REVIEW

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Ultrasonography and Electromyography Activity of Abdominal Muscles in Different Abdominal Exercises: A Systematic Review

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SUMMARY

Objective. The aim of this study was to systematically review current literature on the effectiveness of various exercises and modifications on thickness and electrical activity of abdominal muscles using ultrasonography and electromyography in healthy adults.

Methods. An electronic search was carried out on PubMed, Web of science, ProQuest, Google Scholar, Cochrane and Science Direct databases covering published studies from inception until December 2022. Fourteen papers were then included according to following inclusion criteria: 1) studies assessing abdominal exercises; 2) containing control and intervention groups; 3) conducted on young and healthy samples; 4) full texts being available in English; 5) containing the analysis of at least one of the four abdominal muscles through electromyography or ultrasonography.

Results. The main findings would suggest that stability challenges, rotatory exercise, combination of upper and lower limb movements, sensory cueing and grunting techniques such as Ki-hap make significant improvements in muscle structure and activity.

Conclusions. Despite the averagely fair quality of included papers and difficulty to reach a conclusion with inadequate data, our review suggests that new modifications of both traditional and core exercises can cause improvements in abdominal muscle thickness or activity with the aim of focusing on control and coordination of muscles.

Study registration. The protocol of the present systematic review is registered in the PROSPERO (CRD42022377864).

KEY WORDS

Abdominal muscle; electromyography; training; ultrasonography; exercise.

INTRODUCTION

Abdominal muscles are considered as a structure that provide spinal support and stability for various daily functions (1). The spinal stability needed for activities is provided by the coordinated contraction of muscles such as transverse abdominis (TrA) and internal oblique (IO) which are attached to the thoracolumbar fascia and create lumbar spine stability. These muscles also increase intra-abdominal

pressure for the unstable spine along with the contraction of external oblique (EO) and rectus abdominis (RA) known as very important parts of the trunk due to their action of providing rotatory movements (2). Therefore, core muscles including the abdominals become important and crucial for stabilizing the spine and creating an effective support.
Strengthening these muscles creates a powerful base along with different body movements so that the limbs can function properly relying on the provided trunk support (3). On the other hand, due to the fact that uncontrolled contraction and unorganized recruitment pattern of this muscular structure can lead to conditions such as low back pain (4), a proper exercise plan can prevent future problems. Traditional and core stability exercises such as sit-ups, planks and bridge exercises have been widely used by trainers and physiotherapists. Later, modified forms of exercises have been introduced using balls, devices or unstable surfaces for increasing the proprioceptive challenges and achieving higher activities (5-7). During the process of training, as therapists need to have a better understanding of the changes in muscles by the use of different forms of exercises, methods such as ultrasonography (US) and electromyography (EMG) are being used as reliable tools for the assessment of muscle thickness and electrical activity respectively (8-11).
One review in 2013 that evaluated the effect of different exercises on EMG activation of core muscles including transverse abdominis, suggested free weight exercises over others forms of core exercises (11) and the latest review in 2020 carried out on all four abdominal muscles, evaluated the effect of more exercises including new modifications using EMG method (12). To our knowledge, as there is no review conducted on healthy population, using both EMG and US tools, there is a need for an updated systematic review in this field. The aim of this study was to systematically review the current studies on the effect of different exercises on either EMG or US activity of four abdominal muscles including rectus abdiminis, external oblique, internal oblique, and transverse abdominis.

METHODS

Search strategy

The search strategy was based on the population intervention comparison outcome (PICO) method and included all relevant articles published from inception until December 2022. The procedure was then followed by the PRISMA methods (**figure 1**). An electronic data search was carried out using the online databases of PubMed, Science Direct, ProQuest, ISI web of science, Cochrane, and Google scholar (**appendix 1**). To cover the relevant RCTs for this systematic review, the following keywords were used in the search engines: (Abdominal muscle OR Rectus abdominis OR Internal oblique OR external oblique OR Transverse abdominis) AND (Exercise OR training OR activity OR activation OR growth OR mass OR thickness OR changes OR evaluation OR recovery OR quality OR performance) AND (Ultrasound imaging OR ultrasound OR ultrasonography OR Electromyography OR EMG OR thickness OR changes OR activity OR activation). Related studies suggested by the mentioned databases were also assessed.

