7-6-2012

Systematic review of core muscle electromyographic activity during physical fitness exercises

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Systematic Review of Core Muscle Electromyographic Activity During Physical Fitness Exercises

by

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A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science
Department of Physical Education and Exercise Science
College of Education
University of South Florida

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Date of Approval:
July 06, 2012

Keywords: lumbar multifidus, quadratus lumborum, transverse abdominis, core stability

DEDICATION

I dedicate this thesis to my beloved brother, Matthew, who although has passed, has always and will continue to be my source of inspiration and motivation. Thank you Matt, I am sure you are looking down with a proud smile on your face!

I would also like to thank my mother and father for their persistent support and dedication during the rough times throughout the entire review process. Despite being thousands of miles away, your ability to listen and keep me moving forward had a tremendous impact on the successful completion of this project. Thank you mom and dad as your mental and emotional support were the pillars of foundation in this review.

ACKNOWLEDGEMENTS

I would like to first thank the Department of Physical Education and Exercise Science for allowing and working with me to perform this systematic review. Especially, Dr. Candi Ashley and Dr. Bill Campbell for serving on my committee and valuable manuscript revisions. I would like to offer a special thanks to John Orriola for without his help this project would not be possible. John played an integral role in educating me on the finer details of the systematic review process as well as assisting in the literature search. I also would like to thank Jim Nuzzo for his contributions through his detailed edits and manuscript format suggestions. Finally, a special thanks is owed to Dr. John Mayer who served as a vital component throughout the review process by contributing his previous systematic review experiences, content expertise, along with guidance and holding me to high level of standard during the entire process. The dedicated support from my committee through inspiring and believing in me to take on this comprehensive review has not only yielded a quality final product but also made me a better person academically.

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ABSTRACT

Activating the core muscles through exercise training programs is believed to be important for athletic performance. Considerable attention has been credited to the lumbar multifidus, transverse abdominis, and quadratus lumborum in designing exercise training programs. Numerous core exercise claims and recommendations abound in the fitness and physical therapy communities touting a superior core challenge for these muscles. The plethora of core activation literature with conflicting outcomes has convoluted the process of choosing exercises for an optimal core training approach. Although an abundance of research studies have quantified the muscle activity, collectively, a consensus on the type of exercise that elicits the largest muscle activity does not exist. Therefore, the objective of this investigation was to critically examine the literature and synthesize the muscle activity produced across various physical fitness exercises to determine which type of exercise elicits the largest amplitude for the core muscles in healthy individuals. PubMed, EMBASE, SPORTdiscus, CINAHL, (CCRT) and Web of Science databases were searched revealing 27 studies meeting the inclusion criteria measuring EMG activity during 202 exercises. In absence of research for the quadratus lumborum, no conclusions could be made and bring about concern for current recommendations. Furthermore, the methodological diversity significantly limited the quality of studies meriting standardization for future EMG research. Nonetheless, the current evidence suggests free weight exercises and non-core exercises using external

resistances produce the largest EMG activity for the lumbar multifidus and transverse abdominis, respectively.

CHAPTER ONE: INTRODUCTION

Activating core muscles through exercise training programs has been effective for treatment of musculoskeletal conditions (53) and prevention of injuries (28). The efficacy of core training has led to its believed importance for athletic performance (22, 36). However, a consensus on the core musculature is nonexistent, subsequently, leading to a great deal of confusion in the fitness and strength and conditioning professions (5). In absence of a common definition, consistent core musculature includes the erector spinae, multifidus, quadratus lumborum, transverse abdominis, rectus abdominis, and abdominal obliques. Recent research has highlighted the lumbar multifidus, transverse abdominis, and quadratus lumborum in their functional contributions to the core (35, 49).

The unisegmental lumbar multifidus are the most medial of the lumbar spine muscles ascending from the spinous processes caudally two to five levels, functioning primarily as an extensor of the spine (31). The lumbar multifidus has gained tremendous attention from the Queensland physiotherapy groups research demonstrating that electromyographic (EMG) muscle activity precedes extremity movements in healthy individuals (18) but is delayed in low back pain patients (20). This evidence suggests its preparatory stabilizing effect of the trunk to allow force production at the extremities. Moreover, being twice as large as any other muscle in the lumbar region and unique in its fiber arrangement indicates its architecturally designed to produce very large forces over a narrow range of length (54). Additionally, research has reported a smaller cross sectional area of the lumbar multifidus has been associated with increased hip, groin, and thigh muscle injuries in athletes (16).

