Application of Ultrasonography in the Assessment of Abdominal and Lumbar Trunk Muscle Activity in Participants With and Without Low Back Pain: A Systematic Review

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Abstract

Objective: The purpose of this study was to systematically review the literature regarding which condition (task, position, or contraction type), changes in muscle thickness could be interpreted as muscle activity of trunk muscles.
Methods: Studies that assessed the correlation between changes in muscle thickness measured with ultrasonography (US) and electromyography (EMG) activity were included. Only the data related to abdominal and lumbar trunk muscles in participants with or without low back pain were extracted. The PubMed, ScienceDirect, Ovid MEDLINE, Scopus, Springer, and Cumulative Index to Nursing and Allied Health Literature databases were searched from inception to August 2018. Two independent raters appraised the quality of the included studies using the Critical Appraisal Skills Program checklist.
Results: Fourteen studies were included. The results revealed significant correlations between US and EMG measures for the lumbar multifidus and erector spinae muscle during most contraction levels and postures. For transverse abdominis and internal oblique, US and EMG measures were correlated during low load abdominal drawing or bracing. The correlations were influenced by trunk position for higher intensities of contraction. For the external oblique muscle, correlation was observed only during trunk rotation.
Conclusion: Changes in muscle thickness should not be interpreted as muscle activity for all tasks, positions, and contraction types. Only during prime movement tasks performed with isometric contraction could muscle thickness change be considered as muscle activity. Also, upright postures influenced the relationship between changes in muscle thickness and muscle activity for abdominal muscles. (J Manipulative Physiol Ther 2019;42:541-550)
Key Indexing Terms: *Ultrasound imaging; Electromyography; Paraspinal muscles; Transverse abdominis; Muscle thickness*

Introduction

Muscle training is an integral part of rehabilitation programs.[1,2] To plan an efficient rehabilitation intervention, it is necessary to evaluate muscle activity during different tasks and exercises. Therefore, for clinical rehabilitation or research, a reliable and sensitive measure is required. Several methods are available for the assessment of muscle activity and function.[3] Literature indicates that electromyography (EMG) is a valid tool, which is considered a gold standard technique for evaluating muscle activity.[4,5]

Surface EMG is applied commonly for assessing muscle activity during movement owing to its noninvasive nature compared to needle EMG. Despite its efficiency, there are several limitations regarding measuring deep muscle activity, such as activity cross-talk of the adjacent muscles.[1] This issue is particularly important in participants

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with low back pain (LBP) because several studies have reported altered activity of deep trunk muscles in these participants.[6-8] To confront the cross-talk, needle electrode could be used, which is an invasive technique and inconvenient for participants.[1] Recently, attempts have focused on the use of ultrasonography (US) for evaluating muscle activity as an alternative technique.[9-11]

Ultrasonography is a noninvasive method and can be used to measure changes in muscles thickness as an indicator of the muscle activity. The level of muscle activity is assessed through comparing the thickness of a contracted muscle to its thickness during rest.[3,12-14] Studies have shown US as a reliable tool for assessing changes in muscle thickness.[10,15,16] Nevertheless, high reliability does not confirm its applicability for measuring muscle activity accurately. This could be assessed by investigating the relationship between changes in muscle thickness (measured by US) with other valid acceptable measures determining muscle activity (EMG).[17,18]

The association between changes in muscle thickness and EMG activity has been studied in several muscles such as the transversus abdominis (TrA), internal oblique (IO), external oblique (EO), rectus abdominis (RA), lumbar multifidus (LMU), and erector spinae (ES) muscles.[18] There is a controversy between the studies regarding the correlation examining changes in muscle thickness and EMG activity.[5,15,19-25] In addition to methodological differences between studies, there are many factors that influence the changes in muscle thickness. These factors include the posture, type of muscle contraction (isometric, concentric, eccentric), initial muscle length, contraction of adjacent muscles, amount of tendon stretch, and muscle fibers pennation angle.[10,18] Therefore, it is necessary to investigate that during which task, trunk position, or type of muscle contraction, changes in muscle thickness could be interpreted as muscle activity. The purpose of this study was to systematically review the evidence related to the correlation between changes in muscle thickness with EMG activity of abdominal and lumbar muscles in participants with or without LBP.

