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Review

Validity of Quantitative and Qualitative Assessments of Skeletal Muscles in the Lower Extremities Using Ultrasound Imaging: A Literature Review

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Abstract:

Purpose: To explore the use of ultrasound (US) for quantitative and qualitative assessment of muscles (especially the tongue) in dentistry, we performed investigations using muscles of the lower extremities. These muscles are often used to assess skeletal muscles in general. We aimed to determine whether there was a correlation between quantitative and qualitative assessments of lower extremity muscles using diagnostic US and computed tomography (CT) scans in adults.

Procedure: We conducted a search for English articles published in PubMed and Scopus from its inception up to October 18, 2022. We used a combination of the keywords "muscle," "ultrasonography," and "computed tomography" for the search. Additionally, we manually searched through relevant journals and search engines.

Main findings: After applying the inclusion criteria, we ultimately selected seven studies for inclusion in this review. These seven studies focused on muscle mass and involved ultrasonographic evaluations of muscle thickness and cross-sectional area as well as CT evaluations of muscle volume and cross-sectional area. Two studies also evaluated muscle quality using echo intensity (EI) for US assessment and CT values for CT assessment. In three of the seven studies, there was a significant correlation between the US and CT results. Three studies also determined an intraclass correlation coefficient (≥0.8 in all three) to determine the correlation between CT and US. In both studies that additionally assessed muscle quality, a strong correlation was observed between CT and US measurements.

Conclusion: Our results suggest that US can be used to perform high quality assessments of lower extremity muscles and muscle mass in healthy individuals and patients with mild or moderate disease. In the future, high quality research on the tongue is needed for application to the field of dentistry.

1. Introduction

To improve life expectancy, various efforts are being made to maintain functional lifestyles and prevent malnutrition and loss of muscle mass in older people, which can cause serious lifestyle-impacting diseases. The quality of life of elderly individuals can be improved if functional impairments are detected at an early stage and interventions to prevent, maintain, or reduce these impairments are implemented. It has been noted that muscle weakness is associated with falls[1)]; therefore, maintenance of muscle function in elderly people is extremely important. The prevalence of sarcopenia, or muscle loss that occurs with aging, is also increasing. It has been reported that sarcopenia increases the risk of death and need for nursing care by approximately two-fold[2)]. Sarcopenia can

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be assessed based on skeletal muscle mass, grip strength, and walking speed.

Computed tomography (CT) and magnetic resonance imaging (MRI) have been used for muscle assessments. Muscle mass can be quantified in terms of cross-sectional area using CT or MRI, while muscle quality is assessed using MRI signal intensity and CT values. However, both CT and MRI, while highly precise, have significant costs and require specialized equipment. Moreover, CT involves a large amount of radiation exposure, while MRI is a time-consuming procedure. Considering the potential adverse effects and cost of these tests, simpler methods of evaluation are desirable. Compared to CT and MRI, ultrasonography (US) is inexpensive, fast, and does not expose the patient to radiation. Furthermore, US devices are compact and suitable for bedside use. However, US images are generated based on relative evaluations, and it is difficult to compare the results with those of other imaging modalities. Recently, however, muscle thickness measured by US has come to be used as a quantitative index, while muscle echo intensity (EI) is being used as a qualitative index. Research has indicated a strong correlation between muscle EI and non-contractile tissues such as adipose and connective tissues within skeletal muscles[3], as well as an inverse relationship with muscle strength[4].

Japan has become a super-aging society, and the number of elderly individuals requiring long-term care is increasing. If an evaluation method using US, which can be used easily at the bedside, can be established and be as reliable as CT, it can be expected to be a useful screening tool for muscle in elderly individuals. In recent years, US devices have been used in dentistry for imaging of the head and neck region[5, 6] and for measuring the muscle mass and muscle quality of the tongue[7, 8]. Despite growing interest, the evaluation of muscle mass and quality in the head and neck region using US equipment is still not common. In this review, we will explore the utility of quantitative and qualitative assessment of muscles, especially the tongue, by US in the dental field.

This review aimed to explore the utility of quantitative and qualitative assessment of muscles, especially the tongue, by ultrasonography in dentistry, focusing on the muscles of the lower extremities, to determine if there are differences between ultrasonography and CT assessments.

2. Material and Methods

2.1 Data Search

English articles published from its inception until October 18, 2022 were searched using the MEDLINE (via PubMed) and Scopus databases. A combination of keywords, including "muscle" (MeSH), "ultrasonography" (MeSH), and "computed tomography" (MeSH), was used for the search. In addition, relevant journals and search engines were manually searched.

