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TÜRK FİZYOTERAPİ VE REHABİLİTASYON DERGİSİ

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THE COMPONENTS, PARAMETERS AND OUTCOMES OF CORE STABILITY TRAINING FOR LOWER EXTREMITY DYSFUNCTIONS: A SYSTEMATIC REVIEW OF EXPERIMENTAL TRIALS

ABSTRACT

Purpose: Core stability exercises, widely used for treating low back pain has recently been reported to rehabilitate lower extremity dysfunctions. However, information on the components and parameters of the exercise remains scarce. Hence, the aim of this systematic review was to synthesize evidence on core stability training for lower limb dysfunctions and determine the key components, parameters, and impact of the exercises.

Methods: A systematic search of electronic databases (PubMed, Scopus, ScienceDirect, Ovid, Cochrane, and Google Scholar) was carried out covering the period from January 2000 to March 2024. Articles were screened based on predefined criteria and their quality was assessed by using PEDro scale. Relevant data on the components, parameters, and outcomes of core stability exercise, were extracted and descriptively synthesized.

Results: Out of 2393 articles identified, seven articles met the criteria. Five trials administered exercise programme containing both isometric and isotonic exercises, with curl ups, bridges, quadruped stance and transverse abdominis contraction being the most frequent exercise routines. Most of the studies used isometric exercise with 5-second hold and 6-8 repetitions for each movement while for isotonic exercises most studies used 10 repetitions of 2-3 sets per movement. Significant reduction in pain and improvement in muscle strength, mobility, balance, foot posture and joint stability were reported.

Conclusion: Core stability training shows encouraging outcomes in improving lower limb dysfunctions in nonathletic individuals by enhancing lumbopelvic control. However, due to heterogeneity in studies further research is needed to establish the most effective components and their impact on various lower limb outcomes.

Keywords: Core stability, Exercise therapy, Lower extremity, Postural balance, Proprioception

ALT EKSTREMİTE DİSFONKSİYONLARI İÇİN ÇEKİRDEK STABİLİTE EĞİTİMİNİN BİLEŞENLERİ, PARAMETRELERİ VE SONUÇLARI: DENEYSEL DENEMELERİN SİSTEMATİK BİR İNCELEMESİ

ÖZ

Amaç: Bel ağrısının tedavisinde yaygın olarak kullanılan çekirdek stabilite egzersizlerinin, son zamanlarda alt ekstremite disfonksiyonlarının rehabilitasyonunda etkili olduğu bildirilmiştir. Ancak, egzersizin bileşenleri ve parametreleri hakkında bilgi eksiktir. Bu nedenle, bu sistematik derlemenin amacı, alt ekstremite fonksiyon bozuklukları için çekirdek stabilite eğitimi üzerine kanıtları sentezlemek ve egzersizlerin ana bileşenlerini, parametrelerini ve etkilerini belirlemektir.

Yöntem: Ocak 2000 ile Mart 2024 tarihleri arasında PubMed, Scopus, ScienceDirect, Ovid, Cochrane ve Google Scholar veri tabanlarında sistematik bir arama gerçekleştirilmiştir. Makaleler önceden tanımlanmış kriterlere göre taranmış ve kaliteleri PEDro ölçeği kullanılarak değerlendirilmiştir. Çekirdek stabilizasyon egzersizinin bileşenleri, parametreleri ve sonuçlarına ilişkin veriler çıkarılmış ve betimsel olarak sentezlenmiştir.

Bulgular: Tespit edilen 2393 makaleden yedisi kriterleri karşıladı. Beş çalışma hem izometrik hem de izotonik egzersizler içeren egzersiz programı uyguladı; mekikler, köprüler, dört ayak duruşu ve transversus abdominis kasılması en sık kullanılan egzersiz rutinleriydi. Çalışmaların çoğu, her hareket için 5 saniyelik tutuş ve 6-8 tekrar ile izometrik egzersiz kullandı; izotonik egzersizler için ise çoğu çalışma her hareket için 2-3 setten 10 tekrar kullandı. Ağrıda anlamlı azalma ve kas gücü, hareketlilik, denge, ayak postürü ve eklem stabilitesinde iyileşme bildirildi.

Sonuç: Çekirdek stabilite eğitimi, lumbopelvik kontrolü geliştirerek atletik olmayan bireylerde alt ekstremite fonksiyon bozukluklarını iyileştirmede umut verici sonuçlar göstermektedir. Ancak, çalışmalardaki heterojenite nedeniyle, en etkili bileşenlerin ve bunların çeşitli alt ekstremite sonuçlarındaki etkilerinin belirlenmesi için daha fazla araştırmaya ihtiyaç vardır.

Anahtar Kelimeler: Çekirdek stabilizasyonu, Egzersiz terapisi, Alt ekstremite, Postural denge, Propriosepsiyon

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INTRODUCTION

Core stability training has been considered as one of the fundamental components in musculoskeletal rehabilitation. It has been widely utilized as a therapeutic exercise modality in the management of low back pain (LBP) (1). However, recent studies revealed a significant connection between core stability and lower limb outcomes, suggesting that core stability may contribute to lower limb function and performance (2-4). To elucidate the mechanism underlying the relationship between core stability and lower limb function, a comprehensive understanding of the anatomical framework of the core muscles is essential. In addition, appreciating the impact of core stability on lower limb functions requires a thorough grasp of muscles, joints, and neural control interactions that regulate trunk stability and movement. This complex interaction is critical to human movement and function, and it has spawned various propositions that warrant careful consideration (5).

The primitive concept of core stability emphasized that core stability requires the functional integration of three subsystems which are the passive spinal column, the active spinal muscles and the neural control unit. These subsystems allow an individual to maintain the intervertebral neutral zones within physiologic limits while performing activities of daily living (ADL) (6). Based on this concept, the core muscles are described as a muscular box-shaped or core, which comprises of abdominal muscles at the front, paraspinal muscles and gluteal muscles at the back, diaphragm muscle at the roof and pelvic floor muscles as the bottom of core (7,8).

Several studies investigated the mechanism of these integrating subsystems in relation to upper and lower limb performances and revealed that the torso, upper limbs, and lower limbs are interconnected as kinetic chains (5,9,10). In any athletic activity or spatial movement, there is synchronized activation of core muscles and limbs to ensure that the limbs are optimally positioned and moving at the appropriate velocity to accomplish the task (5,9). In this perspective, the core muscles were described as all anatomical structures between the sternum to the knee with the abdominal region as the centre of the core. Several studies concluded that shoulder and pelvic muscles should also be included in the core musculature because these muscles assist in transferring the energy from the centre of core to the extremities during everyday tasks (5,10).