Methods

This systematic review was conducted according to the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[26] A protocol for this review does not exist.

Inclusion Criteria

The inclusion criteria were as follows: original research that was nonexperimental observational study with correlation design, measuring muscle activity with EMG and changes in muscle thickness using US, assessing abdominal (TrA, IO, EO, and RA) or lumbar muscles (LMU and ES) in healthy participants or participants with LBP.

Exclusion Criteria

All types of review articles (systematic, meta-analysis, and narrative), case studies, and case-control studies that did not contain correlational reports were excluded. Evidence that had not gone through the process of formal peer review (eg, books, letters, reports, and posters) were not included. Studies that used US as a biofeedback or as a guide for EMG electrode placement and studies that assessed muscle activity timings were not evaluated.

Search and Selection

The relevant papers were extracted from the following electronic databases from inception to August 2018: PubMed, ScienceDirect, Ovid MEDLINE, Scopus, Springer, and Cumulative Index to Nursing and Allied Health Literature. The search strategy that was used in PubMed/Medline was as follows: (1) ("sonography" OR "ultrasound" OR "US") AND ("electromyography" OR "EMG" OR "surface electromyography" OR "SEMG" OR "fine wire electromyography" OR "needle electromyography") AND ("paraspinal muscles" OR "back muscles" OR "Multifidus" OR "erector spinae" OR "abdominal muscles" OR "abdominal oblique muscles" OR "external oblique" OR "internal oblique" OR "transverse abdominis" OR "transversus abdominis" OR "rectus abdominis") and (2) 1 AND ((low back pain) OR (lower back pain) OR (low backache)).

Also, the search was limited to English and humans. Finally, the bibliographies of the eligible articles have also been checked to identify additional references missed by the search strategy.

Screening

Two independent reviewers (Sha.S, S.Sh) screened the studies by title and abstract. Potentially relevant full-text articles were retrieved and assessed against the eligibility criteria. Discrepancies on the inclusion of an article were resolved by a third reviewer (I.E.T.).

Data Extraction

Data extraction of the included studies was performed by one author (Sha.S) and confirmed by another author (S. Sh). Extracted data were as follows: participant information (eg, sample size, health status), US imaging method (eg, mode and transducer frequency), type of EMG (needle or surface EMG), position for assessment or contraction strategy, correlation data between EMG muscle activity and changes in muscle thickness (interpretation of the "r" is as follow: < 0.3, 0.3-0.6 > 0.6 show low, moderate and strong relationships, respectively).[27]

Table 1. *The Methodological Scoring System Used to Rate Included Studies*

CASP Scale Questions	Scoring Criteria Used
1. Clearly focused question	Was the research goal and the studied population sufficiently described? (Yes = 1 point)
2. Appropriate design	Was the research design appropriate to answer the study question? (Yes = 1 point)
3. Appropriate recruitment	Were participants randomly selected from the target population? Were the participants appropriate to the study question? Were the participants defined precisely? Were both inclusion and exclusion criteria specified? (If all items were done = 1 point)
4. Test procedure clearly described	Were there sufficient details about ethics of the study? Were the measurement methods sufficiently described? Were the steps taken to reduce measurement bias reported? (If all items were done = 1 point)
5. Appropriate outcomes measured	Did the measures truly reflect what they were supposed to measure? Were the assessors blind to the study? (If all items were done = 1 point)
6. Synchronized EMG/US	Were EMG/US synchronized with a trigger during data collection? (Yes = 1 point)
7. Confounding factors accounted	Were the confounding factors controlled? (If all items were done = 1 point)
8. Reliable measurements	Was the US reliability assessed? (Yes = 1 point)
9. Power calculation/adequate sample size	Was there a power calculation? Was there a sufficient number of participants selected? (If all items were done = 1 point)
10. Appropriate analysis	Did the authors use a suitable statistical method? Were the findings discussed related to the original research question? Do the results of the study fit with other available evidence? (If all items were done = 1 point)
11. Precise statistical results reported	Were all analyzed outcomes reported? (not selective reporting of data) Did the results contain r and *P* value? Were the tables/graphs labeled appropriately and understandable? (If all items were done = 1 point)
12. Ability to generalize	Were the participants representative of the target population? (Yes = 1 point)
Total score	12 points

CASP, Critical Appraisal Skills Program; EMG, electromyography; US, ultrasound.

