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SYSTEMATIC REVIEW

Effectiveness of Proprioceptive Neuromuscular Facilitation on Pain Intensity and Functional Disability in Patients with Low Back Pain: A Systematic Review and Meta-Analysis

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Abstract

Background: This systematic review aimed to investigate the effectiveness of proprioceptive neuromuscular facilitation (PNF) training on back pain intensity and functional disability in people with low back pain (LBP).

Methods: Totally, five electronic databases, including PubMed/Medline (NLM), Scopus, Google Scholar, PEDro, and Cochrane Central Register of Controlled Clinical Trials were searched up to October 31, 2018. Clinical trials with a concurrent comparison group (s) that compared the effectiveness of PNF training with any other physical therapy intervention were selected. Publication language was restricted to English language articles. Methodologic quality was assessed using the PEDro scale. The measures of continuous variables were summarized as Hedges's *g*.

Results: In total, 20 eligible trials were identified with 965 LBP patients. A large effect size (standardized mean difference [SMD]=-2.14, 95% confidence interval [CI]=3.23 to -1.05) and significant effect were observed favoring the use of PNF training to alleviate back pain intensity in patients with LBP. Moreover, large effect size and the significant result were also determined for the effect of PNF training on functional disability improvement (SMD=-2.68, 95% CI=-3.36 to -2.00) in population with LBP. A qualitative synthesis of results indicated that PNF training can significantly improve sagittal spine ROM. Statistical heterogeneity analysis showed that there was considerable statistical heterogeneity among the selected trials for the primary outcomes ($I^2 \geq 86.6\%$).

Conclusion: There is a low quality of evidence and weak strength of recommendation that PNF training has positive effects on back pain and disability in LBP people. Further high-quality randomized clinical trials regarding long-term effects of PNF training versus validated control intervention in a clinical setting is recommendable.

Level of evidence: I

Keywords: Low back pain, Meta-analysis, PNF, Proprioceptive neuromuscular facilitation, Review

Introduction

Low back pain (LBP) is a major global challenge and a quite common symptom in populations worldwide that happens in all age groups from children to the elderly population (1, 2). The Global Burden of Disease Study 2017 reported that between 2007 and 2017, the number of all-age years lived with

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disability (YLDs) attributed to LBP increased by 17.5% (95% uncertainty interval 16.2-19.0%) (3). Several factors have been suggested as potential causes of LBP, including disturbances in trunk proprioception, as well as abdominal and paraspinal muscle weakness (4-6). Therefore, physical therapy interventions, which enhance trunk proprioception, as well as abdominal and back muscle function may optimize clinical and physiological outcomes, thereby improving the quality of life in patients with LBP (7).

Nonpharmacologic interventions are offered as first-line options in patients with chronic LBP since fewer harms are associated with these types of interventions, compared to pharmacologic options (8). Exercise therapy is one of the conservative treatment modalities most frequently used in LBP by physical therapists (9, 10). Bekkering et al. (2003) recommended exercise therapy as the first-line treatment for LBP (11). Proprioceptive neuromuscular facilitation (PNF) training is often used in order to promote or hasten neuromuscular responses by stimulating proprioceptors (7, 12, 13).

The PNF training was first introduced by Margaret (Maggie) Knott (physical therapist) and Herman Kabat (physician) in the 1940s and early 1950s to treat neuromusculoskeletal disorders (14, 15). The primary purpose of this treatment is to help patients enhance movement efficiency and achieve their highest level of functioning (16). The PNF utilizes the body's proprioceptive system and reflexes to inhibit or facilitate muscle contraction (14). Moreover, the PNF techniques are frequently used in the clinical and athletic environments to improve active and passive range of motion (ROM) and agility to enhance motor performance and rehabilitation (17). According to Sharman et al., (2006) the PNF techniques may be effective stretching techniques when the aim is to increase ROM at least in the short-term (17). Furthermore, it has been reported that the PNF techniques can help improve the overall functional ability of patients, such as muscular strength, muscular endurance, joint mobility, joint stability, neuromuscular control, balance, and coordination (18, 19).

To date, 10 specific PNF techniques have been developed and are used by physical therapists worldwide (16). These techniques include rhythmic initiation, replication (also known as hold relax active motion), stretch through the range, stretch at beginning of range, rhythmic stabilization (also known as alternating isometric contractions), a combination of isotonic (also known as agonist reversals), dynamic reversals (also known as slow reversals), stabilizing reversals, hold relax, and contract relax (16). However, the most common types of PNF techniques used in the literature for LBP patients consist of rhythmic stabilization and a combination of isotonics (7). The rhythmic stabilization technique utilizes the alternating isometric contractions of agonists and antagonists against resistance, and no motion is allowed during this technique (20). The combination of isotonic is used when the purpose is to enhance the ability to execute controlled purposeful movements (Kofotolis and Kellis, 2006). It involves the performance of alternating concentric, isometric, and eccentric contractions and is used to improve muscle strength and ROM (21).

In addition to PNF techniques, the PNF movement patterns are functional movements, which are frequently used in daily and sports activities (22). The PNF patterns are characterized by spiral (three-dimensional) and diagonal movements as a result of synergistic muscle activation (22). It has been hypothesized that these exercises may be better suited for improving performance than conventional single-direction or single-plane weight-training programs (17).

Control of the spine is complex and relies on well-coordinated and deep-trunk musculature (23). The PNF patterns, which are a form of neuromuscular control exercises, can aid in restoring control, coordination, and strength of the muscles that control and support the spine, thereby improving pain control (8). Byström et al. (2013) also showed that neuromuscular control exercises resulted in improvements in function in the short and long term; however, the size of the effect was small (24).

A systematic review and meta-analysis conducted by Tong et al. (2017) showed that patients with LBP have altered lumbar spine proprioception, compared to controls (25). Lederman (2010) stated that changes in proprioceptive acuity after musculoskeletal injuries could be due to a competition between nociception and proprioception for central "attention," occurring at reflexive and cognitive levels (26). The PNF training may improve local joint control and muscle sensitivity by enhancing the sensitivity of muscle spindle and Golgi tendon organs, which are responsible for proprioception (27, 28). Accordingly, back pain is expected to be decreased as a result of improved lumbar proprioception (27). Furthermore, poor trunk muscle endurance and excessive fatigability of lumbar paraspinal muscles are often associated with chronic LBP (29). It has been reported that the PNF training may enhance trunk muscle flexibility, strength, and endurance, thereby providing further support to the effectiveness of PNF training for back pain and functional disability improvement (29).

Although PNF techniques and patterns are currently used in clinical practice and research settings for the treatment of LBP patients, no systematic review has yet focused on this topic. A recent narrative review summarized the available evidence for this rehabilitation concept and reported that there was a substantial body of literature, which supported the use of PNF training as a comprehensive rehabilitation concept (16). However, it should be noted that the study conducted by Smedes et al. (2016) is a literature review the design of which does not recommend the use of PNF training (16). In addition, this narrative review did not assess the efficacy of PNF training for specific populations (16). As a result, for the first time, this study was performed to systematically review the literature in order to assess the effectiveness of PNF training on LBP.

Materials and Methods

This systematic review process followed the guidelines of the PRISMA statement, and it was registered on the PROSPERO register (PROSPERO; CRD42018097303)

(30). It is worth mentioning that patient consent and ethical approval were not required for this systematic review.

Identification and selection of studies

Search strategy

A comprehensive search was conducted in Pubmed/ Medline (NLM), Scopus, Google Scholar, PEDro, and Cochrane Central Register of Controlled Clinical Trials from the earliest date until October 31, 2018. Electronic search strategies were developed based on the combined keywords, including *"clinical trial"*, *"PNF"*, and *"low back pain"* to identify English-language studies that evaluated PNF training for adult patients (≥ 18 years) with LBP. The language of publication was restricted to English since Morrison et al. (2012) reported no significant differences between pooled treatment effects in English-language restricted meta-analyses and languages other than English-inclusive meta-analyses in medicine (31). The search strategy was developed around two concepts with medical subject headings terms and keywords adapted to individual databases. Appendix S1 presents the details of the PubMed database search syntax. Reference checking, citation tracking in Google Scholar, and manual searching of ahead-of-print listing in journals of selected articles were performed to ensure that all relevant studies were included. After the search, all articles were imported into Endnote (version X8.1; Clarivate Analytics, PA, USA), and the duplicates were removed. In total, two reviewers (M.P. and M.S.) independently investigated the titles and abstracts of the Endnote library, and disagreements were settled by consensus. After title and abstract screening, full-text articles of potentially suitable trials were obtained to assess their eligibility.

Eligibility criteria

The eligibility criteria were defined according to Patient, Intervention, Comparator, Outcome, Study criteria, and objectives of this study [Table 1].

Types of participants

Participants of this study comprised adult patients of both genders with any type of LBP (acute (<4 weeks), subacute (between 4 and 12 weeks), and chronic (>12 weeks) [Table 1].

Types of interventions

Studies in which PNF techniques and/or PNF patterns were used to decrease back pain or functional disability in patients with LBP were included in this study [Table 1].

Types of outcome measures

The co-primary outcome measures were back pain and functional disability [Table 1].

- The pain was defined as back pain intensity assessed at the time point closest to the end of treatment (35). Pain intensity could be measured with a continuous, self-report scale (e.g., visual analog scale [VAS]), numeric pain rating scale (NPRS), Borg verbal rating pain scale), or a rating scale within a composite measure of back pain (e.g., McGill Pain Questionnaire). The studies that used other measurement tools were not excluded.

Table 1. PICOS criteria for the study

Criteria	Inclusion
P- Population	The population was composed of adult patients (≥18 years) of both genders with LBP. The LBP was defined as pain or discomfort localized below the costal margin and above the inferior gluteal folds with or without leg pain that lasts for at least one day (32, 33).
I- Intervention	The PNF is a rehabilitation technique that is used to stimulate the neuromuscular system to excite the body's proprioceptors in order to produce the desired movement or inhibit or facilitate muscle contraction. In this study, all PNF techniques (i.e., rhythmic initiation, rhythmic stabilization, replication, stretch through the range, stretch at beginning of range, a combination of isotonic, dynamic reversals, stabilizing reversals, hold relax, and contract relax) and movement patterns (i.e., upper and lower extremities [D1 and D2 flexion and D1 and D2 extension], scapular, trunk, pelvis, and neck patterns) were considered for review. It should be noted that when PNF training was used in addition to other treatments, it had to represent at least 50% of the total treatment program to be included (23, 34).
C- Comparator	Other manual therapy techniques, other physical therapy interventions, and sham or control groups
O- Outcomes	The primary outcomes of this systematic review were back pain and functional disability. The secondary outcome was spine range of motion (ROM).
S- Study design	Clinical trials with concurrent comparison group(s) published in peer-reviewed journals with full text available in English; results obtained from opinion pieces, editorials, systematic reviews, narrative reviews, case studies, book chapters, conference abstracts, theses/dissertations, abstracts, and websites were excluded.

• Functional disability was defined as loss of low back-specific function measured at the end of treatment. A functional disability could be measured with a continuous, self-report scale (e.g., Roland Morris Disability Questionnaire [RMDQ]), Oswestry Disability Index [ODI], modified ODI, or Quebec back pain disability score). The studies that used other measurement tools were not excluded.

• The secondary outcome of the measure was spine ROM [Table 1]. The ROM was defined as vertebral column flexion and extension ROM. The spine ROM could be measured with the Schober test, flexicurve technique, and inclinometer. The studies that used other measurement tools were not excluded.