The transverse abdominis has received similar interest from the Queensland group. The transverse abdominis arises from the thoracolumbar fascia at the lateral raphe, the internal aspects of the lower six costal cartilages, where it inserts with the diaphragm, the lateral third of the inguinal ligament and anterior two thirds of the inner lip of the iliac crest (49). Its "belt-like" fiber orientation limits its ability to generate motion but emphasize its relationship to increasing intra-abdominal pressure (8), which is considered to have major effects on lumbopelvic stability (49). The anticipatory contraction of the transverse abdominis has similarly been identified to precede extremity movement in healthy individuals (18) and also is delayed in activation in low back pain patients (19).

Positioned laterally to the lumbar spine is the multisegmented quadratus lumborum which originates from the iliac crest and has insertions on the twelfth rib and transverse processes of the lumbar vertebrae (47). Anatomical texts have concluded the primary role of the quadratus lumborum is lateral flexion (47), whereas myoelectric evidence has also revealed activity during flexion-dominant and extensor dominant tasks (38). Dr. Stuart McGill has heightened the importance of the quadratus lumborum by outlining its generation of frontal plane torque to support and stiffen the torso/pelvis and assist the strength-deficient hip (40). More recent research has examined the contribution of trunk muscularity to sprint run performance and determined the quadratus lumborum to be a significant contributor (25).

Traditionally, muscular function has been deduced from anatomical descriptions, lines of action and attachment, empirical measurements, and subjective perceptions (24, 35). Prescribing exercise based on these traditional methods may elicit an insufficient training approach. Alternatively, knowledge of neuromuscular activity through various physical fitness exercises can contribute to an improved understanding of function and informed prescription. EMG has been the cornerstone technique in measuring the interaction between the nervous and muscular system (48). Recently, other modalities of estimating muscle activation have been implemented including muscle functional magnetic resonance imaging and ultrasound imaging (17, 41).

Implementing core exercise through various training objectives requires different levels of activation necessary to elicit a training response for specific individuals. The choice of exercise is important as the magnitude of the muscle activation reflects whether core strength or core stability is developed (15). Therefore, the relationship between the exercise and activation is critical to designing optimal approaches to be used in rehabilitation as well as strength and conditioning settings (7). Various approaches have been recommended to activate the core muscles. **Traditional core exercises**, such as sit-ups, crunches, and back extensions, are low-load dynamically performed floor exercises that focus on superficial trunk muscles. However, the efficacy of traditional core exercises is limited due to its being nonfunctional (35). **Core stability exercises**, characterized by low-loads and short range of motion, which isolate deep core muscles (i.e. lumbar multifidus, transverse abdominis, quadratus lumborum) have received increased recognition in sports conditioning programs (56). Commonly performed in the quadruped, prone, or supine body position these exercises are designed to maintain dynamic spinal and trunk stability through improving neuromuscular control, strength, and endurance of muscles (52). Despite their effectiveness in rehabilitation settings and reducing injuries, their threshold to stimulate adaptive responses has been doubted for sports performance gains (56). As opposed to core stability exercises, **free weight exercises**, which may activate the core are often performed in the standing position and involve dynamic movements utilizing external resistances with weight supported by the entire body and tax a larger portion of the body's musculature (2). Typical free weight exercises including squats, deadlifts, and lunges are commonplace in strength programs that require muscles to work to stabilize and support the movement of the free weight (7). However, the body's ability to dynamically constrain the free weight may be inadequate in isolating specific deep muscles. **Ball/device exercises** are performed with the addition of equipment with the intention of increasing core muscle activity. Despite numerous claims, the efficacy of using stability balls and other devices including the BOSU ball or power-wheel as compared to the non-device/ball alternative is questionable (27, 56). **Non-core exercises**, which are performed to activate muscles distal to the core, provide a stimulus to the core muscles secondary to the prime (focal) movement. Exercises not intentionally performed to train the core such as the chest-press, shoulder-press, and pull-ups may provide sufficient core activation but their effectiveness is unclear (3).