2.2. Inclusion Criteria

The inclusion criteria were as follows: 1) studies published in English, 2) studies including adult participants, and 3) studies where the same region was evaluated by both US and CT.

Case reports, review articles, studies that evaluated regions other than the lower extremities, studies where the similarity between the US and CT results was not statistically analyzed, and articles that were not readable in their entirety were excluded.

2.3. Study Selection

Two authors (K.F. and K.N.) determined the inclusion criteria and independently conducted the literature search. First, titles and abstracts were selected based on the objectives and criteria. Then, two authors (K.F. and K.N.) verified whether their selections matched and read the matched articles in full to confirm that detailed information was reported. Finally, they (K.F. and H.S.) assessed the efficacy of US in evaluating lower extremity muscles by reviewing the outcomes of the chosen studies.

3. Results

The papers were extracted according to the schematic shown in Figure 1. A summary of the seven extracted papers is shown in Table 1 and Table 2. Three studies included healthy subjects, including athletes[9-11]; one included patients admitted to the intensive care unit (ICU) with nervous system diseases[12]; one included patients with ischemic heart disease[13]; and two included patients with chronic kidney disease[14, 15]. All seven studies investigated muscle mass, and two studies additionally evaluated muscle quality[9, 14]. Muscle mass was evaluated by US in terms of thickness and cross-sectional area and by CT in terms of cross-sectional area and volume. Muscle quality was assessed using US in terms of EI and CT in terms of CT values.

Three studies[9, 10, 14] reported significant correlations between their US and CT results. One study[12] indicated that higher US measurements tended to correspond with greater CT measurements, albeit without statistical significance. Three studies[11, 13, 15] determined intraclass correlation coefficients (ICCs) between US and CT measurements, and all three reported ICCs of ≥0.8. In addition, four studies[10-13] examined the intra-rater reliability for US examinations, and all reported ICC measurements of ≥0.8.

In the two studies[9, 14] evaluating muscle quality, EI (as determined by US) were significantly correlated with CT

