Physica Medica 106 (2023) 102530

Contents lists available at ScienceDirect

Physica Medica

journal homepage: www.elsevier.com/locate/ejmp

Panoramic ultrasound imaging does not produce muscle morphology deformation during imaging acquisition: A validity study

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ARTICLE INFO

Keywords:
Panoramic ultrasound
Diagnostic accuracy study
Ultrasound imaging
Neck
Muscle

ABSTRACT

Purpose: Despite panoramic ultrasound imaging (US) is a promising advance for the morphological and histological assessment of large musculature which cannot be entirely assessed using B-mode, there is no evidence assessing if this technology produces muscle deformation during imaging acquisition. We aimed to analyze differences in size, shape and brightness descriptors between B-mode and panoramic US images and to assess the concordance between both methods.

Methods

We analyzed size (cross-sectional area and perimeter), shape (circularity, aspect ratio and roundness) and brightness (mean echo-intensity) features of cervical multifidus (CM) and short rotators (SR) in 46 healthy volunteers. Images were acquired in B-mode and extended field-of-view mode. For validity analysis, mean differences between methods were calculated. For agreement analysis, intraclass correlation coefficients (ICCs), standard error of measurements (SEM), minimal detectable changes (MDC) and coefficient of variation (CV%) were calculated.

Results: All parameters showed no significant differences between both methods for either CM or SR ($P > 0.05$). Panoramic US showed excellent concordance with B-mode for assessing all CM parameters (all ICCs > 0.9), while for SR the agreement ranged from good-to-excellent (ICC from 0.861 to 0.978).

Conclusion: Panoramic US seems to be a valid tool for assessment of muscle size, shape and brightness as no deformation in comparison with B-mode images was seen. Further research is needed to corroborate these findings comparing panoramic US imaging with Gold Standard methods.

Introduction

Ultrasound Imaging (US) is a diagnostic tool which provides real-time information with non-ionizing radiation, being a quick and low-cost alternative to other methods such as Magnetic Resonance Imaging (MRI) or Computed Tomography (CT) [1]. It is also a therapeutic tool which can be used as support providing visual biofeedback during motor control exercises [2]. Additionally, US not only allows examiners to assess morphology in up to three dimensions (i.e., thickness, cross-sectional area and volume) [3], but also provides muscle histology information based on the brightness of the pixels [4]. Since US images can be processed as 32-bit DICOM files, all pixels are in a 256-grey scale, where connective tissue are brighter compared with muscle fibers and, hence, brighter muscles involve greater presence of connective tissue [5]. In fact, recent studies isolated a range of pixels to determine the percentage of fatty infiltrations inside the muscle, avoiding multiple bias associated with US limitations [6].

However, one of the most important limitations of US is the limited field of view for assessing both the morphology and muscle quality in large muscles even if convex transducers are used. Recent technical advances overcame this difficulty developing the extended-field-of-view US or panoramic US [7]. This technology allows the obtention of a single

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https://doi.org/10.1016/j.ejmp.2023.102530
Received 12 September 2022; Received in revised form 30 November 2022; Accepted 3 January 2023
Available online 10 January 2023

imaging by automatic constructions of B-mode consecutive images acquired during the transducer gliding over the skin [8]. This method has shown a potential utility for clinical examinations, e.g., identification of histological changes in chronic conditions which are associated with poorer prognosis and greater disability and pain [9] or follow-ups in patients with muscle mass loss [10].

Although a recent systematic review showed the acceptable concordance between panoramic US with other gold standard methods, none of the previous studies considered aspects related with muscle morphology shape [11]. Most of the studies included in this review analyzed the agreement for assessing cross-sectional area, thickness, distances or lengths (e.g., cross-sectional area and muscle thickness for assessing muscle size and activation or inter-rectus distance for assessing diastasis recti abdominis), in addition to echo-intensity as a measure of muscle quality [11]. However, during the imaging acquisition the transducer movement and speed need to be constant for avoiding imaging deformations and these parameters do not demonstrate if this phenomenon occurs or not. Therefore, the objective of this study is to compare multiple morphology indicators (i.e., cross-sectional area, perimeter, circularity, roundness, and aspect ratio) and mean echo-intensity in muscles which could be entirely and reliably [6] observed in B-mode (since there is no muscle deformation) between B-mode and panoramic US images.

