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Review Paper: Evaluation of the Activity and Dimensions Changes of the Skeletal Muscles During Different Activities: A Systematic Review

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ABSTRACT

Introduction: The knowledge of muscle function during various activities may affect medical and physical treatments. Recently, ultrasound has been used to assess the activity of skeletal muscles. The relationship between ultrasound data with Electromyography (EMG) and dynamometry has been evaluated in numerous articles. This study aims to review the papers in this topic.

Materials and Methods: By searching the papers in Google Scholar, ScienceDirect, PubMed and PEDro (Physiotherapy evidence database) and then checking the papers referenced to found studies, 28 related papers were chosen and evaluated.

Results: Regarding data recording methods in 28 papers, ultrasound and EMG had been used in 5 papers, ultrasound and dynamometry in 13 cases and all three methods in 10 papers.

Conclusion: Although the relationship between EMG and ultrasound data have been examined in many studies, there are shortages and in some cases lack of mathematical equations and predictive models representing the majority of skeletal muscles. Therefore, quantifying the relationship between ultrasound data with EMG and dynamometry and providing predictive models can be useful in using ultrasound (which is a noninvasive, cheap and available method) in both research and clinical fields.

1. Introduction

The knowledge of muscle function during various activities may influence prescribing medications and physical treatments in various musculoskeletal disorders [1, 2]. In this regard, the standard tool to evaluate the electrical activity of muscles is Electromyography (EMG). EMG recording is done in two ways: needle, and surface EMG. It has many applications such as diagnosis of muscle and nerve disorders and changes, assessment of muscle function and biomechanical models [3]. However, EMG is

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unable to record the electrical activities of some muscles and also some noises interfere in the recorded signals. Because of interference of the signals from other muscles, surface EMG cannot be used to record the activity of deep muscles, instead the needle EMG which is an invasive procedure is used. Studies indicate the thickness change of muscle during its activity [2, 4-7].

Therefore, the electrical activity of muscle can be recorded by determining the changes of its dimensions. The relationship between EMG and ultrasound data of muscles dimension has been mentioned in several articles [2, 4-6, 8-11]. Most of them have reported high correlation between those data [2, 4, 6, 8, 10, 11]. The available methods for assessing the muscle size consist of magnetic resonance imaging, computerized tomography and ultrasonography. Ultrasonography is more appropriate to assess muscle structure because it is cheaper and more accessible. Also the dimension changes of muscle during various activities can be observed using ultrasound in a real-time and non-invasive manner. The reliability of ultrasound techniques to measure different variables at various muscles has been investigated extensively. According to these studies, high reliability has been reported for ultrasound data in measuring the dimensions of skeletal muscles, in both resting and contraction conditions, with needle and surface EMG [5, 12, 13]. Lee et al. obtained a high correlation between ultrasonography and magnetic resonance imaging data in the thickness of cervical multifidus muscle [14].

The first reported use of ultrasound in this field was to measure the size of biceps brachii muscle by a team at Tokyo University in the late 1960s [15]. This process continued until the researchers used ultrasound for measuring the dimensions and other structural parameters of different muscles in 1990 [15]. Various papers studied how the muscles dimensions change during various activities using ultrasound [5, 6, 8, 16-18]. Recently ultrasound has also been used to determine the onset of muscle activity [19, 20].

This study aimed to review the papers with respect to their evaluation of the skeletal muscles activity using ultrasound and related factors, also evaluation of models and mathematical equations on the relationship between ultrasound data with other muscle assessing methods (e.g. EMG and dynamometry), assessment of ultrasound reliability in measuring muscle size as well as the possibility of detecting abnormalities in muscle function using ultrasound.