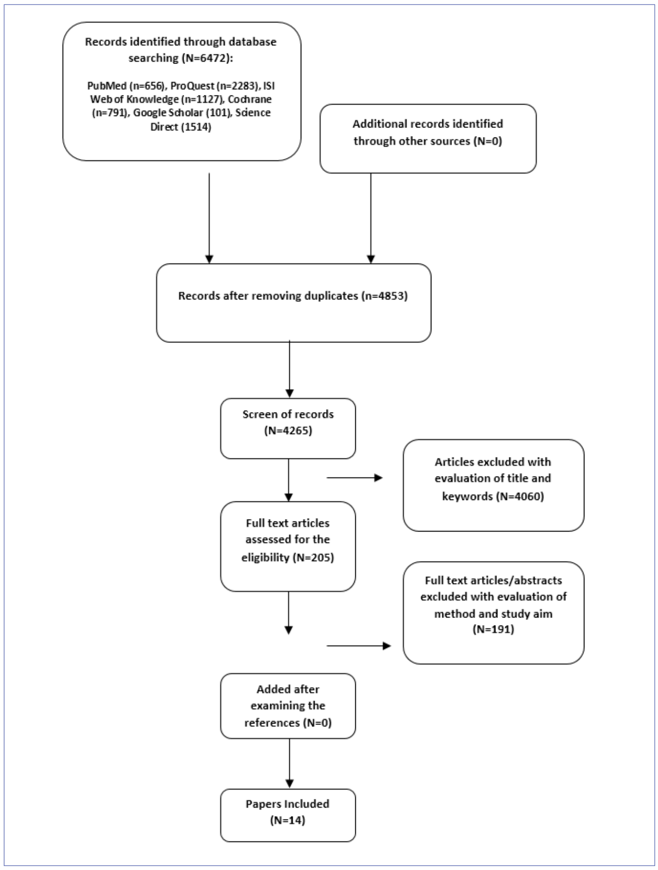

Figure 1. Flowchart indicating the selection of articles through the PRISMA method.

Study selection

Only the articles meeting the following criteria were included: studies assessing abdominal exercises, containing control and intervention groups, conducted on young and healthy samples, the full texts being available in English and containing the analysis of at least one of the four abdominal muscles through EMG or ultrasonography.
Articles including the following criteria were excluded: studies evaluating the effect of different postures, daily

tasks, carried out on unhealthy samples, and specific disorders (such as low back pain or any kinds of neurological deficits).

Included articles were assessed by two reviewers, one of them assessing through the first steps of relevant titles and abstracts and full texts, and the other reviewer assessing the control and experimental groups in order to check and remove the irrelevant ones.

Quality assessment

The Physiotherapy Evidence Database (PEDro) scale is a reliable tool for the assessment of methodological quality of the studies and contains of an 11-item list that checks both internal validity of the RCT and statistical information and finally reports a number based on the items (each item is reported as either 0 being absent or 1 being present). Based on the final reported score, the result is interpreted as poor if 0-3, fair if 4-5, good if 6-8, and excellent if 9-11. After the inclusion of studies, two reviewers examined the RCTs to come up with a PEDro score for each study in the process of quality assessment (**table I**).

Data extraction

The following data were extracted from each study: the author, year of publication, study method, control and intervention groups, conducted intervention, outcome measures, Pedro scale, mean and standard deviation before and after the intervention, and results (**table II**).

Statistical analysis

Because of the heterogeneous data and inadequate information of each outcome, we were unable to perform meta-analysis and therefore the extracted data have been expressed descriptively.