Assessment of Methodological Quality

The included articles were evaluated based on the Critical Appraisal Skills Program (CASP) (CASP UK, Oxford, United Kingdom) checklist for observational studies. The details of the CASP checklist are present in Table 1. This 12-item checklist assesses selection bias, performance bias, measurement bias, and reporting bias.[28,29] These sources of bias mostly affect observational studies.[30] Each question is evaluating a specific type of bias, which is as follows: appropriate requirement assesses selection bias, test procedure clearly described and synchronized EMG/US are related to performance bias, appropriate outcomes measured evaluates measurement bias, and appropriate analysis and precise statistical results reported assess reporting bias. Based on 12 key criteria, the maximum score that each study could obtain was 12. The quality was classified as high (≥9), moderate (range 5-8) or poor (≤4).[29] Disagreements about CASP scores were resolved by discussion until consensus was met.

Results

The literature search yielded 4925 articles after removing duplicates. Based on evaluation of the titles and abstracts, 31 articles seemed to be eligible for review. After review of the full texts, 17 studies were excluded. Finally, 14 studies were selected for full review (Fig 1).[5,15,17,19-25,31-34]

Methodological Quality of the Included Studies

All studies had a clear focused question and appropriate design and used appropriate outcome measure and analysis. No study had a reported power calculation for justifying the sample size. The confounding factors accounted for this review were as follows: not reporting transducer position, scanning point, probe orientation, and the amount of contact pressure for US applicator; not controlling the respiratory phase for US measurement of abdominal muscles; and not reporting skin preparation,

