REVIEW

Characteristics of Stabilizer Muscles: A Systematic Review

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ABSTRACT

Purpose: To identify the main characteristics, based on available evidence, of stabilizer muscles to inform the development of a definition of stabilizer muscles. ***Methods:*** Electronic databases were systematically searched for relevant literature from the databases' inception to June 2013 using keywords related to stability, muscles, and characteristics of stabilizer muscles. Studies that provided at least one characteristic of a stabilizer muscle were included. For the quality assessment, all included articles were categorized as either experimental or opinion-based studies. Methodological quality was assessed using a customized checklist, and data were analyzed with a narrative synthesis involving content analysis. The number of articles providing either direct evidence supporting a link between the characteristic and joint stability or indirect evidence that a muscle considered to be a stabilizer has that characteristic determined the level of significance of that characteristic for stabilizer muscles. ***Results:*** A total of 77 studies met the inclusion criteria. The highest number of articles providing supporting evidence that a particular muscle characteristic plays a stabilizing role related to biomechanical characteristics (27 articles), followed by neurological characteristics (22 articles) and anatomical/physiological characteristics (4 articles). ***Conclusion:*** Based on a synthesis of supporting evidence from the literature, stabilizer muscles can be defined as muscles that contribute to joint stiffness by co-contraction and show an early onset of activation in response to perturbation via either a feed-forward or a feedback control mechanism. These results may guide researchers to investigate which muscles exhibit these characteristics to determine whether particular muscles have a stabilizer rather than a prime mover role during normal functioning.

Key Words: joint instability; joints; muscles; systematic review.

RÉSUMÉ

Objectif : Déterminer les principales caractéristiques des muscles stabilisateurs afin d'éclairer la formulation d'une définition des muscles stabilisateurs basée sur les éléments de preuve disponibles. ***Méthodes :*** On a effectué, dans des bases de données électroniques, une recherche systématique de publications pertinentes depuis le début jusqu'en juin 2013 en utilisant des mots clés liés à la stabilité, aux muscles et aux caractéristiques des muscles stabilisateurs. Les études comportant au moins une caractéristique d'un muscle stabilisateur ont été incluses. Pour les fins de l'évaluation de la qualité, on a classé tous les articles inclus comme études expérimentales ou traduisant une opinion. On a évalué la qualité méthodologique au moyen d'une liste de contrôle personnalisée et analysé les données au moyen d'une synthèse narrative comportant une analyse de contenu. Le nombre d'articles présentant des éléments de preuve directs à l'appui de l'existence d'un lien entre la caractéristique et la stabilité de l'articulation ou un élément de preuve indirect indiquant qu'un muscle considéré comme muscle stabilisateur présentait cette caractéristique a déterminé le niveau d'importance de la caractéristique en question pour les muscles stabilisateurs. ***Résultats :*** Au total, 77 études répondaient aux critères d'inclusion. Le nombre le plus élevé d'articles présentant des éléments de preuve à l'appui du fait qu'une caractéristique musculaire en particulier joue un rôle stabilisateur portait sur les caractéristiques biomécaniques (27 articles), neurologiques (22 articles) et anatomiques/physiologiques (4 articles). ***Conclusion :*** Compte tenu d'une synthèse des éléments de preuve à l'appui tirés des publications, il est possible de définir les muscles stabilisateurs comme des muscles qui contribuent à la rigidité d'une articulation par cocontraction et qui sont activés rapidement en réponse à une perturbation par un mécanisme de contrôle de l'alimentation et de la rétroaction. Ces résultats peuvent aider les chercheurs à étudier les muscles qui montrent ces caractéristiques afin de déterminer si des muscles en particulier ont un rôle stabilisateur plutôt que moteur au cours du fonctionnement normal.

Stability is a commonly discussed concept in physiotherapy and rehabilitation. A lack of stability is recognized as the primary complaint in conditions such as dislocated shoulder, where intervention after joint reduction may focus on an exercise programme to maintain stability through muscle action. The broader concepts of stability, such as "motor control" and "core stability," have evolved as the fundamental principles behind many rehabilitation and preventive programmes.[1–3] Although several attempts have been made to define stability, no single, universally accepted definition is available.

