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Review Article

Ultrasonography as a diagnostic tool for sarcopenia in patients with cirrhosis: Examining the pros and cons

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ABSTRACT

Sarcopenia has emerged as a significant prognostic factor in liver disease, posing a significant risk to patients in terms of morbidity and mortality. However, the evaluation of skeletal muscle mass and quality remains challenging, as cross-sectional imaging is not a suitable screening tool. In order to better include this crucial variable in the routine risk stratification of patients with chronic liver disease, there is an urgent need for simple and reliable non-invasive diagnostic tools for sarcopenia. Therefore, the use of ultrasound techniques has garnered attention as a promising alternative for detecting sarcopenia and muscle abnormalities. This narrative review aims to provide an overview of the current literature on the use of ultrasound as a diagnostic tool for sarcopenia, with particular focus on patients with cirrhosis, emphasizing its potential limitations and future prospects.

1. Introduction

Skeletal muscle abnormalities, including sarcopenia (pathological muscle mass depletion) and myosteatosis (abnormal fat accumulation in the muscles) are common features in patients with cirrhosis. Recently, sarcopenia has become increasingly recognized as a complication of cirrhosis and a prognostic factor for worse outcome. Several studies, particularly in the setting of the waiting list for liver transplantation (LT) have identified sarcopenia as a risk factor for drop-out from the waiting list [1], peri- and post-surgical complications and mortality [2]. However, muscle abnormalities do not represent only a complication of the end stage liver disease or advanced hepatocellular carcinoma (HCC). Indeed, new insights seem to suggest that even in patients with cirrhosis in a compensated stage, low muscle density predicts mortality [3,4]. In patients with Child Pugh (CP) class A or cirrhosis without previous episodes of decompensation, sarcopenia is reported between 10 and 30% [5]. In a study on 452 patients stratified according the classical metrics of severity in liver disease, namely CP class, Model for End-Stage Liver Disease score and hepatic venous pressure gradient, the authors found that sarcopenia was associated with mortality, specifically in compensated and early decompensated stages of cirrhosis. In severe sarcopenia those scores failed to predict mortality, suggesting that using these metrics adjusted for sarcopenia would better assess the prognosis of cirrhosis, particularly in the early stage [5]. The role of sarcopenia has been investigated even in the initial phase of chronic liver disease, particularly in non-alcoholic fatty liver disease (NAFLD). Insulin resistance and myokines secreted by skeletal muscle (IL-6 and irisin) play a key role in the development of both sarcopenia and NAFLD [6], speculating that sarcopenia could perhaps a permissive or favoring factor for NAFLD worsening.

At present, the direct diagnosis of sarcopenia and quantification of skeletal muscle mass require cross-sectional imaging with computer tomography (CT) scan as gold standard [7]. The first studies, done in the LT setting and aiming to assess sarcopenia, had used the lowest quartile of the cross-sectional area of the total psoas area on CT scan imaging [8]. More recently, the use of the CT-measured skeletal muscle index (SMI), calculated as total muscle area at the third lumbar vertebrate (L3) and normalized to height squared (Fig. 1), has become the most well-validated tool to define sarcopenia and correlates strongly with survival. Currently, SMI <50 cm2/m2 in male and <39 cm2/m2 in female patients with cirrhosis can be considered the cut-off defining sarcopenia in the Western population [7].

Abbreviations: HCC, hepatocellular carcinoma; LT, liver transplantation; CT, computer tomography; SMI, skeletal muscle index; US, ultrasound; ICC, infraclass correlation coefficient; DXA, dual-energy X-ray absorptiometry; MRI, magnetic resonance imaging; CEUS, contrast-enhanced ultrasound; MAMC, mid-arm muscle circumference; SWE, share wave elastography; LFI, Liver Frailty Index; SGA, subjective global assessment; CP, Child Pugh; NAFLD, non-alcoholic fatty liver disease.