RESULTS

Description of studies

Data of 14 papers were totally gathered and a descriptive analysis was carried out (**figure 1**). The quality of the studies ranged between 3 (poor) to 10 (excellent) and all the studies failed in blinding of subjects except one paper (17), failed in therapist blinding except 2 papers (17, 22) and failed in assessors blinding except 3 papers (17, 19, 23). According to the follow up time, 5 papers evaluated the immediate effect of the interventions (17, 20, 23-25), 8 papers were assessed a duration of less than 3 months (short term) (13-16, 18, 19, 22, 24), and only one contained a follow up of more than 3 months (long term) (21). In total, 60 exercises were included containing traditional exercises (n = 11), core stability

Table I. PEDro score for each Item and total score.

Quality Items	Q1 Eligibility criteria	Q2 Subjects' randomization into groups	Q3 Concealing allocation	Q4 Groups were similar at baseline	Q5 Subjects' blinding	Q6 Therapists' blinding	Q7 Assessors' blinding	Q8 At least, one main outcome	Q9 All subjects received treatment or control condition	Q10 Findings of between-group statistical comparisons	Q11 Providing both point measurements and variability measurements	Total score
Gong *et al.*	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	No	5
Cho *et al.*	No	Yes	No	Yes	No	No	No	No	No	Yes	No	3
Gong *et al.*	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes	No	5
Cho *et al.*	Yes	Yes	No	No	No	No	No	No	No	Yes	No	3
Catania *et al.*	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	10
Critchley *et al.*	Yes	Yes	Yes	No	No	No	No	No	No	Yes	No	4
Chon *et al.*	Yes	Yes	Yes	No	No	No	Yes	No	No	Yes	No	5
Gong *et al.*	Yes	Yes	No	No	No	No	No	No	No	Yes	No	3
Tanimoto *et al.*	No	Yes	No	Yes	No	No	No	Yes	Yes	Yes	No	5
Niewiadomy *et al.*	No	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes	No	6
Kim *et al.*	Yes	Yes	No	No	No	No	Yes	Yes	Yes	Yes	No	6
Cosio-Lima *et al.*	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes	No	5
Miller *et al.*	No	Yes	No	No	No	No	No	Yes	Yes	Yes	No	4
Hubley-Kozey *et al.*	No	No	No	No	No	No	No	Yes	Yes	Yes	No	3

Table II. Characteristics of the studies on effect of abdominal exercises on muscle thickness and electrical activity.

Author(s)	Year of publication	Participants	Control group Intervention group	The Intervention	Study Type	Outcome Measure (tool)	Quality Status	Muscle ested	Follow-up time
Wontae Gong *et al.*	2018	n = 32 CG: (F:15, M:1) Mean Age: 21.6 ± 0.2 BMI: 21.90 Non-Athletes TG: (F:15, M:1) Mean Age: 22.3 ± 2.1 BMI: 22.60 Non-Athletes	CG: no exercise IG: continuous bridge exe	Continuous bridge exe at prone and side+ ADM	Single blinded RCT	Muscle thickness (US)	Fair	EO, IO, TrA	6 weeks (3 times a week)
Misuk Cho *et al.*	2013	n = 30 CG (F;15, M:1) Mean Age: 20.8 ± 0.3 BMI: 21.33 Non-Athletes TG (F;15, M:1) Mean Age: 20.7 ± 0.3 BMI: 21.45 Non-Athletes	CG: bridge exercise IG: modified wall squat exe	Modified wall squat	No blinding RCT	Muscle thickness (US)	Poor	IO, TrA	6 weeks (3 times a week)
Wontae Gong *et al.*	2015	n = 30 CG (F:15, M:15) Mean Age: 21.7 ± 0.8 BMI: 21.48 Non-Athletes TG (F:15, M:1) Mean Age: 22.4 ± 1.0 BMI: 22.39 Non-Athletes	CG .no exercise IG: dynamic exe utilizing PNF	Dynamic exe utilizing PNF	Single blinded RCT	Muscle thickness (US)	Fair	IO, EO, TrA	6 weeks (3 times a week)

