LNMT are listed when available with results listed as mean ± SD unless noted otherwise. Mean differences and confidence intervals are reported when available. Mean BMI (kg/m^2), age (years ± SD), and sex (m/f) demographics are used to describe the study samples.

*Used a modified lower back machine.

†Included back exercises not specified.

NS, not significant; G, group; -, no information provided.

TABLE 7. Other Outcomes Used in Studies

Isokinetics (eg, trunk, hip, knee)[16,27,31,37,38,40,42]
Electromyography (eg, back, trunk muscles)[27,36]
Range of motion (eg, trunk, hip)[16,23,26,34]
Lumbar schober[29,30]
Tampa scale of kinesiophobia[14]
Pain Self-Efficacy Questionnaire[14]
Pain Locus of Control Questionnaire[14]
Beck depression scale[29]
Short Form-36[17]
Sick leave[23]
Aerobic fitness[20]

Can Clinical Recommendations Be Made?

Lower/Upper Extremity

There is conflicting evidence supporting or refuting the use of LNMT in the rehabilitation of those with injury to LE and no evidence supporting its use after injury to the UE.[11] Different techniques, all of which could be considered LNMT, were used in each trial involving the LE. Further, different MSK injuries/conditions (eg, anterior cruciate ligament insufficiency,[42] hamstring strains,[41] and menisectomies[40]) and limited numbers of studies make it difficult to provide specific rehabilitation guidelines for MSK LE injuries. Based on the results of this review, there is limited literature regarding the implementation of LNMT in those with injuries involving the LE.

Lumbar Region

Generally, this review demonstrates that there is moderate to strong evidence to support LNMT in those with injury to the lumbar region. However, inconsistent patient populations and inconsistent interventions between trials make it difficult to clearly elucidate and translate outcomes. Specifically, the definitions of LBP vary across trials from organic LBP,[37] nonorganic LBP,[37] recurrent LBP,[14] chronic LBP,[35] and mechanical LBP.[15] In addition, these studies lacked current guidelines regarding treatment-based classifications for LBP.[43] Further, 2 of the studies[29,38] related to postoperative rehabilitation of lumbar diskectomies are of poor methodological quality.[11] Such inconsistency makes it difficult to provide specific clinical recommendations or guidelines regarding the utility of LNMT techniques in those with LBP and injury to the lumbar region.

Quality and Bias

On average, the methodological quality of trials was high for studies involving the LE but low for studies involving the lumbar region. Two out of the 3 studies for the LE[40,41] were rated as high quality, whereas this was true for only 8 out of the 25 studies for the lumbar regions.[14–20,22] However, in most other trials, high bias may have been possible due to lack of information, poor allocation concealment, and lack of blinding for subjects, therapists, or assessors. Further, high attrition bias may also be a factor related to subject dropout rate and lack of intention to treat analyses.

Study Limitations

A limitation to this review is the inconsistent terminology used in defining the interventions in question. The search terms used (core, trunk, lumbopelvic, spine, etc) are poorly defined in much of the literature and often conflicting.[10] Further, the term LNMT may also have different interpretations. Such inconsistency is demonstrated by the variety of LNMT interventions used. These included isolated muscle activation of local muscle of the trunk (ie, transversus abdominis and multifidus),[14,35,39] rhythmic stabilization training,[30] exercises incorporating isotonic strengthening exercises of the trunk,[30] functional training of the trunk[42] interventions requiring balance and proprioception,[40] and kettlebell training.[20]

CONCLUSIONS

This review has implications for health care providers, researchers, and fitness practitioners. There is some evidence demonstrating an association between measures of lumbopelvic stability and control in those with injury to the LE and lumbar regions.[44–47] However, based on this review, direct links supporting the efficacy of LNMT after MSK injury are lacking. A better understanding of the mechanisms, implementation, and specificity of such training is necessary to best manage the rehabilitation of individuals after MSK injury. Further, the inconsistencies identified in this review may be reflective of current clinical practices, thus necessitating the need for clearer recommendations and guidelines of LNMT.

Finally, high-quality RCTs are needed to either support or refute the use of LNMT in patients with MSK injury especially regarding the extremities. Based on this review, it is recommended that these RCTs should provide specific recommendations for clinical care and future research endeavors. Additionally, these RCTs should focus on well-defined, homogeneous populations with interventions specifically focusing on the neuromuscular activation of the lumbopelvic musculature. Care should be taken to minimize the incorporation of confounding interventions. Further, it is recommended that outcomes include not only patient-specific clinical outcomes (eg, pain, disability) but also measures of motor control (eg, muscle activation patterns), biomechanics (eg, joint kinematics and kinetics), and return to specific activities (eg, ADLs, work, sport).

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