Methods

Study design

A diagnostic accuracy study with a single group design was conducted to analyze the muscle size, shape and brightness measures difference and concordance between two imaging methods (panoramic US and B-mode US) in two separate sessions (spaced 1 h). The order of the images acquisition was randomly assigned using the software Research Randomizer v.4.0. All images were acquired by the same experienced examiner (+10 years using US for evaluation of musculoskeletal structures) and two independent raters analyzed the images (one analyzed all B-mode images and the other one analyzed panoramic US images to ensure the blinding process and avoid them to have a size and shape reference from the previous imaging method). This study followed the recommendations from the Declaration of Helsinki and was approved by the Ethical Committee of Rey Juan Carlos University prior to the recruitment. In addition, we followed the STAndards for the Reporting of Diagnostic accuracy studies (STARD) checklist/guidelines [12] and the directives of the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) [13].

Participants

A consecutive sample of asymptomatic volunteers without neck pain were recruited in a private University located in Madrid, Spain. Local announcements and flyers were posted around the campus between December 2021 and February 2022. To be eligible for participation in the study, volunteers had to be aged between 18 and 40 years old with no history of neck pain or related-disability. This age range was chosen since older people and clinical populations exhibit significant histological and morphological differences depending on the age and pain/severity and therefore may break the normal distribution of the sample [14]. Exclusion criteria included prior history of whiplash injury; intake of any pharmacological drug or neuromuscular conditions which could alter normal muscle tone (e.g., muscle relaxants or sarcopenia); previous neck or shoulder surgeries; cervical radiculopathy or myelopathy; presence of radiological degenerative changes; or any other underlying medical condition (e.g., tumor or fracture).

Imaging acquisition

The US equipment used for all imaging acquisitions was an Alpinion eCubei8 (Alpinion Medical Systems Co., ltd.; Korea) and a linear transducer (3–12 MHz, E8-PB-L3-12 T). The procedure was identical as described by Valera-Calero et al for B-mode [6] and panoramic US [11] images as both demonstrated excellent reliability for the targeted muscles (cervical multifidus -CM-, and short rotators -SR-). These muscles were selected based on their size (since both could be entirely assessed in a single B-mode image in contrast with other superficial muscles located in the neck/trunk or extremities) and based on their relevance in clinical populations as indicative of neck pain and disability [5,9].

Participants were placed in the prone position with both arms resting at 90° of shoulder abduction and elbows flexed 90°. Cervical lordosis and cranio-cervical positions were controlled into a neutral position. After manual palpation and placing the probe on the C2 spinous process, a caudal glide was performed to locate the surface of C4 spinous process. Equipment parameters were set at 55 dB of gain, dynamic range to 85, brightness to 17, depth to 4 cm, and frequency to 12 MHz for all images.

For acquiring the B-mode image (Fig. 1), the probe was glided laterally until identifying in the same image the lateral tubercle of the spinous process (C4) and the C4-C5 zygapophyseal joint [6]. For panoramic images acquisition, we conducted the protocol inversely as described by Valera-Calero et al [5] (lateral to medial instead of medial to lateral). The probe was glided laterally until hide the lateral limit of the posterior deep neck muscles. Once the muscles disappeared, the examiner started the transducer gliding until locate the C4 spinous process (Fig. 2).

Imaging analysis

All images were saved, exported to DICOM format, codified, randomly ordered, and sent to both raters for analyses using the ImageJ software v.1.42 (National Institutes of Health, Bethesda, MD, USA). Both raters followed meticulously the same instructions for contouring the muscles as described by Valera-Calero et al [5,6].

After contouring both muscles, the following parameters were calculated: 1) Cross-sectional area (the area, expressed in mm^2, of the two-dimensional shape of the muscle); 2) Perimeter (the length, expressed in mm, of the muscles' contour); 3) Circularity (calculated as 4π*Area/Perimeter^2, where a value of 1 indicates a perfect circle); 4) Aspect Ratio (AR is calculated as the division between the major axis and the minor axis); 5) Roundness (calculated as 4*Area/(π*major axis^2, or the inverse of the AR), or the inverse of the aspect ratio); and 6) Mean echo-intensity (the mean brightness of the pixels selection in a 0–255 scale).