Additional evidence explained that the trunk muscles, particularly the deep abdominal muscles, transverse abdominis and multifidus, activate significantly earlier than the lower limb muscles (11). This suggests that the core muscles play a crucial role in establishing a stable foundation before the onset of lower limb movements and forming an excellent solid base for efficient and effective motion (11). Such findings changed the dimensions of the understanding of core stability function whereby the core muscles are reported to have a unique capability to manage the position and movement of the trunk relative to the pelvis and legs which enables the distal limbs to achieve optimal and controlled motion within the connected kinetic chains. This mechanism leverages the stability provided by the core muscles to generate efficient and effective movement patterns (5).

The relationship between core musculature and lower limb mechanics is critical, as core stability deficits can lead to mechanics alteration to the lower limbs and an increased risk of lower limb injuries. For instance, previous studies have shown that the knee pathologies can negatively influence core stability, leading to decreased abduction and external rotation forces, which in turn result in increased knee adduction and internal rotation (12-14). Such alteration subsequently raises the patellofemoral joint reaction forces, contributing to pain and dysfunction (12). Additionally, core stability deficits have been found among individuals with ankle injuries, such as flat feet and ankle sprains (13-15). This makes it evident that core muscles have an effect on lower limbs from the hips to the ankles and strengthening the core, therefore is essential in the prevention and rehabilitation of these injuries, as it may improve overall faulty mechanics, reduce pain, and enhance function.

While several studies have revealed the effects of core stability exercises on speed, balance, strength and performance in the athletic population, (16-20), such prescription of exercises may not be applicable to non-athletes due to the differences in definition. Athletes are engaged in regular competitive training with the primary goal of improving performance and outcomes, while non-athletes participate in physical activity mainly for health, fitness, or leisure purposes. These distinctions suggest that the training intensity, frequency, and objectives differ markedly between these two groups, which could influence the applicability of findings from athletic studies to nonathletic populations (21). Therefore, a systematic review of core stability exercise prescription for nonathletic individuals with lower limb dysfunctions is necessary.

Despite the growing number of studies reporting intervention and exercise parameters have proliferated (22-25), yet none have addressed core stability training. Such a study is highly needed because health practitioners require evidence-based recommendations when formulating an effective plan of care. Hence this comprehensive review was designed to identify the key components, parameters and effects of core stability exercises specifically required for lower limb dysfunctions among nonathletic subjects.

METHOD

Study Protocol

The protocol of this systematic review was registered in the PROSPERO database (registration number: CRD42023491502) and adhered to the PRISMA statement guidelines (26). A specific framework (Table 1) known as the PICOS framework (Population, Intervention, Comparison, Outcome, Study design), was utilized to formulate the following research questions (27).

a. What are the components and parameters of core stability training used in lower extremity dysfunctions?

b. Does core stability training have positive effects on lower extremity dysfunctions?

Eligibility Criteria

Studies were included if they met the following conditions:

Published in English, peer-reviewed, and available in full text.

Published between January 2000 and March 2024.

Included nonathletic participants aged 18 years or older with lower limb dysfunctions as protocols for athletes differ in volume, intensity and specificity to those of nonathletic individuals.

Core stability training was the principal intervention, even if additional lower limb exercises were included as part of control routines or supplementary interventions.

Reported outcomes related to lower extremity function.

Studies were excluded if they:

Involved subjects without lower limb dysfunction, even if core stability exercises were used to address other conditions, such as LBP.

Involved exercises that primarily focused on proprioception training, neuromuscular training, or other interventions and did not explicitly aim to strengthen or stabilize the core musculature as the main component.

Table 1. PICOS framework for systematic review

Components	Descriptions
Population	Non athletic participants aged ≥18 years with lower extremity dysfunctions.
Intervention	Exercises targeting core muscles (spinal stabilization exercise).
Control	Any comparative or controlled treatment.
Outcome	Any outcome assessing improvements in discomfort or function of lower extremities.
Study design	All types of experimental studies

Were case control studies.

Were other non-experimental designs such as commentaries and case reports, reviews and meta-analyses.

Included athletic participants.

Included subjects who underwent surgical treatment of their disorder (e.g. surgical reconstructions of soft tissue structures, arthroplasty etc.) to ensure that the effects observed are solely attributable to core stability exercises rather than confounded by post-surgical recovery processes.

Involved participants less than 18 years of age to ensure findings are applicable to adult population.

Lacked sufficient protocol details.

Included participants with neurological disorders like stroke and spinal pathologies.

Search Strategy

A robust systematic electronic search was conducted by Assessor 1 (S.M.D.) in PubMed, Scopus, Cochrane, Ovid, and Science Direct. In addition, Google Scholar was used as a secondary database in the search strategy. During the search process, the combination of text words and medical subject headings (MeSH) with Boolean operators used were: (Core stability OR Postural balance OR segmental stability) AND (Exercises OR Training) AND (Muscle endurance OR Muscle strength) AND (Lower extremity OR Knee OR Foot) AND (Dysfunctions OR Disorders). Our search strategy focused on core stability as the principal intervention. While lumbopelvic stability is inherently related to core stability, it was not included as an independent search term. The closest MeSH terms available were Posture and Muscle Strength, which were incorporated to ensure relevant studies were captured.

Study Selection

Articles were identified through an initial web search and imported into Mendeley and screened for duplicates by Assessor 1 (S.M.D.) After duplicates removal, S.M.D. performed the title and abstract screening. Finally full texts of the remaining studies were retrieved. The folder of full text articles was shared via Mendeley library with Assessor 2 (S.S.K.), who along with S.M.D. independently reviewed the full-text articles for eligibility, ensuring an unbiased assessment.

Studies that did not meet the inclusion criteria were excluded, with reasons for exclusion systematically documented.

To assess inter-rater agreement between the assessors the percentage agreement was recorded before the discussion. A 3rd Assessor (E.E.K.) was involved in panel discussion to resolve discrepancies between first two assessors based on predefined eligibility criteria, leading to a final selection of studies.

Quality Assessment

The methodological quality of each included article was critically appraised using the PEDro scale by two independent assessors (S.M.D. and S.S.K.). Any disagreements were recorded before discussion, with percentage agreement calculated for the 7 selected studies. Differences were resolved through discussion with a E.E.K. until consensus was reached (28). The PEDro scale evaluates the validity of studies based on 10 criterias including random allocation, concealed allocation, baseline comparability, blinding of subjects and assessors, adequate follow-up, intention-to-treat analysis, and point estimates with variability. Each article was rated on each criterion, resulting in a maximum total score of 10. The quality of the articles was then categorised as poor (0-3), fair (4-5), good (6-8), or excellent (9-10). This assessment ensured that the studies included in the systematic review were critically evaluated for their methodological quality, providing a robust basis for the synthesis of evidence (29).

