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Review

Usefulness of muscle echo intensity for evaluating functional performance in the older population: A scoping review

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ABSTRACT

Muscle echo intensity, as measured by ultrasonography, could be used as a new marker of functional performance in older populations. This scoping review aimed to present evidence on the utility of muscle echo intensity as determined by ultrasonography for assessing functional performance in older adults. The eligibility criterion included observational studies that investigated the associations between muscle echo intensity and functional performance in older adults. Terms, such as "echo intensity" and "older adults", were searched for in databases, such as PubMed, Web of Science, the Cochrane database of systematic reviews, and the Cumulative Index of Nursing and Allied Health Literature, in April 2021. Two independent reviewers screened and extracted the data; 46 papers, of which almost one-third were Japanese, were subsequently identified for inclusion. The representative functional performances included in this review were muscle strength, gait speed, sit-to-stand test results, and timed up-and-go test results. Poor to moderate associations were found between muscle echo intensity and functional performance; however, heterogeneities were observed in the characteristics of study participants. Moreover, the accurate effect size and causal inferences between muscle echo intensity and functional performance remained unclear. Further longitudinal studies are needed to determine these causal inferences.

1. Introduction

Muscle atrophy is a condition that worsens with age and is characterized by a progressive loss of muscle mass (Stock et al., 2018; Cruz-Jentoft et al., 2019). This condition also impairs functional performances, such as muscle strength and walking ability (Chen et al., 2020). The decline in muscle function is thought to be associated with the loss of muscle mass and qualitative changes in the muscles (Stock and Thompson, 2021). Muscle performance has also been linked to a number of factors, including the structure, fiber type, and energy release mechanism (Stock and Thompson, 2021). Previously, computed tomography (CT) was the standard method for assessing muscle quantity and quality. However, studies have demonstrated the utility of ultrasound imaging as an alternative modality (Pillen et al., 2008; Pillen et al., 2009). Data obtained from ultrasound images have revealed that muscle thickness and echo intensity (EI) contribute to muscle strength and neuromuscular and cardiorespiratory performances (Fukumoto et al., 2012; Cadore et al., 2012). Studies showed that measurement of the muscle quantity and quality with ultrasonography had high reliability and validity (Nijholt et al., 2017; Caresio et al., 2015). The modality is, therefore, increasingly attracting attention as a convenient alternative to CT for assessing muscle volume.

Using ultrasound imaging to measure muscle thickness was a common method of evaluating biological tissues in previous decades (Abe et al., 2015). Since muscle thickness and cross-sectional area of the muscle are associated with muscle strength, a way to measure the cross-sectional area of a wide range of muscles using panoramic images was proposed as a more valid method for skeletal muscle mass measurement (Noorkoiv et al., 2010). While muscle thickness is the most common muscle quantity parameter that can be assessed by echo, fascicle pennation angle, fascicle length, and EI were reported to influence muscle strength as muscle quality parameters (Kuschel et al., 2022). In a systematic review, EI was found to be the most popular of them when considering associations to predict the association between muscle quality and clinical outcomes (Casey et al., 2022). Muscle EI has been reported to be useful in the evaluation of muscle strength (Ticinesi et al., 2017) as it can detect connective and adipose tissues within a muscle non-invasively (Pillen et al., 2009). It has been shown to be associated

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with muscle strength (Fukumoto et al., 2012), physical fitness (Cadore et al., 2012), level of daily activity (Lopez et al., 2017), and other functional performances (Yoshiko et al., 2019).

Some studies have investigated the association between the EI of the quadriceps and the strength of knee extension. EI is reportedly associated with the isometric strength of knee extension (Fukumoto et al., 2012), the isokinetic strength of knee extension (Cadore et al., 2012), and the rate of torque development (Lopez et al., 2017). Regarding other functional performance, EI is also reportedly associated with walking speed (Guadagnin et al., 2019), sit-to-stand (STS) test findings, and timed up-and-go (TUG) test findings (Osawa et al., 2017). EI is expected to act as a more feasible substitute for actual performance evaluation in cases where measuring functional performance would be difficult, such as in patients with dementia or those who experience pain while exercising.

Although a narrative review on muscle EI has been published, its purpose was to summarize the changes in EI in response to exercise and propose future consideration of the usefulness of the EI measurement (Wong et al., 2020). Another invited review searched papers from only two databases; the review quality was adversely affected by the limited use of databases (Stock and Thompson, 2021). Many such studies have been conducted on EI for the past 20 years. It is important for the field to develop a comprehensive understanding of EI in regard to functional performance. However, many of the prior studies expressed the following concerns: (1) they were conducted with heterogeneous measurement methods, (2) the participant demographics were diverse, and (3) the control sources varied (Stock and Thompson, 2021). Furthermore, it is unclear which exercise-induced changes seen in EI actually represent normal physiology (Wong et al., 2020). It is difficult to summarize reports of intervention trials (e.g., randomized controlled trials) in which exercise loading and other factors influence EI in the context of uncertainty about their interactions. Additionally, to the best of our knowledge, there have been few high-quality randomized controlled trials examining long-term changes in muscle EI with exercise in older adults. Thus, it is difficult to integrate changes in EI with exercise interventions by using meta-analysis. A scoping review would be a useful way to provide an overview of the gaps in knowledge for such topics (Munn et al., 2018). Therefore, we comprehensively investigated studies on the association of muscle EI measurements obtained from ultrasound images in assessing functional performance in older adults, with the exception of studies that attempted to measure EI before and after exercise interventions, and reported the overview of these studies and factors that may influence EI through this scoping review. We believe that our findings will bridge the gap between current knowledge and future research, contributing to the development of higher quality research and systematic reviews.

2. Materials and methods

This study protocol was written in accordance with the "Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols" (PRISMA-P) guidelines (Moher et al., 2015). Furthermore, this scoping review was conducted in accordance with previously published methodological guidelines for scoping reviews (Peters et al., 2020). The protocol of this review was registered with protocols.io in advance (https://dx.doi.org/10.17504/protocols.io.btibnkan).

2.1. Eligibility criteria

The "participants, concept, and context" framework was used to create the eligibility criteria. Participants were adults 60 years old or older, regardless of health status. The concept of the study was an investigation of the associations between muscle EI (determined using ultrasound imaging) and functional performance (e.g., muscle strength, STS test, and 6-minute walking test results). Lastly, no limitations on the location, race, or sex were imposed in context. However, the publication dates ranged between January 2000 and March 2021, and only observational studies (e.g., cohort studies, case-control studies, and cross-sectional studies) published in English with institutional review board protocol approval were included.

2.2. Search strategy

The search strategy was to identify both published and unpublished studies. A systematic electronic search was conducted on the following databases: PubMed, Web of Science, the Cochrane database of systematic reviews, and the Cumulative Index of Nursing and Allied Health Literature (CINAHL). The key search terms were "echo intensity" and "older adults"; additional details are provided in Appendix 1. A comprehensive literature search was initially performed on April 1, 2021. In September 2021, ClinicalTrials.gov was screened for relevant unpublished studies and gray literature.

2.3. Selection process

All identified articles were collated after the search, and duplicates were removed. After a pilot test, two independent reviewers (M.N. and T.K.) assessed the titles and abstracts of the articles against the inclusion criteria. Potentially relevant sources were retrieved in full, and their citation details were imported into Rayyan (Qatar Computing Research Institute, Ar Rayyan, Qatar) (Ouzzani et al., 2016). Thereafter, the two aforementioned independent reviewers (M.N. and T.K.) assessed the full texts of the selected articles against the inclusion criteria. Detailed reasons for excluding articles that did not meet the inclusion criteria were recorded. Any disagreements that arose between the reviewers at each stage of the selection process were resolved through a discussion with another reviewer (Y.F.). The search results and the study inclusion process (Fig. 1) are presented using a PRISMA flow diagram (Page et al., 2021).