2. Materials and Methods

According to the study purpose, at first the related papers were searched from Google Scholar, ScienceDirect, PubMed and PEDro (Physiotherapy evidence database) databases by using keywords; muscle ultrasonography, the relationship between ultrasound and EMG data, the relationship between ultrasound and force data. After reviewing the databases, 700 related cases (including articles, conference proceedings, thesis, etc.) were obtained in this way. Then, the papers on the relationship between the EMG and ultrasound variables, ultrasound and force variables or both of them, were chosen (224 cases). At last the studies on the relationship between the mentioned variables either using mathematical equations, or quantitative data were selected (22 papers). In the second stage, the selective search for the papers continued with checking the papers referenced to the found studies.

Approximately, 1100 relevant articles were assessed in this way. Of them, the ones that had examined the relationship between mentioned variables using mathematical equations or quantitative data were selected (6 papers). Inclusion criteria for the final selected articles comprised using ultrasound to assess the muscle size and EMG or dynamometry to record the electrical activity and muscle strength, respectively, as well as presenting a mathematical or quantitative relationship between these variables. It should be noted that only English papers have been evaluated in this study. Figure 1 shows the flowchart of our paper selection procedure.

Both writers followed the steps of the study. Papers were assessed in the terms of the subjects (number of the subjects, health status, gender and range of age), the studied variables, type of activities performed by the subjects and their position for data entry, the examined muscle, the investigated ultrasound variables, the obtained results and the reliability coefficients.

3. Results

A total of 28 papers have been evaluated in this study. From the standpoint of data recording methods in 28 papers, ultrasound and EMG have been used in 5 papers, ultrasound and dynamometry in 13 cases and all three methods in 10 papers. Of these papers, 10 provided equations on the relationship between different methods in muscles activity assessment (ultrasound, EMG and dynamometry). Table 1 presents these information. Table 2 summarizes the features and number of subjects in various studies.

Of 28 papers, reliability of ultrasound has been investigated in 10 cases. According to these studies, the reliability of ultrasound to measure the muscle thickness and its changes ranges between 0.41 and 0.987, for muscles