Author(s)	Year of publication	Participants	Control group Intervention group	The Intervention	Study Type	Outcome Measure (tool)	Quality Status	Muscle ested	Follow-up time
Misuk Cho *et al.* (16)	2015	n = 30 CG (F:13, M:2) Mean Age: 21.7 ± 0.3 BMI: 21.45 Non-Athletes TG (F:13 M:2) Mean Age: 22.4 ± 1.0 BMI: 21.14 Non-Athletes	CG. Stable Bridge exe IG: Unstable bridge exe	Bridge exe +ADM on balance pad	No blinding RCT	Muscle thickness (US)	Poor	IO, TrA	6 weeks
Brian Catania *et al.*	2021	n = 31 Mean Age: 20.8 BMI: 24.50 Non-Athletes	CG: Traditional core exe IG: rotary-based exe	Rotatory based exe	Triple blinded RCT	Muscle thickness (US)	excellent	EO, IO	Single session
Duncan J. Critchley *et al.*	2011	n = 34 (F;28, M:6) CG (n = 16) Mean Age: 30 (8) BMI: NS Non-Athletes TG (n = 18) Mean Age: 31.5 BMI: NS Non-Athletes	CG: Conventional strength exe IG: Pilates mat exe	Pilates	No blinding RCT	Muscle thickness (US)	Fair	IO, TrA	8 weeks twice a week
Seung-Chul Chon *et al.*	2010	n = 40 (F:22, M:18) CG (N:20) Mean Age: 24 (1.5) BMI: 20.65 Non-Athletes TG (n = 20) Mean Age: 24(1.6) BMI: 21.61 Non-Athletes	CG:ADM IG: Ankle dorsi flexion +ADM	Ankle dorsi flexion +ADM	Single blinded RCT	Muscle thickness (US) Muscular electrical activity (EMG)	Fair	EO, IO, TrA	2 weeks (5 times a week)

Author(s)	Year of publication	Participants	Control group Intervention group	The Intervention	Study Type	Outcome Measure (tool)	Quality Status	Muscle ested	Follow-up time
Won-tae Gong *et al.*	2015	n = 32 CG (F:8, M:8) Mean Age: 23.72 ± 1.4 BMI: 24.55 Non-Athletes TG (F:8, M:8 Mean Age: 23.17 ± 2.14 BMI: 22.75 Non-Athletes	CG: Bridge exe with sling IG: Bridge exe with sling+vibration	Bridge exe with a sling and vibration	No blinding RCT	Muscle thickness (US)	Poor	IO, TrA	Single session
Michia Tanimoto *et al.*	2008	n = 36 CG (n = 12) Mean Age: 19.8 ± 0.7 BMI: 21.70 Non-Athletes HN (n = 12) Mean Age: 19.9 ± 0.5 BMI: 21.56 Non-Athletes LST (n = 12) Mean Age: 19 ± 0.6 BMI: 20.96 Non-Athletes	CG: sedentary controls IG 1: Low intensity-slow movement IG 2: High intensity-normal movement	Whole body low intensity resistance	No blinding RCT	Muscle thickness (US)	Fair	Abdomen	13 weeks (twice a week)
Paweł Niewiadomy *et al.*	2021	n = 73 CG (n = 33) Mean Age: 24.94 BMI: 22.56 Non-Athletes TG (n = 40) Mean Age: 24.22 BMI: 23.42 Non-Athletes	CG: no exercise IG: rotational movement exe	rotational movement exe	Single blinded RCT	Muscle thickness (US)	Good	EO, IO, TrA	4 weeks