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Although CT scan is frequently performed in cirrhosis, it is far from an ideal screening tool, since it is expensive, time-consuming for patients and uses ionizing radiation which implies stochastic risk of developing neoplasia [9].

Non-invasive, point-of-care and dependable methods for evaluating sarcopenia and skeletal muscle abnormalities would be of utmost significance in hepatology, allowing including the presence and severity of sarcopenia into clinical practice, and orienting prompt therapeutic intervention aimed to counteract muscle depletion.

In this scenario, the use of the ultrasound (US) techniques and the integration of software able to detect sarcopenia and muscle abnormalities look particularly attractive. These techniques have been largely validated in other settings, such as geriatrics [10] and intensive care medicine [11].

The aim of this review is therefore to analyze the current available literature on the use of US as a tool for detecting sarcopenia in patients with cirrhosis, highlighting the possible limitations and the future prospective for the use of this technique.

2. Muscle ultrasound assessment: state of the art

The utilization of US for detecting sarcopenia has been predominantly explored in aging, intensive care, and sports medicine, contexts where the deleterious effect of muscle depletion is well-established. According to the scopes, the published studies have the following design a) transversal studies: aiming generally to assess the reproducibility or validity of the technique; b) case-control studies: comparing two populations (mostly target population vs. healthy subjects) to address possible differences in muscle characteristics; c) longitudinal studies: assessing the evolution of muscle depletion over time, with or without an specific intervention; d) studies aiming at assessing the association of US muscle-related variables and functional parameters or clinical outcomes.

2.1. Key measurable parameters

Recently, a consensus conference sought to standardize the methods applied for the evaluation of sarcopenia through US. They identify five main muscle parameters namely muscle thickness, muscle cross-section area (Fig. 2), pennation angle, fascicle length and echo-intensity, defining them through standardized anatomical landmarks and measuring points for several muscle groups [12] (Table 1). The possibility offered by US of obtaining also architectural parameters (e.g., pennation angle, fascicle length, and echogenicity) seems particularly promising. Although the role of these measurements is still controversial, and especially for pennation angle and fascicle length low inter- and intraoperator reproducibility exist [13], they may represent additional metrics to complement the study of muscles. Other advantages of US are the availability of software and US-related techniques that can be easily utilized for studying qualitative aspect of muscles [10]. Microvascular damage and impaired nitric oxide production have been advocated among the pathophysiological mechanisms of sarcopenia [14] and some studies have claimed microvasculature as markers of sarcopenia. More precisely, reduced vasculature can be responsible of age-related sarcopenia¸this would be particularly true at the muscle capillary due to the decrease in nitric oxide production. This can lead also to mitochondrial abnormalities, generating apoptosis [14]. Microcirculation plays a central role in glucose homeostasis: impaired capillary recruitment and capillary rarefaction may both reduce glucose uptake and contribute to peripheral insulin resistance. This mechanism can see also responsible to the increase in adipose tissue within muscles generating the so-called myosteatois [15]. Additionally, physical activity can increase microvasculature in muscles [10], that can, conversely, decrease with aging [12]. Modern US techniques such as superb microvascular imaging and contrast-enhanced ultrasound (CEUS) allow to assess the muscle microvasculature [16]. Additionally other impaired properties of the muscles can be investigated. Muscle stiffness measured trough share wave elastography (SWE) was applied in some pilot studies, showing that aging is associated with a decline in skeletal muscle stiffness which correlates with muscle weakness [17,18]. These techniques might offer better insight in the pathophysiology of sarcopenia and add information to better depict this condition.