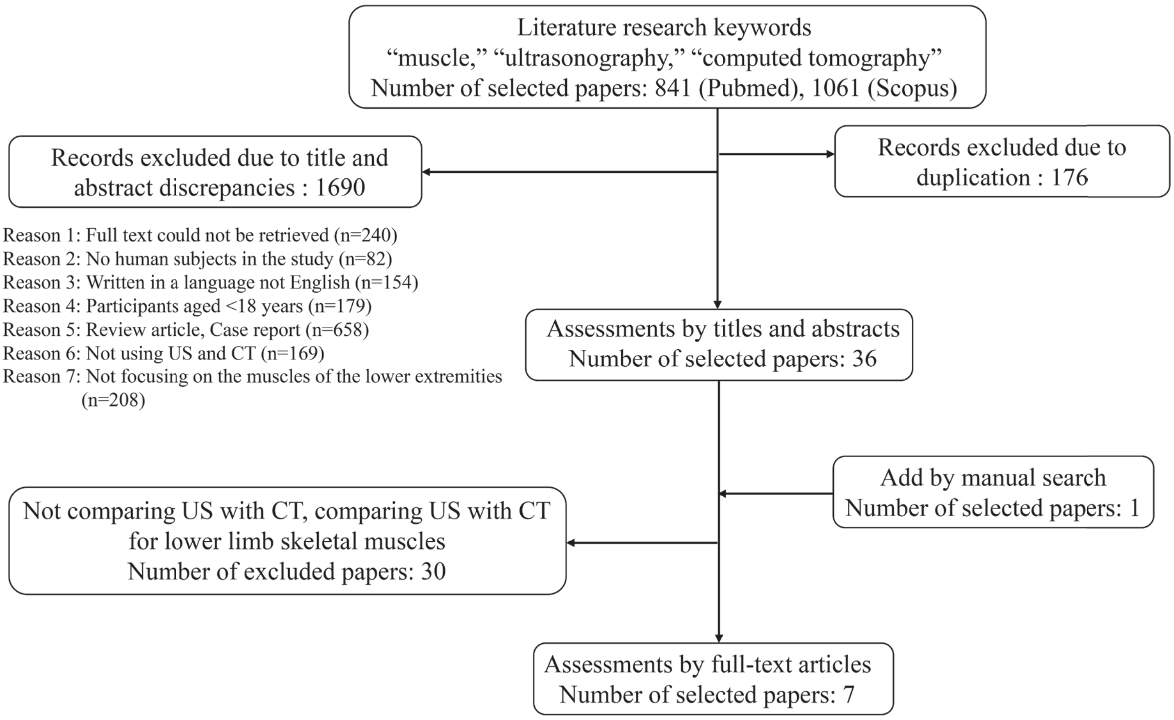

Fig. 1　Literature review strategy

Table 1　Summary of included studies for muscle mass

Authors	Year	Subscription participants	Age	Measurement items	Measurement sites	Results
Sipilä S[9]	1993	Athletes (n=21) Controls (n=15)	73.7 ± 5.6 73.6 ± 2.9	US: thickness, CSA, EI CT：CSA, mean Hounsfield units	Quadriceps muscle	Muscle thickness and CSA measured using US correlated highly with the CSA measured using CT.
Watanabe Y[10]	2018	Young adults (n=19) Older adults (n=21)	22.7 ± 1.5 70.6 ± 4.8	US: thickness, EI CT：CSA, mean Hounsfield units	Thighs	A significant, strong, and prospective correlation was observed between MT and CSA reflecting muscle quantity (r=0.774; p<0.001). The ICC was found to be respectively 0.991 for MT.
Noorkoiv M[11]	2010	Men (n=6)	28.7 ± 4.6	CSA	Quadriceps muscle	The ICC computed between the two techniques ranged between 0.951 and 0.998 (p<0.000). ICCs computed to assess the inter-day reliability were between 0.982 and 0.998 (p<0.001).
Tourel C[12]	2020	Patients admitted to neurological ICU (n=42)	—	Thickness	Quadriceps muscle	There was a tendency for higher ultrasound values to correspond with greater CT values, albeit without statistical significance. Intra-rater reliability of US measurements was excellent, with an ICC of 0.98. Inter-rater reliability was also excellent, with an ICC of 0.96.
Thomaes T[13]	2012	CAD patients (n=20)	68.3 ± 7.3	Diameter	Rectus femoris muscle	The ICC between US and CT was 0.92. The ICC of 0.97 was found for the test-retest reliability of US.
Souza VA[14]	2018	CKD patients (n=100)	73.5 ± 9.22	CSA	Rectus femoris muscle	The Pearson correlation coefficient of US compared to CT measurements was 0.826 (p<0.001). The Bland-Altman plot analysis showed good agreement between the CT and US measurements.
Sahathevan S[15]	2021	Hemodialysis patients (n=26)	56.8 ± 9.06	Thickness, CSA	Quadriceps muscle	The ICC computed between US and CT ranged between 0.92 and 0.94 (p<0.001).

Table 2 Summary of included studies for muscle quality

Authors	Year	Subscription participants	Age	Measurement items	Measurement sites	Results
Sipilä S[9]	1993	Athletes (n=21) Controls (n=15)	73.7 ± 5.6 73.6 ± 2.9	US: thickness, CSA, EI CT：CSA, mean Hounsfield units	quadriceps muscle	There were significant correlations between EI and mean Hounsfield units (r=-0.351; p<0.05).
Watanabe Y[10]	2018	Young adults (n=19) Older adults (n=21)	22.7 ± 1.5 70.6 ± 4.8	US: thickness, EI CT：CSA, mean Hounsfield units	thighs	There were significant and moderate correlations between EI and mean Hounsfield units (r=-0.524; p<0.001). The ICC for the repeated measurements of EI was found to be 0.869.

values ($p<0.05$[9] and $p<0.001$[14]). One study[16] also examined intra-rater reliability and reported an ICC of 0.869.

4. Discussion

4.1. Method of examination

Various image analysis programs are used to evaluate skeletal muscle mass, and it has been reported that the measurements correlate even when different software are used[17].

Various factors can affect the accuracy of US measurements, including the posture of the subject, relaxation of the target muscles, body temperature, operating method and model of the probe, and skill of the measuring technician. No standardized method has been established to minimize the effects of these factors. Measurement in the horizontal supine position is preferable, similarly to CT evaluations. Alterations in the bed angle during measurement causes the knees to bend and lower limbs to exert force, subsequently augmenting the cross-sectional area of the rectus femoris muscle[18]. Among the seven studies selected for the present review, four involved US examinations in a supine, relaxed position[11, 13-15]; one involved examination in a standing, relaxed position[10]; and two did not mention the evaluation position[9, 12]. A correlation between US and CT measurements was found even when US was performed in a standing position, although the number of studies was small. This suggests that the position of the subject at the time of measurement has minimal effects on the results of US and their correlation with CT results.