Joint stability has been defined as "the strength of the bond between the bones in a joint."[4(p.105)] Several theories about stability have been advanced in the litera-

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Box 1 Selection Criteria

Inclusion criteria	Exclusion criteria
• Studies that provided an implied definition of a stabilizer muscle including at least one characteristic: – Anatomic/physiologic ○ e.g., Fibre type – Neurological ○ e.g., Timing of onset – Biomechanical ○ e.g., Angle of pull • English language only	• Intervention studies that did not provide any information about the characteristics of a stabilizer muscle • Studies that were mainly focused on other muscle characteristics, e.g., delayed onset muscle soreness • Animal studies • Abstracts • Dissertations

ture, including the model of active, passive, and neural subsystems;[5,6] local and global stability systems;[2,7,8] core control;[3,7] transarticular muscle forces;[9] dynamic stabilization;[10] and sensory-motor control.[2,8]

All of these concepts and theories strongly suggest that muscles and motor control play an important role in joint stability. For example, many studies have reported that the rotator cuff muscles act as dynamic stabilizers at the glenohumeral joint;[11,12] similarly, the stabilizing systems of the lumbar spine include muscles that control movement and are essential to normal functioning of the spine.[13,14] On this basis, many rehabilitation programmes aim to improve function and motor control of these stabilizer muscles to provide joint stability and protect from injuries.[1–3]

While the importance of muscles to joint stability is recognized, the exact definition and characteristics of stabilizer muscles are less clear and lack supporting evidence.[7,8] Given the apparent importance of stabilizer muscles to normal joint function, understanding their characteristics and, more importantly, exploring the supporting evidence for these characteristics will help identify such muscles when diagnosing musculoskeletal disorders and inform the design of successful rehabilitation programmes.

The aim of our systematic review, therefore, was to determine the key characteristics, based on available evidence, of stabilizer muscles to inform the development of a definition of stabilizer muscles.

METHODS

Data sources and search

We systematically searched four electronic databases (AMED, CINAHL, Medline, and SPORT Discus) for relevant literature from the databases' inception to June 2013 using three search concepts linked together with the AND operator and combining keywords within each concept with the OR operator (see online table for keywords). The first search concept used the term *muscl**; the second used terms related to stability, such as *stabiliz**, *control*, or *stiffness*. Terms used for the third search concept, characteristics, were derived from characteristics commonly mentioned in the literature, such as *feed-forward* and *feedback*, *muscle recruitment*, and *muscle architectural characteristics*.

Study selection

After the initial online searches, we removed all duplicate articles. The selection criteria (Box 1) were then applied to the titles and abstracts by two reviewers working independently. All potentially eligible studies were selected for a full-text review and were assessed by two reviewers who independently reapplied the eligibility criteria. Inclusion in the review was then determined by consensus. Studies were included if they described at least one characteristic of a stabilizer muscle, based on the categories of classification suggested by Ng and colleagues: anatomical/physiological, neurological, or biomechanical.[13]

Quality assessment

We classified the articles as either opinion-based or experimental studies. Since the existing quality appraisal tools were inappropriate for this type of review, we created a customized checklist (see Table 1) to address key sources of bias.[15] Opinion-based studies were considered less subject to bias if they followed a systematic search strategy, and experimental studies were considered less subject to bias if they provided supporting evidence. Supporting evidence was either direct in that it supported the link between the characteristic and joint stability or indirect in that it showed that a muscle considered to be a stabilizer has that characteristic (Table 1). No studies were excluded based on the outcome of the quality assessment.

Data analysis

We used a content analysis approach to collect data about characteristics of stabilizer muscles from selected studies. This involved applying the three principles of content analysis: (1) develop categories before searching for them in the data; (2) select the sample to be categorized; and (3) count or systematically record the number of times each category occurs.[16]

We first developed three categories of characteristics of stabilizer muscles—anatomical/physiological, neurological, and biomechanical—in accordance with the classification

Table 1 Characteristics of Stabilizer Muscles as Described in Current Literature and Quality Assessment of the Included Studies