Quality assessment

The methodological quality of the selected trials was assessed by two reviewers (M.P. and M.S.) independently according to the PEDro scale (36). Item 1 demonstrates the external validity (or 'generalizability' or 'applicability' of the study) and is not considered in the total PEDro score. Items 2-9 refer to the internal validity of a study, and items 10-11 present adequate statistical information to enable proper interpretation of the findings [Appendix S2]. Primary studies, which received scores of ≥ 6 on the PEDro scale, were classified as 'high quality' studies. Trials with a PEDro score of 4-5 were classified as 'fair quality' studies, and trials with scores of ≤ 3 were classified as 'poor quality' studies (23). A Cohen's kappa coefficient (κ) with a corresponding 95% confidence interval (CI) was used to evaluate the level of inter-rater agreement (0-0.20=poor; 0.21-0.40=fair; 0.41-0.60=moderate; 0.61-0.80=good; and 0.81-1=very good) (37). The consensus was reached in case of disagreement.

Data extraction

Data abstraction from the selected trials was undertaken independently by two non-blinded reviewers (M.P. and M.S.) using a standardized and pre-piloted data extraction form. The abstracted data included the description of trial characteristics, such as author name, publication year, country, study design, sample size, the status of health, mean age, body mass index, body mass, stature, gender, outcome measures, description of interventions, and key findings. Following the completion of this phase, one reviewer (M.P.) double-checked the extracted data to avoid any inaccuracies or omissions in the data extracted.

Statistical Methods

Measures of treatment effect

The measures of continuous variables are summarized as Hedges's *g*, if the same primary outcomes were used in the included studies. Since the selected studies had small sample sizes, this effect size was used to calculate standardized mean differences. Effect sizes were calculated using the 'metan' package of Stata software (version 14; Stata Corp., College Station, TX, USA) (38). The data used for estimating effect sizes include sample sizes, means, and standard deviations, both at baseline and post-treatment, for all groups (i.e., treatment and comparison). If continuous outcomes measures were different between trials, the pooled effects were presented with Hedges's *g*; however, the different outcome measures were first converted to a 0 to 100 scale (34). All outcome variables were continuous. For the measurement of effect sizes, three levels were defined as small effect size (SMD < 0.40), medium effect size (0.40 ≤ SMD ≤ 0.70) or large effect size (SMD > 0.70) (34). A clinically important treatment effect was considered when the magnitude of the summary measure was at least medium (34).

Unit of Analysis Issues

When multiple comparisons of one clinical trial were included in one meta-analysis, the 'shared' group was split into two groups with smaller sample sizes to avoid overestimating the number of patients that would create a unit-of-analysis error (39).

Assessment of Statistical Heterogeneity

Statistical heterogeneity among the eligible studies was assessed using the *I2* statistic and Cochran's Q test ($\chi 2$) as recommended by the Cochrane Handbook for Systematic Reviews of Interventions (40). The *I2* statistic were interpreted according to the following guide: 0-40%=no important statistical heterogeneity; 30-60%=moderate statistical heterogeneity; 50-90%=substantial statistical heterogeneity; 75-100%=considerable statistical heterogeneity (41). Statistical heterogeneity was considered before performing a meta-analysis. If *I2* values were >50%, and there was an overlap between the CIs in visual inspection of the forest plot (eyeball test), the results were combined into a meta-analysis using a random-effects model (DerSimonian-Laird method) (23).

Assessment of publication bias

Assessment of publication bias was conducted using the Begg and Mazumdar's rank correlation test and the funnel plot method (23, 42). A *P-value < 0.05* for Begg and Mazumdar's test indicated significant statistical publication bias. Moreover, Duval and Tweedie 'trim and fill' method was performed to investigate the potential influence of a reporting bias (43).

Sensitivity analysis

Sensitivity analysis using the leave-one-out method was performed to determine the effect of each study on the pooled results (37). In addition, if *I2* values were higher than 50%, the 'hetred' package in Stata software (version 11; Stata Corp., College Station, TX, USA) was used to assess the change in between-study heterogeneity when one or more outlier studies were excluded from the calculations (44). Furthermore, subgroup analysis was performed to assess the effectiveness of each PNF exercise or pattern on pain and functional disability improvement in patients with LBP.

Data synthesis

Considering that the selected articles shared basic methodological aspects (e.g., all were clinical trials with a comparison group), and that original studies included individuals with similar characteristics (e.g., patients with LBP), they were pooled for the meta-analysis. Stata

software (version 14; Stata Corp., College Station, TX, USA) was employed to perform the meta-analysis for the primary outcomes of this study. When the trials were sufficiently homogenous, a meta-analysis was performed for the time points of short (<3 months after randomization), intermediate (3-12 months after randomization), and long-term (≥12 months after randomization) follow-up. If there were multiple time points at which the primary outcomes were measured within the same category, a time point was utilized closest to the end of the treatment, 6 months, or 12 months (34).

The overall quality of the evidence and strength of the recommendations were assessed using GRADE, which was applied for those primary outcomes included in the meta-analysis (45). The downgrading process was performed considering 5 domains, including study limitations (e.g., methodological quality/risk of bias), inconsistency (e.g., heterogeneity between trials findings), indirectness of evidence (including other populations or use of surrogate outcomes), imprecision (e.g., small sample size) and reporting bias (e.g., publication bias). The quality of evidence was classified as (i) high quality: further trials are unlikely to change the estimate of effect; the PEDro scale indicated no risks of bias and all domains in the GRADE tool were fulfilled; (ii) moderate quality: further trials are likely to have a significant impact on the estimate of effect, and one of the domains in the GRADE tool was not fulfilled; (iii) low quality: further trials are likely to change the estimate; 2 of the domains were not fulfilled in the GRADE tool; and (iv) very low quality: we are uncertain about the estimate of treatment effect; 3 of the domains in the GRADE tool were not fulfilled (45). The assessment of the strength of recommendations for the primary outcomes was by the quality of evidence, patient value preferences, the balance between desirable and undesirable effects, and wise use of resources (45). Differences in the strength of recommendation were discussed in a consensus meeting.

Results

The flow of studies through the review

Figure 1 illustrates the search results. A total of 256

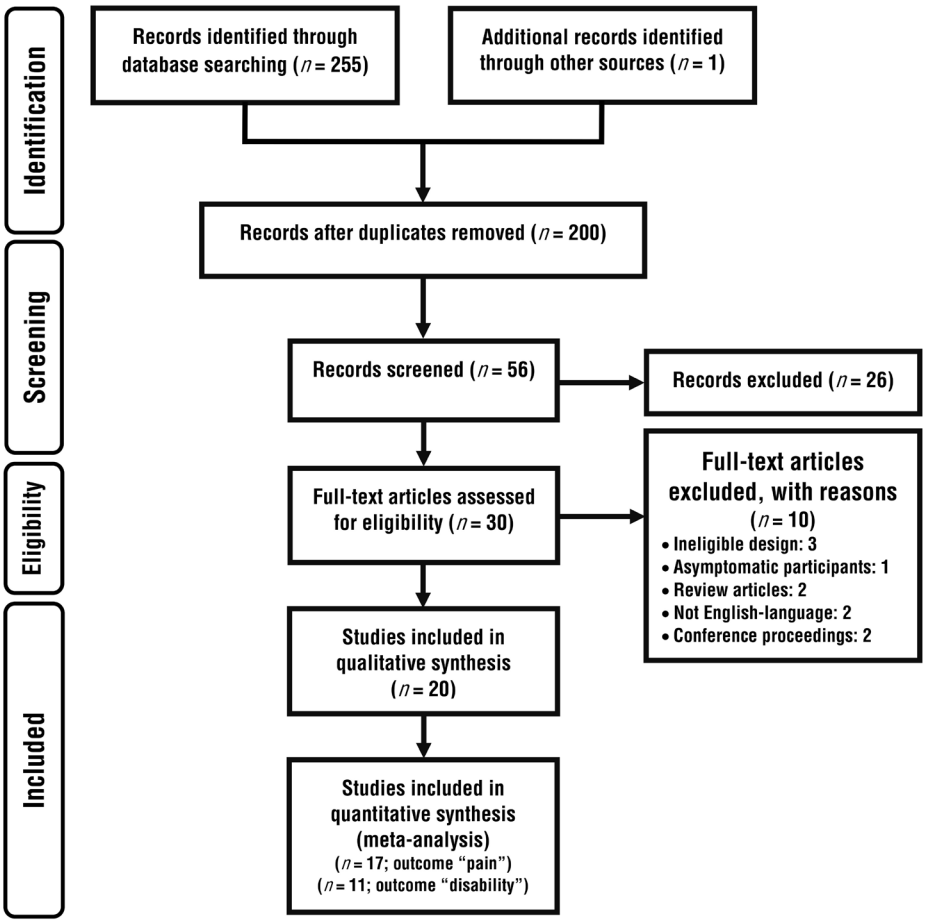

Figure 1. PRISMA flowchart of the study.

studies were retrieved from different databases, and 30 full-text articles were screened for eligibility. It is worth mentioning that one study was not a controlled/clinical study, and two studies used single-subject experimental research designs (46-48). Moreover, one study included healthy subjects, and two studies were published in the Korean language (49-51). Regarding the study design, two studies were review articles, and two studies were conference proceedings (14, 16, 52, 53). Therefore, 20 studies met our inclusion criteria and were finally considered for this review (7, 18, 21, 27, 29, 54-68). In total, three studies examined three or four-arm comparisons, and other studies compared PNF training with any other physical therapy intervention (i.e., educational booklet, exercise, electrotherapy, and manual or release techniques (7, 18, 21, 27, 29, 51, 54-57, 60-67). Out of 20 studies, 12 articles compared PNF training with different forms of exercises (i.e., core stabilization, strengthening, McKenzie exercise, and ball exercise (18, 27, 44, 54, 55, 57, 60, 62-64, 66-68).

Overview of participant characteristics

Appendix S3 provides a summary of the number of included participants as well as their health status, age, and gender. A total of 965 patients with LBP were originally included in the 20 studies, and 12 studies recruited chronic LBP (CLBP) patients (7, 21, 29, 51, 56, 57, 61, 62, 64, 65, 68). Furthermore, one study enrolled mechanical LBP patients, one study included patients with post-partum lumbopelvic pain, two studies recruited non-specific LBP patients, and one study recruited acute and subacute patients with intervertebral disc injury (27, 54, 63, 66, 67). Franklin et al. (2013) and Kotteeswaran et al. (2014) did not provide detailed information on the LBP sub-classification (55, 59). In three studies, female patients were included, and two studies enrolled only male patients with LBP (21, 27, 29, 60, 67). The mean age of the population in the eligible studies at baseline ranged from 22.53 to 60.80 years. Moreover, six trials provided limited information regarding demographic characteristics (27, 57, 59, 61, 65, 68). Finally, sample size determination was only described in three trials (7, 56, 64).