2.2. Reliability of the technique and comparison with reference standard techniques

A recent review evaluated the reliability and validity of US to quantify muscles in older adults [19]. Thirteen out of seventeen studies considered evaluated both intra-rater and inter-rater reliability using intraclass correlation coefficient (ICC) scores. The highest ICC was observed in the assessment of quadriceps femoral muscle (ICC = 0.72 to 1.000). Eight studies evaluated the accuracy of US compared with other techniques considered the benchmark, as dual-energy X-ray absorptiometry (DXA), CT and magnetic resonance imaging (MRI). All analyzed studies found that US is accurate for the assessment of muscles, with correlation coefficients ranging from $r = 0.761$ to $r = 0.911$. Although the major limitation of these studies is the relatively small number of the included patients, the authors concluded that US is a reliable and accurate tool for the assessment of muscle size in older adults. This is particularly true for the largest, accessible muscle, namely the quadriceps femoris, whereas the US assessment of small muscles needs further evaluation [19]. Indeed, different studies analyze different muscle groups. It has been shown that there is a different decline of muscles group with age [10]. This concept of "site-specific sarcopenia" was demonstrated for the quadriceps femoris and abdominal wall muscle thickness, where an age-related decline was observed [20]. Conversely, upper limbs, seemed not be affected by this phenomenon [20]. Particularly, rectus femoris muscle mass possibly declines earlier than biceps femoris, suggesting this specific site as an early marker in the evaluation of sarcopenia in the elderly [21]. This challenges the current assumption of a linear relationship between regional muscle mass and total muscle mass, and is in line with the observation that the latter that only partially

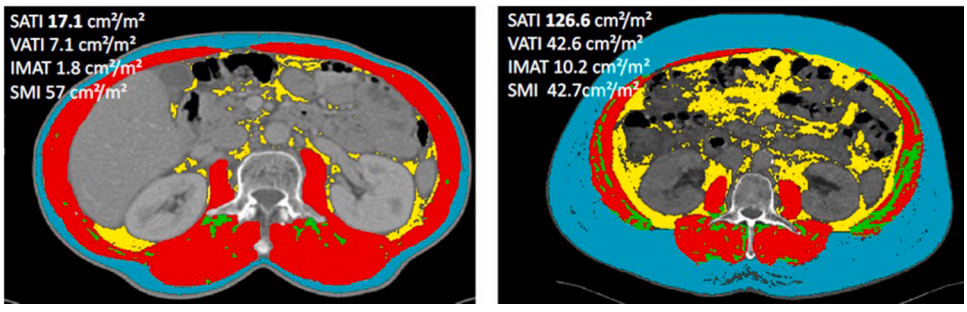

Fig. 1. CT-measured skeletal muscle index (SMI), calculated as total muscle area at the third lumbar vertebrate (L3) and normalized to height squared using one of the commercial available software (SliceOmatic®).