Data Extraction

The characteristics of each study comprising of lead author, year of publication, number of participants, mean age of the participants, participants characteristics, and outcome measurements used in the study were presented in a customized data extraction form. Data relating to the components, parameters and outcomes of core stability training were manually extracted and collected. Exercise components and parameters were collected based on specific categories as outlined in previous studies (22-25), whereby the term "component" is referred to the type and routine of the exercise, while "parameter" is the dosage of exercise (number of sessions per week, number of repetitions and sets, duration of exercise programme, overall length of the exercise programme and exercise progression as well as the mode of exercise application). Furthermore, a subgroup analysis for most frequent core stability exercise routines, type of exercises (isometric or isotonic), duration of treatment (more than 6 weeks or less than 6 weeks) and outcome measures (pain, balance, and functional performance) was performed to enhance clarity. The data was initially extracted by two researchers (S.M.D. and S.S.K.) and subsequently cross-checked and verified by other researchers [E.E.K., Assessor 4 (N.A.A.R.) and Assessor 5 (M.J.)].

RESULTS

A systematic search across various databases yielded a total of 2,392 articles, including 165 from PubMed, 97 from Scopus, 26 from ScienceDirect, 1,003 from Cochrane, 52 from Ovid and 1,049 from Google Scholar. After removing 178 duplicate records using Mendeley, 2,214 unique studies remained for screening. Following title and abstract screening, 2,068 articles were excluded, based on the exclusion criteria, to make sure that included studies involved: subjects without lower limb dysfunction, non-core stability interventions, non-experimental study designs (such as reviews and case reports), athletic participants, juvenile populations, subjects with neurological disorders, and irrelevant studies, leaving 146 articles for further evaluation. Of these, only 101 full-text articles were successfully retrieved and further assessed for eligibility. During this stage, 94 were excluded for various reasons as outlined in Figure 1. Independent analysis of 101 articles by S.M.D. and S.S.K. revealed a 60.87% agreement before discussion, reflecting initial differences in study selection, with S.M.D. selecting 14 articles and S.S.K. selecting 9 articles. Following discussion and analysis with support from E.E.K., ultimately 7 articles met the predefined criteria and were included in the final review. This process is summarized in Figure 1, a PRISMA flow diagram depicting the selection of articles.

Study Characteristics

The characteristics of the included studies were extracted and tabulated in Table 2. The total sample size of the included studies was 237, which included 120 subjects in interventional group and 117 subjects in the control group (30-36). The mean age of the subjects across the seven trials was varying, with the minimum mean age reported as 21 years (33) and the maximum as 56 years (30). All studies were published from 2016 onwards and employed a two- group design, where the experimental groups received core stability exercises as an interventional treatment, while the control groups received conventional exercises as a controlled treatment. This design enabled the studies to compare the effects of core stability exercises to conventional exercises on the outcomes of interest. All studies examined core stability training on various lower extremity conditions, three studies investigated its impact on patellofemoral joint dysfunctions (32,33,35), while one study each explored its effects on knee osteoarthritis (30), mild lower limb discomfort (31), flat feet (34), and anterior cruciate ligament injury (36).

The seven studies employed various tools to assess the outcomes. Balance was evaluated using outcome measures such as the Biodex Balance System (30), Y balance test (31), and star excursion balance test (35). Pain was measured with Visual Analog Scale (VAS) (30-33), Numerical Pain Rating Scale (NPRS) (32) and Kujala Patella-Femoral Scale (AKPS) (35). Functional independence and ADL were assessed using the Knee Injury and Osteoarthritis Outcome Score (KOOS) (30,32) and Lysholm Knee Scale (36). Physical performance was measured with the Timed Up and Go (TUG) test (32). Strength of lower limb muscles was assessed using a handheld dynamometer (31,32) and the

Biodex System (36). Foot posture was evaluated using the Foot Posture Index (FPI) (35) and weight distribution with fore foot load response were also measured (34).

Methodological Quality

The percentage of agreement before the discussion between the two reviewers was 71.43%. with assessors showing agreement on 5 out of 7 seven studies. Quality score of remaining 2 studies were discussed and analysed by 2 assessors with inputs from 3rd Reviewer. Finally, the disagreements were sorted for both the studies. Based on the final PEDro scale assessment, the total scores ranged from 4 to 8 out of 10, indicating moderate to high quality. All studies clearly defined eligibility criteria, with most studies employing random allocation and baseline compatibility. However, a significant weakness across all studies was that the lack of blinding of subjects and