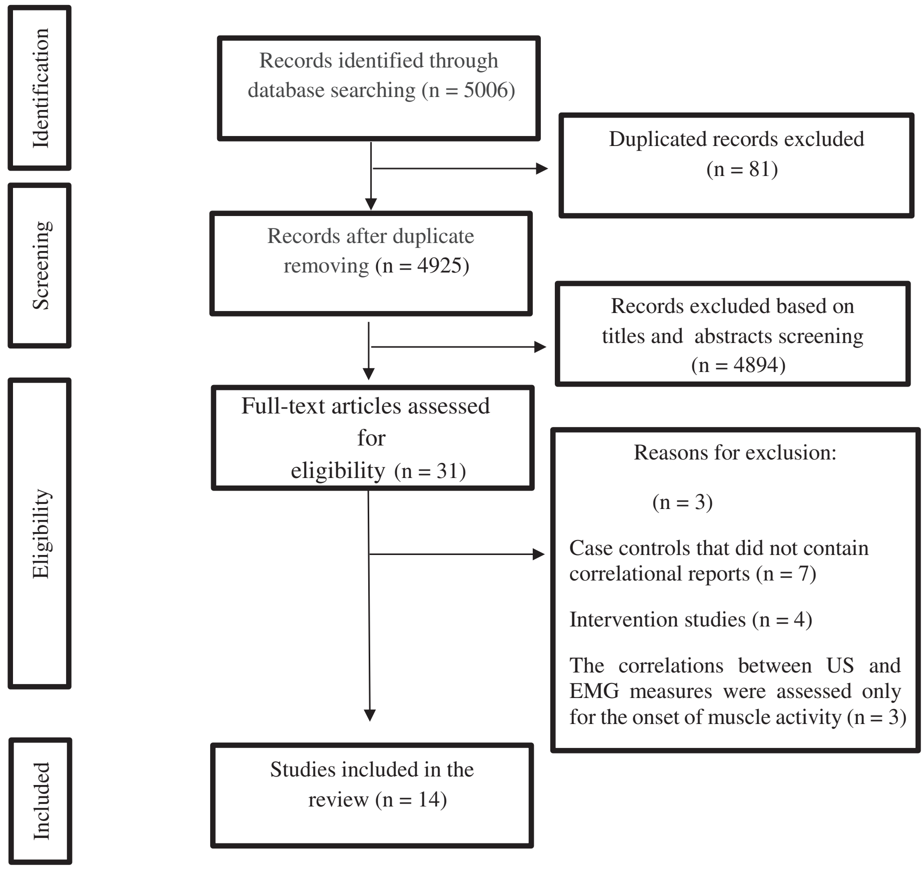

Fig 1. *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram mapping the review.* EMG, electromyography; US, ultrasound.

precisely defined electrode placement, and normalization method for EMG data. Only 3 studies had reported controlling all confounding factors.[31-33] Six studies did not report US reliability assessment,[17,19,20,25,31,34] and 2 studies did not describe testing procedure clearly.[22,25] The EMG and US measurements were synchronized only in 1 study[21]; other studies used a manual technique or did not report their synchronization technique. According to the scoring system, 13 studies were rated as moderate quality,[5,15,17,19-24,31-34] and 1 study was rated as poor quality.[25] The CASP results are present in Table 2.

Correlation Between US (Muscle Thickness) and EMG (Muscle Activation) for Abdominal Muscles

Seven studies assessed the relationship between EMG and US measures for the TrA muscle during a variety of tasks (Tables 3 and 4).[15,17,21-23,25,31] Four studies found moderate to high correlations between EMG and US for the TrA muscle.[17,21,22,31] These findings were observed during abdominal hollowing, abdominal bracing, and automatic activity, with various levels of muscle contraction intensity.[17,21,22,31] Three studies revealed that during low-level contractions there is a moderate to high relationship between EMG and muscle thickness changes of the TrA muscle (r = 0.74-0.90).[17,21,22] For higher intensities of contraction, only 2 studies found correlation between EMG and US (r = 0.46-0.90).[22,31] Three studies found no relationship between changes in thickness of TrA muscle and EMG findings.[15,23,25]

Six studies assessed the relationships between EMG and US measures for IO (Table 3).[15,17,21,23-25] Five studies were similar with the TrA muscle, and the same tasks were used for examining between EMG and US relationship for the IO muscle.[15,17,21,23,25] One study used abdominal hollowing and bracing during a modified sit-kneel position and reported poor correlations between EMG and US measures (IO: r = 0.14).[24] Only 2 studies found strong correlations (r = 0.85) during low-load abdominal contractions (isometric abdominal contraction less than 20% of maximal voluntary contraction, automatic activity of abdominal muscles during knee flexion and extension).[17,21]

Seven studies evaluated the EO (Tables 3 and 4).[15,17,21,24,32-34] Three studies evaluated the EO muscle during trunk rotation,[32-34] which reported significant US and EMG correlations (r = −0.59 to 0.98[32,34]; r^2 = 0.40- 0.89).[33] Four studies evaluated correlations between EMG and US

Table 2. *Critical Appraisal Skills Program Results*

Author	Item 1	2	3	4	5	6	7	8	9	10	11	12	Total Score	Study Quality
Hodges et al[17]	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	6	Moderate
McMeeken et al[22]	Y	Y	N	N	Y	N	N	Y	N	Y	Y	N	6	Moderate
John and Beith[33]	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N	8	Moderate
Kiesel et al[5]	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	N	7	Moderate
Brown and McGill[24]	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	N	7	Moderate
Ferreira et al[21]	Y	Y	N	Y	Y	Y	N	Y	N	Y	Y	N	8	Moderate
Whittaker et al[15]	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	N	7	Moderate
Tahan et al[25]	Y	Y	N	N	Y	N	N	N	N	Y	N	N	4	Poor
Cuesta-Vargas and Gonzalez-Sanchez[19]	Y	Y	N	Y	Y	N	N	N	N	Y	N	N	6	Moderate
Cuesta-Vargas and Gonzalez-Sanchez[20]	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	6	Moderate
Kim et al[32]	Y	Y	N	Y	Y	N	Y	Y	N	Y	Y	N	8	Moderate
Rabello et al[34]	Y	Y	N	Y	Y	N	N	N	N	Y	Y	N	6	Moderate
Djordjevic et al[31]	Y	Y	N	Y	Y	N	Y	N	N	Y	Y	N	7	Moderate
Blanchard et al[23]	Y	Y	N	Y	Y	N	N	Y	N	Y	Y	N	7	Moderate