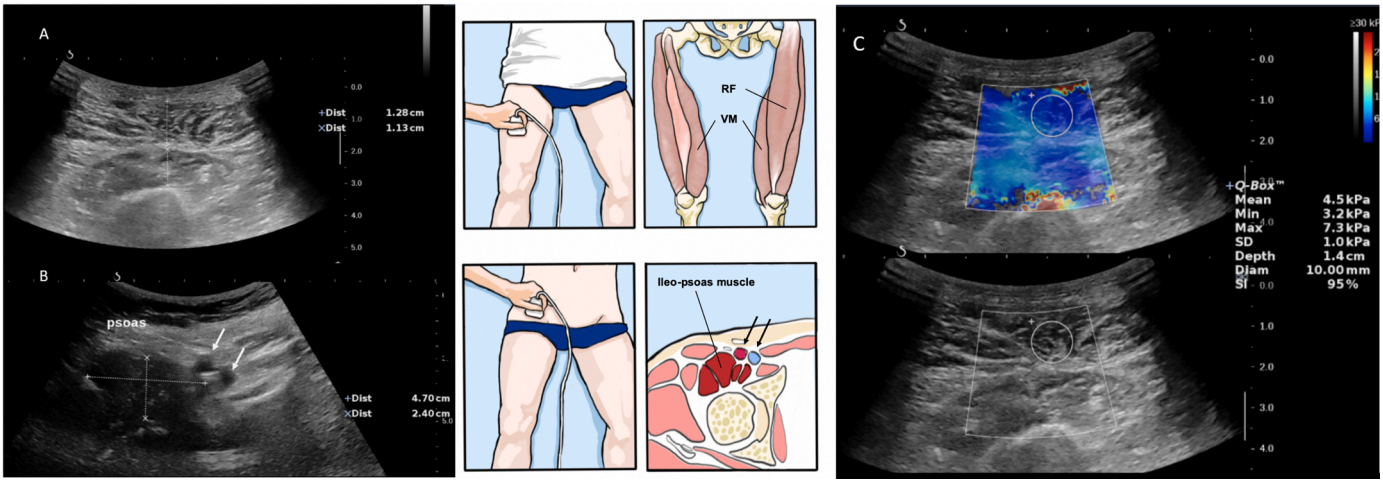

Fig. 2. Overview of US techniques and variables used to assess sarcopenia. Panel A. Muscle thickness of the quadriceps femoris measuring the antero-posterior diameter of the rectus femoris (RF) and of the vastus medialis (VM). Central Panels: schematic illustration of the probe position and anatomical repere to assess muscle mass/sarcopenia with ultrasound. Panel B. Muscle cross-section area of the ileo-psoas muscle. The arrows mark the right iliac artery and vein, used as the landmark to detect the ileopsoas muscle. Panel C. Two dimension-shear-wave elastography (2D-SWE) assessing muscle stiffness.

Table 1
Summary of the main metrics and technique that can be adopted in muscle US studies.

Parameters	Definition	Anatomical site of evaluation	Technical issues	Strength	Limitation
Thickness	Distance between to muscles fascias	Every muscular group (most common thigh and psoas)	Pressure with the probe can influence the results Depending on muscles groups both probes linear and convex can be used	Easy, quick and reproducible Good correlation with gold standard technique and with measures of muscle function	Absence of standardization No established anatomical landmark Detect site-specific sarcopenia, cannot always be extended to sarcopenia in general
Cross-sectional area	Area of the cross section of a muscle perpendicular to its fibers in its largest point.	Lower limb muscular group and psoas	Depending on muscles groups both probes linear and convex can be used	Easy, quick and reproducible Good correlation with gold standard technique and with measures of muscle function	Absence of standardization No established anatomical landmark Not clear correlation with functional parameters
Pennation angle	The acute angle between the fascicle orientation and deep aponeurosis orientation	Pennate muscles of the lower limb (i.e., gastrocnemius medialis)	Specific training of operators needed Results may be influenced by articular position and muscle contraction	Gives information about muscle structure and strength capacity	Active participation of the patient Not clear correlation with functional parameters
Fascicle length	The length of a muscle fascicle projected onto the long axis of the muscle	Pennate muscles of the lower limb (i.e., gastrocnemius medialis)	Specific training of operators needed Results may be influenced by articular position and muscle contraction	Gives information about muscle structure and strength capacity	Active participation of the patient Not clear correlation with functional parameters
Echo-intensity	Gray-scale ultrasound that correlates with the amount of non-contractile tissue in skeletal muscle	Every muscular group (most common thigh and psoas)	Specific training of operators needed Specific software needed	Gives information about myosteatosis	No established anatomical landmark
Diaphragm thickness	Distance between to muscles fascias in diaphrafm	Diaphragm	Specific training of operators needed	Easy, quick and reproducible Good correlation with respiratory function	Not clear correlation with sarcopenia but more with respiratory function
Contrast-enhanced assessment of vascularization or superb microvascular imaging	Special techniques adopted to magnify vasculature	Quadriceps femoris	Specific training of operators needed Specific software needed	Gives information about vascularization	Absence of standardization
Share-wave elastography	Special technique measuring the stiffness of a tissue	Quadriceps femoris	Specific software needed	Easy, quick and reproducible Gives information about muscle structure	Absence of standardization No established anatomical landmark

correlates with functional parameters, such as gait speed [22]. Therefore, US evaluation of site-specific sarcopenia should be obtained and carefully interpreted, particularly in the geriatric setting.