Currently, the body of literature is inconsistent as to which type of exercise elicits the largest activation magnitude for the core muscles, and subsequently, is most appropriate to include in exercise training programs. Therefore, justification to what exercises provide the largest core challenge requires knowledge of the loading the tissues (39). Many studies have determined tissue loads within physical fitness exercise in various capacities and intensities (1, 6, 12, 44, 45, 58). To date, the core activation literature has not been systematized according to activation magnitudes to further justify appropriate exercise prescription and effective progressive overload. Therefore the purpose of this review is to critically examine the literature and synthesize the muscle activity of three core muscles (lumbar multifidus, transverse abdominis, quadratus lumborum) during physical fitness exercises.

CHAPTER TWO: METHODS

Experimental Approach to the Problem

An electronic search was performed using PubMed, EMBASE, SPORTdiscus, CINAHL, Cochrane Central Register of Controlled Trials (CCRT) and Web of Science databases for articles published until January 12, 2012. The search strategy consisted of terms *electromyography* OR *myoactivity* OR *biofeedback* OR *myoelectrical* OR *magnetic resonance imaging* OR *ultrasound* AND *quadratus lumborum* OR *lumbar multifidus* OR *transversus abdominis* AND *exercise** (in various capacities). References cited in articles were further reviewed to locate any additional relevant articles not retrieved within the search.

Study Selection and Inclusion Criteria

Inclusionary and exclusionary criteria used for the review are listed in **Table 1**. To be included in the review, original research articles examining muscle activity of trunk muscles during physical fitness exercise were included and reviewed for content. In the absence of randomized controlled studies, descriptive studies were selected including clinical control trials, cohort studies, and case control studies. Eligibility included exposures being markedly different physical fitness exercises that are commonly performed in a fitness environment. Studies that made comparisons across the same exercises or were uncommon exposures including various movements (i.e. pelvic tilts, abdominal hallowing), postures (i.e. kyphotic, lordotic), ergonomic exposures, and exercises performed using laboratory equipment (i.e. isokinetic dynamometer) were excluded. The outcome of interest was an activation magnitude of any core structures of interest lumbar multifidus, transverse abdominis, or quadratus lumborum with appropriate statistical tests determining significance between exercises. A single reviewer screened titles and abstracts and excluded obviously irrelevant studies. The remaining pertinent studies were reviewed and a second reviewer verified the studies to be excluded. The full text of remaining articles was retrieved and assessed by two independent reviewers.

Data Extraction

A single reviewer extracted data from studies that met the inclusion criteria. Five articles were selected at random and were reviewed by a second reviewer to verify the validity of the data. All exercises were organized into one of five categories for synthesis of data: core stability, traditional core, free weight, machine/device, and non-core (**Table 2**).

Methodological Quality Assessment

All included studies were assessed for methodological quality using the Agency for Healthcare Research and Quality (AHRQ) evidence rating tool (55) and Effective Public Health Practice Project (EPHPP) quality assessment tool. The AHRQ tool assessed nine domains: seven best practice domains and two empirical domains. The criteria for the essential best practice domains assessed: study question, study population, exposure/intervention, outcome measure, statistical analysis, results, and discussion. The remaining two empirically based domains examined compatibility of subjects and funding or sponsorship. The EPHPP assessment tool examined nine domains: selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analyses. Two reviewers assessed the quality of each study using both objective tools and each article was given an overall subjective rating based on the results of the objective tools. The approach we chose was because quality assessment in systematic reviews for observational studies is not common due to the lack of a validated tool. Moreover, reviews that incorporate rating instruments, the assessment criteria used lack a consensus (32).