Reference	Study type	Biomechanical characteristics		Neurological characteristics		Anatomical/ physiological characteristics	Quality assessment			
		Joint compression	Muscle mechanics	Neuromuscular control	Recruitment		O1	O2	O3	E1
Arbanas (2009)[29]	E					✓				N
Bergmark (1989)[7]	O		✓				N	Y	N	
Boettcher (2010)[12]	E	✓			✓					N
Bogduk (1992)[30]	E		✓							N
Borghuis (2008)[1]	O	✓	✓	✓		✓	N	Y	N	
Brown (2005)[82]	E	✓✓✓			✓✓					Y
Brown (2005)[31]	E	✓	✓✓✓							Y
Lin (2011)[33]	E	✓✓✓		✓						Y
Cheng (2008)[34]	E	✓✓								Y
Cholewicki (2002)[37]	E		✓✓✓		✓✓					Y
Cholewicki (1996)[35]	E	✓	✓✓✓							Y
Cholewicki (1997)[36]	E	✓✓✓								Y
Comerford (2001)[2]	O		✓				N	Y	N	
Comerford (2001)[8]	O		✓		✓		N	Y	N	
Cowan (2002)[38]	E			✓	✓					N
Crisco (1991)[39]	E	✓		✓						N
Danneels (2001)[40]	E	✓✓	✓✓		✓✓					N
Davarani (2007)[41]	E	✓✓✓		✓✓✓						N
Day (2012)[11]	E			✓✓	✓✓					N
Delahunt (2006)[42]	E			✓✓✓						N
Franklin (2007)[43]	E	✓✓✓		✓✓✓						N
Gardner-Morse (95)[44]	E	✓	✓✓✓							N
Gardner-Morse (98)[45]	E	✓✓✓		✓✓✓						N
Gibson (2004)[81]	E		✓✓	✓✓						N
Granata (2001)[46]	E	✓		✓✓						N
Granata (2001)[48]	E	✓✓✓	✓	✓✓✓						Y
Granata (2004)[47]	E			✓						N
Granata (2007)[49]	E	✓✓		✓✓						Y
Guieterrez (2009)[19]	O			✓			N	Y	N	
Hides (2008)[50]	E				✓					N
Hodges (1999)[20]	O	✓		✓	✓	✓	N	Y	N	
Hodges (1998)[52]	E	✓		✓✓✓	✓✓✓					Y
Hodges (1996)[51]	E	✓		✓✓✓	✓✓✓					Y
Holmes (2009)[21]	O	✓		✓			N	Y	N	
Hossain (2005)[22]	O				✓		N	CT	N	
Hungerford (2003)[53]	E	✓			✓					N
Huxel (2008)[54]	E	✓	✓✓✓		✓✓					Y
Jemmett (2004)[55]	E		✓✓							Y
An (2002)[18]	O		✓				N	CT	N	
Kalimo (1989)[23]	O					✓	N	CT	N	
Kibler (2006)[3]	O				✓		N	Y	N	
Lee (2000)[58]	E		✓✓✓							Y
Lee (2002)[59]	E	✓	✓✓✓							Y
Lee (2006)[56]	E	✓✓✓		✓						Y
Lee (2007)[57]	E	✓✓✓			✓					Y
Lin (2011)[60]	E	✓✓✓		✓✓						Y