2.3. Muscle US and clinical outcomes

Given the safety of US technique, muscle measurements can be easily

repeated. As such, US can be embedded in cohort studies and is particularly appealing in the clinical setting, where the same operator can longitudinally follow-up the same patients increasing the reliability of the metrics. Moreover, repeated measurements are often applied when interventional studies are put in place. Physical exercise, nutritional supplementation or administration of drugs are interventions for which evaluating changes in muscle architecture using US may be important and possible. Results in this setting up to date were heterogeneous, but generally translated into the increase in muscles area of the group of muscles involved in the exercise training [23,24]. Considering drug therapy of sarcopenia, Atkinson et al. showed that testosterone treatment resulted in a preservation of muscle thickness at 6 months in aging men [25].

Although sarcopenia was claimed in many fields of medicine as a detrimental factor influencing survival [26,27], sarcopenia diagnosed by muscle US assessment did not always correlate with clinical outcomes. US measurement of rectus femoris cross-sectional area was an independent predictor of hospital length of stay, and mortality in intensive care unit after surgery [28]. On the same line, a reduced rectus femoris cross-sectional area was significantly associated with mortality, length of stay, and readmissions in a cohort of 191 elderly patients [29]. Conversely, in a study on 156 older patients higher corrected muscle echo intensity was associated with hospital-associated complications (OR 1.036; 95%CI, 1.001–1.072), while handgrip strength, bilateral thigh muscle thickness, skeletal muscle index, and maximum calf circumference were not [30]. Similarly, in a study assessing bilateral anterior thigh thickness and echo intensity of the quadriceps on admission and 7 days later, no association was found with mortality, frailty, or hospital-associated complications in acute hospitalized older adults [31]. This heterogeneity can be partly explained by the small sample sizes of the studies and their short duration. In fact, it is likely that US-appreciable changes in muscle architecture take longer than few days/weeks. Irrespective of these considerations, it appears clear that further investigation is needed to clarify whether muscle US measures are able to mirror clinical outcomes.

2.4. Technical limitations

Indeed, although extremely promising for rapid clinical application, the use of US in muscle assessment shows some limitations that can affecting the robustness of the available literature, particularly comparing different studies. The main methodological issues concern the absence of a standardized method, regarding for example the type of probe employed, either linear or convex, the anatomic sites of measurement, the posture of the patients during the examination, the position of the probe, the pressure exerted by the probe, and the type of parameters obtained [10]. Despite these limitations, the use of US in assessing sarcopenia still remain relevant, particularly as easy portable tool in daily practice.

3. Muscles US techniques to detect sarcopenia in patients with liver disease

We performed a systematic search on this topic and searched in PubMed, EMBASE and Google Scholar English-language articles published between January 2010 and 30th January 2023 including the following MeSH terms “ultrasound” AND “sarcopenia” AND “liver”. Only original articles were considered (Table 2).

All studies were prospective and included patients with cirrhosis mainly belonging to Child Pugh classes A and B. This is likely due to the a priori exclusion of patients with ascites, given the well-known interference of ascites with psoas muscle US measurements [32]. In addition, most studies excluded patients with advanced HCC to minimize the influence of neoplastic cachexia on measurements.

Measurements of muscles, especially thickness and area, either of psoas muscle and thigh muscles, were possible in all patients with excellent correlations with reference standard measurements (e.g., mid-arm muscle circumference (MAMC); SMI by CT scan and DXA) [32–35]. Tandon et al. [35]. developed a nomogram including sex, body mass index and thigh muscle thickness by US able to identify sarcopenia with the same efficacy of the CT-scan SMI. Other studies considered parameters reflecting muscle function such as handgrip [36], the Liver Frailty Index (LFI) [37] or the subjective global assessment (SGA) [38] as reference standards, again showing good correlation with US measurements.