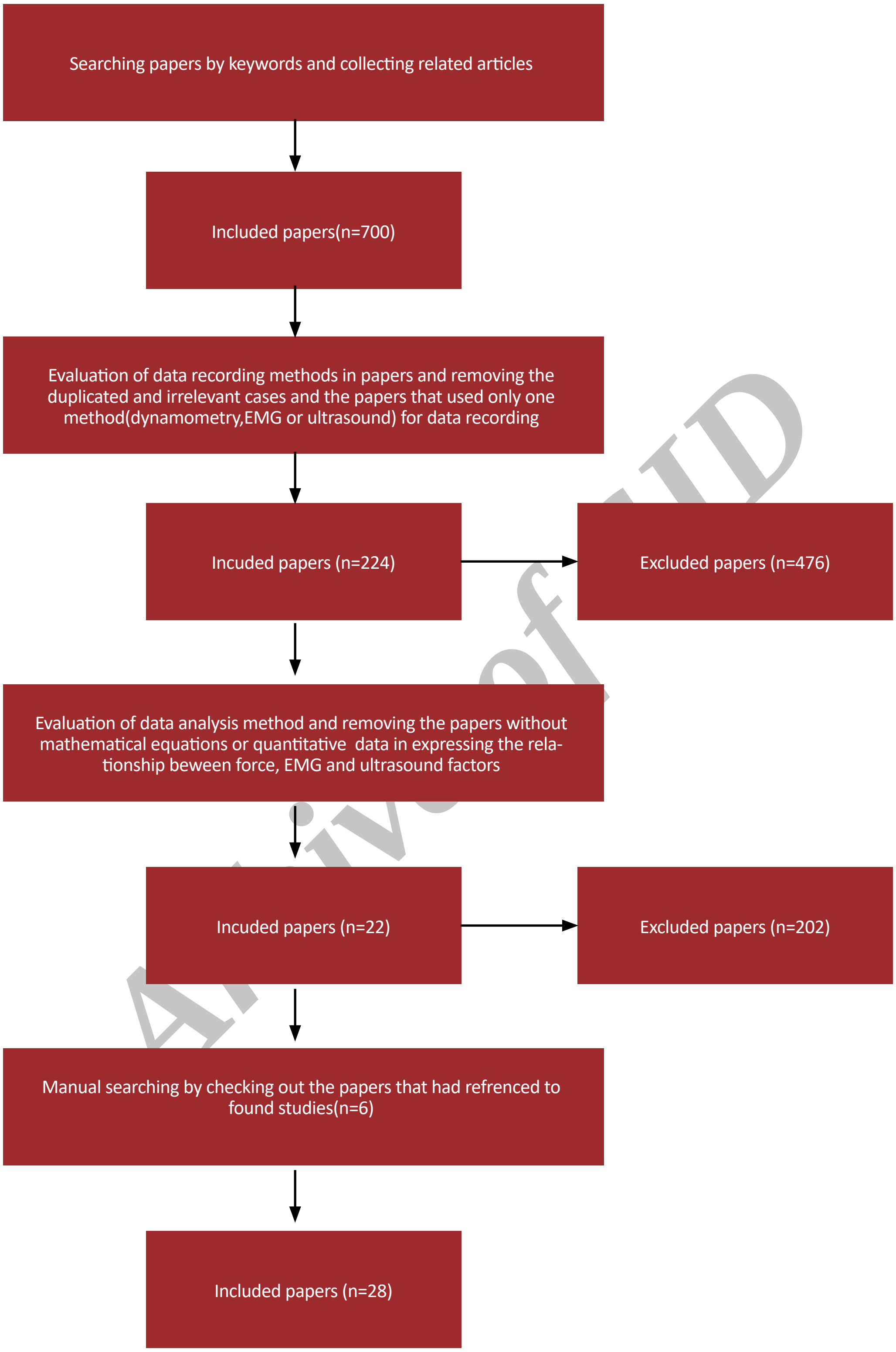

Figure 1. Flowchart of paper selection

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Table 1. Data recording methods in the reviewed papers

Author (Year)	Data Recording Methods			Providing the Equation for the Relationship Between Methods
	Ultrasound	EMG	Dynamometry	
John et al. (2007) [8]	*	*	-	-
Ishida et al. (2015) [37]	*	*	*	*
Ferreira et al. (2011) [9]	*	*	-	-
McMeeken et al. (2004) [10]	*	*	-	-
Ishikawa et al. (2006) [25]	*	*	*	-
Guo et al. (2010) [13]	*	*	*	*
Shi et al. (2008) [6]	*	*	*	*
Dieterich et al. (2014) [12]	*	*	*	-
Chen et al. (2012) [5]	*	*	*	*
Strasser et al. (2013)[29]	*	-	*	-
Abe et al. (2015) [32]	*	-	*	*
Kanehisa et al. (1994) [33]	*	-	*	*
Freilich et al. (1995) [7]	*	-	*	-
Fishman et al. (2004) [24]	*	-	*	-
Kiesel et al. (2007) [2]	*	*	-	-
Hodges et al. (2003) [4]	*	*	-	-
Jung et al. (2011) [34]	*	-	*	-
Ando et al. (2015) [27]	*	-	*	-
Moreau et al. (2010) [28]	*	-	*	*
Bickerstaffe et al. (2015) [26]	*	-	*	-
Lee et al.(2009) [36]	*	-	*	*
Rezasoltani et al. (2002) [35]	*	-	*	-
Rabello et al. (2015) [40]	*	*	*	-
Manal et al. (2008) [41]	*	*	*	-
Brown et al. (2010) [30]	*	*	*	-
Hoffman et al. (2013) [42]	*	-	*	-
Massey et al. (2015) [43]	*	-	*	*
Chauhan et al. (2013) [44]	*	*	*	*

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Table 2. A summary of subjects' characteristics in the reviewed papers