Statistical analysis

All statistical analyses were run with the SPSS software v.25 for Mac OS (IBM, Armonk, NY, USA). First, normal distribution of the data was verified using the Shapiro-Wilk test. Later, descriptive statistics of the sample and by gender were calculated for representing the demography and US characteristics of the sample included in the study. For analyzing the validity of panoramic US, a 2-way mixed-model, consistency-type intraclass correlation coefficient ($ICC_{2,1}$) was calculated. ICC scores were classified as fair ($ICC < 0.50$), moderate ($0.5 < ICC < 0.75$), good ($0.75 < ICC < 0.9$) or excellent ($0.9 < ICC$) [15]. In addition, Standard Error of Measurement (SEM = Standard Deviation of Absolute Error * $\sqrt{}$1-ICC), Minimal Detectable Change (MDC = 1.96 * SEM * $\sqrt{2}$), and coefficient of variation (CV% = Absolute Error / Mean Score * 100) were also calculated. Finally, Student's t-tests for independent samples were performed for assessing the comparability between both US methods, setting a p-value < 0.05 as statistically significant.

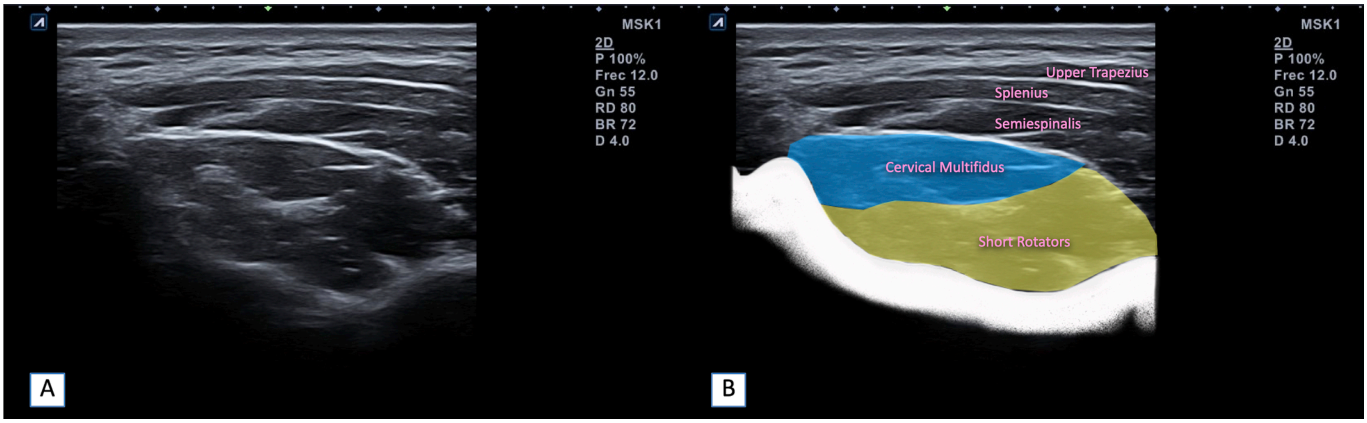

Fig. 1. B-mode ultrasound imaging acquisition of short rotators (yellow) and cervical multifidus (blue).