As anatomical landmark the majority of studies adopted the large muscles of the upper and lower limbs. These are group of muscles easily approachable and less affected by fluid retention. Only one study evaluated the rectus abdominis [38] while four evaluated the psoas muscle. Generally, the linear 5–12 MHz probe was preferred; however, when the psoas was evaluated, the convex 3.5–5 MHz probe was often used [34, 37]. In addition, to improve measurement performance, especially when area was considered, measurements were also adjusted for height, thus producing the correspondent index.

The majority of studies diagnosing sarcopenia using US aimed not only at proving a good correlation with reference standard measurements, but also at assessing whether US measured muscle parameters correlate with clinical outcomes. In Ciocîrlan et al. [38]. rectus abdominis thickness predict survival (HR 0.70; IC 95% 0.53–0.92; $P = 0.01$), whereas Hari et al. [39]. demonstrated that both US-SMI and US-psoas to height ratio were significantly related to hospitalization (HR 0.72, IC 95% 0.62–0.83, $P<0.0001$; HR 0.88, IC 95% 0.84–0.93, $P<0.0001$) and to mortality (HR 0.83, IC 95% 0.70–0.97, $P = 0.022$; HR 0.93, IC 95% 0.88–0.99, $P = 0.017$), respectively. Additionally, interventional studies [40,41] were put in place by the Canadian group of Alberta including thigh muscle thickness among the measurements used to evaluate the efficacy of the intervention. Thigh muscle thickness improved in the exercise group vs. the control group (difference mean 0.06 IC 95% 0.01–0.11, $P = 0.01$).

More recently, a study from India assessed the role of US in evaluating sarcopenic obesity [36]. The authors showed that ultrasound parameters correlate with CT-based sarcopenia indices even in the obese population. Lastly, Becchetti et al. proposed 2D-SWE of the rectus femoris as non-invasive tool to assess the quality of muscles [37]. Rectus femoris muscle stiffness was feasible in all patients, and correlated with LFI. In addition, rectus femoris thickness inversely correlated with LFI.

The main limitations highlighted by all the studies using muscle US in cirrhosis were similar to those in other fields of medicine. These mainly concerned the absence of an ideal reference standard, thus not allowing a clear comparison among the studies. To improve reliability some study utilized adjustment for height [39] or sex [35]. As previously mentioned, another relevant limitation of using US for detecting the thickness of the muscles is represented by the pressure exerted by the probe. Therefore, some studies [35,36] implemented both the compression and feather index. In the first case the provider pressed the probe downward until no further compression of the muscles was possible, while in the second it was a featherweight reading, where the probe was held without any pressure. This is aimed at limiting compression artefact. Poor sonic window in patients with obesity or because of the presence of ascites can represent another barrier to the widespread implementation of US in patients with cirrhosis. This is particularly true when psoas or abdominal wall muscles are considered. Regardless the excellent feasibility rates reported by most studies [34, 39], the epidemic of obesity and non-alcoholic fatty liver disease, that is changing the epidemiology of liver disease, may limit the applicability of muscle US. Only one study [37] showed the applicability of muscle stiffness in patients with cirrhosis. For ultrasound scanners equipped with such software, this measurement could represent an additional information that is easy and quick to obtain. Regarding methods for assessing muscle vascularity, no studies are available in the setting of liver disease.

Table 2
Summary of available studies in liver disease and US use to define sarcopenia.