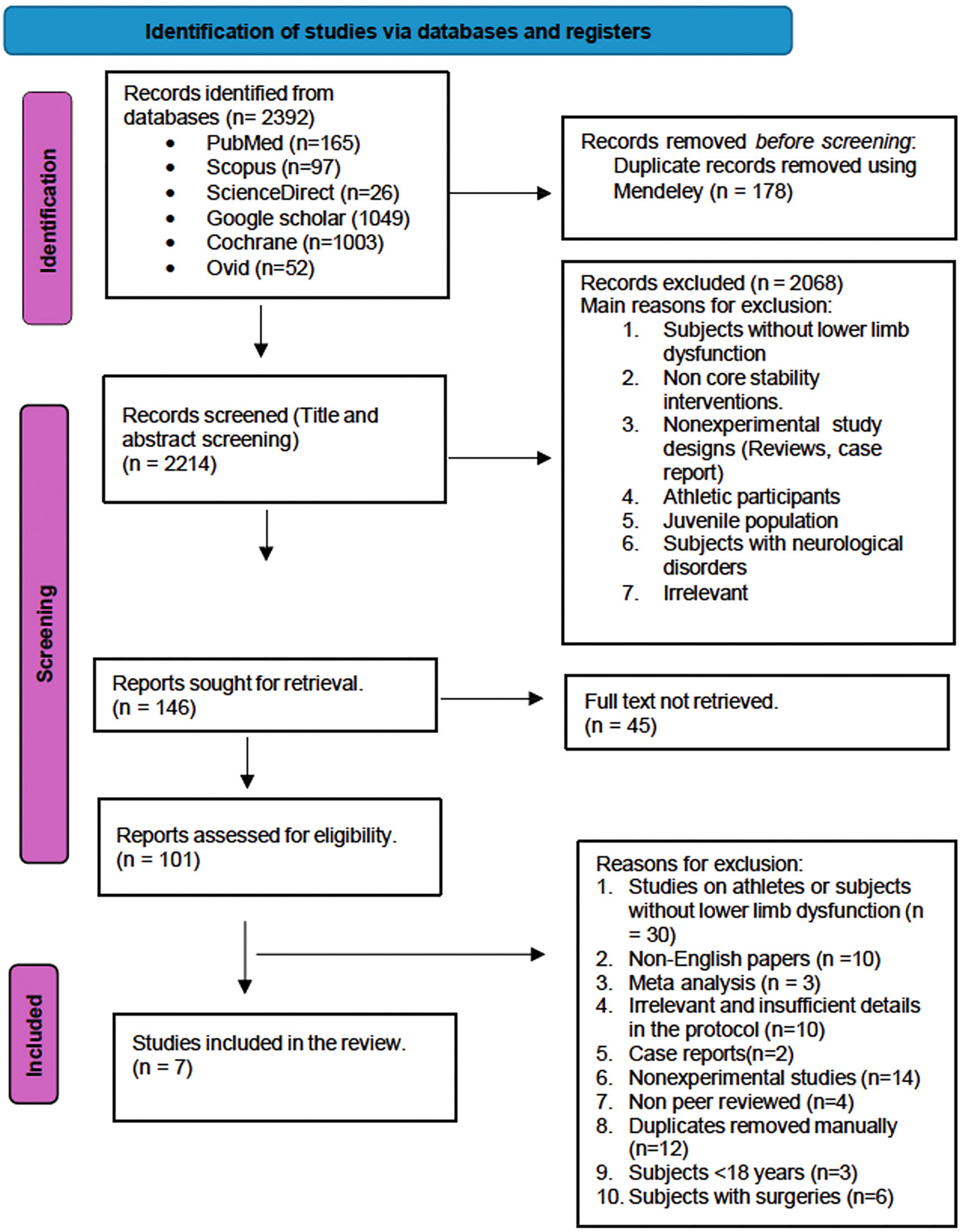

Figure 1. Prisma flow diagram depicting selection of articles (26).

therapists, which could introduce bias. While some studies ensured blinding of assessors (31,35), others did not, further impacting the reliability of the results. Follow-up adequacy was generally well-reported, with minimal dropouts noted in several studies (32-36). Intention-to-treat analysis and between-group comparisons were consistently addressed in all studies, enhancing the robustness of findings. Table 3 provides detailed information on the methodological quality of each study.

Components and Parameters of Core Stability Training for Lower Limb Dysfunctions

This review discovered some commonalities across the seven studies. First, based on the interventional core exercise routines outlined in Table 4, most of the studies had activated the global core muscles (erector spinae, quadratus lumborum, obliques, and rectus abdominis) instead of merely focussing on local/deep

Table 2. Characteristics of selected studies

No.	Author (year)	Patient's characteristics	No. of subjects per group with mean age	Interventions in each group	Outcome measure tools
1.	Lam et al. 2023 (30)	Knee osteoarthritis patients	EG: 10 (56.40±8.87 y.o.) CG: 10 (55.90±7.74 y.o.)	EG: Core stability exercises with conventional exercises (lower limb strengthening and stretching exercises). CG: Conventional exercises (lower limb strengthening and stretching).	VAS - pain, Biodex balance - balance, KOOS - functional independence.
2.	Kim et al. 2020 (31)	Patients with mild lower limb discomfort	EG:10 (32.2±9.9 y.o.) CG: 10 (25.50±5.70 y.o.)	EG: Core stability exercises. CG: Maintain usual lifestyle.	VAS - pain and discomfort, FMS test - physical performance YBT kit - balance, Handheld dynamometer - strength of lower limb muscles.
3.	Hoglund et al. 2018 (32)	Patello-femoral osteoarthritis patients	EG: 10 [50 (46.56) y.o] CG: 10 [52 (49.56) y.o.]	EG: Core stability exercises and hip strengthening exercises. CG: No treatment.	NPRS - pain, KOOS - ADL, TUG - physical performance. Dynamometer - strength of hip and knee musculature.
4	Chevidikunnan et al. 2016 (33)	Patients with patellofemoral pain syndrome	EG: 10 (21.4±1.8 y.o.) CG: 10 (22.2±1.3 y.o.)	EG: Core stability exercises with conventional lower limb strengthening exercises. CG: Conventional lower limb strengthening exercises.	VAS - pain symptoms, SEBT - balance.
5	Pachava et al. 2022 (34)	Flat feet patients	EG: 13 (23.38±1.32 y.o.) CG: 13 (24.15±1.28 y.o.)	EG: Core stability exercises. CG: Foot intrinsic exercises.	FPI-6 - foot posture. Weight distribution %, foot load response was also used.
6	Tazesh et al. 2022 (35)	Patients with patellofemoral pain	EG: 35 (32.1±6.0 y.o.) CG: 35 (32.5±5.9 y.o.)	EG: Core strengthening exercises with routine exercises (lower limbs strengthening and stretching exercises). CG: Routine exercises (lower limbs strengthening and stretching exercises).	VAS - pain. Kujala patella - femoral scale (AKPS) - pain and functional status.
7	Çelik et al. 2017 (36)	Patients with anterior cruciate ligament injuries	EG: 32 (25.0 ± 9.1 y.o.) CG: 29 (25.9 ± 7.5 y.o.)	EG: Pilates exercises with core strengthening exercises. CG: Pilates exercises after week 12.	Lysholm Knee Scale & Cincinnati Knee Rating System – lower limb functions Biodex system – lower limb strength.

AKPS: Anterior Knee Pain Scale, CG: Control Group, EG: Experimental Group, FMS: Functional Movement Screen, FPI: Foot Posture Index, KOOS: Knee Injury and Osteoarthritis Outcome Score, No.: Number, SEBT: Star Excursion Balance Test, TUG: Timed Up and Go test, VAS: Visual Analog Scale, y.o.: Years old, YBT: Y-Balance Test.

Table 3. Methodological quality (PEDro Scale)

Study	1	2	3	4	5	6	7	8	9	10	11	Score
Lam et al. 2023 (30)	√	√	√	√	×	×	×	×	√	√	√	6
Kim et al. 2020 (31)	√	√	×	√	×	×	√	×	√	√	√	6
Hoglund et al. 2018 (32)	√	×	×	√	×	×	×	×	√	√	√	4
Chevidikunnan et al. 2016 (33)	√	√	√	√	×	×	×	√	√	√	√	7
Pachava et al. 2022 (34)	√	√	×	√	×	×	×	√	√	√	√	6
Tazesh et al. 2022 (35)	√	√	√	√	×	×	√	√	√	√	√	8
Çelik et al. 2017 (36)	√	√	√	√	×	×	√	√	√	√	√	8

1: Eligibility criteria, 2: Random allocations 3: Concealed allocation, 4: Comparability at baseline, 5: Patient blinding, 6: Therapist blinding, 7: Assessor blinding, 8: At least 85% follow-up, 9: Intention to treat analysis, 10: Between-group statistical comparisons, 11: Point measures and measures of variability. Item 1 not counted in PEDro Score.

core muscles (transverses abdominis and multifidus). Second, the activation of core muscles was performed through specific activities that mimic daily and sport-specific movements.

In this review, it was observed that core exercise protocols incorporating both isometric and isotonic muscle actions were the most adopted, with five out of seven included studies utilizing a combination of both in their intervention programmes (31,32,34-36). One trial adopted isometric exercises only (30) while one adopted isotonic exercises (33). Most of the exercise programmes were professionally supervised through a combination of face-to-face sessions and telecommunication interaction, with home exercise programme prescribed to supplement the supervised sessions (31,32,35,36).