CHAPTER THREE: RESULTS

Search Results

The literature search process for identifying, screening, and selecting studies is depicted in **Figure 1**. The initial search included EMG, MRI, and ultrasound but was restricted to EMG recording after the search due to the inability to compare amongst different activation measurement techniques. After screening full text articles, twenty-seven studies were deemed eligible. Reasons for excluding studies included comparison within same exposure (n=36), uncommon physical fitness exercises (n=31), not original research (n=16), outcome measures not of interest in particular study (n=13), no muscle of interest (n=6), MRI/ultrasound (n=5), intervention design (n=4), not written in English (n=2) and subjects reported back pain (n=1). The majority of excluded studies were due comparisons between the same exercises and the studies examining exercises or exposures that are not performed in a fitness setting.

Characteristics of Included Studies

Of the 27 included studies all but one (4) reported EMG activity for the lumbar multifidus. Two of 26 studies (21, 45) recorded lumbar multifudus EMG activity via intramuscular electrodes with the remaining using surface electrodes. Fourteen of the 27 studies reported EMG activity for the transverse abdominis. Three of the 14 studies (4, 21, 45) recorded transverse abdominis EMG activity via intramuscular electrodes with the remaining using surface electrodes.

A total of 202 exercises were categorized into one of five categories based on authors' descriptions: 54 core stability exercise, 27 traditional core exercises, 24 free weight exercises, 82 ball/device exercises, and 15 non-core exercises (**Table 2**). Seven exposures were excluded that could not accurately placed into the categories or did not meet inclusion criteria.

Methodological Quality

Each study was assessed using the AHRQ and EPHPP rating instruments. Not all the criteria in each rating instrument could be satisfied therefore the two separate ratings were utilized and final subjective ratings were scored. The observational design of studies prevented the inclusion of high quality randomized controlled trials therefore study quality ranged from low to moderate (**Table 3**). The most common criteria studies failed to achieve were blinding of the outcome assessors, appropriate power calculations, and determining reliability.

Strength of Evidence

The review examined observational studies limiting the articles to moderate and weak quality therefore no strong evidence was found. Within study comparisons between exercise groups are shown in **Tables 4 & 5**.

Lumbar Multifidus:

Moderate Evidence

- EMG activity is greater during free weight exercises compared with ball/device exercises. A moderate strength of evidence that greater lumbar multifidus activity exists in free weight exercises compared with ball/device exercises in three moderate quality studies (6, 14, 44) with one low quality study reporting no differences (7).
- There are no differences for EMG activity during ball/device exercises compared with core stability exercises. Moderate strength of evidence that no differences exists during ball/device exercises compared with core stability exercises in four articles (9, 21, 30, 34) with one low quality article finding greater activity in ball/devices exercises (7).

Limited Evidence

- EMG activity is greater during core stability exercises compared with traditional core exercises. A limited strength of evidence exists that EMG activity is greater during core stability exercises compared with traditional core exercises in two moderate quality studies (45, 57) and one low quality study (10) with no differences reported (24) and contrasting findings (46) from two low quality studies.
- EMG activity is not different during free weight exercises compared with core stability exercises. Limited evidence exists from two low quality studies reporting conflicting findings (7, 10).
- EMG activity is greater during non-core exercises compared with core stability exercises. A limited strength of evidence exists from one low quality study that

lumbar multifidus activity is greater in non-core exercises compared with core stability exercises (7).

- EMG activity is greater during free weight exercises compared with traditional core exercises. Limited evidence exists from one moderate quality study (6).
- There are no differences for EMG activity during ball/device exercises compared with traditional core exercises. Limited evidence exists with three studies reporting greater EMG activity during ball/device exercises (11, 12, 57) and two studies reporting greater activity in traditional core exercises (6, 9).
- EMG activity is greater during free weight exercises compared with non-core exercises. Limited strength of evidence exists from one moderate and one low quality study reporting greater activity during free weight exercises compared to non-core exercises (7, 58).
- EMG activity is greater during ball/device exercises compared with non-core exercises. Limited evidence exists from one moderate and one low quality study that EMG activity is greater for ball/device exercises compared with non-core exercises (7, 23) with one low quality study reporting no differences (59).

No Evidence

- No evidence exists comparing EMG activity during non-core exercises with traditional core exercises.

Transverse Abdominis

Moderate Evidence

- EMG activity is not different during ball/device exercises compared with core stability exercises. Moderate evidence exists from three mixed quality studies (9, 21, 57) reporting no differences between core stability exercises and ball/device exercises with one study reporting greater activity during ball/device exercises (34).