Author(s)	Year of publication	Participants	Control group Intervention group	The Intervention	Study Type	Outcome Measure (tool)	Quality Status	Muscle ested	Follow-up time
Chang-Yong Kim *et al.*	2017	n = 90 CG (F:15, M:15) Mean Age: 24.37 BMI: 22.07 Non-Athletes TG1: (F:15, M:15) Mean Age: 25.17 BMI: 21.79 Non-Athletes TG2: (F:15, M:15) Mean Age: 24.91 BMI: 22.14 Non-Athletes	CG: Crunh only IG 1: Crunh+Ki-hap IG 2: Crunch+ki-hap+verbal encouragement	Ki-hap technique and verbal encouragement	Single blinded RCT	Muscular electrical activity (EMG)	good	EO, IO,RA	1 session
Ludmila M. Cosio-Lima *et al.*,	2003	n = 30 females CG (F:15) Mean Age: 22.87 BMI: 21.49 Non-Athletes TG (F:15) Mean Age: 19.47 BMI: 23.14 Non-Athletes	CG: conventional exe on floor IG: conventional exe on physioball	Conventional exe on physioball	No blinding RCT	Muscular electrical activity (EMG)	Fair	RA	5 weeks
Marilyn I. Miller	1987	n = 40 males CG (M:20) Mean Age: 31.30 BMI: 22.53 Non-Athletes TG (M:20) Mean Age: 31.00 BMI: 23.80 Non-Athletes	CG: back extension exercise IG: back extension +multisensory cuing	Back extension with multisensory cuing	No blinding RCT	Muscular electrical activity (EMG)	Fair	IO, TrA	1 session
CherylL. Hubley-Kozey *et al.*	2010	n = 33 CG (n = 19) Mean Age: 24 BMI: 23.32 Non-Athletes TG (n = 14) Mean Age: 24 BMI: 22.57 Non-Athletes	CG: Dynamic stability exe with stability IG: Dynamic stability exe with instability	Dynamic stability extension +instability	No blinding RCT	Muscular electrical activity (EMG)	Poor	RA, EO	1 session

ADM: abdominal draw-in maneuver; CG: control group; EMG: electromyography; EO: external oblique; IO: internal oblique; PNF: Proprioceptive Neuromuscular Facilitation; RA: rectus abdominis; RCT: randomized control trial; IG: intervention group; TrA: transverse abdominis; US: ultrasonography.

exercises (n = 27), free weight exercises (n = 12), ball/sling/pad/surface exercises (n = 3), and non-core exercises (n = 7) based on core exercise classifications (11). Four papers contained control groups with no types of exercises (13, 15, 21, 22).

Changes in the muscles along with the interventions were evaluated with muscular thickness via ultrasonography (13-22) and muscular electrical activation via electromyography (19, 23-26).

Summary of results

Rectus Abdominis (RA)

All included studies that assessed the changes of RA during exercises were carried out with the EMG tool.

Two studies with score range 3-5 resulted in a significant improvement while doing unstable exercises ($p = 0.04$ for flexion and $p = 0.01$ for extension) or putting body in an unstable position ($p < 0.005$) (24, 26). Another article with good quality (score: 6) concluded that yelling or grunting (verbal activity) highly improved muscle activation ($p = 0.024$) (23).

External oblique (EO)

US findings

Five studies evaluated the effect of exercises on EO muscle thickness using the ultrasound tool. Three studies with scores 5-10 demonstrated statistically greater increase of muscle thickness in intervention groups receiving dynamic exercises utilizing Proprioceptive Neuromuscular Facilitation (PNF) and rotatory exercises (15, 17, 22). However, two studies with the score of 5 reported no significant change in the muscle thickness using continuous bridge exercise compared to no exercise, and abdominal draw-in maneuver (ADM) with ankle dorsiflexion compared to doing ADM alone (13, 19).

EMG findings

Two studies (scores: 4-6) evaluated EMG findings and resulted in significant increase in muscle activation using unstable dynamic exercise and crunch exercise with Ki-hap technique (23, 25).

Internal oblique (IO)

US findings

Nine studies were conducted with ultrasonography evaluations for IO. In six studies (scores: 3-10), interventions of continuous bridge exercise, wall squat, dynamic exercise utilizing PNF, bridge exercise on balance pad, and rotatory movements caused significant increase in muscle thickness (13-17, 22).

According to a study evaluating the effect of Pilates mat exercises (score: 4), the results demonstrated that not only the movements such as Hundreds or standing and supine exercise caused no effect on the thickness of IO, but also imprints movement caused decrease in this outcome (18).