The core stability exercises were employed with a broad range of interventional exercise manoeuvres. One study included exercises such as back bridges, unilateral bridges, and curl-ups (30), while another utilized a range of exercises including curl ups, crisscross, double leg lowering, scissors, shoulder bridges, quadruped stance, Sperman exercise and various core stability movements (31). Another study focused on the activation of the transversus abdominis (TA) muscle in conjunction with pelvic musculature strengthening exercises, emphasizing the coordinated engagement of the TA during training (32). Another study focused on cross curl-ups, side bridges, and quadrupedal stance (33), and yet another implemented a comprehensive set of exercises, including bridges with leg lifts, various plank variations, static curl ups, bicycles, vertical crunches, and trunk rotations (34). Additionally, one study incorporated exercises like lateral walks, abdominal drawing in (TA activation), sidekicks, Quadruped stance, and exercises targeting pelvic musculature especially gluteal muscles (35) and another used diverse set of exercises, such as heel slides, shoulder bridges, heels together toe apart side circles, and swimming (36). The detailed list of exercises used in each study is outlined in Table 4.

To determine the most preferred exercises in core stability programs, a frequency table was formulated. Each exercise routine, along with any variations, was rated in percentages, based on the number of studies that included them, providing a clearer understanding of the most used and preferred exercises in core stability training (Table 5). According to this analysis, exercises, bridges and its variations were the most frequently used (71.42%), followed by curl-ups and quadruped stance with its variations (57.15% each). Transverse abdominis isometric contraction was 3rd most common and preferred exercises (43%), followed by Sperman exercise, transverse abdominis muscle activation, bicycles, double leg lowering and hip musculature strengthening (28.57% each). The details of their frequency are reported in Table 5.

The parameters of core strengthening exercises across the seven trials illustrated in Table 4, depended on the type of exercises. Out of seven, only five trials reported the exercise frequency. As for isometric exercise, 5 seconds hold was commonly prescribed for each exercise (30-32), with 8 repetitions for 2 sets of each exercise (31,32). For isotonic exercises, 10 repetitions of 2- 3 sets for each exercise was frequently pronounced (31-33). In half of the studies exercise programmes were considered as a progressive training as the complexity of the exercises were increased throughout the weeks (32,33,35,36). The total number of treatment sessions varied across the studies, ranging from 10 to 60 sessions. The frequency of interventions weekly also differed, with most of the studies conducting treatment sessions 3 times weekly (30,31,33,36). One study reported frequency interventions 2 times weekly (32); another study reported 6 sessions weekly (34) and one trial conducted 5 sessions weekly (35). Additionally, the duration of the interventions also showed variations, with interventions in three studies lasting for 4 weeks (31,33,34); two studies providing intervention for 6 weeks (30,32); and another two studies applying intervention for 12 weeks (35,36).

The included studies featured a variety of exercise protocol delivery modes. One study administered their exercise protocols as home programs (30), while four studies used face-to- face delivery of intervention (31-34) and one study employed a mixed mode, with subjects starting each new stage of the exercise protocol face-to-face and continuing with

Table 4. Components, parameters and outcomes of core strength training									
No.	Author (year)	Components		Parameters					Outcomes
		Types of exercises	Routines in the interventional core exercises	No. of repetitions and sets	No. of sessions	Length of intervention	Exercise progression	Mode of delivery	
1	Lam et al. 2023 (30)	Isometric	3 exercises: Back bridge, quadruped arm or leg lift and curl up	5 seconds hold of 8 repetitions with 2 sets for each exercise	3 sessions a week	6 weeks	Not specified	Remote supervision	Pain score (VAS) and function significantly improved within EG ($p<0.05$). No statistically significant intergroup difference in any of the outcomes ($p>0.05$)
2	Kim et al. 2020 (31)	Isometric and isotonic	8 exercises: Curl up (roll down and up), criss-cross, double leg lower (up and down), scissors, shoulder bridge, Sperman, cat position, mini-squat	Isometric: 5 seconds hold of 6 repetitions. Isotonic: 10 repetitions with 2 sets each	3 sessions a week	4 weeks	Not specified	Face to face and remote supervision	Ankle pain score significantly lowered in EG ($p<0.05$) and significant improvements in FMS score (hurdle step and trunk stability), balance and in EG ($p<0.05$). No significant improvements in lower limb muscle strength reported ($p>0.05$)
3	Hoglund et al. 2018 (32)	Isometric and isotonic	6 exercises: Prone TA isometric (stabilizer for biofeedback, prone gluteus maximus isometric with knee flexed, hooklying TA isometrics with alternate hip/ knee flexion/ extension, sidelying hip ER with feet together (clamshells), side lying hip abduction, single-leg stance	Isometric: 5 seconds hold of 8 repetitions for each exercise. Isotonic: 10 repetitions with 3 sets for each exercise	2 sessions a week	6 weeks	Yes. Change the routine to be more challenging by modifying the movement of the limbs	Face to face supervision	Significant improvements in pain and function at post intervention ($p<0.05$). Enhanced physical performance in mobility ($p<0.05$) was also reported
4	Chevidikunnan et al. 2016 (33)	Isotonic	3 exercises: Cross curl up, side bridge, quadrupedal stance	20 repetitions for each exercise	3 sessions a week	4 weeks	Yes. Increase number of repetitions after week 2	Face to face supervision	Significant improvement for pain and balance reported in EG ($p<0.05$)

Table 4. Continued

No.	Author (year)	Components		Parameters					Outcomes
		Types of exercises	Routines in the interventional core exercises	No. of repetitions and sets	No. of sessions	Length of intervention	Exercise progression	Mode of delivery	
5	Pachava et al. 2022 (34)	Isometric and isotonic	10 exercises: Bridges with leg lifts, static abs, lower trunk rotation, planks (prone, left, right), bicycles, full vertical crunches, bridges with marching, long arm crunches, trunk rotation with weights, bilateral leg lowering	Isometric: 10-20 seconds hold, 3 sets Isotonic: 5-15 repetitions with 1 set	6 sessions a week	4 weeks	Yes. Change the number of repetitions and sets for each exercise	Face to face supervision	Significant improvement in foot posture of both feet in EG ($p<0.05$) was reported. No improvements in weight distribution and foot load response ($p>0.05$)
6	Tazesh et al. 2022 (35)	Isometric and isotonic	6 exercises: Wall slide (45-degree knee flexion), straight leg raises to 60-degree (sitting), abdominal draw-in exercises, side-lying clamshells, quadruped arm/leg extensions, and side-lying straight-leg raises	Isometric: 20 seconds hold of 15 reps with 2 sets each. Isotonic: 15-20 repetitions with 2 sets each	5 sessions a week	12 weeks	Yes. Change the routine to be more challenging by modified the movement of the limbs	Face to face and remote supervision	Significant improvements in pain and function in EG ($p<0.05$)
7	Çelik et al. 2017 (34)	Isometric and isotonic	9 exercises in week 1: Heel slides, hundreds in supine crook lying, single. Leg heel, side circles, side kick in lying, shoulder bridges, heel together toes apart, parallel, and one leg circle	Isometric: Not reported. Isotonic: 3-4 seconds each repetition. Number of repetitions and sets are not reported	3 sessions a week	12 weeks	Yes. Increase number of repetitions every two weeks with some modification on the exercise routine	Face to face and remote supervised mode	Significant improvement in Lysholm score (knee function) ($p<0.001$), Quadriceps strength ($p<0.05$) was reported In EG (88%) reported improved knee stability compared to only 23% in the control group