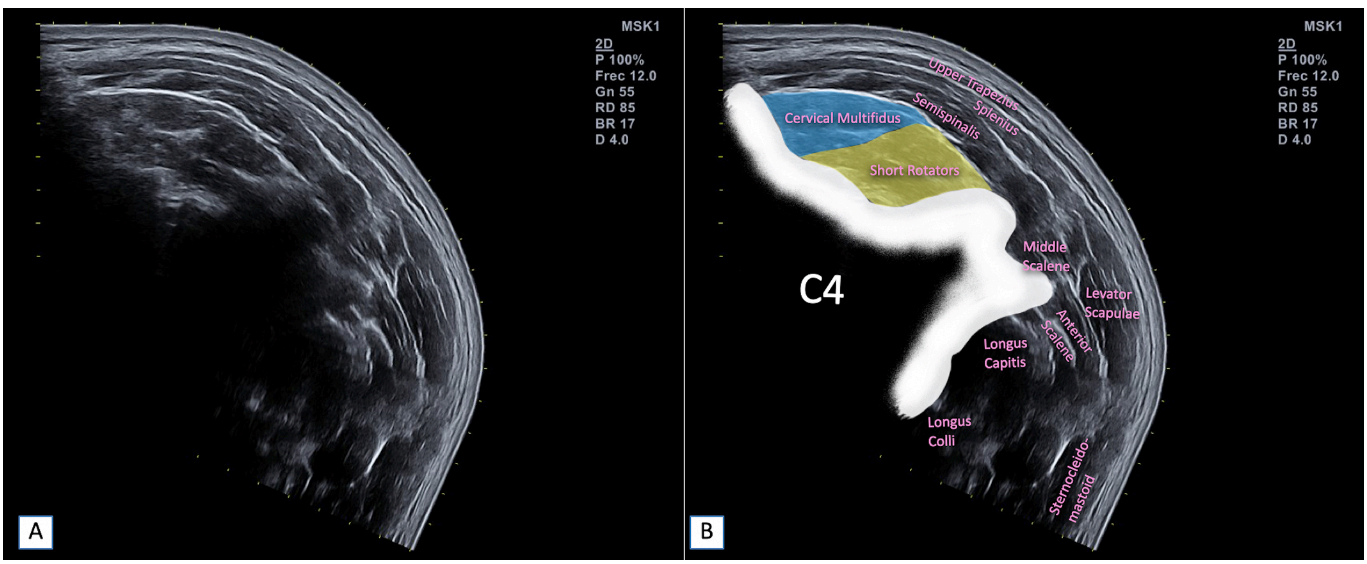

Fig. 2. Panoramic ultrasound imaging acquisition of posterior neck muscles. Short rotators are colored in yellow and cervical multifidus in blue.

Results

From a total of 48 volunteers willing to participate in the study, 2 were excluded due to previous history of whiplash injury. Therefore, 46 individuals (60.8% of them males) were included and analyzed. Demographic and US features (reported values are those calculated based only in B-mode images for avoiding potential deformations) are shown in Table 1. Males and females showed comparable age ($p > 0.05$), but males were significantly taller and heavier (height and weight, $p < 0.001$). Despite the significant size differences found between males and females for both the CM (cross-sectional area $P = 0.002$; perimeter $P = 0.024$) and SR (cross-sectional area $P = 0.015$; perimeter $P = 0.021$), shape descriptors showed no statistically significant differences (all, $P > 0.05$). In addition, females exhibited greater echo-intensity values for both muscles compared with males (CM $P = 0.002$, SR $P = 0.001$).

Table 2 shows the agreement between B-mode and panoramic US focusing on the CM muscle. None of the parameters showed significant differences between B-mode and panoramic US (all $P > 0.05$). Further, the concordance between methods demonstrated excellent agreement for all muscle size descriptors (cross-sectional area and perimeter), shape descriptors (circularity, aspect ratio and roundness) and muscle quality (mean echo-intensity) since all ICC values were > 0.9.

Finally, Table 3 summarizes the concordance estimates between both imaging methods for assessing the SR muscles. Likewise, B-mode and panoramic US showed no statistically significant differences for SR size, shape and quality descriptors (all, $P > 0.05$). However, agreement estimates were slightly worse in comparison with CM. Whilst both methods demonstrated excellent concordance for CM, agreement was excellent for describing cross-sectional area, circularity and mean echo-intensity (ICC > 0.9). Still, both imaging methods demonstrated good agreement for assessing muscle perimeter, aspect ratio and roundness (ICC > 0.860). ICC, SEM and MDC agreement estimates for each muscle are graphically within Fig. 3.

Discussion

Up to the authors' knowledge, this is the first study analyzing whether panoramic US alter or not the muscle size, shape or brightness as a consequence of image compounding errors during the transducer gliding process. In general, we found all parameters to be comparable between methods. In addition, agreement estimates were excellent for CM muscle and good-to-excellent for SR size, shape and quality assessment.

Although this is not the first study reporting morphology and histology by using panoramic US [16–19] nor applied specifically to the posterior neck region [3,20], the main novelty of this study is the inclusion of multiple shape descriptors as well as muscle quality and size estimates comparing B-mode and panoramic US images. Therefore, we

Table 1
Baseline outcomes (mean ± SD) of the sample and detailed by gender.