In one study (score: 5), no significant difference was observed with doing ADM with ankle dorsiflexion compared to doing ADM alone ($p = 0.092$) (19). In another paper (score: 3), the thickness of IO was increased along with the increase of vibration ($p < 0.05$), but it was not much different with the control group (20).

EMG findings

Two studies with the scores of 4-6 evaluating the effects of Ki-hap technique and back extension with multisensory cueing resulted in significant increase in IO activity (23, 25).

Transverse abdominis

US findings

US findings contained 8 articles. Three studies with the scores of 5-10 concluded that the intervention groups with continuous bridge exercise, rotatory based movements, and ADM with ankle dorsiflexion demonstrated significant increase in thickness of TrA (13, 17, 19) and similarly, one study (score: 3) using vibration with sling bridging exercise concluded that there was a noticeable increase in the intervention group compared with control group (bridging with sling) especially with the pressure increase at 38, 42, 46 mmHg ($p < 0.05$) (20). Two studies (scores: 3) with wall squat and bridging on balance pad resulted in statistically great difference in TrA thickness, but no difference was seen between the control and experimental groups ($p > 0.05$) (14, 16). One paper evaluating the effects of Pilates (score: 4) represented that Hundreds. A exercise showed a great increase in TrA ($p = 0.007$) (18) and another study with good quality (score: 6) evaluating the efficacy of rotatory exercises indicated that the overall cross section of Tra+IO+EO was increased with bigger changes in IO and EO rather than TrA ($p < 0.05$) (24).

A paper (score: 5) examining the changes of the whole muscular size of abdomen concluded that both the high intensity-low speed and low intensity-slow movement groups displayed significant increase compared with the control group (21).

EMG findings

EMG findings contained 2 papers. In the study with doing back extension with multisensory cuing (score: 4), the experimental group had greater mean change than the control group that carried out the exercise without cueing (25) and similarly, the study with ankle dorsiflexion and

ADM (score: 5) displayed significant increase in muscle activation (19).

DISCUSSION

Since the abdominal muscles play an important role in supporting and increasing spinal stability, strengthening programs are effectively noticed and information about the various forms of exercises and how effective they are for each muscle becomes important for exercise prescription. This present study aimed to review the evidence on the impact of different abdominal exercises on muscular changes.

According to the findings, most interventions displayed an improvement in the changes of abdominal muscles measured by US and EMG. Modifications such as unstabilizing the exercises by performing them on the balance pad, physioball, sling, and vibration or providing an unstable body position caused positive changes on outcome measures. This can be due to the co-contraction of muscles that try to provide balance (16). Also, adding multisensory cueing (by boosting the coordination and volunteer control) (25) or subjective verbal acting (by cerebral cortex stimulation affecting motor nerves) (23) are shown to be effective, although the result cannot easily be relied on in the study with the multisensory effects since factors such as instability are provided in the training group too. Similarly, rotational movements have positive impact on increasing muscle thickness, but majorly in EO and IO rather than TrA (22). However, a study evaluating Pilates movements demonstrated that with doing the Hundred A, TrA thickness was increased but IO thickness showed a decrease and this change happened only during the training and did not carry on to functional postures of daily activities (18).

However, according to the heterogeneous data and methodological diversity, it is difficult to make a final summation. For instance, while continuous bridge exercise is effective for the increase of IO and TrA thickness, no significant change was seen for EO muscle (13). Another study reported that during ADM with ankle dorsiflexion, the thickness of EO was decreased, but for TrA, there was an increase, and it was not effective for IO (19). The reason goes back to the spatial and temporal summation that stimulate only TrA as target (19). On the other hand, since exercises such as bridging and dynamic movements with PNF have been compared with control groups that received no exercises, it cannot be concluded whether these activities are more effective than the other types or not (13, 15).