Author (Year)	Subjects Number	Gender	Age (Year) Mean±SD	Health Status
John et al. (2007) [8]	Isometric trunk rotation: 24	9 M, 15 F	24.5±0.5	Healthy
	Hollowing: 10	6 M, 4 F	23.6±0.5	Healthy
Ishida et al. (2015) [37]	13	M	19.6±1.2	Healthy
Ferreira et al. (2011) [9]	EMG and ultrasound: 20	-	Patient: 27.8±5.1 Healthy: 32.7±10.6	10 with low back pain and 10 healthy
	Reliability: 20	-	51.6±15.5	With low back pain
Mc Meeken et al. (2004) [10]	EMG and ultrasound: 9	4 M, 5 F	40.7±2.7	Healthy
	Reliability: 13	6 M, 7 F	39.7±2.3	Healthy
Ishikawa et al. (2006) [25]	8	M	29.3±5.3	Healthy
Guo et al. (2010) [13]	9	M	30.7±4.9	Healthy
Shi et al. (2008) [6]	7	M	27±2	Healthy
Dieterich et al. (2014) [12]	Surface EMG: 15	6 M, 9 F	28±7.9	Healthy
	Needle EMG:6	5 M, 1 F	39±7.9	Healthy
Chen et al. (2012) [5]	9	6 M, 3 F	31.2±1.8	Healthy
Strasser et al. (2013) [29]	26 young and 26 elderly	-	Young: 24.2±3.7 Elderly: 67.8±4.8	Healthy
Abe et al. (2015) [32]	86	43 M, 43 F	18-34	Healthy
Kanehisa et al. (1994) [33]	53	27 M, 26 F	18-25	Healthy
Freilich et al. (1995) [7]	138	58 M, 80 F	F: 28.3±7.6 M: 30.1±7.7	Healthy
Fishman et al. (2004) [24]	18	Patient: 2 M, 7 F Healthy: 2 M, 7 F	Patient: 32-66 Healthy: 33-65	9 with myositis and 9 healthy
Kiesel et al. (2007) [2]	5	2 M, 3 F	28.0±5.6	Healthy
Hodges et al. (2003) [4]	Tibialis: 5 Arm: 5 Abdomen: 3	Tibialis: 4 M, 1 F Arm: M Abdomen: M	27-45	Healthy
Jung et al. (2011) [34]	9	M	23.4±2.9	Healthy
Ando et al. (2015) [27]	11	M	21.9±0.9	Healthy
Moreau et al. (2010) [28]	30	Patient: 9 M, 9 F Healthy: 2 M, 10 F	Patient: 12.0±3.2 Healthy: 12.3±3.9	18 cerebral palsy and 12 healthy
Bickerstaffe et al. (2015) [26]	60	67% of two groups F	Patient: 63±8 Healthy: 59±14	48 patients with post-polio syndrome and 12 healthy
Lee et al. (2009) [36]	20	15 M, 5 F	24.3±4.7	Healthy
Rezasoltani et al. (2002) [35]	6	M	18-24	Healthy
Rabello et al. (2015) [40]	18	M	25±8	Healthy
Manal et al. (2008) [41]	16	8 M, 8 F	M: 24±3.6 F: 24±4.2	Healthy
Brown et al. (2010) [30]	5	M	25.2±3.8	Healthy
Hoffman et al. (2013) [42]	10	M	21.5±1.5	Healthy
Massey et al. (2015) [43]	15	M	20±2	Healthy
Chauhan et al. (2013) [44]	15	M	24.4±3.2	Healthy

Abbreviations: M: Male; F: Female; EMG: Electromyography

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Table 3. Ultrasound reliability to measure muscle dimensions