EG: Experimental Group, ER: External Rotation, FMS: Functional Movement Screen, No.: Number, TA: Transversus Abdominis, VAS: Visual Analog Scale.

home exercises for the remaining sessions (35). Another study conducted face-to-face sessions for the first 6 weeks, followed by home exercises for the remaining 6 weeks (36).

Outcomes of Core Stability Training

The outcomes of the studies revealed notable improvements in various measures depending on the interventions (Table 4). Out of seven, four studies found statistically significant reduction in pain outcomes (31-33,35), two trials reported significant improvements in lower limb strength (31,36), three studies demonstrated positive impacts on functional independence (22,35,36), two studies reported significant outcomes in physical performance (31,32), two studies discovered significant differences in balance (31,33), one study showed positive findings on foot posture (35) and one study reported significant improvements in knee stability (36) after core stability training. Across the seven trials, the pain outcome was evaluated using subjective measures like VAS, KOOS and NPRS.

The Biodex Balance System, KOOS, TUG test, a dynamometer, the AKPS, Lysholm Knee Scale, and Cincinnati Knee Rating System were used to measure functional independence and physical performance. As for lower limb strength outcomes, the objective instruments used were a dynamometer and a Biodex isokinetic machine. The balance outcome was measured by the Biodex Balance System and Star Excursion Balance Test while foot posture was measured by the FPI-6.

Subgroup Analysis for Exercise Type, Duration, and Outcome Measures

To address the heterogeneity among the included studies in terms of exercise protocols, intervention duration, and outcome measures, a subgroup analysis was performed. This aimed to clarify whether variations in muscle contraction type, treatment duration, or specific outcomes influenced the effectiveness of core stability training for lower extremity dysfunctions. Detailed summary of subgroup analysis is reported in Table 6.

Exercise Type: Five trials used combination of isometric and isotonic exercises and reported improvements in all outcomes except weight distribution and foot load response (31,32,34-36).

Intervention Duration: Interventions lasting less than 6 weeks in three studies (31,33,34) reported positive outcomes in all outcomes while one study (34) reported improvements in foot posture and no changes in weight distribution and

Table 5. Most frequently employed core stability exercises across included studies

Exercise category	Variations or modifications used	Number of studies incorporating exercise (n)	Frequency among studies (%)	7
Bridges with all variations	Back bridges	n=1 (30)	14.28%	
	Unilateral bridges	n=1 (30)	14.28%	
	Shoulder bridges	n=2 (31, 34)	28.57%	71.5%
	Bridges with marching	n=1 (34)	14.28%	
Curl ups	-	n=4 (30, 31, 33, 34)		57.15%
Quadruped stance or birddog	Quadruped with arm leg raises	n=3 (30, 33, 35)	42.85%	
	Quadruped to trunk raise and lowering	n=1 (31)	14.28%	57.15%
Sperman exercises	-	n=2 (31, 36)		28.57%
Bicycles or crisscross	-	n=2 (31, 34)		28.57%
Double leg lowering	-	n=2 (31, 34)		28.57%
Side lying clamshells	-	n=2 (32, 35)		28.57%
Side lying straight leg raise or side kicks	-	n=2 (35, 36)		28.57%
Sigle leg stance	-	n=2 (32, 36)		28.57%
Transverse abdominins (TA) contraction	Isometric TA contraction Isometric contraction of TA with hip knee flexion and extension	n=2 (32, 35) n=1 (32)	28.57% 14.28%	43%
Side bridges	-	n=1 (33)		14.28%
Planks	-	n=1 (34)		14.28%
Vertical crunches	-	n=1 (35)		14.28%
Scissors	-	n=1 (31)		14.28%
Hundreds	-	n=1 (36)		14.28%
Mini squat	-	n=1 (31)		14.28%
Trunk rotation	Lower trunk rotation	n=1 (34)	14.28%	28.57%
	Trunk rotation with weights	n=1 (34)	14.28%	
Side circles	-	n=1 (36)		14.28%
Heels together toe apart	-	n= 1 (36)		14.28%
One leg circle	-	n=1 (36)		14.28%
Straight leg raise	-	n=1 (35)		14.28%
Wall slides	-	n=1 (35)		14.28%
Gluteal muscle isometrics	-	n=1 (32)		14.28%

foot load response. While exercise protocols lasted six or more than 6 weeks in four studies (30,32,35,36) with significant improvements in all outcomes except for one trial (30).

Outcome Measures: Five pain focussed studies (30-33,35) demonstrated significant pain relief except one (30). Three trials (30,31,33) assessed balance, with two studies demonstrating significant improvements (31,33). Four studies assessed subjects for functional independence (30,32,35,36) with all reporting positive improvements except one study (30). Two out of seven studies measured physical performance (31,32) and both reported significant improvements. Similarly, two studies (31,36) assessed lower limb muscle strength, and one study reported significant changes in strength (36). One study used foot posture, weight distribution and foot load response demonstrated significant outcomes in foot posture only (34). Only one study assessed knee stability and showed significant improvements (36).

DISCUSSION

To the best of authors' knowledge, this is the first systematic review which collected evidence of the components, parameters and outcomes of core stability exercise for lower limb dysfunctions. However, only seven (n=7) studies were selected finally, which is a small number, compared to the initial number of studies identified in web search (n=2392). This decrease in the number was primarily due to very strict exclusion criteria, where only studies using core stability training on subjects with musculoskeletal lower limb musculoskeletal disorders in nonathletic population and have not undergone any surgical procedures of the dysfunction were included. This purposeful exclusion was necessary because, protocols of core stability exercises for athletic population cannot be applicable to nonathletic participants, due to difference of fitness levels and to subjects undergone surgeries, because postoperative rehabilitation involves more cautious and modifies approach in the early stages of progress, which may be different from the standard core stability protocols. This led to the exclusion of maximum number of studies, maximum of which were mostly falling in either of these categories.