The included RCTs considered a specific type of exercise without applying different frequencies or repetitions. Only one study considered the effect of intensity and speed of movement that changes in both criteria resulted in improvements on abdominal muscle thickness (21). Most papers were fairly qualified (13, 15, 18, 19, 21, 24, 25), and except 4 papers with poor quality and high risk of bias (14, 16, 20, 26), the other papers can almost be reliable. Except two studies with a high number of participants (22, 23), and one study with long-term follow-up (21), the sample sizes were small and follow ups were mostly immediate and short time. Besides, all studies were carried out on healthy population and these conclusions cannot be used the same for conditions such as low back pain. There is also a concern over the education of the movements in the studies about whether the exercises were properly conducted by the participants or not. Therefore, further studies need to be done with the assessments of frequency changes and number of repetitions of movements, duration and speed changes, larger sample sizes, long-term follow ups, and higher qualities.

Overall, despite the discrepancies and inadequate data, it is clear that how exercises and new modifications affect the outcomes and according to the findings, therapist and trainers can decide which movement to choose for each muscle. Therefore, with making small changes such as adding vibration, unstable surface, grunting, visual and sensory cueing, changing the speed, combining upper limb and lower limb movements and using free weight movements rather than isolated conventional exercises, significant improvements can be made.

CONCLUSIONS

This study systematically reviewed the present evidence on the effect of various exercises on muscular changes using ultrasonography and electromyography. Despite the averagely fair quality of the included papers and difficulty to reach a conclusion with inadequate data, our review suggests that new modifications of both traditional and core exercises such as stability challenges, adding vibration, sensory cueing or subjective verbal acting, rotational based activities and combination of upper and lower limbs' movements can cause improvements in the abdominal muscle thickness or activity with the aim of focusing on the control and coordination of muscles. These strengthening techniques can contribute as a factor in preventing future problems such as low back pain and help to provide better abdominal and spinal performance for both stability and dynamic goals.

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None.

DATA AVAILABILITY

Data are available under reasonable request to the corresponding author.

CONTRIBUTIONS

NT: conceptualization. NT, HP: methodology. HP, AD: investigation. AD, MKZ: quality assessment; HP, MKZ: writing – original draft. AD, NT: writing – review & editing.

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CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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ONLINE SUPPLEMENTS

Appendix 1. Data search.

Search strategy

PubMed : 656

((((((Abdominal muscle) OR (Rectus abdominis)) OR (Internal oblique)) OR (external oblique)) OR (Transverse abdominis)) AND ((Exercise*) OR (training*))) AND (((((((Ultrasound imaging) OR (ultrasound)) OR (Electromyograp*)) OR (EMG)) OR (thickness)) OR (activit*)) OR (activation)) Filters: Clinical Trial, Randomized Controlled Trial

Web of science: 1127

1. ((((ALL=("Abdominal muscle")) OR ALL=("Rectus abdominis")) OR ALL=("Internal oblique")) OR ALL=("external oblique")) OR ALL=("Transverse abdominis")
2. (ALL=(Exercise*)) OR ALL=(training*)
3. ((((((ALL=("Ultrasound imaging")) OR ALL=(ultrasound)) OR ALL=(Electromyograp*)) OR ALL=(EMG)) OR ALL=(thickness)) OR ALL=(activit*)) OR ALL=(activation)

Combined syntax: #11 AND #2 AND #3

ProQuest: 2283

("Abdominal muscle" OR "Rectus abdominis" OR "Internal oblique" OR "external oblique" OR "Transverse abdominis") AND (Exercise* OR training*) AND ("Ultrasound imaging" OR ultrasound OR Electromyograp* OR EMG OR thickness OR activit* OR activation)

Google Scholar: 101

allintitle: (muscle) AND (Exercise OR training) AND ("Ultrasound imaging" OR ultrasonography OR sonography OR Electromyography)

Science Direct: 1514

("Abdominal muscle" OR "Abdominal muscles") AND (Exercise OR training) AND (Ultrasound imaging OR ultrasound OR sonography OR Electromyography OR EMG)

Cochrane: 791

(Abdominal muscle OR Rectus abdominis OR Internal oblique OR external oblique OR Transverse abdominis) AND (Exercise OR training) AND (Ultrasound imaging OR ultrasound OR Electromyography OR EMG OR thickness OR activity OR activation) in Title Abstract Keyword