Limited Evidence

- There are no differences for EMG activity during traditional core exercises compared with core stability exercises. Limited evidence from two moderate quality studies found no differences between traditional core exercises and core stability exercises (45, 57).
- There were inconsistent findings for ball/device exercises compared with traditional core exercises. A limited strength of evidence with two moderate quality studies reporting greater transverse abdominis activity during ball/device exercises (11, 12) with one low and one moderate quality study reporting no differences (9, 57), and one low quality study reporting greater activity during traditional core exercises (21).
- EMG activity is greater during non-core exercises compared with ball/device exercise and with free weight exercises. A limited strength of evidence exists from one moderate quality study that transverse abdominis activity is greater in non-core exercises compared with ball/device exercises and free weight exercises (58).

No Evidence

- No evidence exists for EMG activity during the following comparisons: free weight exercises with core stability exercises, free weight exercises with ball/device exercises, free weight exercises with traditional core exercises, non-core exercises with core stability exercises, and non-core exercises with traditional core exercises.

Quadratus Lumborum

No Evidence

- No evidence exists for EMG activity in any study for all comparisons of any quality.

CHAPTER FOUR: DISCUSSION

Core stability and traditional core exercises have dominated the fitness and physical therapy arenas as the superior choice for achieving the greatest muscle activity for training the core musculature. The abundance of equivocal core activation literature has led to an environment where exercise prescription does not appear to be based upon scientific merit.

Lumbar Multifidus

In seeking the greatest lumbar multifidus EMG activity, the systematic review revealed clear evidence supporting dynamic free weight exercises. Free weight exercises, when compared with all other core-training modalities, provided the greatest EMG activity. It should be noted that free weight exercises used additional loading with external resistances with most authors standardizing the load to the one repetition maximum. The only study that reported significantly less EMG activity during free weight exercises utilized no external resistance (10).

Upon examination of the literature, evidence supporting significant lumbar multifidus EMG activity during core stability exercises is equivocal. Greater EMG activity for core stability exercises seems to exist when compared to traditional exercises. Interestingly, evidence clearly indicates no differences in muscle activity between core stability exercises and ball/device exercises. Exercises designed to isolate lumbar multifidus using prone, supine, and quadruped body positions and body weight resistance may be effective when compared to traditional core exercises but evidence does not support their efficacy otherwise. The implementation of an additional device or stability ball did not provide a training advantage for the multifidus. Therefore, the findings of the review cannot warrant the use of such devices.

Transverse Abdominis

Core stability exercise recommendations are often prescribed to isolate the transverse abdominis, however, their efficacy is unsupported by this review. Core stability exercises showed no differences in muscle activity when compared to traditional exercises such as the abdominal crunch and curl-up (45, 57). Additionally, in comparing core stability exercises to the same exercises with the addition of a ball/device clearly revealed no differences. Therefore, it seems apparent that the addition of balls and devices to seek additional transverse abdominis EMG activity is unwarranted.

An interesting finding was the effectiveness of non-core exercises in activating the transverse abdominis. Compared to free weight squats, dead lifts, and exercises utilizing the BOSU ball, EMG amplitudes were greatest in overhead pressing exercises (58). It should be noted that the overhead pressing exercises utilized external resistances, which likely contributed to the increased transverse abdominis activity. Overall, the evidence for transverse abdominis EMG activity is largely inconsistent amongst the included studies and quality studies are lacking making it difficult to make additional conclusions at this time.

Quadratus Lumborum

The importance of the quadtratus lumborum is purported in numerous publications and has received increased presence in training regimens. Interestingly, our search allocated a total 1681 studies, of which only 22 studies examined the quadratus lumborum. However, none of the identified studies met the inclusion criteria. The dearth of research on the quadratus lumborum leads us to suggest the numerous claims are based on empirical findings and thus are unsubstantiated.