Baseline	Sample (n = 46)	Males (n = 28)	Females (n = 18)	Between-Gender Differences
Demographic characteristics				
Age (years)	21.2 ± 5.3	21.5 ± 6.3	20.8 ± 3.1	0.7 (−3.5;4.9) p = 0.732
Height (m)	1.74 ± 0.09	1.79 ± 0.07	1.66 ± 0.04	0.12 (0.07;0.18) p < 0.001
Weight (kg)	68.4 ± 11.7	74.5 ± 11.2	59.0 ± 3.2	15.5 (8.3;22.6) p < 0.001
Cervical multifidus ultrasound characteristics				
Area (mm^2)	92.5 ± 18.7	99.1 ± 18.5	82.2 ± 13.9	16.8 (6.5;27.1) p = 0.002
Perimeter (mm)	50.2 ± 6.0	51.8 ± 6.2	47.7 ± 4.9	4.1 (0.6;7.5) p = 0.024
Circularity (0–1)	0.46 ± 0.06	0.46 ± 0.06	0.46 ± 0.06	0.00 (−0.03;0.04) p = 0.851
Aspect Ratio	3.54 ± 0.69	3.51 ± 0.74	3.58 ± 0.62	0.07 (−0.35;0.49) p = 0.738
Roundness	0.29 ± 0.05	0.29 ± 0.06	0.28 ± 0.04	0.01 (−0.02;0.04) p = 0.505
Mean Echo-intensity (0–255)	40.2 ± 11.2	36.2 ± 10.1	46.5 ± 10.2	10.3 (4.1;16.5) p = 0.002
Short rotators ultrasound characteristics				
Area (mm^2)	126.6 ± 25.2	133.7 ± 21.5	115.6 ± 27.1	18.2 (3.7;32.7) p = 0.015
Perimeter (mm)	50.9 ± 4.6	52.1 ± 3.9	49.0 ± 5.1	3.2 (0.5;5.9) p = 0.021
Circularity (0–1)	0.60 ± 0.06	0.61 ± 0.06	0.58 ± 0.07	0.02 (−0.01;0.07) p = 0.175
Aspect Ratio	2.65 ± 0.56	2.60 ± 0.55	2.75 ± 0.58	0.16 (−0.18;0.50) p = 0.351
Roundness	0.39 ± 0.08	0.40 ± 0.09	0.38 ± 0.08	0.02 (−0.03;0.07) p = 0.442
Mean Echo-intensity (0–255)	39.6 ± 13.5	24.5 ± 10.3	37.5 ± 14.6	12.9 (5.6;20.2) p = 0.001

not only provide novel information supporting the use of panoramic US for size, shape and quality observations in large muscles which could not be assessed entirely without this technology. In addition, our results could be interpreted as a methodological quality reinforcement of previous research using panoramic US imaging, particularly in those articles analyzing the same regions as we analyzed [3,20], where bias related with muscle deformations during the imaging acquisition could be suspected.

As commented previously, we decided to conduct this study in the posterior deep neck muscle since they can be entirely acquired in a single B-mode image to be compared with panoramic US and due to their clinical relevance in neck musculoskeletal conditions. For instance, although a previous study focusing on women with fibromyalgia syndrome showed no significant between-sides asymmetries of CM nor SR musculature [21,22], available evidence in patients with whiplash associated disorders found pain intensity to be associated with CM muscle size, symptoms duration, and disability with deep neck extensors shape and brightness, and pain sensitivity with shape, brightness and muscle histology [5,23,24].

In addition, since this study found panoramic US to be a valid tool, previous research providing normative values of posterior neck muscles morphology and histology in asymptomatic subjects [3] could now be interpreted as non-deformable values and further research should focus on muscle size, shape and histological characteristics under different conditions (e.g., during isometric contraction of the musculature) and applied in clinical populations since those are currently the main limitations of panoramic US reported in available literature [11].

Thus, our results showed that the cross-sectional area, perimeter and mean echo-intensity differences found between both imaging methods were comparable to those obtained by Valera-Calero et al comparing two B-mode images in their intra- and inter-examiner reliability study for both muscles [6,25]. Based on these findings, we could suggest either B-mode or panoramic US methods not only to be used in cross-sectional designs due to the good-to-excellent concordance between methods, but also to be used for longitudinal designs as the capacity of panoramic US imaging to detect real changes (no attributable to measurement errors) was also comparable to those obtained in pain-free populations assessed with B-mode images [6,25].