Table 1 *(Continued)*

Reference	Study type	Biomechanical characteristics		Neurological characteristics		Anatomical/ physiological characteristics	Quality assessment			
		Joint compression	Muscle mechanics	Neuromuscular control	Recruitment		O1	O2	O3	E1
MacDonald (2006)[24]	O	✓		✓			N	Y	N	
Macintosh (1986)[61]	E	✓								N
Matějka (2006)[62]	E					✓✓✓				Y
Mcgill (2003)[10]	O	✓					N	Y	N	
Morris (2012)[63]	E	✓								N
Ng (1998)[13]	O					✓	N	Y	N	
Norris (1995)[14]	O	✓					N	CT	N	
Norris (1995)[26]	O	✓				✓	N	Y	N	
Norris (1995)[25]	O	✓					N	Y	N	
O'Sullivan (1997)[65]	E		✓							N
O'Sullivan (1998)[64]	E	✓								N
Panjabi (1989)[66]	E		✓	✓						N
Panjabi (1992)[5]	O		✓	✓			N	Y	N	
Panjabi (1992)[6]	O		✓				N	Y	N	
Panjabi (1994)[27]	O		✓	✓			N	Y	N	
Radebold (2000)[67]	E				✓					N
Regev (2011)[68]	E					✓✓✓				Y
Rodosky (1994)[69]	E		✓✓✓							Y
Sakurai (1998)[70]	E		✓							N
Silfies (2005)[72]	E	✓		✓						N
Silfies (2009)[71]	E				✓					N
Sinkjær (1991)[73]	E	✓	✓		✓✓					Y
Stokes (2000)[74]	E	✓	✓							N
Stokes (2011)[75]	E	✓	✓		✓					N
van Dieën (2003)[76]	E				✓✓✓					Y
Vera-Garcia (2006)[77]	E	✓✓✓	✓							Y
Ward (2006)[78]	E		✓✓			✓✓✓				Y
Ward (2009)[79]	E		✓✓		✓	✓✓				Y
Wattanaprakomkul (2011)[80]	E				✓✓					Y
Williams (2001)[28]	O			✓			N	Y	N	
Total Count		40	30	28	23	10				
Count of records with direct supporting evidence		11	8	7	3	3				
Count of records with indirect supporting evidence		3	5	5	7	1				
Total count of records with any supporting evidence		14	13	12	10	4				

O1 = Was a specific search strategy described?; O2 = Were important, relevant studies included?; O3 = Did the authors check the quality of the included studies?; E1 = Did they provide any supporting evidence in relation to stability?; E = experimental study; O = opinion-based study; ✓ = characteristic reported; ✓✓ = characteristic reported with indirect supporting evidence; ✓✓✓ = characteristic reported with direct supporting evidence; Y = Yes; N = No; CT = Can't tell.

by Ng and colleagues.[13] Individual sentences, terms, or paragraphs that related to a characteristic were identified in each article. Thereafter, we used an axial coding approach to link these selected characteristics of stabilizer muscles to the original three categories via subcategories.[17] For each study, consistent with the third principle of content analysis, we recorded the occurrence of stabilizing characteristics and whether or not the study found supporting evidence (direct or indirect) to link the characteristic to stability. The number of