N, no (no point); *Y*, yes (1 point).
Items: 1. clearly focused question, 2. appropriate design, 3. appropriate recruitment, 4. test procedure clearly described, 5. appropriate outcomes measured, 6. synchronized EMG/US data collection, 7. confounding factors accounted, 8. reliable measurements, 9. power calculation/adequate sample size, 10. appropriate analysis, 11. precise statistical results reported, 12. ability to generalize; quality rating: high quality, ≥9; moderate quality, (range 5-8); poor quality, ≤4.

measures during other abdominal tasks that reported no correlations.[15,17,21,24] Only 1 study assessed the correlation between US and EMG measures of RA muscle during active straight leg raise test and abdominal draw-in maneuver that reported no correlation (Table 3).[15]

Correlation Between US (Muscle Thickness) and EMG (Muscle Activation) for Paravertebral Muscles

Five studies assessed LMU[5,31,32] and ES.[19,20] Two studies[19,20] reported strong correlation between US and EMG measures (r = 0.72-0.98) for a wide range of muscle contraction intensities during isometric trunk extension in the sitting position. Also, the other 3 studies found significant correlation between EMG and US measures (r = 0.36-0.79) during trunk extension in prone position (Tables 4 and 5).[5,31,32]

Correlation Between US (Muscle Thickness) and EMG (Muscle Activation) in Participants With LBP

Three studies compared muscle thickness changes between participants with LBP and healthy participants (Tables 3, 4).[15,21,31] Two studies[21,31] suggested that muscle thickness changes assessed by US are correlated with muscle activities in both patients with LBP and healthy controls. Only 1 study found no correlation between US and EMG data in both groups.[15]

Discussion

This study systematically reviewed the literature regarding the relationship between changes in muscle thickness and EMG of abdominal and lumbar trunk muscles. The studies that reported significant correlations between EMG and US measures of TrA and IO muscles were performed during isometric contraction.[17,21] Only 2 studies were performed during dynamic activity.[15,23] Whittaker et al measured the similarity of changes in magnitude and timing of EMG signals with changes in muscle thickness during the entire performance of active straight leg raise and abdominal draw-in maneuver.[15] Blanchard et al used trunk motion (lifting task) for assessing the relationships between US and EMG measures.[23] Both of the studies found no correlations between US and EMG measures.[15,23] These

Table 3. *Details of Studies on the Correlations Between US and EMG Measures for the Abdominal Muscles*