2.4. Data extraction

Two independent reviewers (M.N. and T.K.) extracted data from the included papers using a data extraction sheet that the authors had developed. The extracted data included the year of publication, country of origin, aims/purpose, specific details of the study population, outcomes, study methods, and key findings relevant to the review question.

2.5. Descriptive statistics

Tables have been used to express the data extracted from the evidence. An online tool was used to create the diagram (https://www.mapchart.net/).

3. Results

3.1. Search results

A total of 955 titles and abstracts were identified in the database searches. Upon eliminating duplicates, 855 articles were screened using their titles and abstracts. The full text of the 91 remaining articles was then reviewed for eligibility. Finally, 46 articles were included in this review (Fig. 1). We reviewed each paper's reference list and found no additional reports that met the eligibility criteria for inclusion.

3.2. Study overview

Table 1 listed the study overview, including the lead author's country of residence, the body parts targeted for muscle EI evaluation, the ultrasound methods, and the functional performance. The included articles were published after 2012, with most published after 2017. A total of 19 studies (41.3 %) were conducted in Japan (Fukumoto et al., 2012;

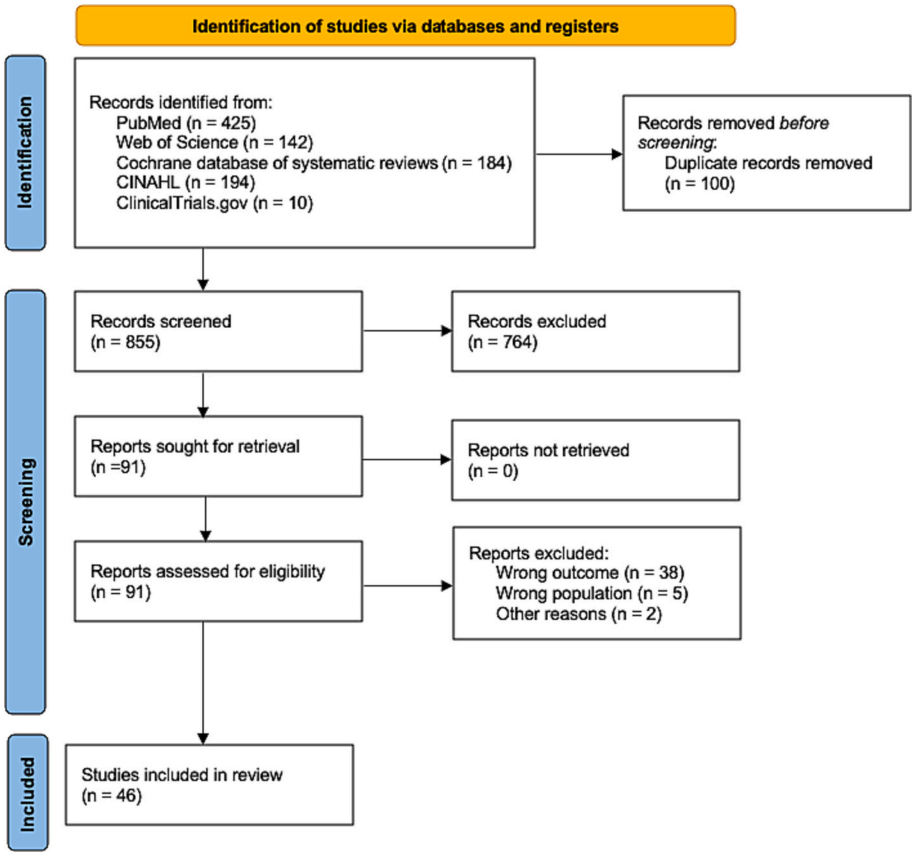

Fig. 1. Flow chart of the search strategy and results.

Watanabe et al., 2013; Nishihara et al., 2014; Masaki et al., 2016; Akima et al., 2017; Yamada et al., 2017; Akazawa et al., 2017; Osawa et al., 2017; Taniguchi et al., 2017; Akagi et al., 2018; Kawai et al., 2018; Yoshiko et al., 2018; Fukumoto et al., 2018; Yoshiko et al., 2019; Akazawa et al., 2019; Yamaguchi et al., 2019; Chantaramanee et al., 2019; Hara et al., 2020; Akima et al., 2020). Fourteen studies (30.4 %) were performed in the United States (Palmer and Thompson, 2017; Mota and Stock, 2017; Gerstner et al., 2017; Magrini et al., 2018; Mota et al., 2018; Stock et al., 2018; Harris-Love et al., 2018; Harris-Love et al., 2019; Olmos et al., 2019; Palmer et al., 2020; Olmos et al., 2020; Farrow et al., 2020; Bali et al., 2020; Komforti et al., 2021). Five studies (10.9 %) were performed in Brazil (Cadore et al., 2012; Rech et al., 2014; Wilhelm et al., 2014; Lopez et al., 2017; Guadagnin et al., 2019). Two studies (4.3 % per country) were performed in the United Kingdom (Maddocks et al., 2014; Wilson et al., 2019) and Taiwan (Chang et al., 2018; Chang et al., 2019). Finally, one study each (2.2 % per country) was performed in Austria (Strasser et al., 2013), Iran (Rajabkhah et al., 2020), Spain (Mirón Mombiela et al., 2017), and Switzerland (Wearing et al., 2019) (Table 1, Fig. 2).

The most commonly analyzed aspect was the association between thigh muscle EI and muscle strength during knee extension; there were a number of reports examining the relationship between the forearm and lower leg muscle EI and the strength of their target muscles. Additionally, in studies examining muscle strength, the maximum torque or force was the most common metric associated with muscle EI. Moreover, handgrip strength, rate of torque development, and power were used to measure muscle strength.

Regarding the ultrasound methods, most reports (43 studies, 93.5 %) used a linear probe, and only one study (Chantaramanee et al., 2019) used a convex probe. A total of 37 studies (80.4 %) used transverse images, and among them, 11 reports from the USA used panoramic images of the muscle for the EI calculation (Palmer and Thompson, 2017; Gerstner et al., 2017; Magrini et al., 2018; Mota et al., 2018; Stock et al., 2018; Olmos et al., 2019; Palmer et al., 2020; Olmos et al., 2020; Farrow et al., 2020; Bali et al., 2020; Komforti et al., 2021). Four studies (Strasser et al., 2013, Mota and Stock, 2017, Harris-Love et al., 2018, Harris-Love et al., 2019) used longitudinal images, and one study (Masaki et al., 2016) used both transverse and longitudinal images. A clear frequency was described in 34 studies, and it ranged from 6 to 13.6 MHz. In one study (Chang et al., 2018), the frequency ranged from 4 to 15 MHz, and was automatically adjusted according to the depth and focal zone. Other ultrasound device settings (e.g., gain and depth) were varied depending on the participant and target muscle. Most reports involved the participant being in a resting position while single captioned images of the target muscle were taken. Those images were used to calculate the EI using an image analysis software such as ImageJ.

3.3. Study outcomes

Table 2 lists the statistical methods and main findings. Many studies (37 studies, 80.4 %) examined bivariate correlation analyses between EI and functional performance, such as Pearson's product-moment correlation coefficient. In 29 studies (63.0 %), multivariate analyses including such as multiple linear regression analyses or partial correlation coefficients were used, with adjustment for possible confounding factor such as age, sex, or BMI.