With regard to application of the US probe, a tilt angle of $<5^\circ$ is believed to have no significant effect on the measurement[19]; however, for accurate results, the measurements are often taken in the short-axis view with the probe contact perpendicular to the direction of the course of the muscle[20, 21]. Although four[10, 12-14] of the seven studies specified vertical application of the probe with minimal pressure, there was no mention of the angle; moreover, the US equipment used in these studies varied and the gain, depth, and frequency were inconsistent. Therefore, measurements from different studies cannot be directly compared. Moreover, due to the characteristics of US, EI weakens as the tissue depth increases, obscuring the image and restricting the clearly measurable area. Furthermore, at the boundary between tissues with different acoustic impedances, some of the US wave energy is reflected and some is transmitted; therefore, the skill and experience of the technician performing the measurement may have an impact on the results for areas with small muscles and soft tissues. However, for the studies included in this review, all measurement sites pertained to a muscle group (rectus femoris, vastus medialis, vastus lateralis, and vastus intermedius) in the lower extremities. These muscles are relatively structurally independent from the surrounding tissues, so it is assumed that the influence of differences in technician skill would be small. The results of this review should be interpreted with caution because of the small number of studies included and heterogeneous measurement methods in each.

4.2. Assessment of muscle mass

The study which evaluated critically ill patients admitted to ICU[12] found no significant correlations in results between CT and US measurements. A previous study reported rapid muscle atrophy (defined as a 10% decrease in the cross-sectional area of the rectus femoris on US examination) after admission to ICU; approximately 18% atrophy was observed over 10 days[22]. It is possible that a correlation between the two techniques in Tourel's study[12] was not identified because muscle wasting was underestimated in critically ill patients owing to a variety of factors. In the present review, four of the seven studies reported intra-rater reliability values for US muscle mass measurements[10-13], with one also reporting inter-rater reliability[12]. ICCs for intra-rater reliability ranged from 0.98 to 0.998, while the ICC for inter-rater reliability was 0.96. According to Landis et al., ICCs of ≥ 0.81, ≥ 0.61, and ≥ 0.41 indicate almost perfect, substantial, and moderate reliability, respectively[23]. Therefore, US measurement of muscle mass in the lower extremities is considered reliable.

4.3. Assessment of muscle quality

The two studies[9, 14] which evaluated muscle quality used healthy subjects, and both found a strong correlation between US and CT measurements. CT examinations can provide absolute values in the form of CT values, enabling a relatively accurate assessment of skeletal muscle mass. Furthermore, CT values are considered useful for qualitative skeletal muscle assessments[24]. From an anatomical aspect, it has been reported that reduced CT values are indicative of fatty degeneration within skeletal muscles[25, 26]. Watanabe[10] reported an ICC of 0.869 for the intra-rater reliability of EI measured by US; this indicates almost perfect reliability. However, given that only two studies evaluated muscle quality using US (EI), and both studies included only healthy subjects, we cannot conclude that muscle assessment by US is useful for critically ill patients.

4.4. Assessment in the dental field

In dentistry, quantitative and qualitative assessments of tongue musculature can be relevant for evaluating patient health. The tongue plays an important role in oral functions such as mastication, swallowing, and articulation. In recent years, US equipment has been used to evaluate muscle mass and muscle quality of the tongue from the submental skin[7, 8]. The present review suggests that US may be useful to assess muscle mass in the lower extremities. The tongue contains more connective tissue and is more mobile than the lower extremities, and the distance from the submandibular space to the tongue is longer, making it difficult to extrapolate the results of the present study to the tongue. Although there have been no reports of an association between lower extremity muscle mass and tongue muscle mass, it has been reported that tongue thickness is related to brachial muscle area, which is an appendicular skeletal muscle[27]. Although embryologically distinct, both the tongue and lower extremity muscles are comprised of striated muscle, and therefore, with further research, US could be used to assess muscles in the tongue as well.

5. Conclusion

Our results suggest that US can be used to evaluate the lower extremity muscles with high quality and can be used in healthy individuals and patients with mild or moderate disease. As more studies are conducted on the tongue, we believe that US might be available in the dental field in the future to assess the tongue muscles.

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