Methodology considerations and outcome measures

Out of 20 studies, nine articles have been conducted in India, whereas the remaining clinical trials were from South Korea (51, 54, 62, 68), Greece, Iran, Poland, and Thailand (7, 21, 27, 29, 55-57, 59-61, 63-67) [Appendix S3]. Furthermore, five of the included studies were randomized controlled trials, and the other 15 were randomized clinical trials (7, 18, 21, 27, 29, 54-68). The PNF techniques were used in 12 studies, whereas the PNF patterns were utilized in five studies, and three studies used both PNF techniques and PNF patterns (7, 18, 21, 27, 29, 54-68). The most common PNF techniques used in the eligible trials were the combination of isotonic and rhythmic stabilization (7, 21, 27, 29, 55, 57, 58, 60, 63, 64, 66, 67). Except for one study, all other studies have evaluated pain intensity in patients with LBP (7, 18, 21, 27, 29, 54-68). Additionally, 13 trials have investigated functional disability as the primary outcome (7, 18, 21, 27, 29, 55, 56, 58, 60, 63-65, 67). Measurement of spine ROM was performed in seven studies (18, 21, 29, 55, 56, 60, 63). In the majority of the retrieved studies, total treatment duration varied from three to six weeks (7, 18, 21, 27, 29, 54-64, 67, 68). However, in a study performed by Mistry et al. (2015), treatments were delivered for 10 sessions over 6 months. The LBP patients generally performed three sets of 15 repetitions of each PNF exercise (7, 21, 27, 29, 54-58, 60, 63, 65).

Quality assessment

Table 2 tabulates the results of the quality assessment. The level of inter-rater agreement of quality assessment was good (κ=0.76±0.22). In terms of quality assessment, a median PEDro score of 4 (interquartile range=2-5) indicated a fair methodological quality of the included studies. More specifically, of the 20 trials, three studies were of high quality according to the PEDro scale (7, 29, 64). In total, eight studies were rated as fair quality, and nine studies (18, 21, 27, 29, 54-62, 65, 67, 68) were graded as low quality. Criteria that were not met most frequently were allocation concealment, blinding of patients, therapists, and assessors, and intention-to-treat analysis. The percentage of trials that met each of the PEDro scale items is presented in Table 2.

Effects of interventions

Since the study carried out by Kofotolis et al. (2008) had more than two groups, the present study was divided into two studies (rhythmic stabilization plus transcutaneous electrical nerve stimulation [TENS] vs. TENS alone) (29). In addition, the study conducted by Kofotolis and Kellis (2006) was divided into two studies (rhythmic stabilization vs. normal daily activities, and a combination of isotonic vs. normal daily activities) (21).

Effects on back pain intensity

Totally, 15 out of 20 trials reported back pain intensity at baseline and short-term follow-up (7, 21, 27, 29, 54-60, 62, 63, 67, 68). Moreover, two trials evaluated back pain at baseline and intermediate-term follow-up, and one study did not assess back pain intensity (18, 65, 68). In addition, two trials did not report the number of patients in each group or sufficient data on back pain intensity to enable statistical pooling (61, 66). Therefore, three studies were excluded from the meta-analysis (18, 61, 66). The PNF training was found to be effective in alleviating back pain intensity at short-term follow-up, compared to other physical therapy interventions (SMD=-2.06; 95% CI=-3.24 to -0.88) [Figure 2A]. However, in the two studies that assessed back pain intensity at intermediate-term, the effect size of PNF training was large but not significant (SMD=-2.80) with a range from -6.67 to 1.07 [Figure 2A] (64, 65). Finally, the summary measure indicated large significant between-group differences on mean change scores for back pain intensity at post-treatment (SMD=-2.14; 95% CI=-3.23 to -1.05) [Figure 2A]. The effect size of each study is presented in Figure 2A.

Furthermore, the result demonstrated that the effect of PNF training on improving back pain intensity in patients

Table 2. Study quality according to the PEDro scale[a]

#	Author	Year	Journal	Total PEDro score	1	2	3	4	5	6	7	8	9	10	11
1	Areeudomwong et al.	2017	Musculoskeletal Care	7/10[b]	☺	☺	☺	☺	☹	☹	☺	☺	☹	☺	☺
2	Byuon and Son	2012	Journal Physical Therapy Science	5/10	☺	☺	☹	☺	☹	☹	☹	☺	☹	☺	☺
3	Franklin et al.	2013	IOSR Journal of Nursing and Health Science	3/10	☺	☺	☹	☹	☹	☹	☹	☺	☹	☺	☹
4	George et al.	2013	International Journal of Current Research	3/10	☺	☺	☹	☹	☹	☹	☹	☺	☹	☺	☹
5	Hosseinifar et al.	2016	International Journal of Pharmaceutical Research & Allied Sciences	5/10	☺	☺	☹	☺	☺	☹	☹	☺	☹	☺	☹
6	Jadeja et al.	2015	International Journal of Physiotherapy	3/10	☺	☺	☹	☹	☹	☹	☹	☹	☹	☺	☺
7	Kim and Lee	2017	Journal of Exercise Rehabilitation	5/10	☺	☺	☹	☺	☹	☹	☹	☺	☹	☺	☺
8	Kofotolis and Kellis	2006	Physical Therapy	5/10	☺	☺	☹	☺	☹	☹	☹	☺	☹	☺	☺
9	Kofotolis et al.	2008	Clinical Rehabilitation	6/10[b]	☺	☺	☹	☺	☺	☹	☹	☺	☹	☺	☺
10	Kotteeswaran et al.	2014	International Journal of Pharma and BioSciences	5/10	☺	☺	☺	☹	☹	☹	☺	☺	☹	☺	☹
11	Kumar and Moitra	2015	Indian Journal of Physiotherapy and Occupational Therapy	1/10	☹	☹	☹	☹	☹	☹	☹	☹	☹	☹	☺
12	Kumar et al.	2011	International Journal of Sports Science and Engineering	4/10	☺	☺	☹	☺	☹	☹	☹	☹	☹	☺	☺
13	Lee et al.	2014	Journal of Physical Therapy Science	5/10	☺	☺	☹	☺	☹	☹	☹	☺	☹	☺	☺
14	Malla et al.	2018	International Journal of Medical Research & Health Sciences	2/10	☺	☹	☹	☹	☹	☹	☹	☹	☹	☺	☺
15	Mavromoustakos et al.	2015	Journal of Physical Activity, Nutrition, and Rehabilitation	**6/10**[b]	☺	☺	☺	☺	☹	☹	☺	☺	☹	☹	☺
16	Mistry et al.	2015	National Journal of integrated research in medicine	2/10	☺	☺	☹	☹	☹	☹	☹	☹	☹	☺	☹
17	Olczak et al.	2008	Fizjoterapia Polska	2/10	☹	☹	☹	☺	☹	☹	☹	☹	☹	☺	☹
18	Park and Seo	2014	Journal of Physical Therapy Science	4/10	☺	☺	☹	☺	☹	☹	☹	☹	☹	☺	☺
19	Tanvi et al.	2013	IOSR Journal of Dental and Medical Sciences	1/10	☺	☹	☹	☺	☹	☹	☹	☹	☹	☹	☹
20	Young et al.	2015	Journal of Physical Therapy Sciences	3/10	☺	☺	☹	☹	☹	☹	☹	☺	☹	☺	☹
Percentage of articles meeting each PEDro item					90%	80%	15%	60%	10%	0%	15%	60%	0%	85%	60%

[a] PEDro Scale: 1, eligibility criteria and source of participants; 2, random allocation; 3, concealed allocation; 4, baseline comparability; 5, blinded participants; 6, blinded therapists; 7, blind assessors; 8, >85% follow-up; 9, intention-to-treat analysis; 10, between-group comparisons; 11, point estimates and variability.

[b] indicates high quality studies.

with LBP was clinically important (SMD=-2.14). Standard statistical tests for statistical heterogeneity indicated that there was considerable statistical heterogeneity in back pain intensity among the eligible studies ($\chi 2$=519.35, P=0.00, *I2*=96.5%).

Effects on functional disability

Out of 20 trials, 10 studies reported functional disability scores at baseline and short-term follow-up (7, 18, 21, 27, 29, 55, 56, 58, 60, 63). Only one randomized clinical trial examined disability at baseline and intermediate-term follow-up (64). Moreover, nine studies did not evaluate disability (54, 57, 59, 61, 62, 65-68). The results of the meta-analysis showed that PNF training was effective in reducing disability at short-term (SMD=-2.74; 95% CI=-3.53 to-1.96) and intermediate-term (SMD=-2.24; 95% CI=-2.80 to -1.68) follow-ups, compared to other physical therapy interventions [Figure 2B]. The overall pooled SMD showed large significant between-group differences on mean change scores for disability at post-treatment

(SMD=-2.68; 95% CI=-3.36 to -2) [Figure 2B]. The effect size of each study is presented in Figure 2B.

Moreover, the result showed that the effect of PNF training on improving functional disability in people with LBP was clinically important (SMD=-2.68). Standard statistical tests for heterogeneity demonstrated that there was considerable statistical heterogeneity in functional disability among the selected trials ($\chi 2$=81.93, *P=0.00*, *I2*=86.6%).

Effects on spine ROM

The meta-analysis was not performed for the secondary outcome (i.e., spine ROM) since the eligible studies used various instruments for measuring sagittal spine ROM. Therefore, a qualitative synthesis of results was performed. A recently published study compared PNF techniques (rhythmic stabilization and combination of isotonic) with core stabilization exercises performed on a Swiss ball (63). The result indicated that PNF

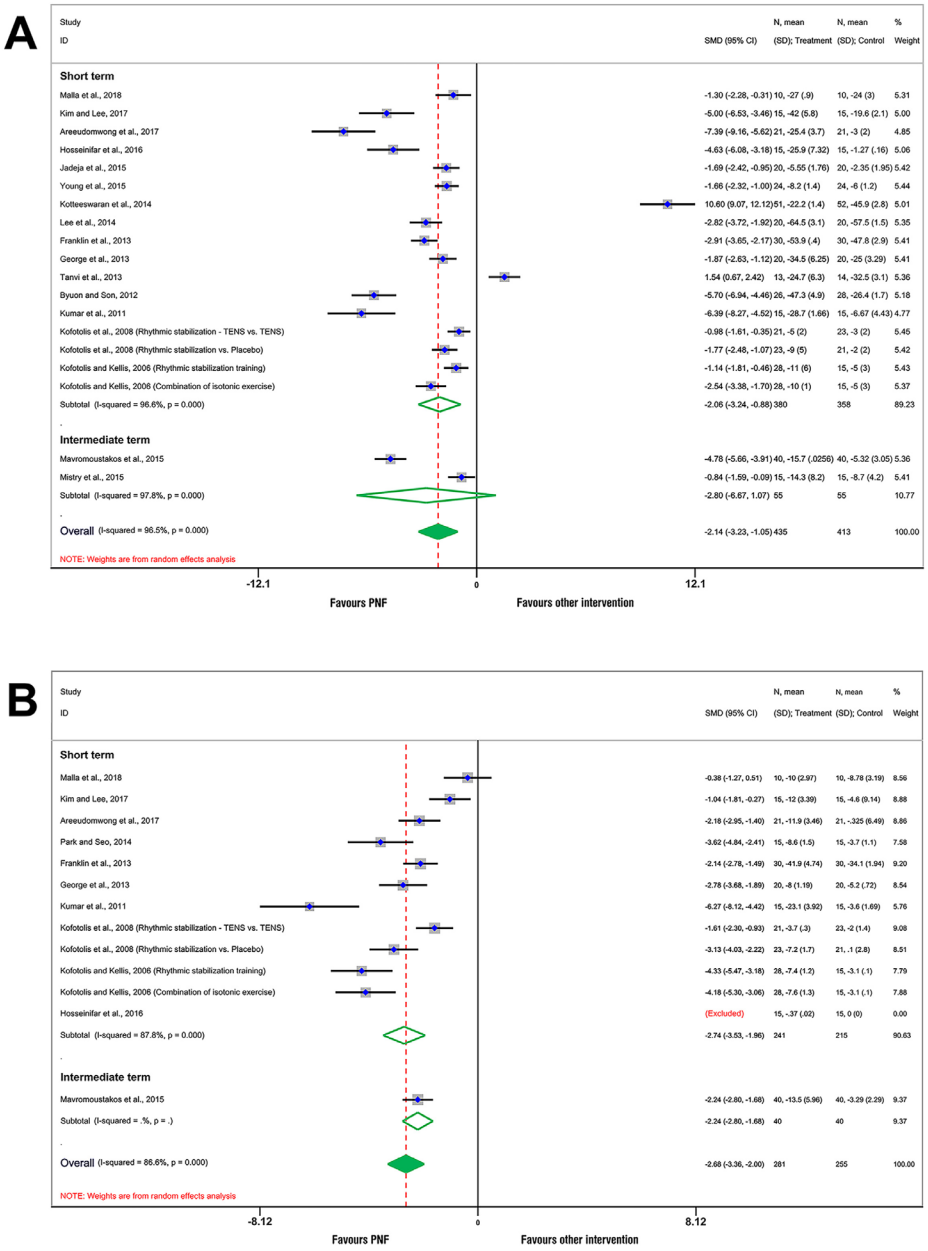

Figure 2. Forest plot of comparison: PNF training versus all other physical therapies, outcome: A; pain, and B; disability. ♦=effect size for one trial; horizontal line=95% confidence interval; ♦=pooled effect size for all trials.