Author (Year)	Muscle	Factors	ICC	SEM	CV
John et al. (2007) [8]	External oblique abdominal	TH	0.923	-	-
Ferreira et al. (2011) [9]	External oblique abdominal, Internal oblique abdominal, Transverse abdominal	TH measurement by a trained operator	0.81-0.97	3.38%	-
		TH measurement by an untrained operator	-0.41-0.78	6.01%	-
		Between operators	-0.48-0.78	6.71%	-
McMeeken et al. (2004) [10]	Transverse abdominal	Between day reliability of ultrasound's B mode with linear transducer	0.963-0.977	0.03 mm	-
		Between day reliability of ultrasound's M mode with linear transducer	0.939-0.994	0.04 mm	-
		Between transducers with M mode	0.870-0.963	0.14 mm	-
Guo et al. (2010) [13]	Rectus femoris	Width	0.986	0.13 cm	-
		TH	0.987	0.04 cm	-
		CSA	0.978	0.48 cm^2	-
Dieterich et al. (2014) [12]	Gluteus medius	TH in rest (Surface EMG)	0.935-0.986	-	-
		TH in rest (Needle EMG)	0.868-0.960	-	-
		TH in contraction (surface EMG)	0.943-0.975	-	-
		TH in contraction (needle EMG)	0.911-0.972	-	-
	Gluteus minimus	TH in rest (Surface EMG)	0.896-0.957	-	-
		TH in rest (Needle EMG)	0.804-0.939	-	-
		TH in contraction (surface EMG)	0.828-0.923	-	-
		TH in contraction (needle EMG)	0.751-0.920	-	-
Chen et al. (2012) [5]	Rectus femoris	CSA	0.987	0.15 cm^2	-
Strasser et al. (2013) [29]	Quadriceps	TH	0.85-0.97	-	-
Ando et al. (2015) [27]	Quadriceps	TH	0.966	-	-
		Pennation angle	0.949	-	-
		Fascicle length	0.836	-	-
Lee et al. (2009) [36]	Cervical multifidus	-	-	-	4.6%-11.6%
Rezasoltani et al. (2002) [35]	Semispinalis capitis	APD	0.91	-	-
		LD	0.94	-	-
		APD×LD	0.95	-	-

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Abbreviations: TH: Thickness; CSA: Cross Sectional Area; EMG: Electromyography; APD: Anterior Posterior Dimension; LD: Lateral Dimension; ICC: Intraclass/Interclass Correlation Coefficient; SEM: Standard Error of Measurement; CV: Coefficient of Variation

Table 4. A summary of the test conditions and obtained results in the investigated papers

Author (Year)	Subject Position	Activity	Muscle	Ultrasound Factors	Results
John et al. (2007) [8]	Supine	Isometric trunk rotation, Hollowing	External oblique abdominal	TH	Correlation between TH with EMG is significant during isometric trunk rotation but it is not significant in abdominal hollowing.
Ishida et al. (2015) [37]	Supine	Craniocervical flexion	Deep cervical flexor and sternocleidomastoid	TH	There is an inverse relationship between the deep cervical flexor muscles TH with sternocleidomastoid muscle activity at pressures of 26 and 28 mm Hg.
Ferreira et al. (2011) [9]	Supine	Knee flexion and extension	External and internal oblique abdominal, transverse abdominal	TH	The correlation between ultrasound and EMG data is low in the external oblique abdominal muscle but it is fair to good in internal oblique and transverse abdominal muscles.
McMeeken et al. (2004) [10]	Supine	Hollowing	Transverse abdominal	TH	There is a significant correlation between TH increasing and EMG of the transverse abdominal muscle, high reliability for ultrasound.
Ishikawa et al. (2006) [25]	Sitting	Plantar flexion	Soleus	TH, Fascicle length	Increasing of TH in 2 days after exhaustive stretch-shortening cycle exercise; there is a significant correlation between TH change and torque between 2 hours and 2 days after exercise.
Guo et al. (2010) [13]	Sitting	Isometric knee extension	Rectus femoris	CSA, width/TH	Nonlinear relationship (polynomial 3) between ultrasound and torque as well as between EMG and torque.
Shi et al. (2008) [6]	Sitting	Elbow flexion	Biceps	TH, Pennation angle	Exponential relationship between normalized EMG with muscle deformation as well as EMG and pennation angle, linear relationship between normalized torque with muscle deformation as well as normalized torque and pennation angle.
Dieterich et al. (2014) [12]	Supine	Isometric hip abduction	Gluteus medius and minimus	TH	TH change of the gluteus medius muscle can be estimated using of torque and surface EMG, but it is not appropriate for the gluteus minimus muscle.
Chen et al. (2012) [5]	Sitting	Isometric knee extension with increasing force with three different speeds	Rectus femoris	CSA	The relationship between CSA and torque has a high regression coefficient with square regression model. Ultrasound is less dependent on the contraction speed than electromyography.
Strasser et al. (2013)[29]	Sitting	Leg extensions	Quadriceps	TH, Pennation angle	TH is more correlated with MVC in two groups. In multiple regression analysis, vastus medialis TH has the most correlation with MVC is elderly person.