Review Limitations

This systematic review had certain limitations that prevented the results to be summarized into a quantitative analysis. The absence of universally accepted quality assessment tools for observational studies presented difficulty in judging validity and weighing results. Nonetheless, the AHRQ and EPHPP were modified to guide a subjective rating for each study. Our review reported numerous low quality studies due to the methodological diversity which was similarly reported in a recent review of abdominal exercise by Monfort-Panego (42). The absence of complete reporting in various authors' mixed methods designs of studies including exercises not fully described, no exercise familiarization, lack of a standardized electrode placement, small sample sizes, body fat percentage not reported, inadequate and diverse normalization and signal processing techniques.

EMG normalization is routinely expressed as a percentage of maximum neural drive recorded while a subject performs a maximum voluntary isometric contraction (MVIC) of the desired muscle (29). However, four articles (7, 23, 50, 57) expressed their outcomes as absolute levels of microvolts. The variability between authors' description and performance of exercises was another concern. Several exercises had the same title but were performed markedly different while numerous exercises were performed uniformly but were titled differently.

Another potential issue arises when measuring neuromuscular activity of deep trunk muscles whereas potential electrical interference of adjacent muscles may be detected (crosstalk). In avoidance, three studies (4, 21, 45) measured EMG activity via intramuscular wire electrodes directly inserted into the muscle. The remaining articles utilized surface electrodes, which have been shown to accurately determine deep muscle activity (1, 33, 37). Nonetheless, standardized electrode placement for recording muscle activity is highly inconsistent amongst authors. Furthermore, only four authors (11-13, 44) reported subcutaneous fat, which has been shown to reduce surface EMG amplitude and increase electrical interference (26).

The fibers of the transverse abdominis have been found to be fused with the internal oblique muscles, lacking clear separation (33, 37). Numerous authors in the present review reported the combined activity (34, 57, 58). Therefore, the difficulty in differentiating these two muscles and the sensitivity of cross talk inherent with surface electrodes the transverse abdominis and internal oblique were represented as the combined activity of the two muscles. The lumbar multifidus presented similar methodological issues in lacking standardized electrode placement. Numerous authors reported different electrode placement for the same muscle and similar placement for different muscles. For example, muscle terminology for electrode placement 2-3cm lateral to the L5 spinous process was reported as lumbar erector spinae (57), lumbar back extensors (43), lumbar-sacral erector spinae (14), and erector spinae (34, 58). Other authors grouped the lumbar multifidus surface electrode placement location amongst the lumbar paraspinals (11-13) or lumbar extensor muscles (51). Inexplicit electrode placement for the lumbar multifidus from numerous recording sites and various muscle terminologies resulted in the grouping of the paraspinal muscles based upon authors' descriptions which is a limitation of the review.

Future Research

The lack of research on the quadratus lumborum warrants future studies to examine myoelectrical relationships during exercise to develop effective training strategies. A strong emphasis to clarify methodological uncertainties include standardized electrode placement, EMG normalization to MVIC, reporting body fat percentages, and accurate terminology and description of exercises. The absence of a validated quality assessment rating instrument for observational studies should direct future research toward filling this gap. The core-training stimulus provided during non-core exercises offers a unique core challenge that deserves further attention.

CHAPTER FIVE: PRACTICAL APPLICATIONS

The choice of exercise is important as the magnitude of its activation reflects the training adaptation. Knowledge of the different activation magnitudes from various core exercises can assist the practitioner or clinician make informed decisions for appropriate exercises and progressions for core exercise training programs. Free weight exercises, involving dynamic movements such as squats and deadlifts, produced the largest activation magnitudes for the lumbar multifidus. The maintenance of upright posture in performing non-core exercises such as overhead presses with external resistances produces large activation magnitudes for the transverse abdominis. Implementing ground based free weight exercises provides an optimal core challenge that can be adapted into exercise training programs.

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APPENDICES

APPENDIX A: Tables

Table 1 - Inclusionary and exclusionary criteria.

Inclusionary	Exclusionary
Healthy	Current/Previous back pain (author disclosure)
Within subjects design	Between subjects design/Intervention
Different physical fitness exercise comparison	Same exercise comparison, uncommon physical fitness exposure
Outcome measure was activation magnitude for LM, TrA, QL	Fatigue/Activation Timing

*LM = lumbar multifidus; TrA = transverse abdominis; QL = quadratus lumborum

Table 2 – Table of exercises.