Author/ Study Quality	n/ Status	Muscles	US Mode/ Transducer	Needle/ SEMG	Position for Assessment/ Contraction Strategy	Result
Hodges et al[17] /moderate	3/A	TrA, IO, EO	NR/5-Hz linear array	Needle	Sitting/isometric abdominal muscle contraction	Strong correlations were observed for contractions levels less than 12% MVC for TrA (r = 0.90) and 22% MVC for IO muscle (r = 0.84). No correlations were observed for EO muscle (r = 0.23).
McMeeken et al[22] /moderate	9/A	TrA	M/5-MHz curvilinear array	Needle	Supine/abdominal hollowing and Valsalva maneuvers (MVC)	Strong relationship was found between US and EMG measures (R2 = 0.87).
John and Beith[33] /moderate	24/A	EO	B and M/5-MHz curvilinear array	SEMG	Crook lying/isometric trunk rotation and ADIM	Significant correlation was found between US and EMG measures only during isometric trunk rotation for most participants (21 of 24) (r2 = 0.60-0.891). No pooled data were reported.
Brown and McGill[24] /moderate	5/A	IO, EO	B/6- to 13-MHz linear array	SEMG	Upright/abdominal bracing and hollowing in a modified sit-kneel position	Poor correlation was found between US and EMG measures (EO: r = 0.22, IO: r = 0.14).
Ferreira et al[21] /moderate	10/A 10/LBP	TrA, IO, EO	NR /5-MHz curved array	Needle	Supine/isometric knee flexion or extension	Poor correlation was seen between US and EMG measures for EO muscle (r = 0.28). There was a strong correlation for TrA (r = 0.74) and IO muscles (r = 0.85).
Whittaker et al[15] /moderate	7/A 7/LBP	TrA, IO, EO,RA	B/5-MHz curvilinear array	Needle	Supine /ASLR and hook lying/ADIM	The peak cross correlation coefficient values were low for both tasks (during ASLR: TrA: r = 0.22-0.29, IO: r = 0.24-0.34, EO: r = 0.25-0.27, RA: r = 0.22-0.29) (during ADIM: TrA: r = 0.3-0.32, IO: r = 0.35-0.39, EO: r = 0.27-0.3, RA: r = 0.3-0.32) No pooled data were reported for the regression analysis.
Tahan et al[25] /poor	30/A	TrA, IO	B/7.5-MHz linear array	SEMG	Supine/abdominal hollowing maneuver with and without PFM contraction	There was no relationship between EMG and US measures (correlations for both TrA and IO were reported together, r = 0.02-0.04).
Rabello et al[34] /moderate	18/A	EO	NR /5- to 12-MHz linear array	SEMG	Sitting/forward flexion, right lateral flexion and left axial rotation	There were significant correlations between EMG and US measures in both tasks for most participants (during forward flexion: 13 of 18 participants, during right lateral flexion and left axial rotation: 12 of 18 participants). There was variability across participants. R values were not pooled.
Blanchard et al[23] /moderate	11/A	TrA, IO	B/7.5-MHz linear array	SEMG	Standing/lift while wearing the weight lifting belt and Valsalva maneuver	No relationship was found between US and EMG measures (IO: R2 < 0.11 for all conditions. TrA: R2 < 0.13 for all conditions).

A, asymptomatic; *ADIM*, abdominal draw-in maneuver; *ASLR*, active straight leg raise test; *B*, brightness mode; *EMG*, electromyography; *EO*, external oblique; *IO*, internal oblique; *LBP*, low back pain; *M*, motion mode; *MVC*, maximal voluntary contraction; *NR*, not reported; *PFM*, pelvic floor muscle; *RA*, rectus abdominis; *SEMG*, surface electromyography; *TrA*, transversus abdominis; *US*, ultrasound.

findings during dynamic tasks could be a result of the effect of muscle length on both the activity level of motor units and changes in muscle thickness.[18,35] Changes in the muscle thickness could be present during dynamic contractions, with little or no change in the activity level of motor units or vice versa.[18] In this respect, any changes

Table 4. *Details of Studies on the Correlations Between US and EMG Measures of the Abdominal and LMU Muscles*

Author/ Study Quality	n/ Status	Muscles	US Mode/ Transducer	Needle/ SEMG	Position for Assessment/ Contraction Strategy	Result
Kim et al[32] /moderate	30/A	EO, LMU	B/7.5-MHz linear array	SEMG	Supine/trunk rotation at 4 different MMT grades Prone/lumbar spine extension at 4 different MMT grades	The correlations between US and EMG measures were moderate (EO: r = 0.61, LMU: r = 0.59).
Djordjevic et al[31] /moderate	37/A 36/LBP	TrA, LMU	B/3- to 6-MHz curvilinear array	SEMG	Supine/ADIM Prone/head, upper trunk, and contralateral arm lifting	Significant correlation was found between the US and EMG measures of TrA muscle, in both groups and both sides (r = 0.46- 0.63). Significant correlations were observed for LMU of both sides in asymptomatic participants (r = 0.36 - 0.38), and in the LMU of the right side in LBP participants (r = 0.43).