This review has two principal objectives, which are to identify the components and parameters of core stability rehabilitation program that can improve the outcomes of lower extremity functions and to investigate the effects of core muscle training on various outcomes among individuals suffering from lower extremity disorders.

Effect of Core Exercises on Lower Extremity Dysfunction

The effects of core stability training on lower extremity dysfunctions are evident after a thorough survey of literature, hence supporting the connection between core muscle strength and lower extremity functions as suggested by several studies (14,37). This review covered seven studies that investigated the effects of core muscle activation on lower extremity outcomes.

One study reported that participants in the core stability exercises group had shown similar outcomes in balance, pain score, and KOOS as compared to participants who had received routine rehabilitation exercise (30). Additionally, one study found no significant effect of core stability exercises on weight distribution and foot load response (34), while another did not observe any impact on lower limb strength (31). Despite these findings, remaining all studies demonstrated significant effects in various outcomes like pain, balance, functional independence, lower limb muscle strength, physical performance, foot posture, and knee stability (31-34).

To gain a clearer understanding, a subgroup analysis based on the types of outcome measures used, revealed that the most frequently assessed outcomes were pain, balance, and functional performance, whereas lower limb strength, physical performance, foot posture, knee stability, and weight distribution were less commonly evaluated. Most studies reported significant improvements in pain, balance, physical performance and function (31-33,35-36). Findings related to lower limb strength were mixed, with some studies showing improvement while others did not (31,36). Notably, foot posture and knee stability, each assessed in only one study showed positive outcomes (34,36). In contrast, weight distribution, also assessed in one study, showed no improvement (34). With most studies demonstrating positive results in these domains, suggesting that while core stability training generally contributes positively to lower limb function, the impact may vary depending on the specific domain assessed. Additionally, the heterogeneity in assessment tools used across studies limits direct comparisons but highlights the variety of functional improvements associated with core training.

Before drawing firm conclusions, the methodological quality of the included studies must be considered. None of the studies employed blinding of patients or therapists (30-36), and four lacked assessors blinding as well (30,32-34). Two studies did not implement concealed allocation during sampling (31,32), and one study lacked randomisation altogether (32). In three studies, fewer than 85% of participants completed the intervention (30-32). Additionally, three trials had short-term follow-up periods (31,33,34), while four had moderate-term follow- ups (30,32,35,36), leaving the long-term sustainability of improvements unclear. Five studies had small sample sizes ranging from 20 to 26 participants (30-34), with two of them being feasibility or pilot trials, whereas only two studies had larger samples (35,36). Finally, the considerable heterogeneity in exercise protocols, participant characteristics, and outcome measures makes it difficult to draw generalizable conclusions regarding the efficacy of core stability training for lower limb dysfunctions.

Despite these methodological limitations, the overall findings of the included studies align with previous observational studies that have highlighted a link between core muscle function and lower limb pathologies (15,38,39). Additionally, several clinical trials conducted in athletic populations have reported significant improvements in lower limb performance following core stability training (16-20,40). However, caution is warranted when extrapolating these findings to nonathletic populations, as differences in baseline fitness levels, physical activity, and health status may influence outcomes. Thus, while supportive evidence exists, further high-quality research on diverse populations is needed to strengthen the generalizability of these findings.

Efficacy of core stability training on lower limb disorders has been increasingly explored recently due to its emphasis on enhancing lumbopelvic control and dynamic stability. Although studies on other rehabilitation strategies, such as neuromuscular training and strength training, have shown promising results in lower limb rehabilitation (41,42). The findings of this review highlight the specific and unique role of core stability training in addressing movement deficits and functional impairments associated with lower limb dysfunctions. Core stability training is particularly effective in improving lumbopelvic control, which is vital for proper lower limb movement patterns and overall functional performance (15).

While neuromuscular training enhances proprioceptive feedback and muscle recruitment, and strength training focuses on isolated muscle groups, core stability exercises target the deep stabilizing muscles essential for coordinated movement, by establishing a stable base for every lower limb movement (5,11).This integrated approach improves not only the individual muscle function but also the dynamic stability of the entire kinetic chain, which is crucial for reducing the risk of injury and improving performance in activities requiring complex motor skills (43,44).

Building on the earlier discussion, it can be assumed that the observed improvements in lower limb functions following core stability training may be attributed to the foundational role of the core within the kinetic chain. Activation of the core muscles, particularly those responsible for lumbopelvic control, provides proximal stability that is essential for efficient and coordinated distal movements. Although this relationship may be bidirectional, the evidence from this review suggests that core stability contributes significantly to enhancing lower limb performance through its central role in the kinetic chain. Further research is warranted to explore and confirm the directional influence and underlying mechanisms involved.

Components and Parameters of Core Stability Exercises

Based on analysis, the combination of isometric and isotonic exercises was found to be the most favoured approach in five out of seven trials reviewed. The scientific rationale behind this finding may lie in the complementary nature of these two types of muscle actions. While isometric exercises promote sustained activation of slow-twitch muscle fibres essential for postural control and stability, isotonic exercises involve dynamic movements that enhance strength and functional performance. Together, they may provide a more comprehensive stimulus for improving core strength and stability, leading to better outcomes in lower limb function (45). As for the parameter of isometric exercise, 5-second hold with 8 repetitions per set was commonly used in the trials. While there is no consensus on the optimal duration to sustain the isometric contraction, previous review reported that sustained contractions of 5 seconds to 30 seconds per repetition were reported to be effective in improving maximal muscle strength and muscle mass, respectively (46). For isotonic exercises, 10 to 15 repetitions with 2 to 3 sets were most common prescription.

Across the seven trials reviewed, various core stability exercise routines were employed, including abdominal curls, bridges, side bridges, planks, quadrupedal stances, Sperman exercise, crisscross, vertical crunches, scissors, trunk rotations, transverse abdominis contractions, pelvic musculature strengthening and certain pilates exercises with modifications made in some of these basic exercise postures. These modifications include bridges (e.g., back bridge, unilateral bridge, shoulder bridge), quadruped exercises (e.g., arm lift, arm and lower extremity lift), curl-ups (e.g., curl up, roll down and up, cross curl ups), trunk rotations (with and without weights). Most frequently used exercises across seven trials were bridges (71.5%), followed by curl-ups and quadruped stance (each 57.15%) and isometric contraction of transverse abdominis contraction (43%). Sperman exercises, bicycles, double leg lowering, gluteal muscle exercises, transverse abdominis isometrics and single leg stance were next (each 28.57%) and remaining exercises were used less frequently, each comprising 14.28%. While all studies included multi-exercise interventions, curl ups, quadruped stance and bridges were among the most used exercises in studies reporting significant improvements in outcomes. However, due to the multi-component nature of these interventions, the effectiveness of any single exercise cannot be definitively determined. Instead, this review highlights the core components frequently incorporated in effective intervention programs, offering insight into exercises that may contribute to improved outcomes.