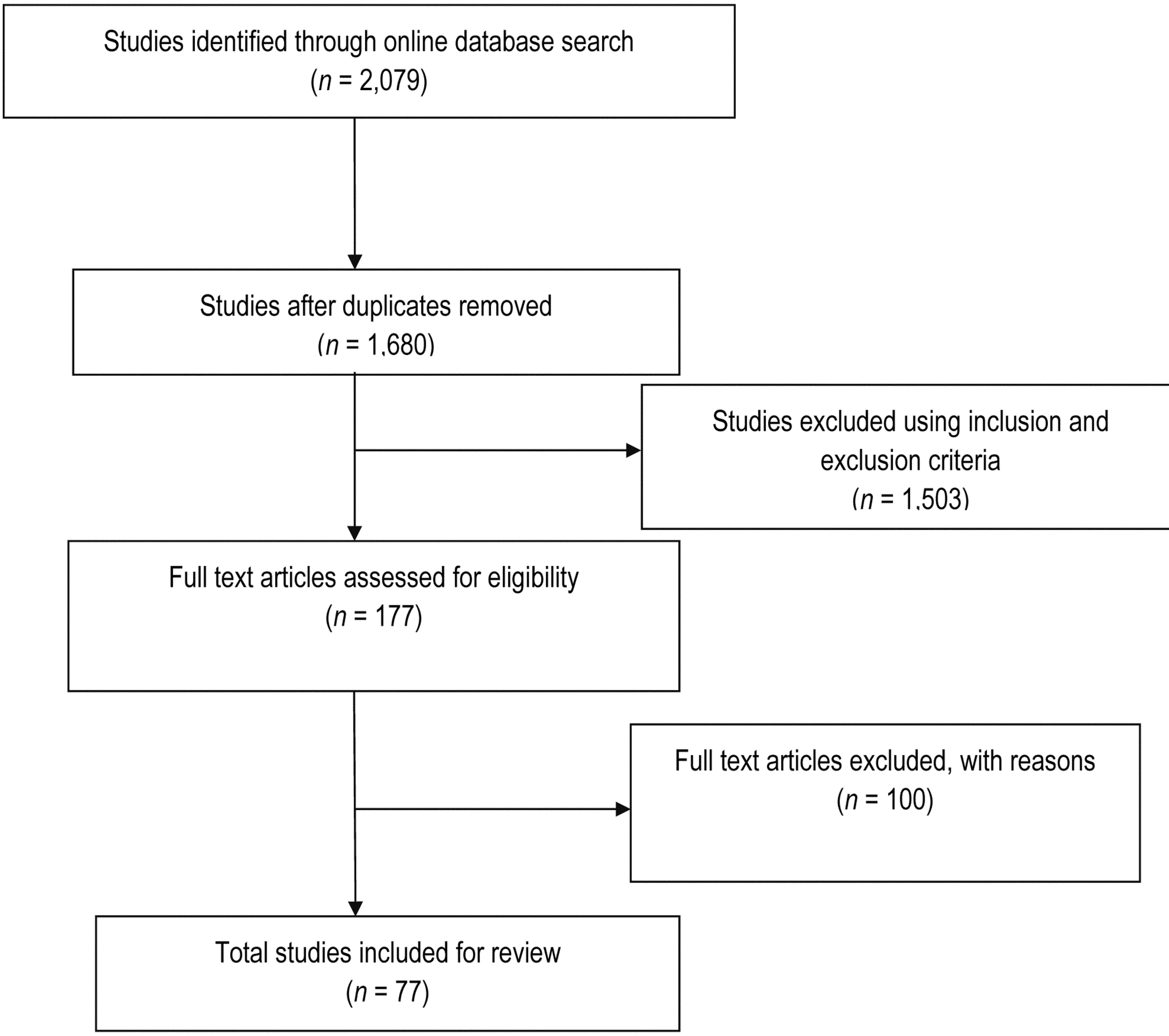

Figure 1 Selection process for included studies.

articles that provided supporting evidence linking a particular concept to stability determined its level of significance in describing a characteristic of stabilizer muscles.

RESULTS

Yield

Our initial searches identified a total of 2,079 articles. After applying our selection criteria, 77 studies were selected for review (see Figure 1).

Quality assessment

Of the 77 included studies, 21 were opinion-based studies,[2,3,5–8,10,13,14,18–28] and the remaining 56 were experimental studies[11,12,28–81] (see Table 1). Our quality analysis found that none of the opinion-based studies provided information on their search strategy or on the quality of the included studies; they provided only low-level evidence on the stabilizing characteristics of muscles, as they referred to studies that included experimental evidence based on other studies. Of the 56 experimental studies, 36 provided supporting evidence: 26 provided direct evidence to support a link between the characteristic and joint stability, and 10 provided indirect evidence that a muscle considered to be a stabilizer has that characteristic (Table 1).

Characteristics of stabilizer muscles

Axial coding identified 11 characteristics, which were grouped in sub-categories as required under the original three categories of the characteristics of stabilizer muscles (see Figure 2). Definitions of the key characteristics and their relationship to joint stability are presented in Box 2.

Characteristics associated with the biomechanical category were reported 70 times; 18 studies reported direct evidence and nine studies reported indirect supporting