Author (Year)	Subject Position	Activity	Muscle	Ultrasound Factors	Results
Abe et al. (2015) [32]	Anatomical position, sitting by putting the hand on the table	Hand grip in standing position with 90° of elbow joint	hand and forearm	TH	There is a direct relationship between TH and hand grip in ulna and dorsal interosseous muscles in women and ulnar muscle in men.
Kanehisa et al. (1994) [33]	Sitting	Knee and elbow flexion and extension	Extensor and flexor muscles of the knee and elbow	CSA	Muscle CSA was lower for women in both areas (especially arm). Regression models for both genders show a high correlation between the CSA and the muscle strength, except elbow extensor muscles in men and elbow flexors muscles in women.
Freilich et al. (1995) [7]	Sitting	Knee extension	Quadriceps	TH	There was a significant correlation between quadriceps TH and MVC for both genders, TH were higher for men than women.
Fishman et al. (2004) [24]	Sitting	Isometric contraction in 60 and 90 degrees of knee joint	Rectus femoris	APD, LD	APD increase and LD decrease during contraction in all subjects, average of dimension changes is higher for the control group, relatively high correlation between TH and strength during contraction.
Kiesel et al. (2007) [2]	Prone	90° arm flexion and 120° shoulder abduction	Lumbar multifidus	TH	High correlation between EMG and ultrasound.
Hodges et al. (2003) [4]	Tibialis anterior and arm: Abdominal muscles: Supine	Dorsiflexion, 90° flexion of shoulder and arm, hollowing	Tibialis anterior, brachialis, biceps, external and internal oblique abdominal, transverse abdominal	TH, Fascicle length, Pennation angle	High correlation between EMG and ultrasound, the greatest change in TH occurs in up to 50% of MVC.
Jung et al. (2011) [34]	Sitting	Fingers isometric flexion	lumbrical muscles of hand	CSA	Moderate to good correlation between muscle CSA and MVC for second, third and fourth lumbrical muscle.
Ando et al. (2015) [27]	Supine	Isometric knee extension	Quadriceps	TH, Fascicle length, Pennation angle	High correlation between TH and pennation angle of vastus intermedialis with MVC.
Moreau et al. (2010) [28]	Supine	Isometric knee extension	Rectus femoris, vastus lateralis	TH, Fascicle length, Fascicle angle	High correlation between vastus lateralis muscle TH and MVC in both groups.
Bickerstaffe et al. (2015) [26]	Supine	Isometric knee extension	Quadriceps	TH	There are significant differences between the two groups in measured parameters, TH and strength is low in patients, there is a high correlation between TH and knee strength in patients.
Lee et al. (2009) [36]	Sitting	Isometric neck extension	Cervical multifidus	TH	No difference between the vertebrae, the greatest change in TH occurs in 50% of MVC.
Rezasoltani et al. (2002) [35]	Sitting	Isometric neck extension	Semispinalis capitis	APD, LD, APD×LD, LD/APD	Increase of APD×LD and decrease of LD/APD during contraction.