Authors (year)	Country	Type of study	Number of patients (M/F)	Mean age (IQR)	Etiology (%)	Child Pugh class (%)	HCC (%)	US technique	Anatomical landmark	Surrogate of sarcopenia	Prevalence of sarcopenia	Main finding
Becchetti et al. (2023) [37]	Switzerland	Prospective Cohort	44 (24/20)	59 (49–66)	Viral 15.9 ALD 61.4 NAFLD 15.9 Others 6.8	A 43.2 B 36.4 C 20.5	4.5	B-mode + 2D SWE Convex probe Muscle thickness, area and stiffness	Rectus femoris (RF) and of the vastus medialis (VM). Rectus femoris muscle stiffness (RFMS). ileo-psoas muscle area normalized for height (IP index)	LFI SMI by CT scan (of a subgroup)	9.1% were Frail according to LFI	RFMS did not correlate with LFI. IP-index was lower in frail patients (1.7 vs 1.0 cm2/m2, $p = 0.024$). RF thickness inversely correlated with LFI (r −0.578: $p<0.001$)
Sakai et al. (2022) [33]	Japan	Prospective Comparative	30 (30/-)	78 (70–82)	Viral 46.6 ALD 33.3 Others 20.1	Chronic hepatitis 40.1 A 33.3 B 23.3 C 3.3	100	B-mode Linear probe Muscle thickness and subcutaneous fat thickness lower limb (SFT-LL)	6 muscles in the lower limbs + SFT-LL of calf	SMI <42 cm2/m2 and grip strength <26 kg SFT-LL <5 mm.	90% according to SMI value	SMI correlate with SFT-LL
Dhariwal et al. (2022) [36]	India		52 (40/12)	51 (44–54)	Viral 19 ALD 48 NAFLD 29 Others 4	A 44.2 B 42.3 C 13.5	Exclusion criteria	B-mode Linear probe Muscle thickness	Quadriceps and forearm muscles, thickness and feather index	SMI <39 cm2/m2 for women and <50 cm2/m2 for men and handgrip compared to the new metrics	38.5% according to SMI value	A positive correlation with SMI was seen for all parameters in the entire cohort.
Woodward et al. (2021) [32]	Australia	Prospective Cohort	42 (36/14)	56 (48–60)	Viral 62 ALD 12 Others 26	A 36 B 35 C 29	52	B-mode Probe not mentioned Muscle thickness	Upper arm, forearm, tight and total	MAMC, BIS, ultrasound muscle thickness (USMT) and radiological methods (DXA, CT skeletal muscle area) compared to a reference measurement of body cell mass derived from a multi-compartment model using isotope dilution tests and DXA.	–	USMT offered no advantage over traditional bedside techniques (MAMC, BIS), particularly in patients with ascites.
Ciocîrlan et al. (2019) [38]	Romania	Prospective Cohort	61 (41/20)	58.03 ± 10.8	Viral 45.9 ALD 39.3 Others 14.8	A 26.4 B 45.9 C 27.7	Exclusion criteria	B-mode Linear and convex probe Muscle thickness	Right and left-side rectus abdominis (RA) and psoas	Surrogate continues variables of handgrip strength, MAMC and subjective global assessment (SGA).	–	Only RA thickness correlated with MAMC and handgrip strength and decreased with increasing SGA class. RA thickness predict survival (HR 0.70; IC 95% 0.53–0.92; $P = 0.01$)
Hari et al. (2019) [39]	Slovenia	Prospective Case control	54 (39/15)	63 ± 11	ALD 67 NAFLD 15 Others 18	–	13	B-mode Linear probe Muscle thickness	Psoas muscle	Ultrasound Psoas to height ratio (US-PTHR) as mean of psoas diameter divided by patient's	US-PTHR was 20 mm/m (range: 13–26 US-SMI was 3.2 cm2/m2 (range:	US-PTHR and US-SMI were significantly related to hospitalization (HR 0.72, IC 95% 0.62–0.83, $P<0.0001$; HR 0.88, IC 95% 0.84–0.93,

(*continued on next page*)

Table 2 (*continued*)