The correlation coefficients between muscle EI and muscle strength ranged from −0.670 to −0.172 (Kawai et al., 2018; Cadore et al., 2012). Some studies also reported associations between muscle EI and walking ability; the absolute values of the correlation coefficients ranged from 0.178 to 0.480 (Chang et al., 2019; Rech et al., 2014). Muscle EI was reported to be most commonly correlated with maximum gait speed (Nishihara et al., 2014; Masaki et al., 2016; Akima et al., 2017; Chang et al., 2018; Yoshiko et al., 2018; Stock et al., 2018; Harris-Love et al.,

Table 1
Study overview from the 46 included papers.

Authors (year)	Lead author's country of residence	Population and sample size (mean age)	Body part targeted for echo intensity evaluation	Muscles	Ultrasound methods			Functional performance
					Type of probe	Imaging plane	Frequency	
Fukumoto et al. (2012)	Japan	Healthy, middle-aged, and elderly women (*n* = 92; 70.4 ± 5.5 years)	Thigh	RF	Linear	Transverse	8 MHz	Maximal isometric torque of knee extension
Cadore et al. (2012)	Brazil	Healthy elderly men (*n* = 31; 65.5 ± 5.0 years)	Thigh	RF	NR	NR	7.5 MHz	Maximal isometric and isokinetic torques of knee extension, peak oxygen uptake, maximum aerobic workload, and workloads at ventilatory thresholds evaluated on a cycle ergometer using a maximal incremental test
Strasser et al. (2013)	Austria	Elderly outpatients with neck, shoulder, and upper extremity pain (*n* = 26; 67.8 ± 4.8 years)	Thigh	RF, VI, VL, and VM	Linear	Longitudinal	7.25 MHz	Maximal isometric force of knee extension
Watanabe et al. (2013)	Japan	Elderly men living independently (*n* = 184; 74.4 ± 5.9 years)	Thigh	RF	Linear	Transverse	NR	Maximal isometric torque of knee extension
Wilhelm et al. (2014)	Brazil	Sedentary healthy men (n = 50; 66.1 ± 4.5 years)	Thigh	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Linear	Transverse	9 MHz	One repetition maximum, maximal isometric torque and RTD of knee extension, peak and average power of knee extension and countermovement jump, and 30-second STS test results
Maddocks et al. (2014)	United Kingdom	Healthy elderly individuals (n = 18; 63 ± 10 years) and patients with chronic obstructive pulmonary disease (*n* = 17; 68 ± 10 years)	Lower leg	TA	Linear	Transverse	8 MHz	Maximal isometric force of ankle dorsiflexion
Rech et al. (2014)	Brazil	Healthy, active, and elderly women (*n* = 45; 70.28 ± 6.2 years)	Thigh	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Linear	Transverse	9 MHz	Maximal isometric torque and RTD of knee extension, 30-second STS, UGS test findings, and handgrip strength
Nishihara et al. (2014)	Japan	Elderly individuals (*n* = 19; 73 ± 3.2 years)	Thigh	RF and VI	Linear	Transverse	8.8 MHz	5-m UGS/MGS, TUG test findings, and maximum isometric torque of knee extension
Masaki et al. (2016)	Japan	Middle-aged and elderly women (*n* = 35; 72.9 ± 7.4 years)	Trunk	Erector spinae, psoas major, and lumbar multifidus	Linear	Transverse, longitudinal	8 MHz	UGS and MGS
Lopez et al. (2017)	Brazil	Healthy sedentary older men (*n* = 50; 66 ± 5.4 years)	Thigh	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Linear	Transverse	9 MHz	30-second STS test findings
Palmer and Thompson (2017)	United States	Older men (n = 17; 72 ± 5 years)	Thigh	Hamstrings	Linear	Transverse (panoramic)	12 MHz	Maximal isometric torque and RTD of hip extension
Osawa et al. (2017)	Japan	Elderly individuals (*n* = 108; 90.3 ± 1.4 years)	Thigh	RF and VI (the mean value was considered for the two muscles)	Linear	Transverse	8 MHz	TUG and PA
Akima et al. (2017)	Japan	Healthy elderly individuals (*n* = 64; 72.0 ± 5.0 years)	Thigh	RF and VL (the mean value was considered for the two muscles)	Linear	Transverse	10 MHz	Sit-up, supine-up, 10-repetition STS test

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Table 1 (*continued*)

Authors (year)	Lead author's country of residence	Population and sample size (mean age)	Body part targeted for echo intensity evaluation	Muscles	Ultrasound methods			Functional performance
					Type of probe	Imaging plane	Frequency	
								findings, 5-m MGS time, and 6MWD
Mota and Stock (2017)	United States	Older men (n = 13; 74 ± 6 years)	Thigh	RF	Linear	Longitudinal	12 MHz	Maximal isometric force and endurance of knee extension
Yamada et al. (2017)	Japan	Community-dwelling older men (81.6 ± 7.4 years) and women (79.7 ± 6.9 years); *n* = 100	Thigh	RF, VL, and quadriceps femoris (mean of RF and VL; the mean value was considered for the two muscles)	Linear	NR	7.5 MHz	Presence of low muscle function (slower 5-m UGS and/or lower handgrip strength) determined using the definition provided by the Asian Working Group for Sarcopenia
Akazawa et al. (2017)	Japan	Older women who were unable to walk (dependent group; *n* = 25), frail older women (frail group; *n* = 22), and healthy older women (healthy group; *n* = 22)	Thigh	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Linear	Transverse	NR	Maximal isometric torque of knee extension, functional independence measure gait score, gait independence, and frailty
Taniguchi et al. (2017)	Japan	Elderly women living independently in the community (*n* = 179; 74.1 ± 4.9 years)	Thigh	RF	Linear	Transverse	8 MHz	Maximum isometric torque of knee extension
Gerstner et al. (2017)	United States	Older, healthy, and recreationally active men (*n* = 20; 69.5 ± 3.1 years)	Lower leg	Gastrocnemius	Linear	Transverse (panoramic)	10 MHz	%decrease in torque and %increase in the velocity of maximal concentric isokinetic contraction of ankle plantarflexion (mean and peak power; from 0.52 to 2.09 rad·s^{-1})
Mombiela et al. (2017)	Spain	Individuals (*n* = 112; 63.0 ± 15.8 years)	Thigh	RF	Linear	Transverse	NR	Handgrip strength and frailty
Akagi et al. (2018)	Japan	Elderly men (73 ± 5 years) and women (72 ± 7 years); *n* = 33	Lower leg	Lateral gastrocnemius and soleus (the mean value was considered for the two muscles)	Linear	Transverse	7 MHz	Maximal isometric torque of ankle plantarflexion
Kawai et al. (2018)	Japan	Community-dwelling older adults (*n* = 1239; 72.8 ± 5.3 years)	Thigh	RF	Linear	Transverse	6 MHz	Maximal isometric torque of knee extension
Chang et al. (2018)	Taiwan	Community-dwelling elderly adults (*n* = 140; aged >65 years)	Thigh, brachium, and lower leg	Biceps brachii, triceps brachii, RF, and medial gastrocnemius	Linear	Transverse	4 to 15 MHz (automatically adjusted)	Handgrip strength, 5-m MGS, and dynapenia without sarcopenia (lower handgrip strength and normal skeletal muscle mass index)
Magrini et al. (2018)	United States	Older women (*n* = 18; 74.87 ± 5.83 years)	Thigh	RF	Linear	Transverse (panoramic)	12 MHz	Maximal isometric torque of knee extension and power and velocity during STS movements
Yoshiko et al. (2018)	Japan	Elderly men and women (n = 22; 78 ± 8 years)	Thigh, brachium, and trunk	RF, biceps femoris, triceps brachii, and multifidus	Linear	Transverse	10 MHz	Maximal isometric torque of knee extension, functional reach, 30-second STS test findings, 5-m UGS/MGS, handgrip strength, and TUG test findings
Mota et al. (2018)	United States	Recreationally active older men (n = 22; 69 ± 3 years)	Lower leg	Gastrocnemius	Linear	Transverse (panoramic)	10 MHz	Velocity development rate of maximal isokinetic ankle plantarflexion
Stock et al. (2018)	United States	Older adults (n = 23; 74 ± 7 years)	Thigh	RF	Linear	Transverse (panoramic)	12 MHz	Maximal isometric torque and RTD of knee