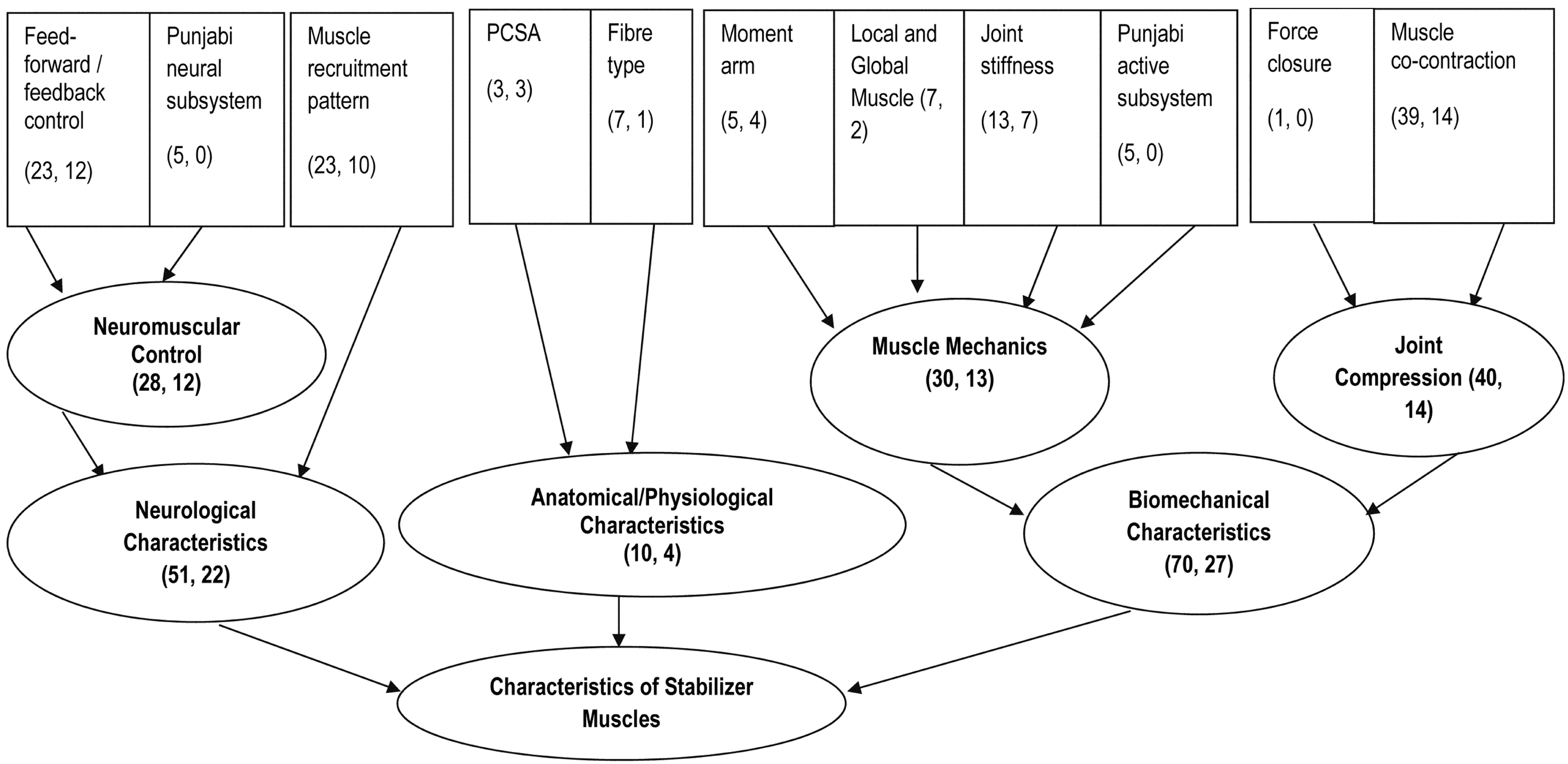

Figure 2 Characteristics of Stabilizer Muscles. Figures in parenthesis (a, b) represent the number of studies reporting that characteristic (a) and number of studies with supporting evidence (b).
PCSA = Physiological Cross Sectional Area

Box 2 Definitions of Muscle Characteristics and Their Relationship to Joint Stability