techniques and core stabilization exercises were effective in improving lumbar flexion (mean difference [MD]=8.5º±0.7º; and MD=10.2º±0.6º, respectively) and extension (MD=5.2º±0.2º; and MD=5.2º±0.7º, respectively) ROM in patients with CNLBP (63). Hosseinifar et al. (2016) showed that PNF patterns significantly increased lumbar flexion (MD=1.8±0.75 cm) and extension (MD=0.87±0.09 cm) ROM after four weeks (56) [Table 2]. In another study, Park and Seo (2014) evaluated the effects of scapular and pelvic PNF patterns on lumbar sagittal plane ROM (18). The result of the present study indicated that lumbar flexion (MD=1±1.6 cm) and extension (MD=12±1 cm) significantly increased after the intervention in the experimental group (18). However, the difference in lumbar ROM in the comparison group was not significant after the intervention (*P>0.05*) (18). A study conducted by Franklin et al. (2013) reported that the combination of isotonic of trunk flexors significantly improved trunk flexion (MD=2.83±0.18 cm) and extension (MD=1.34±0.04 cm) ROM in patients with chronic LBP (55). Furthermore, Kumar et al. (2011) demonstrated that the combination of isotonic combined with conventional physical therapy can increase lumbar flexion (MD=3.51±1.09 cm) and extension (MD=1.05±0.25 cm) ROM, compared to conventional physical therapy alone in recurrent mechanical CLBP patients (60). There is also evidence that rhythmic stabilization technique and rhythmic stabilization technique combined with TENS can increase lumbar flexion (MD=2.8±3.2 cm; and MD=1.6±1 cm, respectively) and extension (MD=3±0.4 cm; and MD=7±4.1 cm, respectively), compared to TENS alone or placebo treatment at eight-week follow-up (29). Finally, Kofotolis and Kellis (2006) compared two PNF techniques (rhythmic stabilization and combination of isotonic) with lumbar flexion-extension ROM (21). After eight weeks, both rhythmic stabilization and combination of isotonic groups showed significant improvements (MD=8±0.1 cm, and MD=8.1±2.8 cm, respectively), compared to the control group (21).

Sensitivity analysis

The impact of individual trials on the overall meta-analysis estimates was evaluated. The results of leave-one-out sensitivity analysis revealed that the eligible trials had influences on the pooled SMDs of pain outcome ranging from -2.98 (95 % CI=-3.72 to -2.24) after excluding the study conducted by Tanvi et al. (2013) to -2.51 (95 % CI=-3.28 to -1.73) after excluding the study performed by Areeudomwong et al. (2017) (7) [Figure 3A]. Moreover, for the outcome "functional disability", the sensitivity analysis demonstrated that the eligible studies had also an influence on the pooled SMDs ranging from -2.87 (95 % CI=-3.52 to -2.22) after excluding the study by Malla et al. (2018) (63) to -2.45 (95 % CI=-3.07 to -1.82) after excluding the study carried out by Kumar et al. (2011) (60) [Figure 3B].

The sensitivity analysis for pain outcome by the 'hetred' command showed that 10 studies should be excluded to reduce the *I2* to <50% (7, 54-56, 58-60, 62, 64, 67) [Table 3A]. For the outcome "functional disability", the 'hetred' command indicated that five studies were the source of heterogeneity (21, 29, 58, 60, 63) [Table 3B].

Subgroup analyses of PNF types were performed for the primary outcomes. Due to the limited number of studies in each PNF type, a conclusive result could not be achieved. However, the results showed that a combination of PNF techniques and patterns had a greater beneficial effect on pain reduction than a PNF technique or pattern alone. Furthermore, the contract-relax technique improved functional disability more than other PNF techniques or patterns in patients with LBP [Figure 4].

Quality of evidence and strength of recommendation

The quality of evidence for the primary outcomes was investigated using the GRADE tool [Table 4]. For the outcome "pain", there was low-quality evidence (downgraded due to study limitations (i.e., poor quality studies), inconsistency, publication (or reporting) bias, and upgraded due to large effect size) that PNF training could decrease pain in patients with LBP. For the outcome "functional disability", there was low-quality evidence (downgraded due to study limitations (i.e., poor quality studies), inconsistency, publication (or reporting) bias, and upgraded due to large effect size) that PNF training could improve functional disability in patients with LBP. The strength of recommendation was weak for the primary outcomes (i.e., pain and functional disability).

Assessment of publication bias

Evidence of publication bias was found for pain and disability outcomes as the funnel plots showed asymmetries [Figure 4]. Furthermore, the Begg and Mazumdar's rank correlation tests also demonstrated that publication bias was significant for pain (z=2.24, *P=0.02*) and disability (z=2.54, *P=0.01*) outcomes. However, the application of the trim and fill method did not identify any missing study, and therefore, left the pooled estimates unchanged.

Discussion

The current study systematically reviewed and conducted a meta-analysis regarding the efficacy of PNF training on LBP individuals. The two main findings of this review were as follows: *i*) Evidence from the summary measures suggests that PNF, either used alone or in combination with other physical therapy approaches, successfully decreased back pain intensity, functional disability, and increased lumbar spine ROM in people with LBP; and *ii*) There was considerable statistical heterogeneity among the eligible studies for the primary outcomes.

There is low evidence across the eligible trials that PNF training improves back pain intensity in patients with LBP. The overall summary measure was large favoring the use of PNF training to decrease back pain intensity in patients with LBP. Moreover, the effect size estimated

for each trial also supports the positive effects of the application of PNF training. The clinical benefits from the use of PNF training were seen either in combination with other physical therapy interventions (e.g., electrotherapy and exercise) or using PNF training alone, and were always superior to the control interventions. Areeudomwong et al. (2017) reported that PNF training may improve the activity of the paraspinal muscles, which enhances the stability of the lumbar spine in both static and dynamic conditions (7). They assumed that increased lumbar spine stability may contribute to the reduction in back pain intensity in patients with LBP (7). On the other hand, neurophysiologic studies have linked pain exacerbation in the lumbar spine with disturbances in the mechanoreceptors and perhaps with impairment of the superior proprioception centers (e.g., the somatosensory cortex (conscious proprioception) or the cerebellum [unconscious proprioception]) (71-73). Franklin et al. (2013) stipulated that exercise programs that enhance proprioception (e.g., PNF training) may be beneficial for improving pain in the CLBP population (55). A previous study also suggested that PNF training can target movement-related pain memories by applying the exposure without danger principle (64).

In a study conducted by Kofotolis and Kellis (2006), it has been shown that the application of rhythmic stabilization and combination of isotonic exercises did not improve back pain intensity immediately after training (21). They mentioned that pain symptoms in patients with CLBP may be affected by social or psychological factors, which may not be improved easily by a 4-week exercise program (21). However, the back pain intensity level

A

Influence analysis of each study on the pooled estimate of "pain" measure

Study omitted	Estimate	95% CI
Areeudomwong 2017	-1.8708727	-2.9561939 to -0.78555161
Byuon 2012	-1.9427668	-3.0377574 to -0.847776
Franklin 2013	-2.0968614	-3.2540722 to -0.93965065
George 2013	-2.1563411	-3.321435 to -0.99124724
Hosseinifar 2016	-2.0059719	-3.1225495 to -0.88939434
Jadeja 2015	-2.1672723	-3.3350201 to -0.99952441
Kim 2017	-1.9880848	-3.1009152 to -0.87525451
Kofotolis 2006 (CI)	-2.1178594	-3.2714121 to -0.96430647
Kofotolis 2006 (RS)	-2.1989	-3.3695493 to -1.0282507
Kofotolis 2008 (RS vs. Placebo)	-2.1623759	-3.3333411 to -0.99141079
Kofotolis 2008 (RS-TENS vs. TENS)	-2.2082131	-3.3828852 to -1.0335406
Kotteeswaran 2014	-2.750001	-3.5555768 to -1.9444252
Kumar 2011	-1.9255298	-3.0267177 to -0.82434201
Lee 2014	-2.1019845	-3.2492082 to -0.95476073
Malla 2018	-2.1874397	-3.3335466 to -1.0413327
Mavromoustakos 2015	-1.987869	-3.0905149 to -0.88522315
Mistry 2015	-2.2152071	-3.3729002 to -1.057514
Park 2014	-2.1388543	-3.2299576 to -1.0477511
Tanvi 2013	-2.345402	-3.4320905 to -1.2587137
Young 2015	-2.1693521	-3.3465438 to -0.9921605
Combined	**-2.1388544**	**-3.2299577 to -1.0477511**

B

Influence analysis of each study on the pooled estimate of "disability" measure

Study omitted	Estimate	95% CI
Areeudomwong 2017	-2.7394342	-3.4900141 to -1.9888542
Byuon 2012	-2.6773508	-3.3562822 to -1.9984193
Franklin 2013	-2.7499235	-3.516813 to -1.983034
George 2013	-2.676461	-3.4123125 to -1.9406095
Hosseinifar 2016	-2.6773508	-3.3562822 to -1.9984193
Jadeja 2015	-2.6773508	-3.3562822 to -1.9984193
Kim 2017	-2.8324187	-3.5322142 to -2.1326232
Kofotolis 2006 (CI)	-2.5383115	-3.2159073 to -1.8607157
Kofotolis 2006 (RS)	-2.5253091	-3.1962547 to -1.8543633
Kofotolis 2008 (RS vs. Placebo)	-2.6407454	-3.3656523 to -1.9158384
Kofotolis 2008 (RS-TENS vs. TENS)	-2.7933505	-3.5350404 to -2.0516605
Kumar 2011	-2.4458628	-3.0739944 to -1.8177314
Lee 2014	-2.6773508	-3.3562822 to -1.9984193
Malla 2018	-2.8688817	-3.5197392 to -2.2180245
Mavromoustakos 2015	-2.7447271	-3.5267844 to -1.9626696
Mistry 2015	-2.6773508	-3.3562822 to -1.9984193
Park 2014	-2.5989773	-3.3032556 to -1.8946991
Tanvi 2013	-2.6773508	-3.3562822 to -1.9984193
Young 2015	-2.6773508	-3.3562822 to -1.9984193
Combined	**-2.6773508**	**-3.3562823 to -1.9984192**