Author (Year)	Subject Position	Activity	Muscle	Ultrasound Factors	Results
Rabello et al. (2015) [40]	Sitting	Forward flexion, right lateral flexion and left axial rotation of trunk	External oblique abdominal	TH	There is a great variability of correlations between EMG and ultrasound measures and it suggests that ultrasound is not a valid measures of this muscle activity.
Manal et al. (2008) [41]	Sitting	Isometric ankle plantar and dorsiflexion	Tibialis anterior, lateral gastrocnemius, medial gastrocnemius and soleus	Pennation angle	A significant positive linear relationship between normalized EMG and pennation angle for all muscles.
Brown et al. (2010) [30]	Sitting	Abdominal hollow and brace and isometric contractions	Transverse abdominal, internal and external oblique abdominal	TH	There is no definitive relationship between increases in muscle activation and muscles TH in internal and external oblique abdominal.
Hoffman et al. (2013) [42]	Walking	Prolonged backward downhill walking	Gastrocnemius	Fascicle length	Human gastrocnemius muscle fascicles experience relatively small strains during prolonged backward downhill walking that causes muscle damage
Massey et al. (2015) [43]	Sitting	Knee extension	Quadriceps femoris	Fascicle length, Pennation angle	There is a curvilinear relationships between fascicle length and pennation angle with knee-extension torque level.
Chauhan et al. (2013) [44]	Sitting	Knee extension	Rectus femoris, vastus lateralis	Pennation angle, TH	The relationship between EMG and TH demonstrated a strong correlation. There is no significant correlation between EMG and pennation angle for the vastus lateralis.

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Abbreviations: TH: Thickness; CSA: Cross Sectional Area; EMG: Electromyography; APD: Anterior Posterior Dimension; LD: Lateral Dimension

width between 0.94 and 0.986 and for cross sectional area between 0.95 and 0.987 (Table 3). In general, Table 4 summarizes the investigated studies and their findings.

4. Discussion

Knowing the function of different muscles during certain activities can greatly affect the treatment process [1, 2]. Because of the limitations of EMG such as its high noise level in some cases and being invasive for deep muscles, the ultrasound has been used to assess the activity of skeletal muscles while performing different activities [1, 21-23]. This study aimed to review the studies on the relationship between ultrasound data with EMG and dynamometry in the skeletal muscles.

According to conducted studies, there is a high reliability in assessing the dimensions of skeletal muscles by ultrasound (Table 3). With regard to the examined muscle, the following classifications can be generally done: The muscles of the lower extremities, The muscles of the upper extremities and trunk and The cervical muscles.

Muscles of the lower extremities

Chi-Fishman et al. showed a thickness increase and lateral dimension decrease of rectus femoris muscle during isometric knee contraction in both genders [24]. Also, a high correlation has been reported between muscle thickness change for soleus muscle [25], quadriceps [7, 26, 27], rectus femoris [24], the tibialis anterior [4, 11] and vastus lateralis [28] with force and EMG data in numerous articles in healthy subjects. However, most of the papers have used the qualitative approach to explain the relationship between these two factors. Using regression models, Strasser et al. reported that the muscle thickness correlated more with the maximum voluntary isometric contraction in the quadriceps muscles in both elderly and young people [29]. Nonetheless, Dieterich et al. indicated that for the gluteus minimus muscle the relationship between EMG and muscle thickness measured by ultrasound is very low [12].