Characteristics	Definition
Feed-forward control	An anticipatory correction in motor behaviour that allows rapid muscle action before movement.
Feedback control	Modification of the ongoing movement using information from sensory receptors, so that muscle onset would be expected in response to the sensory feedback.
Punjabi's neural subsystem	Receives information from the various force and motion transducers located in ligaments, tendons, muscles, and neural control centers; determines specific requirements for spinal stability; and causes the active subsystem to achieve the stability goal.[5]
Recruitment pattern	Concepts of timing patterns and timing of onset. To maintain stability, the muscles should activate at the right time and sequence,[5] and the recruitment patterns are modulated according to the demands placed on the joint.[53,82]
Physiological cross-sectional area (PCSA)	An indication of muscle thickness and force-generating capacity; defined as the total area of the cross-sections perpendicular to the muscle fibres. The larger the PCSA, the more the stability.[79]
Fibre type	There are two main types of muscle fibres: Type 1 fibres are the slow-twitch fibres with high oxidative capacity that are suited for long-lasting and more tonic stability work. Type 2 fast-twitch fibres have a high glycolytic capacity and are recruited when fast and vigorous contraction is needed.[23]
Moment arm	The perpendicular distance from line of muscle force to the axis of joint rotation.[30] Shorter moment arm is related to increased stability.[62]
Local and global muscles	Local muscles are the deep muscles that have their origin or insertion close to a joint. These muscles control joint stiffness and are essential for stability.[7] The global muscles are the large superficial muscles. These muscles are torque generators for joint motion.[7]
Joint stiffness	Muscle force can directly contribute to joint stiffness;[7] the greater the stiffness, the more stable the structure.[54]
Punjabi's active subsystem	Consists of the muscles and tendons surrounding the spinal column. The active subsystem is the means through which the spinal system generates forces and provides the required stability to the spine.[5]
Force closure	Muscle forces acting across the joint to create stability.
Muscle co-contraction	Simultaneous contraction of both the agonist and the antagonist around a joint to hold a stable position.

evidence of their stabilizing role (Table 1 and Figure 2). The two sub-categories under this category were joint compression and muscle mechanics. The two characteristics to describe joint compression were muscle co-contraction and force closure. The muscle co-contraction characteristic collected the highest number of studies, providing supporting evidence for a stabilizing role (direct in 11 studies; indirect in 3 studies); for example, Huxel and colleagues (2008) provided direct evidence for muscle co-contraction by demonstrating that moderate levels of muscle activation can increase glenohumeral joint stiffness and stability.[54] Muscle mechanics was described by four characteristics: joint stiffness, moment arm, local and global muscles. and Panjabi's active subsystem (Figure 2).

Characteristics associated with the neurological category were reported 51 times; 10 studies provided direct supporting evidence and 12 studies provided indirect supporting evidence for the stabilizing role of these characteristics (see Table 1 and Figure 2). Twelve studies provided supporting evidence for neuromuscular control, described by two characteristics: feed-forward/feedback control and Panjabi's neural subsystem. Another important characteristic under the neurological category was recruitment patterns, supported by evidence from 10 studies (see Figure 2); for example, Day and colleagues (2012) provided indirect evidence by comparing the activity levels and recruitment patterns between rotator cuff and global shoulder muscles, concluding that the rotator cuff muscles function as a dynamic stabilizer by demonstrating a feed-forward muscle activation pattern.[11]

Characteristics associated with the anatomical/physiological category were reported least often: only 10 times—in three studies that provided direct evidence and one study that provided indirect supporting evidence for their stabilizing role (see Table 1 and Figure 2). This category consists of two characteristics: fibre type and physiological cross-sectional area (PCSA) (see Figure 2). For example, Ward and colleagues (2009) provided indirect evidence by investigating the architectural properties of the multifidus muscle, reporting that its architectural design (low fibre length and high PCSA) supports its role as a stabilizer.[79]

DISCUSSION

Our findings suggest that, based on supporting evidence from the literature, the key characteristics associated with stabilizer muscles are muscle co-contraction, feed-forward/feedback control, and muscle recruitment patterns. It is important to note that two-thirds of this supporting evidence comes from studies that demonstrate a direct link between these characteristics and joint stability, while the remaining one-third of the evidence is indirect (i.e., muscles are described as stabilizers because they have these characteristics).

The biomechanical characteristic of muscle co-contraction had the highest number of articles providing supporting evidence for joint stability, which suggests that it is the most important characteristic of stabilizer muscles. Co-contraction of muscles can cause joint compression, which leads to stability at a joint.[12] Co-contraction between paraspinal and abdominal muscles has been suggested to contribute to trunk stability.[35,36,76]

The other important biomechanical characteristic was joint stiffness. Muscle force contributes to joint stiffness directly, and the greater the stiffness, the more stable the structure.[39,54] In a situation of static equilibrium, muscle stiffness serves to stabilize a joint; however, depending upon muscular orientation and the direction in which the force is applied, muscle contraction may either stabilize or destabilize the joint.[18,31,58] For example, if the transarticular component of muscle force is greater than its swing component, it will act to stabilize the joint, but if the swing component is stronger, then the joint will move in its direction of pull.[9] Incorporating this knowledge into stability models may assist clinicians in recognizing unstable events that could lead to injury.