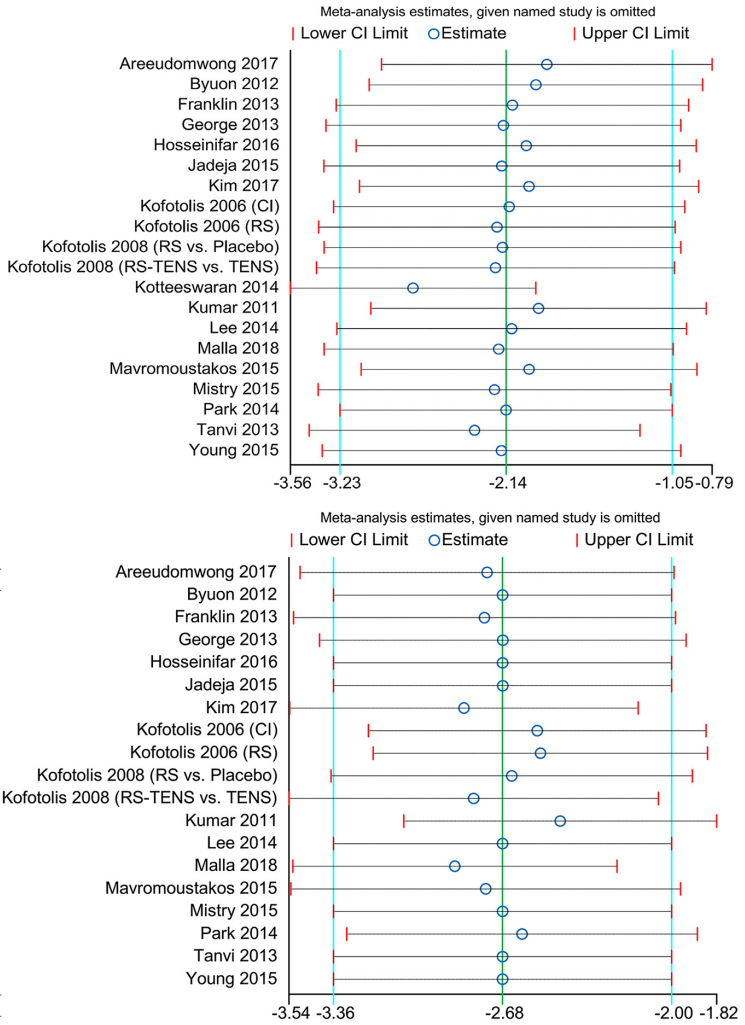

Figure 3. Influence analyses of each study on the pooled estimates of primary outcomes: A; pain, and B; disability. The left, middle, and right vertical lines are indicators for the minimum, mean, and maximum value of total effect size, respectively.

Table 3. Sensitivity analysis for heterogeneity

Study	Step	Heterogeneity (I^2; %)
A: Pain		
Kotteeswaran et al. (2014)	1	93.46207
Tanvi et al. (2013)	2	91.67078
Mavromoustakos et al. (2015)	3	90.50734
Areeudomwong et al. (2017)	4	88.61831
Byuon and Son (2012)	5	85.20895
Kumar et al. (2011)	6	81.70974
Kim and Lee (2017)	7	77.55412
Hosseinifar et al. (2016)	8	70.30742
Franklin et al. (2013)	9	59.96315
Lee et al. (2014)	10	45.61245
Data after omission of studies: Effect size and 95% CI=0.22 (0.18 - 0.29) Q=14.709249 I^2=45.612452% *P-value* for heterogeneity=0.06		
B: Disability		
Malla et al. (2018)	1	84.02032
Kumar et al. (2011)	2	80.35833
Kim and Lee (2017)	3	75.70641
Kofotolis and Kellis (2006) (Rhythmic stabilization)	4	69.60426
Kofotolis and Kellis (2006) (Combination of isotonics)	5	54.12913
Kofotolis et al. (2008) (Rhythmic stabilization-TENS vs. TENS)	6	39.00089
Data after omission of studies: Effect size and 95% CI = 0.08 (0.05 – 0.12) Q = 8.1968409 I^2 = 39.00089% *P-value* for heterogeneity = 0.15		

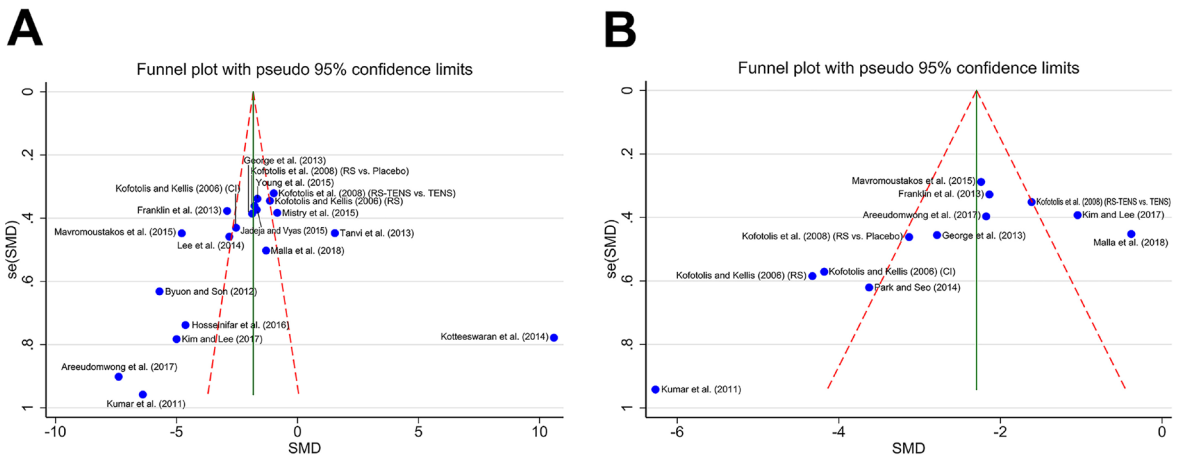

Figure 4. Funnel plots for the assessment of publication bias for primary outcomes: A; pain, and B; disability. It demonstrates asymmetries in the funnel plots.

Table 4. Grades of Recommendation, Assessment, Development, and Evaluation quality of evidence and strength of recommendation for the primary outcomes

Outcome	Study limitations	Inconsistency	Indirectness	Imprecision	Publication bias	Effect size	GRADE quality	Recommendation
Pain (SMD = -2.14; 95% CI = -3.23 to -1.05; I^2 = 96.5%)	-1[a]	-1[b]	Not serious	Not serious	-1[c]	+1[d]	⊕⊕⊖⊖ (Low)	Weak
Disability (SMD = -2.68; 95% CI = -3.36 to -2.00; I2= 86.6%)	-1[a]	-1[b]	Not serious	Not serious	-1[c]	+1[d]	⊕⊕⊖⊖ (Low)	Weak

[a] Downgraded one level as the majority of trials scored ≤ 6 on the PEDro scale (69).
[b] Downgraded one level as the I^2 value was > 50% (23).
[c] Downgraded one level due to suspected publication bias (70).
[d] Upgraded one level due to large effect size (69).
The symbols ⊕⊕⊖⊖ indicate how many of the items were fulfilled (for each ⊕, 1 item was fulfilled and corresponds to the different levels of evidence).

was significantly decreased four and eight weeks after training in both experimental groups, compared to the comparison group (21).

Sharman et al. (2006) reviewed the mechanisms of PNF technique effects on ROM (17). Autogenic inhibition (nonreciprocal inhibition, autogenetic inhibition, or inverse myotatic reflex) refers to inhibitory input to an agonist muscle (i.e., the prime mover) and its synergists concomitant with an excitatory input to opposing (antagonist) muscles (17, 74). The inhibition of the agonist motoneuron pools and the excitation of antagonist motoneurons have resulted from Golgi tendon organs within the same muscle via group Ib interneurons (74). The decreased efferent (motor) drive to the muscle through autogenic inhibition is a factor assumed to facilitate agonist muscle elongation (17). The hold-relax technique includes a maximal isometric contraction of the lengthened agonist muscle (s) in order to take advantage of autogenic inhibition.

On the other hand, the contract-relax technique utilizes reciprocal inhibition mechanism, which is defined as the inhibition of antagonistic alpha motoneurons activity through contraction of the agonistic muscle(s) under the control of supraspinal centers (75, 76). The Ia muscle spindle afferents innervate the homonymous alpha motoneuron, which causes the muscle to contract (75). Simultaneously, an inhibitory interneuron is innervated at the alpha motoneuron, which synapses onto the antagonist muscle (s) (76). The activation of this inhibitory interneuron prevents excitation of the antagonist alpha motoneuron pool and diminishes antagonist muscle (s) contraction. In addition, other mechanisms, such as viscoelastic properties of the musculotendinous unit (i.e., creep and stress relaxation phenomena) and changes in stretch perception or stretch tolerance have been proposed in the literature as possible mechanisms of increasing ROM following the application of the PNF techniques (17, 77).

The second main result of this review is that considerable statistical heterogeneity was evident across the eligible trials for the primary outcomes. The possible explanations for this considerable heterogeneity may be the differences in the included trials regarding the control intervention, differing patients' baseline characteristics, number of cases and controls, and variations in the dosage and duration of treatment.

To evaluate the presence of publication bias in this review, two funnel plots were generated [Figure 4]. The Begg and Mazumdar's rank correlation tests showed that publication bias was evident in the meta-analysis of the selected studies. The possible explanations could be the quality of included studies, non-published trials with negative results, or those showing no different findings, small sample size, and the number of trials in each separate meta-analysis.

A narrative review conducted by Smedes et al. (2016) recommended that well-designed clinical trials that are comprehensively detailed are required to investigate the efficacy of PNF training in rehabilitation (16). In a similar vein, our study showed that only 20% of total eligible studies were deemed high quality, and the majority of the included studies only evaluated the short-term effects of PNF training on pain and disability in patients with LBP (7, 29, 56, 64).

There are some limitations to our systematic review that should be acknowledged. The results of the studies included in this review mainly refer to short-term changes after intervention. Therefore, it is impossible to draw robust conclusions about the efficacy of PNF training at long-term follow-up. Moreover, a limited number of clinical trials were available to investigate the effectiveness of PNF training on LBP at intermediate-term follow-up. This limits the conclusions that can be derived from the meta-analyses. In addition, the majority of selected studies did not conduct a power analysis to estimate the required sample size. Therefore, the external validity of the results may be compromised. The

eligible studies presented several methodological limitations. The most frequent limitations were related to non-blinding methods, allocation concealment, and intention-to-treat analysis. Finally, database searching was limited to English language articles, which might be suggestive of publication bias.

Future randomized controlled trials should consider the methodological limitations observed in the trials selected for this systematic review in order to improve their methodological quality. Moreover, future studies including an appropriate number of participants should investigate intermediate- and long-term follow-up of patients with LBP treated by PNF training.