A, asymptomatic; *ADIM*, abdominal draw-in maneuver; *B*, brightness mode; *EMG*, electromyography; *EO*, external oblique; *LBP*, low back pain; *LMU*, lumbar multifidus; *MMT*, manual muscle test; *SEMG*, surface electromyography; *TrA*, transversus abdominis; *US*, ultrasound.

in muscle length would influence the relationship between muscle activity and muscle thickness, due to the properties of the elastic series component.[17]

Another finding of this review was the effect of muscle contraction intensity on the correlation between US and EMG measures of TrA and IO muscles. All studies that found significant correlations between muscle thickness changes and EMG activity of TrA and IO muscles were during low levels of muscle contraction intensity.[17,21,22,31] Only 3 studies assessed higher intensities of muscle contraction,[17,22,31] of which 1 study found no correlations between US and EMG measures for contractions intensities above 20% of maximal voluntary contraction,[17] whereas 2 studies reported significant correlations.[22,31] The controversial findings could be due to methodological differences such as the task and testing position. McMeeken et al and Djordjevic et al used abdominal hollowing in supine position,[22,31] whereas Hodges et al assessed abdominal muscle activity during isometric activity of all abdominal muscles (abdominal bracing) during sitting position.[17] As a result of simultaneous high activation of all the abdominal muscles, several factors would restrain muscle expansion, such as increased compression forces of the adjacent muscles, stiffening of the connective tissue,[24] and increased intra-abdominal pressure.[23] In addition, the sitting position that was used in the study by Hodges et al[17] would likely lead to the shift of abdominal contents that prevents maximum shortening of abdominal muscle (increasing muscle thickness).[15]

The level of muscle activity and changes in muscle thickness are influenced by the resting state of the muscle, such as the initial muscle length and the initial level of muscle activity. These factors might have altered the US and EMG correlations in the upright postures compared with supine position. Therefore, any interpretations in changes in abdominal muscle thickness and relating it to muscle activity during upright postures should be done cautiously.

The studies that have assessed the EO muscle during trunk rotation reported significant correlations between US and EMG measures.[32-34] This movement is known as the prime movement of the EO muscle.[33] Accordingly, the ability of US to measure muscle activation may depend on the specific biomechanical demand of the task. Muscle thickness is dependent on fascicle angle and fascicle length.[36] Therefore, the type of muscle contraction and the plane of action would influence changes in muscle thickness. During axial rotation, the EO muscle works in the direction of its fibers; this induces the greatest change in muscle thickness. Also, studies that had assessed the correlations during the prime movement task of the tested muscle reported higher correlations.[5,19,20,22,31-33] Rabello et al reported lower correlations compared to the other studies conducted on the EO muscle during axial rotation.[34] This could be due to the sitting position used in their study, whereas studies that applied trunk rotation during lying position reported higher correlations.[32,33]

The results related to RA muscle were not assessed systematically because only 1 of the included studies had measured the correlation between US and EMG measures regarding this muscle.[15] The RA muscle is a superficial abdominal muscle, and it is likely that surface EMG can measure its activity accurately.

All the studies on the LMU and ES muscles applied a task that was the prime movement of the tested muscle. These studies showed moderate to strong correlations between US and EMG measures during trunk extension in sitting and prone positions. These findings were presented for a wide range of muscle contraction intensities.[5,19,20,31,32] In comparison with the abdominal region, paravertebral muscles showed higher associations between US and EMG measures during sitting position with high intensities of contraction. This diverse finding could be obtained due to several reasons: first, muscular layers of the abdominal region are mechanically linked by strong connective tissues.[37] In this case, the force generated by one muscle is transmitted to the adjacent

Table 5. *Deails of Studies on the Correlations Between US and EMG Measures of LMU or ES Muscles*

Author/Study Quality	n/ Status	Muscles	US Mode/ Transducer	Needle/ SEMG	Position for Assessment/ Contraction Strategy	Result
Kiesel et al[5] /moderate	5/A	LMU	NR/5-Hz curvilinear array	Needle	Prone/head, upper trunk, and contralateral arm lifting	Strong correlation was reported between US and EMG measures of LMU muscle in range 19%-34% of MVC (r = 0.79).
Cuesta-Vargas and Gonzalez-Sanchez[19] /moderate	46/A	ES	NR	SEMG	Sitting with extension of 45° from vertical/moderate and low isometric trunk and hip extension	Strong correlation was seen between US and EMG measures of ES muscle during isometric lumbar extension at low and moderate intensity (r = 0.726-0.92).
Cuesta-Vargas and Gonzalez-Sanchez[20] /moderate	30/A	ES	NR /8.5-MHz linear	SEMG	Sitting with extension of 45° from vertical/33% and 100% of the MVC force	Strong correlation was found between the US and EMG measures (R2 = 0.837-0.986).