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Table 1 (*continued*)

Authors (year)	Lead author's country of residence	Population and sample size (mean age)	Body part targeted for echo intensity evaluation	Muscles	Ultrasound methods			Functional performance
					Type of probe	Imaging plane	Frequency	
								extension, 10-m/400-m MGS
Harris-Love et al. (2018)	United States	Community-dwelling men (*n* = 30; 62.5 ± 9.2 years)	Thigh	RF	Linear	Longitudinal	13.6 MHz	Handgrip strength, maximal isokinetic torque of knee extension, and 10-m UGS/MGS
Fukumoto et al. (2018)	Japan	Community-dwelling older adults (*n* = 131; 72.9 ± 5.2 years)	Thigh	RF	Linear	Transverse	8 MHz	PA and 4-year changes in maximal isometric torque of knee extension
Akazawa et al. (2019)	Japan	Older inpatients (*n* = 103; 84.0 years [78.0–89.0 years])	Thigh	RF and VI (the mean value was considered for the two muscles)	Linear	Transverse	NR	Food intake level scale scores
Yamaguchi et al. (2019)	Japan	Community-dwelling elderly individuals (*n* = 139)	Head	Masseter muscle	Linear	Transverse	NR	Handgrip strength, UGS, and occlusal force
Chantaramanee et al. (2019)	Japan	Healthy elderly individuals (*n* = 94; 71.10 ± 4.13 years)	Head	Tongue muscles	Convex	Perpendicular, and tilted 45° to the Frankfurt horizontal plane	NR	Tongue pressure and oral diadochokinesis
Harris-Love et al. (2019)	United States	Older adults (n = 17; 65.1 ± 6.5 years)	Thigh	RF	Linear	Longitudinal	13.6 MHz	Handgrip strength
Guadagnin et al. (2019)	Brazil	Community-dwelling older individuals (*n* = 15; 75.4 ± 5 years)	Thigh and lower leg	VL, biceps femoris, RF, TA, and medial gastrocnemius	Linear	Transverse	7.5 MHz	UGS and MGS
Yoshiko et al. (2019)	Japan	Elderly men and women (*n* = 209; 73.7 ± 2.8 years)	Thigh	RF	Linear	Transverse	10 MHz	Handgrip strength, 5-repetition STS test findings, TUG, supine-up, 5-m UGS/MGS time, 6MWD, and PA
Wearing et al. (2019)	Switzerland	Nursing home residents (n = 30; 85.6 ± 7.1 years)	Thigh and brachium	RF and biceps brachii	Linear	Transverse	12 MHz	Level of dependence for activities of daily living
Chang et al. (2019)	Taiwan	Older participants (*n* = 129; 26 of these presented with the metabolic syndrome; >65 years)	Thigh, brachium, and lower leg	Biceps brachii, triceps brachii, RF, and medial gastrocnemius	NR	Transverse	NR	Handgrip strength and 5-m UGS
Wilson et al. (2019)	United Kingdom	Healthy older adults (*n* = 39; >65 years) and frail older adults (*n* = 31; >65 years)	Thigh	RF	Linear	Transverse	NR	Hand grip strength, 4-m UGS time, and frailty
Olmos et al. (2019)	United States	Healthy older men (n = 15; 65.3 ± 3.2 years)	Lower leg	Lateral gastrocnemius	Linear	Transverse (panoramic)	12 MHz	Power of ankle plantarflexion
Palmer et al. (2020)	United States	Healthy elderly men (*n* = 19; 73 ± 4 years)	Thigh	Long head of the biceps femoris, semitendinosus, and semimembranosus (the mean value was considered for the three muscles)	Linear	Transverse (panoramic)	12 MHz	Sway index with the eyes closed or open
Hara et al. (2020)	Japan	Healthy community-dwelling individuals (*n* = 74; 76.8 ± 9.0 years)	Head	Masseter muscle	Linear	Parallel to the occlusal plane	NR	Maximum biting force and displacement of the masseter muscle during forceful biting
Olmos et al. (2020)	United States	Healthy older men (n = 15; 65.33 ± 3.26 years)	Lower leg	Gastrocnemius	Linear	Transverse (panoramic)	NR	Torque, RTD, and impulse of maximal isometric ankle plantarflexion
Farrow et al. (2020)	United States	Older women (*n* = 23; 71.4 ± 5.2 years)	Thigh	VL	Linear	Transverse (panoramic)	12 MHz	Reactive strength index during countermovement jump

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Table 1 (*continued*)

Authors (year)	Lead author's country of residence	Population and sample size (mean age)	Body part targeted for echo intensity evaluation	Muscles	Ultrasound methods			Functional performance
					Type of probe	Imaging plane	Frequency	
Akima et al. (2020)	Japan	Pre-old individuals (n = 96; 69.3 ± 2.7 years) and old individuals (n = 36; 79.0 ± 2.9 years)	Thigh	RF, VL, and quadriceps femoris (mean of RF and VL)	Linear	Transverse	10 MHz	Sit-up, supine-up, 10-repetition STS test findings, 5-m MGS, 6MWD, and handgrip strength
Bali et al. (2020)	United States	Older adults (n = 25; 71 years)	Thigh	RF and VL (the mean value was considered for the two muscles)	Linear	Transverse (panoramic)	10 MHz	Torque and fatigability of maximal concentric knee extension
Rajabkhah et al. (2020)	Iran	Patients with amyotrophic lateral sclerosis (n = 18; 53.8 ± 12.1 years)	Forearm and lower leg	Abductor digiti minimi, abductor pollicis brevis, TA, and sum score (mean of three muscles)	Linear	Transverse	NR	Motor unit number index, manual muscle testing results, amyotrophic lateral sclerosis functional rating scale-revised scores, 9-hole peg test findings, handgrip strength, and pinch test findings
Komforti et al. (2021)	United States	Community-dwelling older adults (n = 90; 74 ± 6 years)	Thigh and lower leg	VL, RF, medial gastrocnemius, and lateral gastrocnemius	Linear	Transverse (panoramic)	10 MHz	4-m MGS

BMI: body mass index; MGS: maximum gait speed; NR: not reported; PA: physical activity; RF: rectus femoris; RTD: rate of torque development; STS: sit-to-stand; TA: tibialis anterior; TUG: timed up-and-go; UGS: usual gait speed; VI: vastus intermedius; VL: vastus lateralis; VM: vastus medialis; 6MWD: 6-min walking distance.