Limitations

Despite our findings are promising, several limitations should be acknowledged. Firstly, we conducted this validity study comparing panoramic US images with B-mode images. Although we considered B-mode images not to be deformed, this imaging method is not a Gold Standard since is also based on US physics and several artefacts could potentially affect the image. In order to confirm current findings, further research should compare these parameters with those obtained in MRI or CT. Secondly, we only assessed two muscles in a specific location in healthy subjects. Further research should consider other locations and further clinical populations to corroborate the validity of this method. In addition, we only included subjects within a specific range of age. Further research conducted in older people with different US characterization may clarify the clinical utility of this tool since the peak prevalence of neck pain is estimated at more advance ages [26]. Finally,

Table 2
Summary of concordance estimates between B-mode and panoramic US for assessing cervical multifidus muscle.

Baseline	B-Mode	Panoramic US	Difference	$ICC_{2,1}$ (95% CI)	SEM	MDC	CV (%)
Area (mm^2)	92.5 ± 18.7	93.8 ± 19.5	1.3 (−6.6;9.2) p = 0.740	0.993 (0.998;0.996)	0.2	0.5	2.57
Perimeter (mm)	50.2 ± 6.0	51.9 ± 6.5	1.7 (−0.8;4.3) p = 0.180	0.929 (0.872;0.961)	0.4	1.2	4.53
Circularity (0–1)	0.46 ± 0.06	0.45 ± 0.06	0.00 (−0.02;0.03) p = 0.685	0.959 (0.926;0.977)	0.00	0.00	5.17
Aspect Ratio	3.54 ± 0.69	3.64 ± 0.71	0.10 (−0.19;0.39) p = 0.491	0.914 (0.845;0.953)	0.06	0.19	4.34
Roundness	0.29 ± 0.05	0.27 ± 0.06	0.01 (0.00;0.04) p = 0.228	0.946 (0.902;0.970)	0.00	0.00	7.52
Mean Echo-intensity (0–255)	40.2 ± 11.2	41.3 ± 11.2	1.0 (−3.5;5.7) p = 0.647	0.991 (0.984;0.995)	0.3	1.0	7.14

Table 3
Summary of concordance estimates between B-mode and panoramic US for assessing short rotators muscles.

Baseline	B-Mode	Panoramic US	Difference	$ICC_{2,1}$ (95% CI)	SEM	MDC	CV
Area (mm^2)	126.6 ± 25.2	126.4 ± 23.8	0.2 (−9.9;10.3) p = 0.971	0.976 (0.957;0.987)	0.8	2.5	3.66
Perimeter (mm)	50.9 ± 4.6	49.1 ± 4.0	1.74 (−0.06;3.55) p = 0.058	0.861 (0.749; 0.923)	0.8	2.3	5.87
Circularity (0–1)	0.60 ± 0.06	0.61 ± 0.08	0.01 (−0.01;0.04) p = 0.473	0.900 (0.818; 0.945)	0.01	0.02	3.33
Aspect Ratio	2.65 ± 0.56	2.55 ± 0.51	0.09 (−0.12;0.32) p = 0.387	0.877 (0.779;0.932)	0.01	0.03	1.15
Roundness	0.39 ± 0.08	0.41 ± 0.09	0.01 (−0.02;0.05) p = 0.375	0.882 (0.786; 0.934)	0.01	0.02	7.50
Mean Echo-intensity (0–255)	39.6 ± 13.5	31.2 ± 13.3	1.5 (−4.0;7.0) p = 0.589	0.978 (0.961;0.988)	0.5	1.3	8.61