A, asymptomatic; *EMG*, electromyography; *ES*, erector spinae; *LBP*, low back pain; *LMU*, lumbar multifidus; *NR*, not reported; *SEMG*, surface electromyography; *US*, ultrasound.

muscles.[38] Thus, the amount of thickening in each muscle is dependent upon the activation level of the surrounding muscles. Second, abdominal content compresses the abdominal muscles during upright postures,[15,39] which influences the changes in muscle thickness, whereas the paravertebral muscles are less affected by the shift of the abdominal content during upright postures.[39,40] This notion could be supported by the studies that found moderate to high correlations between US and EMG measures during sitting positions. This was in contrast to the findings of studies on abdominal muscles that have found no or a low relationship between EMG and US measures during upright postures.[23,24,34]

Three studies had included participants with LBP, of which 2 studies had assessed lateral abdominal wall muscles[15,21] and 1 study had measured the TrA and LMU.[31] These studies showed that all the existing factors that influenced the relationship between US and EMG measures in healthy participants were similar for participants with LBP. The number of studies including participants with LBP was scarce, thereby the results of this review should be interpreted with caution to the LBP population.

Limitations

In this review, only English-language studies were included, therefore, language bias should be considered. Additionally, the review protocol was not registered in the International Prospective Register of Systematic Reviews. Most of the studies had relatively small sample sizes, and most of them studied healthy individuals during isometric contraction. Therefore, the results from these studies could not be extrapolated to other groups of patient populations with dynamic contractions. Further studies are required to assess the correlations between US and EMG measures in patients with LBP and other types of musculoskeletal disorders. None of the included studies had considered the level of physical activity or sport performance and sporting category. These factors influence muscle morphology[41,42] and therefore could alter the correlation between US and EMG measures. Future research is required to investigate the correlation between US and EMG in different physical activity levels and sport categories.

Conclusion

Considering the results of the 14 reviewed articles, the relationship between changes in muscle thickness and muscle activation is complicated and may be influenced by several factors. It seems that, in supine position and during prime movement tasks with isometric contraction, changes in abdominal muscle thickness could be interpreted as muscle activity. For higher intensities of abdominal muscle contraction, upright postures might influence the association between US and EMG measures. Unlike abdominal muscles, the US and EMG correlations of the paravertebral muscles were not influenced by the testing position and muscle contraction intensity. If the presence and influence of these factors on changes in muscle thickness are not taken into consideration, inaccurate conclusions may occur regarding muscle activity.

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Contributorship Information

Concept development (provided idea for the research): Sha.S., S.Sh., I.E.T.

Design (planned the methods to generate the results): Sha.S., S.Sh.

Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): Sha.S., S.Sh., I.E.T.

Data collection/processing (responsible for experiments, patient management, organization, or reporting data): Sha.S., S.Sh., Shi.S.

Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): Sha.S., S.Sh., Shi.S.

Literature search (performed the literature search): Sha.S., S.Sh., Shi.S.

Writing (responsible for writing a substantive part of the manuscript): Sha.S., S.Sh., Shi.S.

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Practical Applications

- Changes in thickness of abdominal muscles could be indicated as changes in muscle activity for all intensities of muscle contraction during prime movement tasks performed in lying position with isometric contractions.
- Changes in paravertebral muscle thickness could be used as an indicator of muscle activity during all intensities of isometric muscle contraction, regardless of the testing position.
- Application of US as detector of muscle activity during dynamic tasks and high levels of muscle contraction may be questionable.

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