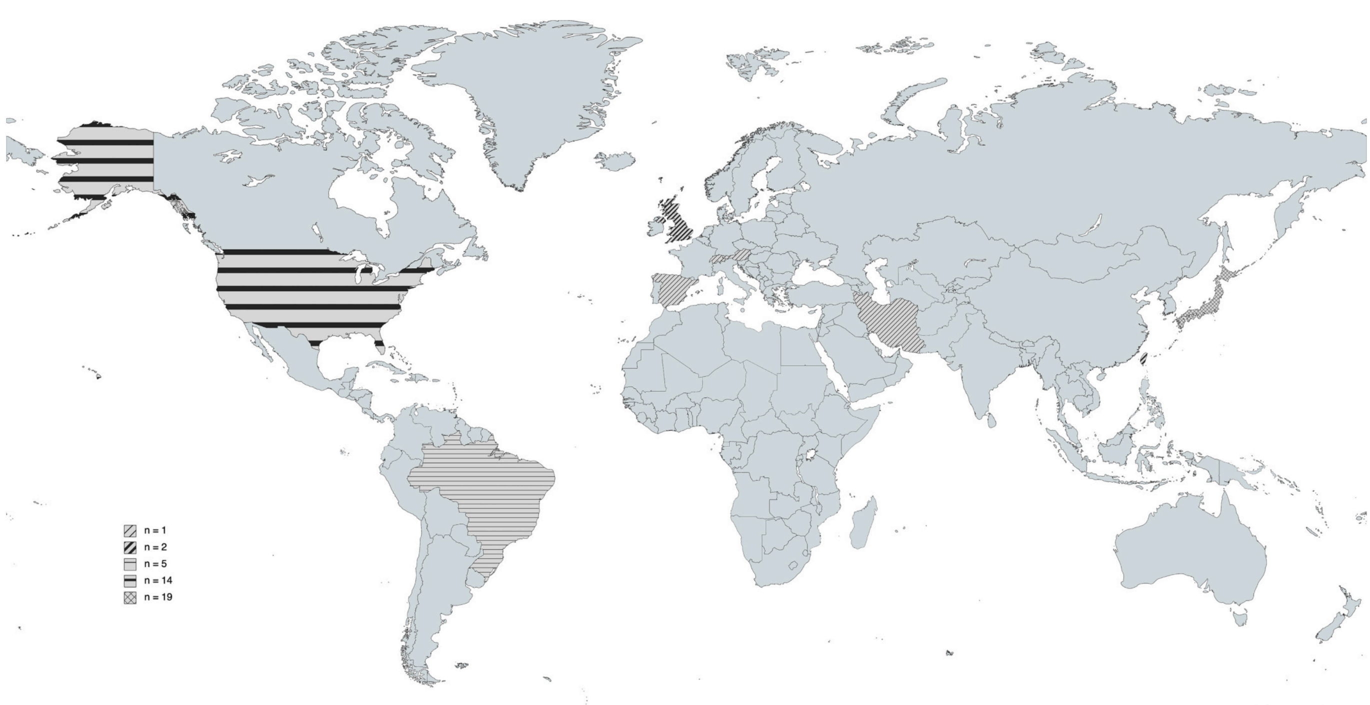

Fig. 2. Distribution of studies by country.

2018; Chang et al., 2019; Guadagnin et al., 2019; Yoshiko et al., 2019; Akima et al., 2020; Komforti et al., 2021) and normal gait speed (Nishihara et al., 2014; Rech et al., 2014; Masaki et al., 2016; Yamada et al., 2017; Yoshiko et al., 2018; Harris-Love et al., 2018; Yamaguchi et al., 2019; Guadagnin et al., 2019; Yoshiko et al., 2019; Wilson et al., 2019).

Associations between muscle EI and other performance tests were also frequently reported. The STS test was the most common functional performance associated with muscle EI; the correlation coefficients ranged from −0.595 to −0.296 (Akima et al., 2020; Wilhelm et al., 2014). The TUG test was the next most common performance test that showed an association with muscle EI. The only significant correlation coefficient between them was observed as 0.57 (Yoshiko et al., 2018). Other studies investigated the associations between muscle EI and the following assessments: physical activity (Osawa et al., 2017; Fukumoto et al., 2018; Yoshiko et al., 2019), diadochokinesis (Chantaramanee et al., 2019), Food Intake Level Scale scores (Akazawa et al., 2019), jump height (Wilhelm et al., 2014; Farrow et al., 2020), and sway indexes (Palmer et al., 2020). Detailed information on the correlation coefficients is presented in Table 2.

Table 2
Study outcomes from the 46 included papers.

Authors (year)	Sample size	Muscles	Statistical methods	Main findings
Fukumoto et al. (2012)	92	RF	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with maximal isometric torque as a dependent variable	EI was correlated with the maximal torque after controlling for age or MT ($r = -0.33$**). Stepwise regression analyses revealed that the EI and MT (but not the age and BMI) were independently associated with the maximal isometric torque.
Cadore et al. (2012)	31	RF	Pearson's product-moment correlation coefficient	EI was correlated with the maximal isometric and isokinetic torques ($r = -0.67$** to -0.48*) and with the workloads at ventilatory thresholds evaluated on a cycle ergometer using a maximal incremental test ($r = -0.50$** to -0.46*).
Strasser et al. (2013)	26	RF, VI, VL, and VM	Pearson's product-moment correlation coefficient, simple random effect mixed models with maximal isometric forces as a dependent variable	There were no significant associations between the maximal isometric forces and EI.
Watanabe et al. (2013)	184	RF	Pearson's product-moment correlation and partial correlation coefficient	Partial correlation analysis, with age, height, weight, and fat thickness as the control variables, revealed that the EI was correlated with the maximal isometric torque ($r = -0.301$**).
Wilhelm et al. (2014)	5	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Pearson's product-moment correlation coefficient	The EI of the quadriceps and all individual EIs were correlated with the 30-s STS test findings and power during a countermovement jump ($r = -0.746$* to -0.285*). There were significant correlations between all EI variables, one repetition maximum, maximal torque, and RTD at 0.2 s ($r = -0.657$* to -0.280*). However, only the vastus medialis EI and the quadriceps EI were correlated with the RTD at 0.05 s ($r = -0.393$* to -0.304*).
Maddocks et al. (2014)	18 (healthy elderly individuals) 17 (patients with chronic obstructive pulmonary disease)	TA	Pearson's product-moment correlation coefficient, Spearman's rank correlation coefficient, multiple linear regression analysis (stepwise method) with maximal isometric force as a dependent variable	EI was related to the force (r = −0.46***). Multiple linear regression analysis using a stepwise model revealed that the EI, cross-sectional area, age, and chronic obstructive pulmonary disease status were associated with the maximal isometric force.
Rech et al. (2014)	45	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Pearson's product-moment correlation coefficient	The quadriceps EI was correlated with the 30-second STS test findings, maximal isometric torque, and handgrip strength ($r = -0.493$** to -0.334*). The quadriceps EI was correlated with the RTDs 0–0.1 s, 0–0.25 s, and 0–0.3 s ($r = -0.386$** to -0.346**).
Nishihara et al. (2014)	19	RF and VI	Pearson's product-moment correlation coefficient	EI was not associated with any functional performances.
Masaki et al. (2016)	35	Erector spinae, psoas major, and lumbar multifidus	partial correlation coefficient and multiple linear regression analysis (stepwise method) with UGS and MGS as a dependent variable	Partial correlations with age as a control variable and Stepwise regression analysis revealed that the EIs of the lumbar back muscles were not associated with the UGS or MGS.
Lopez et al. (2017)	50	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	Pearson's product-moment correlation coefficient, and multiple linear regression analysis (stepwise method) with the 30-s STS test findings as a dependent variable	The quadriceps EI showed a correlation with the 30-s STS test findings ($r = -0.564$***). Multiple stepwise linear regression demonstrated that the EI and the RTD, but not the MT, explained the 30-s STS test findings.
Palmer and Thompson (2017)	17	Hamstrings	Pearson's product-moment correlation coefficient	The EI was correlated with RTD ($r = -0.642$*).
Osawa et al. (2017)	108	RF and VI (the mean value was considered for the two muscles)	Multiple linear regression analysis (stepwise method) with TUG and PA as a dependent variable	The EI was associated with both the TUG and a moderate-to-vigorous PA when adjusted for age, sex, BMI, and MT. However, the association between the EI and TUG disappeared after adjusting for the PA.
Akima et al. (2017)	64	RF and VL (the mean value was considered for the two muscles)	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with EI as a dependent variable	The quadriceps EI was correlated with the supine-up, 10-repetition STS, and 6MWD test findings in older men ($r = 0.535$**, 0.492*, and -0.470*, respectively), and only with the 10-repetition STS test findings in women ($r = 0.385$*).
Mota and Stock (2017)	13	RF	Pearson's product-moment correlation coefficient	The EI was correlated with the normalized maximal isometric force ($r = -0.580$*).
Yamada et al. (2017)	100	RF, VL, and quadriceps femoris (mean of RF and VL; the mean value was considered for the two muscles)	*t*-Test for comparison between older individuals with low muscle function and those with normal muscle function	The EI was higher in older individuals with a low muscle function than in those with a normal muscle function.