In the neurological category, feed-forward/feedback control and muscle recruitment pattern had the highest number of articles providing supporting evidence, indicating that they are the most important characteristics in this category. The neuromuscular system can make use of both feed-forward and feedback components to maintain stability.[46] Support for the theory that transversus abdominis (TA) stabilizes the lumbar spine by a feed-forward mechanism is suggested by the delayed activation of TA muscles in people with low back pain.[51] The recruitment pattern involves the concepts of timing patterns and timing of onset; to maintain stability, the muscles should activate at the right time and sequence,[5] and recruitment patterns are modulated according to the demands placed on the lumbar spine.[53,82]

Other characteristics related to joint stability reported in the literature include biomechanical characteristics (e.g., local or deep muscles that have their origin and insertion close to a joint, short moment arms[78,79]) and anatomical/physiological characteristics (e.g., high proportion of type I fibres, large PCSA[29,79]). However, these characteristics were less often reported and the articles rarely provided supporting evidence for them.

On the basis of these results, stabilizer muscles can be defined as those that contribute to joint stiffness by co-contraction and show an early onset in response to perturbation via either a feed-forward or feedback control mechanism. This definition is based on a literature review; further research is required to determine the robustness of the definition and to ascertain whether muscles considered to be stabilizers do in fact exhibit one or more of these characteristics.

This definition has direct implications for researchers and the potential to influence clinical practice. It provides characteristics of stabilizer muscles based on existing evidence that may guide researchers to investigate which muscles exhibit these characteristics to determine whether particular muscles have a stabilizer rather than a prime mover role during normal functioning. If stabilizer muscles are fundamentally different in function from prime movers, clinicians should diagnose pathology and rehabilitate these muscles in a way that emphasizes stabilizing characteristics. This knowledge will help clinicians to design specific diagnostic tests, detect abnormal function, and provide condition-specific rehabilitation. Many of the characteristics of stabilizer muscles currently mentioned in the literature are based largely on authors' opinions and assumptions. There are examples of muscles that are reported to act as stabilizers, but due to the lack of supporting evidence, most of these suggestions appear to be largely based on theory. For example, the vastus medialis oblique (VMO) is widely recognized as a key stabilizer of the knee joint and is often targeted in the treatment of patellofemoral pain syndrome (PFPS). Various forms of treatment are suggested for this condition, commonly involving strengthening and activating the VMO to maintain knee joint stability,[83,84] but other non-specific exercise programmes appear to be equally effective in reducing pain associated with PFPS,[83,84] which raises questions about rehabilitation based on the stabilizing function of the VMO. A better understanding of the characteristics of stabilizer muscles could lead to important changes in how impairments in such muscles are assessed and treated.

Limitations

This review found that anatomical/physiological characteristics had the smallest amount of supporting evidence. It is possible that characteristics such as PCSA and short moment arm did not appear important on our list because such studies typically not only require access to cadaveric material but are very labour intensive and may therefore be less likely to be conducted and published.

CONCLUSION

Our review identified the key characteristics associated with stabilizer muscles as muscle co-contraction, feed-forward/feedback control, and muscle recruitment patterns. To the best of our knowledge, this is the first review to systematically report characteristics and inform the definition of stabilizer muscles based on existing supporting evidence. Future research is needed to investigate the evidence for these characteristics in muscles that are reported to act as stabilizers. Better-informed identification of muscles acting as stabilizers has significant implications for assessment and rehabilitation regimens in musculoskeletal physiotherapy.

KEY MESSAGES

What is already known on this topic

Identification of the characteristics of stabilizer muscles has been largely based on opinions, theories, and evidence from single studies.

What this study adds

To the best of our knowledge, this is the first study to critically evaluate the current understandings and beliefs regarding the characteristics of the stabilizer muscles and to present a basic definition as well as a list of the characteristics of stabilizer muscles based on a synthesis of the supporting evidence from the literature. By providing a list of evidence-based characteristics and a definition of stabilizer muscles, our study adds to and complements previous reports of the characteristics of stabilizer muscles.

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