Table 6. Subgroup analysis of core stability interventions: exercise type, duration, and outcome measures

Subgroup analysis based on exercise type		
Exercise type	**Number of studies**	**Findings**
Isometric only	n=1 (30)	No significant improvement in pain, balance, or functional performance compared to conventional exercise group (30).
Isometric + isotonic	n=4 (31-36)	Significant improvements in pain, function, trunk stability, balance, physical performance, foot posture, lower limb muscle strength and knee stability (31, 32, 34-36).
Isotonic only	n=1 (33)	No improvements in weight distribution and foot load response (34).
		Significant improvements in pain and balance (33).
Subgroup analysis based on intervention duration		
Intervention duration	**Number of studies**	**Findings**
<6 weeks	n=3 (31, 33, 34)	Improvements noted in balance, trunk stability, foot posture, and pain (31, 33, 34).
		No improvements for weight distribution and load response (34).
≥6 weeks	n=4 (30, 32, 35, 36)	Majority of studies (32, 35, 36) reported improvements in pain, ADLs, quality of life, functional tests, and lower limb muscle strength.
		One study (30) showed no improvements in pain, balance, or function.
Subgroup analysis based on outcome measures		
Outcome measure	**Number of studies**	**Findings**
Pain	n=5 (30-33, 35)	All studies except one (30) reported significant improvements in pain.
Balance	n=3 (30, 31, 33)	All studies except one (30) reported significant improvements in balance.
Functional independence	n=3 (30, 32, 35, 36)	All studies except one (30) reported significant improvements in functional independence.
Physical performance and mobility	n=2 (31, 32)	Both studies reported significant improvements in physical performance (31, 32).
Lower limb muscle strength	n=2 (31, 36)	One study reported no significant improvements (31) while other study reported significant improvement (36).
Foot posture and weight distribution	n=1 (34)	Significant improvements in foot posture but no significant improvements in weight distribution and foot load response (34).
Knee stability	n=1 (36)	Significant improvements in knee stability reported (36)

These exercise routines activated both global muscles of the core (erector spinae, quadratus lumborum, obliques, and rectus abdominis) and local muscles (transverse abdominis and multifidus). It has been suggested that rehabilitation strategy should incorporate all muscles around the trunk as the global muscles of the core produce torque to counter external force, while the local muscles of the core (transverses abdominis and multifidus) stabilize the trunk (47).

The findings from the selected studies (30-36), show that the overall duration and delivery modes of the core stability training across the seven trials varied. However, most of the trials involved 3 sessions weekly (30,31,33,36), with a range from 2 to 6 times per week. The duration of these programs spanned from 4 to 12 weeks, with each session lasting 30 to 60 minutes. The heterogeneity in the length of the intervention was due to the different training dosages employed in the trials.

A finer analysis of the seven trials revealed that three studies with intervention durations of less than six weeks reported positive outcomes, while three out of four studies with durations of six weeks or more also demonstrated favourable results. One trial, which did not report significant improvements compared to conventional treatment, had an intervention period of six weeks. This suggests that the duration of intervention, whether less than or equal to six weeks did not markedly influence the overall effectiveness. This observation aligns with findings from previous epidemiological studies, which suggest that the effects of increase in muscle strength is evident after after 4 weeks of strength training (48).

Limitations

A key limitation of this review is the small number of included studies (n=7), which may limit generalizability. This resulted from strict inclusion criteria focusing on nonathletic adults with lower limb dysfunctions managed conservatively. While enhancing specificity and clinical relevance, it excluded many studies on athletic, neurologically impaired populations, and participants who had undergone surgeries, whose core stability programs are typically more advanced or condition-specific respectively.

The methodological quality of the included studies ranged from fair to good. Common flaws included lack of patient and therapist blinding in all studies, lack of assessor blinding in more than half, absence of concealed allocation in some trials, and incomplete follow-up data in others. These methodological weaknesses may have introduced various forms of bias and affect the internal validity of the findings.

Furthermore, there was considerable heterogeneity across studies in terms of exercise protocols, outcome measures, and participant characteristics. The absence of standardized core stability training protocols and differing assessment tools reduced the ability to directly compare study outcomes. These variations, along with small sample sizes in most studies and the absence of long-term follow-up data, limit the reliability and sustainability of the reported effects. Due to these substantial differences in study designs and interventions, conducting a meta-analysis was not feasible. The variability in training duration, intensity, frequency, and targeted muscle groups restricted meaningful statistical pooling.

Lastly, because core stability exercises were delivered as part of multi-component interventions in all included studies, it was not possible to isolate and determine the effectiveness of specific exercises or routines. This prevents drawing firm conclusions on which components are most beneficial or have the greatest impact on lower limb dysfunctions.

Despite these limitations, the studies consistently reported positive outcomes related to core stability training for lower limb dysfunctions, suggesting that this intervention may be effective in improving functional performance and reducing movement deficits. However, caution should be exercised when interpreting these findings.

Future Research Directions

Future studies should aim to overcome the methodological limitations identified in this review, such as incorporating larger sample sizes, long-term follow-ups, ensuring better blinding, and implementing standardized protocols for core stability training.

Well-designed randomized controlled trials that isolate specific exercise components and focus on regions of the lower limbs (e.g., hip, knee, ankle) are needed to clarify their differential effects of each component. Long-term follow-up data should also be included to assess the durability of the intervention outcomes. Additionally, comparative studies evaluating core stability training against other rehabilitation strategies such as neuromuscular or strength training would provide deeper insights into the relative efficacy of each approach.

To enable meaningful meta-analytical evaluations in the future, it is essential that studies minimize heterogeneity in terms of intervention protocols, outcome measures, and participant characteristics. Standardizing these aspects will not only improve the comparability of findings across studies but also will enhance the quality and applicability of findings.

CONCLUSION

This review provides initial evidence suggesting a meaningful relationship between core stability and lower limb functions, paving the way for more comprehensive experimental studies to explore this connection further. Activation of core muscles seems to provide a stable base for the execution of lower limb movements, highlighting the importance of kinetic chains in rehabilitation. Combination of isometric and isotonic exercises particularly curl-ups, bridges, quadruped postures and isometric contraction of transverse abdominis were most frequently used. However, the effects of individual exercises could not be isolated due to the multi- component nature of the interventions. Given this limitation future research should explore individual effects of each exercise routine in various lower limb dysfunctions. This will offer a deeper and clearer insight about the most effective components of core stability training and their effect on the outcomes of rehabilitation.

Even though the core stability exercises showed the promise of encouraging results, short term follow ups, smaller sample sizes, methodological weaknesses, and heterogeneity in studies restricted a definitive conclusion. Therefore, despite encouraging outcomes, further high quality, targeted research is necessary to optimize study design and clinical application.

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