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Table 2 (*continued*)

Authors (year)	Sample size	Muscles	Statistical methods	Main findings
Akazawa et al. (2017)	25 (dependent group) 22 (frail group) 22 (healthy group)	RF, VI, VL, VM, and quadriceps femoris (the mean value was considered for the four muscles)	One-way analysis of variance for comparison between groups. Pearson's product-moment correlation coefficient, the Kendall correlation test, and multiple linear regression analysis (stepwise method) with maximal isometric torque and functional independence measure gait score as a dependent variable	The EI in the dependent group was correlated with the maximal isometric torque ($r = -0.635$**) and functional independence measure gait score ($r = -0.344$*). The EIs were significantly higher in the dependent and frail groups than in the healthy group.
Taniguchi et al. (2017)	179	RF	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with maximum isometric torque as a dependent variable	Multiple linear regression analysis performed using the stepwise method indicated that the EI, MT, and extracellular water/intracellular water ratio in the upper thigh (but not the age, BMI, and knee pain) were independently associated with the maximal isometric torque.
Gerstner et al. (2017)	20	Gastrocnemius	Pearson's product-moment correlation coefficient	The EI corrected for subcutaneous fat was related to the %decrease in torque ($r = 0.526$*) and %increase in peak power ($r = -0.524$*).
Mirón Mombiela et al. (2017)	112	RF	Analysis of variance and the Kruskal-Wallis test for comparison among frailty stages Pearson's product-moment correlation coefficient and Spearman's rank correlation coefficient for handgrip strength	Higher values of EI were associated with a lower handgrip strength and greater frailty. There was a correlation between the EI and the handgrip strength (men: $r = -0.355$**; women: $r = -0.522$**).
Akagi et al. (2018)	33	Lateral gastrocnemius and soleus (the mean value was considered for the two muscles)	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with maximal isometric torque as a dependent variable	Stepwise regression analysis revealed that both the muscle volume and EI were significant contributors to the maximal isometric torque.
Kawai et al. (2018)	1239	RF	Pearson's product-moment correlation coefficient and partial correlation coefficient	EI showed a correlation with the maximal isometric torque after controlling for age in men ($r = -0.200$**). A correlation was also observed between the EI and the knee extension torque ($r = -0.172$**) in women.
Chang et al. (2018)	140	Biceps brachii, triceps brachii, RF, and medial gastrocnemius	Pearson's product-moment correlation coefficient for handgrip strength and 5-m MGS. Logistic regression analysis with the presence of dynapenia as a dependent variable	The handgrip strength was associated with the EIs of the biceps brachii ($r = -0.253$*), triceps brachii ($r = -0.308$*), and rectus femoris ($r = -0.353$*) muscles. No muscle EIs were associated with the 5-m MGS or dynapenia.
Magrini et al. (2018)	18	RF	Pearson's product-moment correlation coefficient	There were no significant associations between any functional performances and EI.
Yoshiko et al. (2018)	22	RF, biceps femoris, triceps brachii, and multifidus	Pearson's product-moment correlation coefficient multiple linear regression analysis (stepwise method) with EIs as a dependent variable	The EI in the multifidus was found to be significantly correlated with the knee extension torque ($r = -0.59$*), functional reach ($r = -0.44$*), STS test findings ($r = -0.50$*), handgrip strength (r = −0.44*), 5-m MGS ($r = 0.42$*), and TUG findings ($r = 0.57$*). The EI of the multifidus was explained by the combination of muscle mass and the TUG ($R = 0.81$, adjusted $R^2 = 0.61$**).
Mota et al. (2018)	22	Gastrocnemius	Pearson's product-moment correlation coefficient	The plantar flexor rate of velocity development was related to the EI ($r = -0.491$*).
Stock et al. (2018)	23	RF	Pearson's product-moment correlation coefficient	After controlling for age and height, the normalized torque, RTD200, 10-m MGS, and 400-m MGS were correlated with the EI values of the rectus femoris corrected for the subcutaneous fat ($r = -0.500$*, −0.424*, −0.491*, and −0.481*, respectively).
Harris-Love et al. (2018)	30	RF	Pearson's product-moment correlation coefficient	EI was related to grip (r = −0.41*), adjusted grip (r = −0.50**), 60°/s knee extension ($r = -0.38$*), adjusted 60°/s knee extension ($r = -0.47$**), 180°/s knee extension ($r = -0.41$*), and adjusted 180°/s knee extension (r = −0.49**).
Fukumoto et al. (2018)	131	RF	Multiple linear regression analyses with 4-year change in EI as a dependent variable Partial correlation coefficient between 4-year changes in EI and those in maximal isometric torque	The difference in the PA at baseline was a significant predictor of the 4-year changes in the EI. Changes in EI were not significantly related with those in maximal isometric torque after controlling for baseline age, sex, BMI, and changes in MT.
Akazawa et al. (2019)	103	RF and VI (the mean value was considered for the two muscles)	Pearson's product-moment correlation coefficient, Kendall's tau rank correlation coefficient, and multiple linear regression analysis with food intake level scale scores as dependent variable	The EI was related to the food intake level scale score (r = −0.20**). Multiple regression analysis revealed that the EI, number of medications, and subcutaneous fat thickness of the thigh were independently associated with the food intake level scale scores.
Yamaguchi et al. (2019)	139	Masseter muscle	Pearson's product-moment correlation coefficient, Spearman's rank correlation	The EI was related to the handgrip strength ($r = -0.42$*), UGS ($r = -0.27$*), and occlusal

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Table 2 (*continued*)