According to the clinical trials included in this systematic review, it can be concluded that although the effects of the primary outcomes were large, there was the low quality of evidence revealing the positive effects of PNF training on back pain intensity and functional disability in patients with LBP. The strength of recommendation was also weak. In the current systematic review, the statistical heterogeneity analysis showed that there was considerable statistical heterogeneity among the eligible trials for the primary outcomes ($\chi 2$ with $P<0.05$ and $I2$ >75% for both primary outcomes). Due to the lack of sufficient data on lumbar ROM, a formal meta-analysis was impossible. However, a qualitative synthesis of evidence indicates that PNF training can improve lumbar spine ROM in the population with LBP. Further high-quality randomized controlled trials should assess the long-term effects of PNF training on back pain intensity, functional disability, and lumbar ROM in patients with LBP. Finally, it is recommended that clinicians use a combination of PNF techniques and patterns in patients with LBP to improve back pain.

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APPENDIX S1. Search strategy for PubMed/Medline (NLM).

(((“muscle stretching” AND exercise*) OR (static AND stretching) OR (passive AND stretching) OR (relaxed AND stretching) OR (static-passive AND stretching) OR (“static passive” AND stretching) OR (isometric AND stretching) OR (active AND stretching) OR (static-active AND stretching) OR (“static active” AND stretching) OR (ballistic AND stretching) OR (dynamic AND stretching) OR (“proprioceptive neuromuscular facilitation”) OR (PNF) OR (PNF AND stretching) OR (“proprioceptive neuromuscular facilitation” AND stretching)) AND ((low* AND “back pains”) OR (low* AND “back pain”) OR (“low back” AND pain*) OR (“lower back” AND pain*) OR (“low back” AND ache*) OR (low AND “back ache”) OR (low AND “back aches”) OR (low AND backache*) OR (“low back pain” AND recurrent) OR lumbago OR (“low back pain” AND postural) OR (“low back pain” AND mechanical) OR (“low back pain” AND “posterior compartment”) OR (back AND pain*) OR backache* OR (back AND ache*) OR “back pain without radiation” OR (vertebrogenic AND “pain syndrome”) OR (vertebrogenic AND “pain syndromes”) OR (“vertebrogenic pain” AND syndrome*) OR “back pain with radiation”)).

APPENDIX S2. The PEDro 11-item scale (from PEDro database, www.pedro.org.au)	
1. Eligibility criteria were specified	no □ yes □ where: ___
Subjects were randomly allocated to groups (in a cross-over study, subjects were randomly allocated an order in which treatments were received)	no □ yes □ where: ___
Allocation was concealed	no □ yes □ where: ___
The groups were similar at baseline regarding the most important prognostic indicators	no □ yes □ where: ___
There was blinding of all subjects	no □ yes □ where: ___
There was blinding of all therapists who administered the therapy	no □ yes □ where: ___
There was blinding of all assessors who measured at least one key outcome	no □ yes □ where: ___
Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	no □ yes □ where: ___
All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by “intention to treat”	no □ yes □ where: ___
The results of between-group statistical comparisons are reported for at least one key outcome	no □ yes □ where: ___
The study provides both point measures and measures of variability for at least one key outcome	no □ yes □ where: ___

APPENDIX S3. Studies are presented in time-ordered manner from most recent to oldest by year of publication

#	Article, type of study	Participant characteristics	Treatment	Treatment details	Outcome measures	Conclusion
1	Malla *et al.* (2018), randomized clinical trial	20 CNLBP participants **Experimental group:** *n*: 10 Mean age: 33.7 ± 6.66y **Comparison group:** *n*: 10 Mean age: 31.5 ± 4.83y	**Experimental group:** RS (alternating [trunk flexion-extension] isometric contractions against resistance) in a seated position **Comparison group:** Motor control exercises (including sit-up and back extensor exercises on a swiss ball)	Treatment interventions were applied 5 times a week for 5 weeks, with each session lasting about 15 min; **Experimental group:** 3 sets of 15 repetitions at maximal resistance for 10 seconds, with rest intervals of 30 s for each trunk pattern, and 60 s after completing 15 repetitions for each set Reassessments were performed at the end of treatment sessions	Pain intensity (VAS), functional disability (RMDQ), and lumbar flexion and extension ROM (baseline digital inclinometer)	After intervention, the results indicated a significant improvement in pain, functional disability, and ROM in patients with NLBP employing RS technique as well as motor control exercise on the swiss ball. However, both interventions showed to be similarly effective in decreasing pain, disability and increasing ROM in patients with NLBP
2	Areeudomwong *et al.* (2017), randomized clinical trial	42 CNLBP participants **Experimental group:** Sex: 6♂ 15♀ Mean age: 35.4 ± 10.3y Mean height: 162.5 ± 10.5cm Mean body mass: 55.6 ± 7.3kg **Comparison group:** Sex: 5♂ 16♀ Mean age: 36.2 ± 9.9y Mean height: 163.7 ± 9.4cm Mean body mass: 55.8 ± 8.5kg	**Experimental group:** Alternating isometric contractions of trunk flexor and extensor muscles against maximal resistance in a seated position + alternating concentric and eccentric contractions of trunk flexors (CI) in a seated position + trunk PNF pattern using bilateral diagonal upper limbs movements against maximal resistance in a seated position **Comparison group:** Educational booklet (including information about anatomy and LBP causes, an active self-management approach to LBP encouraging the patient to identify postures/movements that are painful, activity for enhancing recovery, and rehabilitative exercises)	Treatment interventions were applied 5 times a week for 4 weeks, with each session lasting about 30 min; **Experimental group:** 3 sets of 15 repetitions for each PNF intervention, with rest intervals of 30 s between the sets, and 60 s after completing 15 repetitions for each trunk PNF pattern; Reassessments were performed at the end of 4th and 12th weeks	Pain intensity (NPRS), functional disability (RMDQ), health-related quality of life (SF-36 V.2), patient satisfaction (Global Perceived Effect Scale), and lumbar erector spinae muscle activity (surface EMG)	After 4 weeks, participants in the experimental group showed a significant reduction in pain intensity and functional disability, and improved patient satisfaction and health-related quality of life compared to the comparison group. These effects were still significant at the 12-week follow-up assessment. Lumbar erector spinae muscle activity in the experimental group was significantly increased throughout the measurement periods compared to the comparison group
3	Kim and Lee (2017), randomized clinical trial	30 CLBP participants **Experimental group:** Sex: 8♂ 7♀ Mean age: 39.8 ± 5.47y Mean height: 168.73 ± 7.27cm Mean body mass: 67.6 ± 9.51kg **Comparison group:** Sex: 9♂ 6♀ Mean age: 39.4 ± 5.69y Mean height: 168.73 ± 8.01cm Mean body mass: 67.07 ± 9.65kg	**Experimental group:** Warm-up (stretching, ROM exercises, RI, HR, or CR) + PNF patterns (bilateral asymmetrical lower extremity, flexion-adduction-external rotation lower extremity [D1 flexion], extension-adduction-internal rotation upper extremity [D2 extension], chopping, neck flexion, trunk flexion) + PNF techniques (RS, SR, RI, and CI) + cool-down (stretching, ROM exercises, RI, HR, or CR) **Comparison group:** Electrotherapy (hot pack [80°C] + interfacial current therapy [2,000–2,500 Hz] + ultrasound [0.8–1 MHz])	Treatment interventions were applied 5 times a week for 6 weeks; **Experimental group:** Warm-up for 10 min, main exercises for 30 min (3 sets of 8-15 repetitions), and cool-down for 10 min (a total of 50 min); **Comparison group:** Hot pack for 20 min, interfacial current therapy for 20 min, and ultrasound for 10 min (50 min total treatment time); Reassessments were performed at the end of 6th week	Pain intensity (VAS), functional disability (ODI), and FEV_1 (spirometer)	After a 6-week treatment, the improvements in FEV_1, pain intensity, and functional disability were significantly greater in the experimental group than in the comparison group

APPENDIX S3. Continued

4	Hosseinifar *et al.* (2016), randomized controlled trial	30 CNLBP participants **Experimental group:** *n*: 15 Mean age: 40.53 ± 10.83y Mean height: 166.33 ± 4.7cm Mean body mass: 68.33 ± 0.6kg **Comparison group:** *n*: 15 Mean age: 40.33 ± 11.37y Mean height: 162.33 ± 4.11cm Mean body mass: 66.53 ± 7.02kg	**Experimental group:** Head, neck and upper (DFR, DFL, DEL, DER) trunk and lower trunk (DFR, DFL, DEL, DER) patterns + electrotherapy (burst-mode TENS [pulse width, 200 µs; frequency, 100 Hz; burst frequency, 2 Hz] + hot pack) **Comparison group:** Electrotherapy (burst-mode TENS [pulse width, 200 µs; frequency, 100 Hz; burst frequency, 2 Hz] + hot pack)	Treatment interventions were applied 5 times a week for 4 weeks; **Experimental group:** 3 sets of 15 repetitions of each exercise, resting time between repetitions and sets was 30 s and 60 s, respectively; **Comparison group:** TENS for 20 min, and hot pack for 20 min; Reassessments were performed at the end of 4th week	Pain intensity (McGill Pain questionnaire), functional disability (ODI), lumbar lordosis (flexible ruler), and lumbar flexion and extension ROM (modified-modified Schober test)	After a 4-week treatment, pain intensity, functional disability, and lumbar spine ROM were improved significantly in the experimental group. However, the degree of lumbar lordosis was not changed after treatment. Furthermore, there was a significant difference between the 2 groups regarding pain intensity, functional disability, and mobility of lumbar spine
5	Jadeja *et al.* (2015), randomized controlled trial	40 (28 12) postural CLBP participants, aged between 20 to 40 years	**Experimental group:** IFT (small sweep; frequency, 90-100HZ) + RS (alternating [trunk flexion-extension] isometric contractions against resistance) + CI (alternating concentric and eccentric contractions of agonists without relaxation, resisted active concentric contraction [trunk flexion], resisted eccentric contraction [trunk flexion], and resisted maintained contraction [trunk flexion-extension]) + conventional back exercises (abdominal contraction, single knee to chest stretch, abdominal curl ups, prone on elbows, prone on hands, bridging, straight leg raises, postural advice) **Comparison group:** IFT (small sweep; frequency, 90-100HZ) + conventional back exercises (abdominal contraction, single knee to chest stretch, abdominal curl ups, prone on elbows, prone on hands, bridging, straight leg raises, postural advice)	Treatment interventions were applied 5 times a week for 4 weeks, IFT: 15 min; **Experimental group:** RS: 3 sets of 15 repetitions at maximal resistance, rest intervals of 30 s and 60 s were provided after the completion of 15 repetitions for each pattern and between sets, respectively; CI: 5 s contraction, 3 sets of 15 repetitions against maximal resistance were performed. Rest intervals were the same as those described above **Comparison group:** participants were asked to perform 10 repetitions of each exercise with 5 s hold Reassessments were performed at the end of 4th week	Pain intensity (VAS), core muscles strength (Core Stability Gradation), health-related quality of life (SF-36)	There was a significant improvement in VAS score in both groups, but the experimental group showed more significant improvement than the comparison group. In addition, there was a significant improvement in core muscles strength and SF-36 score in the experimental group
6	Kumar and Moitra (2015), randomized clinical trial	30 NLBP participants, aged between 20-40 years	**Experimental group:** Contract relax technique of the hamstrings **Comparison group 1:** Muscle energy technique (PIR) of the hamstrings **Comparison group 2:** Static stretching of the hamstrings	Treatment interventions were applied 5 consecutive days a week for 4 weeks; Reassessments were performed at the end of 4th week	Pain intensity (NPRS), AKE (universal goniometer)	There was significant improvement in pain intensity and active knee extension ROM in the muscle energy technique and contract relax technique groups compared to the static stretching group