Muscles of the upper extremities and trunk

Kiesel et al. [2] found a high correlation between EMG data and thickness of lumbar multifidus muscle using the linear regression model. For abdominal muscles, the relationship between EMG and thickness change of transverse abdominal muscle has been reported in several studies [4, 9, 10]. The relationship between these two factors is high in internal oblique abdominal muscle [4, 9]. Regarding the external oblique abdominal muscle, Hodges et al. reported that activity of this muscle cannot be predicted by its thickness change during abdominal hollowing; a result that was verified later by John and Beith and Brown et al. [4, 8, 30]. The correlation between EMG and muscle thickness in the external oblique abdominal muscle is low during knee extension and flexion but it is high during isometric trunk rotation [8, 9]. In other words, the correlation between muscle thickness and EMG data for this muscle increases only when it functions as an agonist muscle [8]. Thus, the type of activity affects the relationship between EMG and ultrasound data of muscle thickness.

With regard to arm, forearm and hand muscles, a significant correlation has been reported between EMG and these muscles dimensions in the arm flexor and extensor muscles; biceps brachii, brachialis, forearm radius, forearm ulna, fingers and dorsal interosseous muscles [4, 6, 31-34]. The relationship between these two factors, especially in the biceps brachii muscle is high. Jun et al. has shown an exponential relationship between the normalized EMG and the deformation of the biceps brachii muscle [6].

The cervical muscles

Soltani et al. [16] showed an increase in semispinalis capitis muscle thickness during the isometric neck extension and dimension changes of these muscle during cervical flexion and extension [16, 35]. Also Rahnama et al. reported that the anterior posterior dimension of cervical multifidus muscle becomes larger with higher forces while its lateral dimension gets thinner [17]. For this muscle, the maximum thickness change has been reported to be 50% of the maximum voluntary isometric contraction force [36]. Recently, a significant negative correlation has been reported between the thickness of the deep cervical flexor muscle with activity of sternocleidomastoid muscle which has been recorded with EMG and also for posterior cervical muscles [37, 38].

5. Conclusion

According to this brief review, the relationship between the EMG and ultrasound data of muscle thickness have been basically evaluated qualitatively in most cases and mathematical equations and predictive models have been neglected to interpret the relationship between these two data types in the muscles of the upper and lower extremities and trunk. For the cervical muscles, in spite of numerous studies in the field of the cervical muscles activity, no quantitative and mathematical relationship between ultrasound and EMG data for posterior cervical muscles has been defined.

Thus, it seems that finding the mathematical equations and predictive models for the relationship between muscle activity (recorded by EMG and dynamometry) and its thickness change (obtained from ultrasound) during different activities can be useful to better assess the skeletal muscles activities in research and clinical studies. Sound knowledge of damaged and healthy muscles activities is also useful in prescribing appropriate physiotherapy and rehabilitation treatments as well as sports decisions. Moreover, with the aid of different factors such as the location of the muscle (whether superficial or deep), muscle morphology, type of activity and the relationship between ultrasound data with EMG and dynamometry in the certain muscle, the proper procedure to evaluate the activity of each muscle can be determined.

In this regard, some of the extracted data and equations from this review helped us write an article on the relationship between EMG and muscles thickness changes. In this paper, we evaluated the relationship between EMG and ultrasound data of muscle thickness in skeletal muscles using quadratic model of "Response Surface Method." Predictive models were provided for this relationship in muscles separately; muscles in the upper extremities and trunk, as well as lower extremity muscles and finally both muscle groups together. The findings indicate a significant correlation between two methods in many investigated muscles. Also results show that the type of joint activity and the type of muscle can affect the relationship between activity rate and thickness changes of skeletal muscles [39].

In general, despite the numerous studies on the association of ultrasound images with EMG and dynamometry, there is a shortage of the mathematical equations and predictive models for majority of skeletal muscles. Hence, quantifying the relationship between ultrasound data with EMG and dynamometry and providing predictive models can be useful in using ultrasound (that is a noninvasive, cheap and available method) in both research and clinical studies.

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Conflict of Interest

The authors declared no conflicts of interest.

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