Authors (year)	Sample size	Muscles	Statistical methods	Main findings
			coefficient, and multiple linear regression analysis with EI as a dependent variable	force ($r = -0.23$*). Multiple regression analyses identified BMI, handgrip strength, UGS, and MT (but not age, sex, SMI, calf circumference, tooth loss, and occlusal force) as the significant factors associated with the EI during contraction.
Chantaramanee et al. (2019)	94	Tongue muscles	Multiple linear regression analysis with EI as a dependent variable	Multiple regression analysis revealed that the middle-tongue thickness and pronunciation of /ta/ (but not age, tongue pressure, and pronunciation of /ka/) were the significant independent variables for EI at the middle tongue, and basal tongue thickness and pronunciation of /ka/, but not age, tongue pressure, and pronunciation of /ta/, were significant independent variables for EI at basal tongue.
Harris-Love et al. (2019)	17	RF	Linear regression analyses, multiple linear regression analyses with handgrip strength as a dependent variable	Multiple linear regression analyses revealed that compared to EI, the handgrip strength showed a stronger association with the shape or dispersion parameters from statistical models fitted to a grayscale intensity histogram.
Guadagnin et al. (2019)	15	VL, biceps femoris, RF, TA, and medial gastrocnemius	Pearson's product-moment correlation coefficient	No significant associations between the EI and functional performance were observed.
Yoshiko et al. (2019)	209	RF	One-way analysis of variance for comparison among the three EI groups A stepwise discriminant analysis with the EI groups as dependent variable	Compared to the low EI group, the high EI group exhibited a significantly lower SMI, shorter 5-m MGS time, and shorter 6MWD. Furthermore, compared to the mid-EI group, the high-EI group had a shorter moderate-intensity PA time. Stepwise linear discriminant analysis identified the 6MWD, SMI, and moderate-intensity PA time (but not the muscle mass, fat mass, BMI, and other functional or PA parameters) as the factors that allowed a differentiation into the high, mid, and low EI groups.
Wearing et al. (2019)	30	RF and biceps brachii	Spearman's rank correlation coefficient, logistic regression analysis	Negligible correlations were observed between the EI and the level of dependence for activity of daily living.
Chang et al. (2019)	129	Biceps brachii, triceps brachii, RF, and medial gastrocnemius	Correlation analyses	The biceps brachii EI was related to the handgrip strength ($r = -0.300$***). The triceps brachii EI was related to the handgrip strength ($r = -0.302$***). The rectus femoris EI was related to the UGS ($r = -0.178$*) and the handgrip strength ($r = -0.319$***).
Wilson et al. (2019)	39 (healthy older adults) 31 (frail older adults)	RF	Pearson's product-moment correlation coefficient, partial correlation coefficient, and Spearman's rank correlation coefficient for handgrip strength and 4-m UGS time Independent Kruskal-Wallis and post hoc pairwise comparisons for between-group comparison	The EI was correlated with the adjusted handgrip strength ($\rho = -0.529$***) and the UGS ($\rho = -0.302$***). These associations were significant after controlling for bilateral anterior thigh thickness. EI increased with frailty.
Olmos et al. (2019)	15	Lateral gastrocnemius	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with power as a dependent variable	The EI was correlated with the power ($r = -0.387$*). Stepwise multiple regression analysis identified RTD (but not the EI, torque, age, and cross-sectional area) as a predictor for power.
Palmer et al. (2020)	19	Long head of the biceps femoris, semitendinosus, and semimembranosus (the mean value was considered for the three muscles)	Pearson's product-moment correlation coefficient	The sway index with the eyes closed, but not with the eyes open, was related to the EI ($r = 0.474$*).
Hara et al. (2020)	74	Masseter muscle	Pearson's product-moment correlation coefficient, Spearman's rank correlation coefficient, and multiple linear regression analysis with the maximum biting force and displacement of the masseter muscle during forceful biting as a dependent variable	The maximum bite force was correlated with the masseter muscle EI ($r = -0.460$***). Displacement of the masseter muscle during forceful biting was also correlated with the masseter muscle EI ($r = -0.574$***). The Multivariate analysis revealed that the maximum bite force was significantly correlated with the number of teeth, but not with masseter muscle MT or EI, and that displacement of the masseter muscle during forceful biting was correlated with masseter muscle EI.
Olmos et al. (2020)	15	Gastrocnemius	Partial correlation coefficient	The EI was correlated with the RTD from the onset of contraction to 50 ms thereafter ($r =$

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Table 2 (*continued*)

Authors (year)	Sample size	Muscles	Statistical methods	Main findings
				−0.45*), and was correlated with the torque at 50, 100, and 200 ms from the onset of contraction (r = −0.44*, −0.38* and −0.38*, respectively), after controlling for age.
Farrow et al. (2020)	23	VL	Pearson's product-moment correlation coefficient	EI was related to the reactive strength index (r = −0.443*).
Akima et al. (2020)	96 (pre-old individuals) 36 (old individuals)	RF, VL, and quadriceps femoris (mean of RF and VL)	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with the EI as a dependent variable	The EI of RF was correlated with the supine-up test findings (r = 0.225*), STS test findings (r = 0.268**), and handgrip strength (r = −0.256*) in the Pre-old group, and with the 5-m MGS (r = 0.426*) in the Old group. The EI of VL was correlated with the handgrip strength (r = −0.283*) in the Pre-old group and the 5-m MGS (r = 0.389*) in the Old group. The EI of quadriceps was correlated with the STS test findings (r = 0.203*) and the handgrip strength (r = −0.296**) in the Pre-old group, and with the 5-m MGS (r = 0.473**) in the Old group.
Bali et al. (2020)	25	RF and VL (the mean value was considered for the two muscles)	Pearson's product-moment correlation coefficient, multiple linear regression analysis (stepwise method) with the EI as a dependent variable	The raw EI was associated with the peak torque (r = −0.527***) and specific torque (r = −0.335*). The corrected EI was also associated with the peak torque (r = −0.453***) and specific torque (r = −0.337*).
Rajabkhah et al. (2020)	18	Abductor digiti minimi, abductor pollicis brevis, TA, and sum score (mean of three muscles)	Pearson's product-moment correlation coefficient	The EI in the abductor digiti minimi muscles was associated with the 9-hole peg test findings (r = 0.71**). The EI in the abductor pollicis brevis muscles was associated with the amyotrophic lateral sclerosis functional rating scale-revised scores (r = −0.59*), 9-hole peg test findings (r = 0.69**), handgrip strength (r = −0.76*), pinch test findings (r = −0.84**), and motor unit number index (r = −0.60*). The EI in the tibialis anterior muscles was associated with manual muscle testing (r = −0.68**) and the motor unit number index (r = −0.69**). The EI of sum score was associated with 9-hole peg test findings (r = 0.71**), handgrip strength (r = −0.79*), and the motor unit number index (r = −0.67**).
Komforti et al. (2021)	90	VL, RF, medial gastrocnemius, and lateral gastrocnemius	Pearson's product-moment correlation coefficient and multiple linear regression analysis (stepwise method) for 4-m MGS	The 4-m MGS was associated with the EIs in the RF (r = −0.300**), VL (r = −0.282**), and medial gastrocnemius (r = −0.328**). However, in stepwise regression analyses with the 4-m MGS as the dependent variable, the EI, cross-sectional area, and subcutaneous adipose tissue thickness of all muscles were excluded and the chair stand test findings, heel-rise test findings, and handgrip strength were included.

BMI: body mass index; EI: echo intensity; MGS: maximum gait speed; MT: muscle thickness; PA: physical activity; RF: rectus femoris; RTD: rate of torque development; SMI: skeletal muscle mass index; STS: sit-to-stand; TA: tibialis anterior; TUG: timed up-and-go; UGS: usual gait speed; VI: vastus intermedius; VL: vastus lateralis; VM: vastus medialis; 6MWD: 6-min walking distance.
*: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

4. Discussion

In this scoping review, we systematically searched for and presented studies that assessed the association between muscle EI and functional performance in older adults. Many of these studies were conducted in Japan. The functional performances typically included tests of muscle strength, walking speed, and speed of standing up. Moreover, some studies included patients with amyotrophic lateral sclerosis (Rajabkhah et al., 2020) or chronic obstructive pulmonary disease (Maddocks et al., 2014). For the past decade, this field of research has seen an increase in the number of studies related to muscle EI (Fukumoto et al., 2012).

The most frequently measured functional performance was muscle strength (Table 2, Appendix 2) and the most frequently reported association was between the EI of the quadriceps muscle and the maximal muscle strength during knee extension. The muscle volume or thickness was closely related to the muscle strength (Fukunaga et al., 2001); EI was correlated with the muscle strength, independent of the muscle thickness and participant age (Fukumoto et al., 2012; Watanabe et al., 2013). This is because EI represents the quality of the muscle, not the quantity (Young et al., 2016).