APPENDIX S3. Continued

7	Mavromoustakos *et al.* (2015), randomized clinical trial	80 CLBP participants **Experimental group:** Sex: 23♂ 17♀ Mean age: 40.35 ± 9.62y Mean height: 171 ± 5cm Mean body mass: 74.38 ± 7.91kg **Comparison group:** Sex: 22♂ 18♀ Mean age: 40.88 ± 1.28y Mean height: 1.70 ± 0.08cm Mean body mass: 74.65 ± 8.36kg	**Experimental group:** PNF techniques in different starting positions: supine (RI, replication, exercise [keeping pelvic neutral position during hips movements in a hook lying position, keeping upper trunk neutral position during hips and pelvis movements, bridging, bridging with pelvis movements, gait stimulation, rolling from supine to side lying]) + sitting (SR, exercise [upper trunk flexion/extension with minimal lower trunk rotation, body transfers on the chair in different directions were performed with and without arms use, sit-to-stand movement]) + standing (RI, replication) All exercises were performed using CI, HR, and CR **Comparison group:** General exercise using a published protocol (Koumantakis et al., 2005)	Treatment interventions were applied for 6 weeks and each session lasted about 60 min; **Experimental group:** RI and replication were initiated from week 1, while SR and CI gradually introduced from week 2 and fully implemented from week 3 onwards, the intensity of exercise started from 5 repetitions X 5 s contraction (weeks 1-2), it progressed to 7 repetitions X 7 s; contractions (weeks 3-4) and increased to 10 repetitions X 10 s contractions (weeks 5-6); **Comparison group:** The intensity was the same as the experimental group; Reassessments were performed at the end of 6th and 8th weeks	Pain intensity (McGill pain questionnaire), functional disability (RMDQ), psychological status (Emotions Scale)	After a 6-week treatment, pain intensity decreased more in the experimental group than the comparison group. Functional disability decreased in the experimental group, while the comparison group showed an improvement only immediately after the program. Finally, positive emotions increased significantly only in the experimental group, while there was a reduction in negative emotions for both groups
8	Mistry *et al.* (2015), randomized clinical trial	30 CLBP participants, aged between 20 to 60 years **Experimental group:** *n*: 15 **Comparison group:** *n*: 15	**Experimental group:** Modified HR for the hamstrings in the supine position + conventional physical therapy (abdominal and extensor isometric exercise + hot pack) **Comparison group:** ART + conventional physical therapy (abdominal and extensor isometric exercise + hot pack)	Treatment interventions were applied for 10 sessions over a period of 6 months; **Experimental group:** 7 counts hold time, 5 s relax time, 3 repetitions; **Comparison group:** 5 repetitions; Reassessments were performed at the end of treatment sessions	Pain intensity (VAS), functional disability (MODI), AKE (unknown)	Both techniques improved hamstrings flexibility and reduce pain and disability in CLBP patients. However, the experimental group showed significant improvement compared to the comparison group
9	Young *et al.* (2015), randomized clinical trial	48 elderly participants with CLBP **Experimental group:** *n*: 24 **Comparison group:** *n*: 24	**Experimental group:** PNF patterns **Comparison group:** Swiss ball training	Treatment interventions were applied for 50 min per day, 3 times a week for 6 weeks; Reassessments were performed at the end of treatment sessions	Pain intensity (VAS), dynamic balance (FRT [cm]) and TUG [cm]), static balance (mean velocity of COP in X and Y directions during standing)	After intervention, both groups showed a significant improvement in pain intensity, dynamic balance, and static balance. However, there was no significant difference in the dynamic balance, and pain intensity results between the 2 groups
10	Lee *et al.* (2014), randomized clinical trial	40 CLBP participants **Experimental group:** *n*: 20 Mean age: 34.75 ± 0.85y Mean height: 174.07 ± 1.05cm Mean body mass: 71.25 ± 4.59kg **Comparison group:** *n*: 20 Mean age: 34.2 ± 0.69y Mean height: 172.85 ± 1.24cm Mean body mass: 70.75 ± 3.81kg	**Experimental group:** PNF combination patterns (sprinter/skater posture in bridge, side-lying, sitting, standing positions) **Comparison group:** Ball exercises (pelvic tilts while sitting on the ball; lying back on the ball, hip lifts while lying back on the ball, and marching was performed while lying with the chest on the ball and crunching, followed by arching while holding the ball between the calves, moving the body right and left while lifting the legs on the ball, bridging, and right and left stretches while leaning on the ball),	Treatment interventions were applied 4 times a week for 6 weeks **Experimental group:** 15 min; **Comparison group:** 15 s rest interval between sets, Pelvic tilt: 2 sets, 20 repetitions, Hip lift: 2 sets, 10 s hold time, Marching: 1 set, 10 s, Stretch: 10 s; Reassessments were performed at the end of 2nd, 4th and 6th weeks	Pain intensity (VAS), muscle activity (surface EMG)	After 6 weeks intervention, the experimental group showed significant improvements in pain intensity and muscle activity compared to the comparison group

APPENDIX S3. Continued

11	Kotteeswaran *et al.* (2014), randomized clinical trial	103 LBP participants **Experimental group:** Sex: 32♂ 19♀ Mean age: 26.83 ± 6.24y **Comparison group:** Sex: 32♂ 19♀ Mean age: 27.42 ± 5.23y	**Experimental group:** IFT (beat frequency, 80-120HZ) + contract relax technique of the hamstrings in a supine position **Comparison group:** IFT (beat frequency, 80-120HZ) + dynamic soft tissue mobilization (deep longitudinal strokes were applied to the entire hamstrings in the prone and supine positions + active knee extension with 5 deep distal to proximal longitudinal strokes over the hamstrings)	Treatment interventions were applied 3 times a week for 4 weeks; IFT: 10 min; Both groups were treated for 5 repetitions with a rest of 20 s between repetitions in 1 session Reassessments were performed at the end of treatment sessions	Pain intensity (NPRS), AKE (universal goniometer)	The results indicated that both groups showed significant improvement after 4 weeks. However, the dynamic soft tissue mobilization was more effective than the contract relax technique in improving AKE and decreasing pain in LBP patients
12	Park and Seo (2014), randomized clinical trial	30 obese participants with LBP **Experimental group:** Sex: 15♂ Mean age: 34.5 ± 9.1y Mean height: 174.1 ± 6.1cm Mean body mass: 76.1 ± 3.2kg BMI: 29.1 ± 2.8kg/m^2 **Comparison group:** Sex: 15♂ Mean age: 33.5 ± 8.2y Mean height: 176.8 ± 3.3cm Mean body mass: 77.8 ± 6.2kg BMI: 28.4 ± 1.3kg/m^2	**Experimental group:** Scapular PNF patterns in a supine position (anterior depression – posterior elevation) and pelvic patterns (anterior elevation – posterior depression) + conventional physical therapy (hot pack, IFT, ultrasound, and rest) **Comparison group:** Strengthening exercise (warm-up [stretching], flexion exercise, extension exercise, and cool-down) + conventional physical therapy (hot pack, IFT, ultrasound, and rest)	Treatment interventions were applied 3 times a week for 4 weeks, with each session lasting about 30 min, Rest: 5 min; **Comparison group:** Warm-up: 5 min, Flexion and extension exercises: 10 min, Cool-down: 5 min; Reassessments were performed at the end of treatment sessions	Functional disability (ODI), lumbar flexion and extension ROM (cm; measurements were taken from the ground to the participants' chins)	The experimental group showed significant differences in the disability index and lumbar flexibility from the comparison group. Lumbar flexion and extension ROM and functional disability improved significantly in the experimental group. However, there were no significant changes in the comparison group after intervention
13	Franklin *et al.* (2013), randomized clinical trial	53 patients with LBP **Experimental group:** Sex: 15♂ 12♀ Mean age: 33.11 ± 8.10y **Comparison group:** Sex: 14♂ 12♀ Mean age: 33.73 ± 8.01y	**Experimental group:** SWD (continuous mode) + CI of trunk flexors with maximal resistance **Comparison group:** SWD (continuous mode) + core stability exercise (curl up, side bridges, bird dog)	Treatment interventions were applied 4 weeks **Experimental group:** 45-60 min per day, 20-30 min SWD, resisted active concentric contraction for 5 s (trunk flexors), resisted eccentric contraction for 5 s (trunk flexors), 3 sets and 15 repetitions; **Comparison group:** In the first 2 weeks, the exercises were performed in clinic and in the second 2 weeks the exercises were performed at home (home exercise), 20 repetitions for each exercise, 20-30 min SWD; Reassessments were performed at the end of 4th weeks	Pain intensity (VAS), functional disability (MODI), lumbar flexion and extension ROM (modified-modified Schober test)	After 4 weeks intervention, the PNF group shows highly significant improvement in all the outcomes measures as compared to core strengthening