Authors (year)	Country	Type of study	Number of patients (M/F)	Mean age (IQR)	Etiology (%)	Child Pugh class (%)	HCC (%)	US technique	Anatomical landmark	Surrogate of sarcopenia	Prevalence of sarcopenia	Main finding
										height (unit in mm/m) and the Ultrasound Skeletal muscle index (US-SMI) as Π*psoas radius square divided by patient's height square (unit in cm2/m2).	1.2–5.5). US-PTHR and US-SMI were significantly higher in control subjects vs. patients	$P<0.0001$) and mortality (HR 0.83, IC 95% 0.70–0.97, $P = 0.022$; HR 0.93, IC 95% 0.88–0.99, $P = 0.017$), respectively.
Kobayashi et al. (2018) [34]	Japan	Prospective Case control	234 (143/91)	67.9 [32]–85	–	A 64.5 B 31.7 C 3.8	61.5	B-mode Convex probe Muscle area	Ileopsoas	SMI compared to iliopsoas area and IP-index (area adjusted for the height). IP-index for defining sarcopenia was 189.2 for males and 180.6 for females.	33.3% according to SMI value	SMI and IP index showed correlations in both sexes. IP-index is an independent risk factors for sarcopenia.
Kruger et al. (2017) [41]	Canada	Prospective Interventional	40 (23/17)	57± 8.5	Viral 30 ALD 27.5 NAFLD 25 Others 17.5	A 70 B 30 C -	Exclusion criteria	B-mode Probe not specified Muscle thickness	Right quadriceps muscle (the rectus femoris and vastus intermedius)	Muscle thickness with and without probe compression adjusted for height	–	Improvement of non-compression index (cm/m^2) in the intervention group pre and post (1.25 ± 0.40 vs.1.31 ± 0.38, $P = 0.05$). No further difference with the usual group of care.
Tandon et al. (2016) [35]	Canada	Prospective Cohort	159 (89/70)	57.5 ± 10.4	Viral 31 ALD 29 NAFLD 23 Others 17	A 60 B 33 C 7	Exclusion criteria	B-mode Probe not specified Muscle thickness	Right quadriceps muscle (the rectus femoris and vastus intermedius)	Muscle thickness with and without probe compression adjusted for height compared to SMI by CT-scan	43% of patients had sarcopenia (in cross-sectional imaging)	A nomogram including sex, body mass index and thigh muscle thickness by US can identify sarcopenia as well as SMI by CT-scan (AUROC for male and female of 0.78 and 0.89, respectively)
Zenith et al. (2014) [40]	Canada	Prospective Interventional	19 (15/4)	57.6 ± 6.7	Viral 32 ALD 32 Others 36	Only A and B	Exclusion criteria	B-mode Probe not specified Muscle thickness	Right quadriceps muscle (the rectus femoris and vastus intermedius)	Muscle thickness with and without probe compression adjusted for height	–	Thigh muscle thickness ($P = 0.01$) was significantly higher in the exercise group compared with controls.

Abbreviations: ALD: alcoholic liver disease; NAFLD: non-alcoholic liver disease; CT: computer tomography; LFI: Liver Frailty Index; HCC: hepatocellular carcinoma; US: ultrasound; BIS bioelectrical impedance spectroscopy, MAMC: mid-arm muscle circumference; SMI: skeletal muscle index; DXA: Dual-energy X-ray absorptiometry: SWE: shear wave elasography.

4. Conclusion

To conclude, despite the high heterogeneity among the studies, we found that ultrasound in detecting sarcopenia in advanced liver disease is safe, feasible and showed excellent correlation with the gold standard measurements for sarcopenia and can represent a valid tool in daily practice. Furthermore, an association between unfavorable outcomes and sarcopenia defined by US has been documented. This data calls for additional studies addressing standardization, but also underline how the inclusion of this point-of-care technique in daily practice might benefit risk stratification and potentially simplify clinical decision-making regarding need of intervention for sarcopenia in cirrhosis.

Authors' contributions

CB: literature revision and drafting of the manuscript; AB: supervision and improvement of the manuscript; critical revision of the manuscript for important intellectual content. All the authors: approval of the final version of the manuscript.

Declaration of Competing Interest

No potential conflicts of interest nor financial support to declare.

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