When interpreting the correlation coefficients, it is common to express each as an absolute value as follows; <0.3: poor, 0.3 to 0.5: fair, 0.6 up to 0.8: moderate, and at least 0.8: very strong (Akoglu, 2018). In the studies included in this review, the strength of the correlation coefficients varied considerably between the studies, ranging from poor to moderate. Since the confidence intervals were wide and low in precision, it would be desirable to verify the correlation coefficients with higher precision through further research. One reason for the variations was the lack of uniformity in how EI was measured. There are many ultrasound device settings that influence EI, such as frequency, focus depth, image depth, and gain. High-frequency ultrasound can improve the axial resolution of the image but has low tissue penetration (Lieu, 2010). Therefore, EI obtained at high frequency is more attenuated than that at low frequency, especially for deeper muscles. A focus adjusting at depth of muscle mitigate the attenuation of EI and improve the accuracy of EI as a measure of muscle quality (Fukumoto et al., 2022). EI obtained at higher gain is substantially higher than that at lower gain, while changing image depth may not be problematic for EI (Girts et al., 2022). Optimal device setting which maximize the accuracy of EI as a measure of muscle quality should be clarified in future. In addition, observer dependent factors such as the adjustment of the probe could influence EI. For example, tilting angle of probe during imaging is reported to influence EI more than MT (Dankel et al., 2020). Within the same study, the adjustment of the probe (such as compressive stress or tilting angle) was often standardized (Harris-Love et al., 2014; Nakanishi et al., 2021). However, such standardizations differed across various studies. This may have led to inconsistent results, even though EI measurements were performed in similar participants. Another methodological factor responsible for poor to moderate EI correlation coefficients is the subcutaneous fat thickness (Young et al., 2015). Some studies have used an index that calibrated EI with the subcutaneous fat thickness (Young et al., 2016). Future studies should focus on developing a measurement method that overcomes these problems.

Based on evidence that the quadriceps muscle EI is related to knee extension strength, many studies have been conducted on the association between muscle EI and gait ability. Muscle EI is generally related to rate of torque development and muscle power (Rech et al., 2014; Wilhelm et al., 2014; Lopez et al., 2017; Palmer and Thompson, 2017; Stock et al., 2018; Olmos et al., 2020). Although other confounding factors need to be taken into account, the strength of the association of muscle EI with performance is likely to be greater than the strength of the association of muscle EI with muscle mass and thickness, i.e., the muscle quantity index. However, because many of the existing studies on this topic were cross-sectional in design, the causal inference remains unknown. In future studies, EI should be considered a muscle morphological factor that affects gait ability. In addition to the gait ability, several other functional performances have also been associated with muscle EI. However, the correlation coefficients varied from poor to moderate, and only a few studies investigated the association as a secondary outcome. Furthermore, the certainty of this evidence remains unclear due to the relatively small sample size of some studies. Recently, the STS and TUG tests seem to be the most popular metrics (Rech et al., 2014; Wilhelm et al., 2014; Lopez et al., 2017; Akima et al., 2017; Yoshiko et al., 2018; Akima et al., 2020). Future studies should carefully calculate sample sizes for primary outcomes.

The participants in the studies reviewed herein were heterogeneous in terms of their characteristics. Studies have indicated that factors such as gender, age, race, and ethnicity can all influence muscle EI values (Stock and Thompson, 2021; Melvin et al., 2014). In future interventional and observational studies, the race of the participants, outcomes, and target muscles should be carefully considered and determined by reference to previous studies. Furthermore, sex, age, body mass index, and subcutaneous fat thickness must be considered potential confounders of muscle EI (Osawa et al., 2017; Mirón Mombiela et al., 2017). Moreover, no study included in this scoping review established a uniform method of measuring muscle EI. Further studies in this discipline might yield different results even if a systematic review was performed. Thus, it is advisable to describe the details of muscle EI measurement in advance.

We performed a scoping review rather than a systematic review to obtain an exhaustive and broad range of information on the association between muscle EI and functional performance in older adults. However, this review has several limitations. First, although we obtained a considerable amount of information, the risk of bias was not assessed. Although risk-of-bias assessments are not mandatory in scoping reviews, an evaluation of the quality of the included studies may lead to the discovery of new issues and different conclusions. Furthermore, based on the data we were able to collect, a future meta-analysis of correlation coefficients appears to be feasible. Second, many studies that reported on the associations between muscle EI and functional performance were cross-sectional in design. Therefore, some of our findings are difficult to explain causally. More longitudinal studies in the future will clarify the causal inference between muscle EI and functional performance. Third, there is a lack of reports on the validity of the measurement method itself. Few studies have demonstrated the superiority of muscle EI measurement over the conventional method of directly measuring functional performance. Thus, to improve the outcomes of the participants, future studies are needed to understand the pathophysiology reflected by EI, the use of EI as a diagnostic tool, and its cost-effectiveness.

5. Conclusion

EI is an ultrasound imaging parameter that can represent a variety of functional performances. There is still a lack of clarity regarding the accurate effect size and causal inferences between muscle EI and functional performance. Future longitudinal studies should clarify its causal inferences with different functional performances.

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Data availability

Data will be made available on request.

Acknowledgments

Not applicable.

Appendix 1. Search strategy

PubMed search strategy

(((“muscle, skeletal”[MeSH Terms] OR “muscle”[Title/Abstract]) AND (“ultrasonography”[MeSH Terms] OR “ultrasonography”[Title/Abstract] OR “echogenicity”[Title/Abstract] OR “echo intensity”[Title/Abstract]))) AND ((“geriatric*”[All Fields] OR “elder*”[All Fields] OR “old-age”[All Fields] OR “pensioner*”[All Fields]) AND (“geriatric*”[All Fields] OR “elder*”[All Fields] OR “old-age”[All Fields] OR “pensioner*”[All Fields]))

Web of Science search strategy

((Muscle AND (echogenicity[tiab] OR “echo intensity”[tiab]))) AND ((Geriatric* or Elder* or old-age or pensioner*))

CENTRAL search strategy

((MeSH descriptor: [Muscles] explode all trees) AND (ultrasonography or echogenicity or “echo intensity”):ti,ab,kw) AND ((MeSH descriptor:

[Geriatrics] explode all trees) OR (MeSH descriptor: [Aged] in all MeSH products))
CINAHL search strategy

((MH "Muscle, Skeletal") AND (TI (ultrasound or echogenicity or "echo intensity") OR AB (ultrasound or echogenicity or "echo intensity"))) AND (MH "Geriatrics" OR MH "Aged" OR (TI(Geriatric* or Elder* or old-age or pensioner*)) OR (AB(Geriatric* or Elder* or old-age or pensioner*)

Appendix 2. Count of each performance outcome studied

Types of outcomes	Outcome details	Count
Body part targeted for the echo intensity evaluation	Thigh	36
	Lower leg	11
	Brachium	4
	Head	3
	Trunk	2
	Forearm	1
Performance-related muscle strength parameters	Force or torque	24
	Handgrip strength	13
	Rate of torque development	5
	Power	4
	Velocity	2
	Displacement of the masseter muscle during forceful biting	1
	Endurance	1
	One repetition maximum	1
	Peak oxygen uptake	1
	Workload	1
	Fatigability	1
	Impulse	1
	Manual muscle testing	1
	Motor unit number index	1
	Pinch test	1
	Rate of velocity development	1
	Tongue pressure	1
Performance-related gait ability parameters	Maximum gait speed	11
	Usual gait speed	11
	6-minute walk test	3
	Functional independence measure gait score	1
	Gait kinematics	1
	Independence	1
Other performance tests	Sit-to-stand test	8
	Timed up-and-go test	4
	Supine-up	3
	Jump performance	2
	Sit-up	2
	Functional reach test	1
	Sway index	1
Others assessments	Physical activity	3
	Frailty	3
	ADL dependence	1
	ALS functional rating scale-revised	1
	Diadochokinesis	1
	Food Intake Level Scale	1
	9-hole peg test	1

ADL: activities of daily living; ALS: amyotrophic lateral sclerosis.

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