APPENDIX S3. Continued

14	George *et al.* (2013), randomized controlled trial	40 men with mechanical LBP aged between 18-45 years	**Experimental group:** CI of trunk flexion and extension with maximal resistance in a high sitting position + conventional strengthening exercise (curl ups, trunk extension, leg lifts, exercise for transversus abdominis in the 4-point kneeling or prone lying, exercise for lumbar multifidus in the prone lying or sitting, co-contraction of the transversus abdominis and lumbar multifidus in the upright position) **Comparison group:** Conventional strengthening exercise (curl ups, trunk extension, leg lifts, exercise for transversus abdominis in the 4-point kneeling or prone lying, exercise for lumbar multifidus in the prone lying or sitting, co-contraction of the transversus abdominis and lumbar multifidus in the upright position)	Treatment interventions were applied 3 weeks **Experimental group:** 5 s isometric contraction (trunk flexion and extension), 3 sets of 15 repetitions, 30 s rest interval between repetitions, 60 s rest interval between sets; Total treatment duration of trunk PNF training: 30-35, min; **Comparison group:** Each exercise consisted of 15 repetitions with 6 s hold time in the beginning and gradually progressed to 10 s; Total treatment duration of conventional exercises: 25-30 min Reassessments were performed at the end of treatment sessions	Pain intensity (VAS), functional disability (MODI), transversus abdominis activation capacity (stabilizer pressure biofeedback unit)	The results showed that trunk PNF training along with conventional strengthening exercises in subjects with mechanical LBP induces a greater improvement on pain and functional disability as compared to conventional strengthening exercises alone. However, no significant difference was found between 2 groups in transversus abdominis activation capacity
15	Tanvi *et al.* (2013), randomized clinical trial	27 women with post-partum lumbo-pelvic pain **Experimental group:** *n*: 13 Mean age: 28.28 ± 3.79y Mean height: 156 ± 4cm Mean body mass: 59.78 ± 6.47kg BMI: 24.37 ± 2.39kg/m^2 **Comparison group:** *n*: 14 Mean age: 27.23 ± 4.81y Mean height: 158 ± 12cm Mean body mass: 64.19 ± 7.06kg BMI: 25.64 ± 4.80kg/m^2	**Experimental group:** IR + PNF techniques in a seated position (alternating [trunk flexion-extension] isometric contractions against resistance with no motion intended; and CI [concentric, isometric and eccentric contraction of agonists without relaxation]) **Comparison group:** IR + lumbo-pelvic stabilization exercises (abdominal hollowing, quadruped abdominal hollowing, unilateral abduction, unilateral knee raise, bilateral knee raise, unilateral heel slide and bilateral heel slide)	Treatment interventions were applied 3 weeks **Experimental group:** IR: 15 min, 10 s hold time, 2 sets with 15 repetitions and 10 min rest between 2 techniques; **Comparison group:** IR: 15 min, The exercise programme was performed every day for 1 month except on Sunday (24 sessions), 10-15 repetitions (10 times in first 12 sessions and 15 times at other 12 sessions); Reassessments were performed at the end of 2nd and 4th weeks	Pain intensity (NPRS), functional disability (Quebec back pain disability score), trunk flexor and extensor static and dynamic endurance (curl-up and Sorenson tests)	The results indicated that both groups demonstrated improvements in static and dynamic muscle endurance, pain and functional disability. However, the comparison showed significantly greater improvements than the experimental group
16	Byuon and Son (2012), randomized clinical trial	54 patients with NLBP **Experimental group:** *n*: 26 Mean age: 58 ± 6.3y Mean height: 159.6 ± 9cm Mean body mass: 56.3 ± 8.1kg **Comparison group:** *n*: 28 Mean age: 60.8 ± 5.7y Mean height: 155 ± 5.4cm Mean body mass: 55.8 ± 8.1kg	**Experimental group:** Hot compress + IFT + PNF pattern (lower extremities flexion, adduction, external rotation with knee flexion, sprinter, and lifting) **Comparison group:** Hot compress + IFT + lumbar stabilization exercise (supine, bridge, quadruped, standing)	Treatment interventions were applied 4 times a week for 6 weeks **Experimental group:** Hot compress: 20 min, IFT: 20 min, 3 sets, 15 repetitions in each set, 10 s hold time, 10 s rest time; **Comparison group:** Hot compress: 20 min, IFT: 20 min, 3 sets, 15 repetitions in each set, 10 s hold time, 10 s rest time; Reassessments were performed at the end of treatment sessions	Pain intensity (VAS), repositioning error (digital goniometer)	Although both groups showed significant reduction in pain intensity and repositioning error after 6 weeks, the experimental group demonstrated significantly greater improvements than the comparison group

APPENDIX S3. Continued

17	Kumar *et al.* (2011), randomized controlled trial	30 male patients with recurrent mechanical CLBP **Experimental group:** *n*: 15 Mean age: 24.07 ± 2.19y Mean height: 170.73 ± 5.46cm Mean body mass: 66.93 ± 9.02kg **Comparison group:** *n*: 15 Mean age: 22.53 ± 2.85y Mean height: 170 ± 3.57cm Mean body mass: 68.07 ± 6.48kg	**Experimental group:** CI (concentric, isometric and eccentric contraction of agonists without relaxation in a seated position) + conventional physical therapy (alternate knee to chest, pelvic bridging, pelvic rolling, alternate arm leg extension [for both sides]) **Comparison group:** conventional physical therapy (alternate knee to chest, pelvic bridging, pelvic rolling, alternate arm leg extension [for both sides])	Treatment interventions were applied 5 times a week for 4 weeks **Experimental group:** 3 sets of 15 repetitions, rest intervals of 30 s and 60 s were provided after the completion of 15 repetitions for each pattern and between sets, respectively; **Comparison group:** 3 sets of 15 repetitions, rest intervals of 30 s and 60 s were provided after the completion of 15 repetitions for each pattern and between sets, respectively; Reassessments were performed at the end of treatment sessions	Pain intensity (VAS), functional disability (MODI), trunk flexion endurance (curl-up), trunk extension endurance (Sorenson tests), and lumbar flexion and extension ROM (fingertip-to-floor)	The experimental group demonstrated significant improvements in lumbar mobility, muscle endurance, pain intensity, and functional disability. However, the comparison group also showed improvement in pain intensity and functional disability. Moreover, the difference in functional disability between the 2 groups was significant after intervention
18	Kofotolis et al. (2008), randomized controlled trial	92 women with CLBP **Experimental group 1:** *n*: 23 Mean age: 41 ± 5.5y Mean height: 166.2 ± 0.8cm Mean body mass: 69 ± 3.9kg BMI: 24.9 ± 1.2kg **Experimental group 2:** *n*: 21 Mean age: 37.5 ± 8.6y Mean height: 169 ± 0.5cm Mean body mass: 69.7 ± 3.9kg BMI: 24.3 ± 1.4kg **Comparison group 1:** *n*: 23 Mean age: 41.2 ± 5y Mean height: 168.5 ± 0.7cm Mean body mass: 70 ± 4.3kg BMI: 24.6 ± 1kg **Comparison group 2:** *n*: 21 Mean age: 42.2 ± 7.8y Mean height: 169.9 ± 0.5cm Mean body mass: 69.1 ± 6.9kg BMI: 23.8 ± 1.7kg	**Experimental group 1:** RS (alternating [trunk flexion-extension] isometric contractions against resistance, no motions intended) **Experimental group 2:** RS + TENS treatment in a prone position (4 electrodes were applied on the fascia thoracolumbalis and approximately 10 cm proximal to this, along the midline of the muscle) **Comparison group 1:** TENS treatment in a prone position (4 electrodes were applied on the fascia thoracolumbalis and approximately 10 cm proximal to this, along the midline of the muscle) **Comparison group 2:** Placebo stimulation at the same sites for the same duration and period as the comparison group 1, using placebo units identical to the real TENS units in appearance, with the indicator lamp lit up when being switched on	Treatment interventions were applied 5 times a week for 4 weeks. Training sessions had a total duration of 30–45 min **Experimental group 1:** 10 s hold time, 3 sets of 15 repetitions, 30 s rest interval between repetitions, 60 s rest interval between sets; **Experimental group 2:** RS parameters were the same as the Experimental group 1, TENS parameters: Pulse duration of 200 μs and a frequency of 4 Hz using a 'strong but comfortable' level of stimulation; **Comparison group 1:** The programme consisted of 40–45 min of TENS treatment; Reassessments were performed immediately after, 4 weeks, and 8 weeks post intervention	Pain intensity (Borg verbal rating pain scale), functional disability (ODI), total lumbar ROM (flexicurve technique), dynamic and static flexion endurance (curl-up test), dynamic and static extension endurance (modified Sorenson test)	The experimental group 1 and experimental group 2 displayed statistically significant improvements in pain intensity and functional disability, lumbar extension ROM, dynamic endurance of trunk flexion, and static endurance of trunk extension compared with the remaining groups. In addition, treatment with TENS (the comparison group 1) was more effective than treatment with a placebo (the comparison group 2), less effective than a combination of RS and TENS (the experimental group 2), and adds no apparent benefit to that of RS alone (the experimental group 1)
19	Olczak et al. (2008), randomized clinical trial	60 acute and subacute patients with intervertebral disc injuries **Experimental group:** *n*: 30 Median age: 55.5 (33-69)y Median height: 170 (158-185) cm Median body mass: 66 (56-79) kg **Comparison group:** *n*: 30 Median age: 54 (28-68)y Median height: 170.5 (158-187)cm Median body mass: 67.5 (58-80)kg	**Experimental group:** Scapula, pelvis, and upper limb PNF patterns + PNF techniques (hold relax) + abdominal roll **Comparison group:** Hyperextension in a prone position, hyperextension with various types of additional pressure, and flexion in a supine position + abdominal roll	Reassessments were performed immediately on completion of the treatment and during a long-term follow-up evaluation at 6 months after the end of treatment.	Pain intensity (diagram on the McKenzie examination chart, VAS), lumbar flexion and extension ROM (Saunder digital inclinometer), and abdominal and paraspinal muscle strength (Nicholas manual muscle tester)	There was more rapid pain reduction, improvement of ROM, strength and fewer relapses in the experimental group. The positive effects of the treatment were sustained over the 6-month follow-up

APPENDIX S3. Continued

20	Kofotolis and Kellis (2006), randomized clinical trial	86 women with CLBP **Experimental group 1:** *n*: 28 Mean age: 40.6 ± 6.4y Mean height: 165.7 ± 8.4cm Mean body mass: 68.8 ± 3.8kg BMI: 25.2 ± 1kg **Experimental group 2:** *n*: 28 Mean age: 41.8 ± 7.7y Mean height: 168.6 ± 5.6cm Mean body mass: 70.1 ± 4.4kg BMI: 24.8 ± 1.7kg **Comparison group:** *n*: 30 Mean age: 42.1 ± 8.4y Mean height: 169.2 ± 4.2cm Mean body mass: 69.6 ± 6.1kg BMI: 24.3 ± 0.7kg	**Experimental group 1:** Warm-up (stationary bicycling, stretching exercises) + RS (alternating [trunk flexion extension] isometric contractions against resistance, no motions intended) + cool-down **Experimental group 2:** Warm-up (stationary bicycling, stretching exercises) + CI [concentric, isometric and eccentric contraction of agonists (trunk flexion) without relaxation]) + cool-down **Comparison group:** The comparison group was instructed to avoid structured exercise or activities other than those required for normal daily living	Treatment interventions were applied 5 times a week for 4 weeks. Training sessions had a total duration of 30–45 min **Experimental group 1:** Stationary bicycling: 7-10 min, RS: 10 s hold time, 3 sets of 15 repetitions at maximal resistance, 30 s rest interval between repetitions, 60 s rest interval between sets; **Experimental group 2:** Stationary bicycling: 7-10 min, CI: 5 s hold time, 3 sets of 15 repetitions at maximal resistance, 30 s rest interval between repetitions, 60 s rest interval between sets; Reassessments were performed immediately after, 4 weeks, and 8 weeks post intervention	Pain intensity (Borg verbal rating pain scale), functional disability (ODI), total lumbar ROM (flexicurve technique), dynamic and static flexion endurance (curl-up test), dynamic and static extension endurance (modified Sorenson test)	The application of 4-week RS and CI PNF programmes increased the muscle endurance of people with CLBP. Back pain intensity and functional disability also decreased significantly. The results suggested that short-term programmes with dynamic or static PNF exercises were particularly effective in improving trunk muscle endurance and mobility as well as in reducing back pain symptoms and improving functional performance in people with CLBP. Because the CI group showed greater improvements, the use of dynamic PNF exercises for the management of CLBP appears to be more effective

Abbreviations: AKE: active knee extension; ART: active release technique; BMI: body mass index; CI: combination of isotonics; CLBP: chronic non-specific low back pain; CNLBP: chronic non-specific low back pain; CR: contract-relax; DEL: diagonal, extension with rotation to left; DER: diagonal, extension with rotation to right; DFL: diagonal, flexion with rotation to left; DFR: diagonal, flexion with rotation to right; EMG: electromyography; FEV_1: forced expiratory volume at 1 s; HR: hold-relax; IFT: interferential therapy; IR: infra-red radiation; LBP: low back pain; MODI: modified Oswestry disability index; NLBP: non-specific low back pain; NPRS: numerical rating scale; PNF: proprioceptive neuromuscular facilitation; RI: rhythmic initiation; RMDQ: Roland–Morris disability questionnaire; ROM: range of motion; RS: rhythmic stabilization; SR: stabilizing reversals; SWD: short-wave diathermy; TENS: transcutaneous electrical nerve stimulation; VAS: visual analogue scale.