Core Stability	Traditional Core	Free Weight	Ball/Device	Non-Core	Excluded
Elbow-toe	Curl-up	Squat	Quadruped arm/leg lift*	Pull-up	Pelvic tilt
Quadruped arm/leg lift	Cross curl-up	Deadlift	Back extension*	Chin-up	Sitting march
Prone plank	Lateral flexion	Lateral step up	Supine bridge*	Overhead press	Reference posture
Side bridge	Back extension	Lunge	Prone plank*	Chest press	Dynamic edge
Supine bridge	Side-lying hip abduction		Curl-up*		Forward flexion
Quadruped leg extension	Superman		Ab circle		Dynamic flexion
Dying bug	Flying squirrel		Deadlift**		Dynamic flexion**
	Reverse crunch		Overhead press**		
	Crunch		Biceps curl*		
	Single leg kick		Side Bridge*		
	Double leg kick		Superman*		
	Swimming		Ab revolutionizer		
			Power wheel		
			Ab rocker		
			Ab roller		
			Ab doer		
			Ab twister		
			Ab slide		
			Torso track		
			SAM		
			Roll-out*		
			Pike*		
			Knee-up*		
			Single-leg squat*		
			Rolls*		
			Perfect pull-up		
			Supine ball hold between legs*		
			Hanging knee-up (straps)		

* = stability ball; ** = BOSU ball

Table 3 - Study quality of included studies

Author	Year	Rating
Nuzzo	2008	2
Okuba	2010	2
Lehman	2005	1
Schwanbeck	2009	1
Konrad	2001	1
Youdas	2010	1
Mori	2004	1
Bjerkefors	2010	1
Colado	2011	2
Comfort	2011	1
Ekstrom	2007	1
Oliver	2010	1
Willardson	2010	2
Stevens	2007	1
Drake	2006	1
Willardson	2009	2
Hamlyn	2007	2
Imai	2010	1
Kohler	2010	1
Escamillia	2006	2
Escamillia	2006	2
Escamillia	2010	2
Marshall	2010	2
Marshall	2005	2
Menacho	2010	1
Behm	2005	1
Souza	2001	1
1 = low quality; 2 = moderate quality		

Table 4 - Outcome matrix for lumbar multifidus

	Traditional Core	Free Weight	Ball/Device	Non-Core
Core Stability	Oliver 2010: TC > CS Konrad 2001: TC = CS Okubo 2010: TC < CS Ekstrom 2007: TC < CS Willardson 2010: TC < CS	Comfort 2011: FW > CS Ekstrom 2007: FW < CS	Drake 2007: BD = CS Comfort 2011: BD > CS Lehman 2005: BD = CS Marshall 2005: BD = CS Imai 2010: BD = CS	Comfort 2011: NC > CS
Traditional Core		Colado 2011: FW > TC	Willardson 2010: BD > TC Escamillia 2010: BD > TC Escamillia 2006: BD > TC Colado 2011: BD < TC Drake 2006: BD < TC	
Free Weight			Comfort 2011: FW = BD Colado 2011: FW > BD Nuzzo FW 2008: FW > BD Hamlyn 2007: FW > BD	Comfort 2011: FW > NC Willardson 2009: FW > NC
Ball/Device				Youdas 2010: BD = NC Comfort 201: BD > NC Kohler 2010: BD > NC

Table 5 - Outcome matrix for transverse abdominis

	Traditional Core	Free Weight	Ball/Device	Non-Core
Core Stability	Willardson 2010: TC = CS Okubo 2010: TC = CS		Marshall 2005: CS < BD Willardson 2010: CS = BD Drake 2006: CS = BD Imai 2010: CS = BD	
Traditional Core			Willardson 2010: BD = TC Escamilla 2010: BD > TC Escamillia 2006: BD > TC Drake 2006: BD = TC Imai 2010: BD < TC	
Free Weight				Willardson 2009: NC > FW
Ball/Device				Willardson 2009: NC > BD