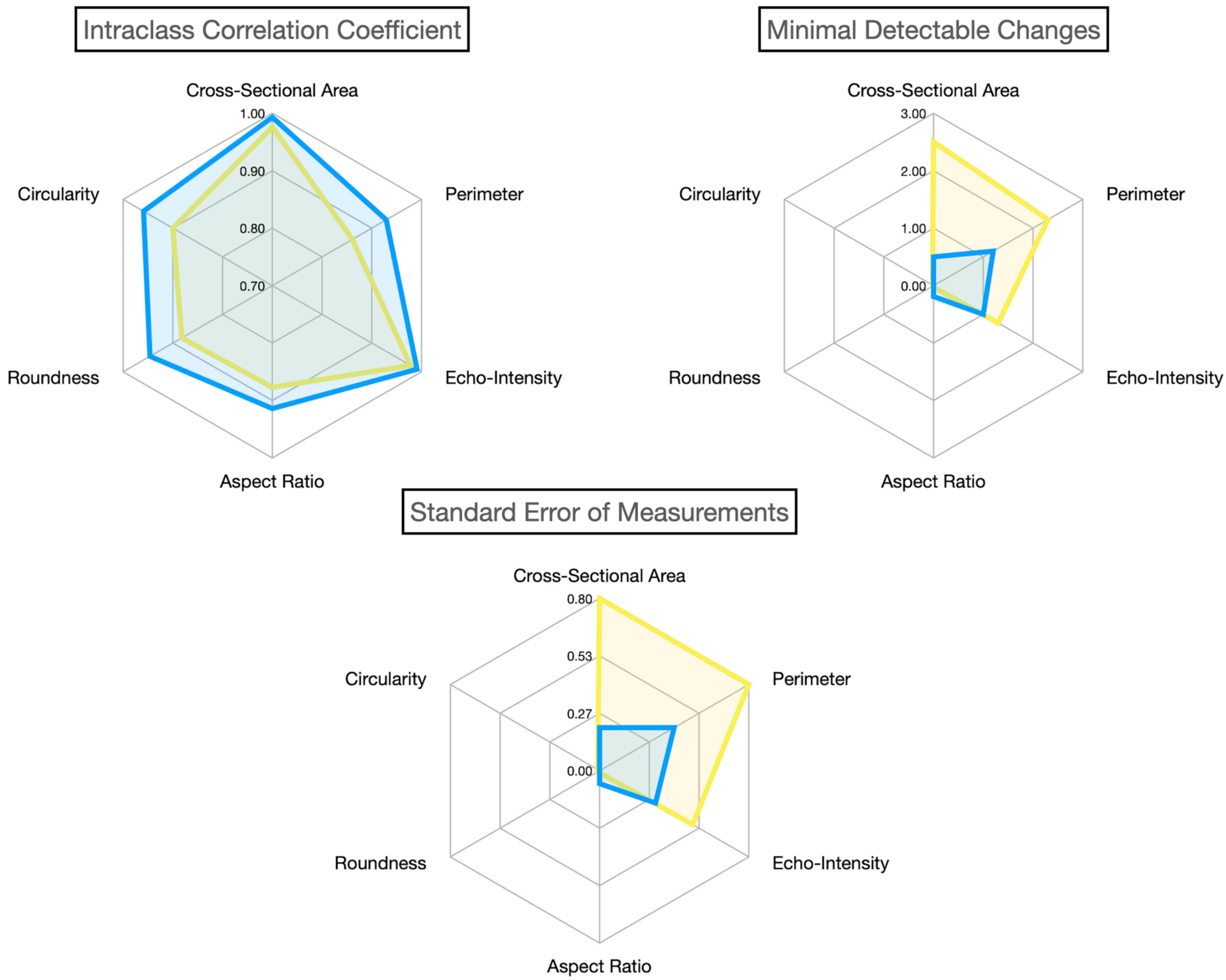

Fig. 3. Agreement estimates between extended field-of-view and B-mode ultrasound for assessing shape, size and brightness of short rotators (yellow) and cervical multifidus (blue).

all the images were acquired by just one experienced examiner. Further studies should assess the impact of different factors in this method's validity including the examiners' experience [27] or demographic and anthropometric characteristics of the participants [28] as previous studies found them to play a relevant role in US imaging acquisition.

Conclusion

This study found that panoramic US do not alter deep neck extensors size, shape or bright obtained with B-mode US at C4-C5 level. The agreement between both methods for assessing cross-sectional area, perimeter, circularity, aspect ratio, roundness and mean echogenicity of CM muscle was excellent and good-to-excellent for SR muscles. Finally, the capacity of extended-field of view for detecting true changes (score differences non-attributable to measurement errors) was comparable to those reported in the literature for B-mode US. Therefore, panoramic US could be used for research purposes in both cross-sectional and longitudinal designs to obtain reliable size, shape and brightness scores.

Ethical statement

The current study was conducted according to the Declaration of Helsinki and was approved by the Institutional Ethics Committee of Rey Juan Carlos University (URJC 3001201801618).

CRediT authorship contribution statement

Juan Antonio Valera-Calero: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition. **Gustavo Plaza-Manzano:** Methodology, Software, Validation, Investigation, Writing – review & editing, Visualization. **Ricardo Ortega-Santiago:** Conceptualization, Methodology, Software, Validation, Investigation, Writing – review & editing, Visualization. **César Fernández-de-las-Peñas:** Methodology, Software, Validation, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Umut Varol:** Methodology, Software, Validation, Investigation, Data curation, Writing – review & editing, Visualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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