APPENDIX B: Figures

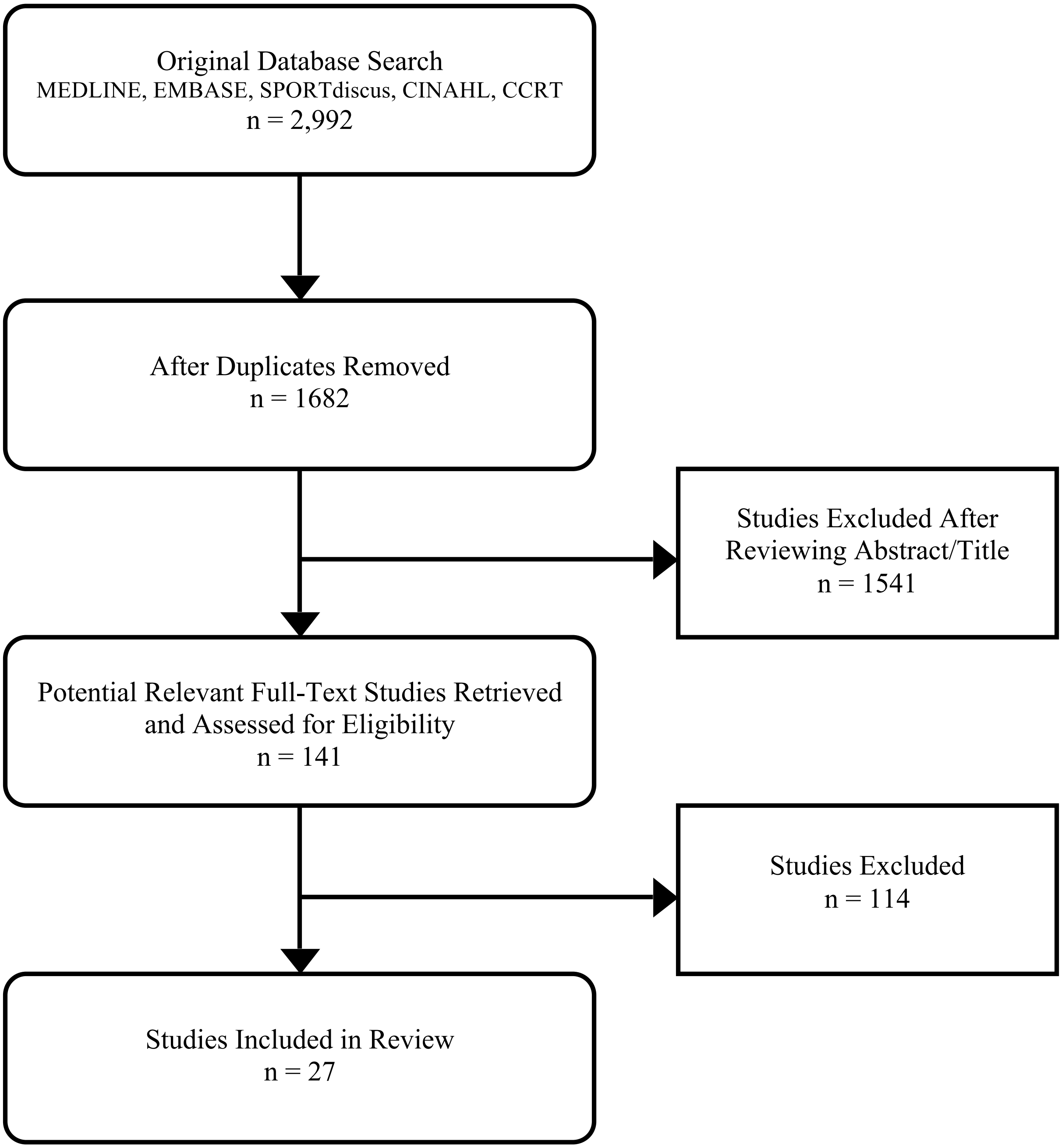

Figure 1 – Flow chart of evidence search.

APPENDIX C

Key Abbreviations

TrA – Transverse abdominis
LM – Lumbar multifidus
QL – Quadratus lumborum
IO – Internal oblique
MRI – Magnetic resonance imaging
EMG – Electromyography
MVIC – Maximum voluntary isometric contraction
CS – Core stability
TC – Traditional core
FW – Free weight
BD – Ball/Device
NC – Non-Core