EGYPTIAN JOURNAL OF ANAESTHESIA
2020, VOL. 36, NO. 1, 227–233
https://doi.org/10.1080/11101849.2020.1820813

Ultrasonography evaluation of rectus femoris and anterior tibialis muscles for nutritional assessment in cirrhotic patients undergoing major abdominal surgery

Eman Sayed Ibrahim, Amany Ahmed Zayed, Hatem Amin and Nadia Mohee El Deen Bahgat

Liver Institute, Menoufia University, Shebeen Elkom, Egypt

ABSTRACT

Objectives: This prospective cohort study evaluate the reliability of ultrasonography in nutritional assessment for patients with liver cirrhosis undergoing major abdominal surgery by follow up the quantitative and morphological changes of rectus femoris (RF) and anterior tibialis (AT) muscles.

Methods: Seventy-two adults cirrhotic patients, subjective global assessment grade (SGA A&B) scheduled for major abdominal surgery were assessed preoperative and postoperative days (POD) 1, 3, 5 and 7 in ICU using anthropometric measurements, laboratory investigations, ultrasonography for cross-sectional area (CSA), anteroposterior (AP) and laterolateral (LL) diameters of (RF) and (AT) muscles and record hospital stay time.

Results: We reported significant decrease in all measures of RF and AT muscle masses (CSA, AP and LL) diam. started early after ICU admission up to 7 days. All statistically significant decreased compared to POD0 and 1 ($p = 0.000$). There was 0.56%, 2.05%, 3.28% and 3.67% loss of CSA of RF at POD1, POD3, POD5 and POD7 correspondingly. As well as there was 0.23%, 1.03%, 1.84%, 2.49% loss of CSA of AT in POD1, POD3, POD5 and POD7 correspondingly. Echogenicity score of both muscles were significant increase in POD3, 5 and 7 compared to POD0 ($p = 0.000$).

Conclusion: We used the ultrasound easily for skeletal muscle assessments as well as it helped us to detect the qualitative changes of these muscles and subsequently it can be used as a nutritional assessment tool in LC patients. Muscle US is an emerging tool can used in nutritional guided protocol on malnourished hepatic patient in the future.

ARTICLE HISTORY
Received 12 August 2020
Revised 31 August 2020
Accepted 3 September 2020

KEYWORDS
Ultrasonography; nutritional assessment; rectus femoris; anterior tibialis; cirrhotic patients

1. Introduction

lack of mass and function of skeletal muscles (sarcopenia) is very common postoperative complication especially after major surgery which caused by inflammatory and metabolic stress response corresponding with the extent of the surgical trauma [1] . It observed early in the first day after admission to ICU and may persist for long time then after affecting mainly antigravity muscle groups [2]. Sarcopenia is associated with high morbidity and mortality [3,4].

Liver cirrhosis and malnutrition are reciprocally related to each other. Liver cirrhosis leads to malnutrition due to decrease uptake, altered absorption and metabolism of many nutrients. Meanwhile, malnutrition enhances liver cirrhosis and may enhance liver disease [5]. The moderately and severely malnourished patients had lower survival rates than normal patients.

The SGA is commonly used to assess nutrition in cirrhotic patients. However previous studies reported its low sensitivity, in the majority of patients with liver cirrhosis [6,7].

In hepatic patients, handgrip strength (HGS) was demonstrated by Hirsch et al [8]. To be a good tool for nutrition assessment. However, it has many measurement errors due to different method used in it [9]. Axial CT of psoas muscle area at third lumbar vertebrae level has been used for assessing sarcopenia [10], but it has a high cost, with difficulty to deliver the patient to the site of CT in addition to the hazards of exposure to such high doses of radiation. Bioimpedance Analysis (BIA) is a noninvasive technique for measuring body composition and correlated well with Child- Pugh classification in LC patients [10], but the use of it is still limited to the places where it's provided.

Ultrasonographic evaluation of skeletal muscles (especially rectus femoris and anterior tibialis) is a promising tool for assessment muscle changes through time. It is a bedside technique, can be used by non-specialized personnel [11]. As well, ultrasonography is able to detect quantitative data in muscles as CSA, AP and LL diameter. In addition,

CONTACT Eman Sayed Ibrahim emansayed825@gmail.com Liver Institute, Menoufia University, Giza, Egypt

Registration number: Liver Institute Review Board (IRB) No: 00158/2019. The study was registered at clinical trial.gov ID NCT 04099875.

it evaluates echogenicity as qualitative data of the muscles. Increased echogenicity is an indicator of myofiber depletion. We hypothesized that ultrasonography is a simple qualitative and quantitative assessment for sarcopenia in LC patients after major surgery.

2. Methods

We started patient enrollment after having ethical approval by the Menoufia University National Liver Institute Review Board (IRB) No: 00158/2019. The study was registered at clinical trial.gov ID NCT 04099875. Patient consent was taken before the study. The study was prospective cohort carried out in the National Liver Institute. We screened 78 adult patients with liver cirrhosis undergoing major abdominal surgery. Six patients were excluded from the study due to either refusal to share in the study or severe malnutrition. Participant's inclusion criteria, aged 18–60 yrs. Cirrhotic patient: child A, B, undergoing major abdominal surgery, e.g. Hepatic resection, bypass surgery, Whipple operation, Splenectomy, Colectomy, Common bile duct Exploration. Patients with systemic malignancy, malabsorption syndromes, metabolic syndromes (Hyperthyroidism), neuromuscular diseases, laparoscopic Surgery, immune suppression including treatment with corticosteroids, patients on parenteral nutrition, orthopedic issues such as skeletal fractures and immobilization were excluded from the study. Each patient was assessed using three assessment tools, nutritional history and subjective global assessment SGA, laboratory data and muscle ultrasonography all of them was done on five occasions preoperative, postoperative day (POD 0, 1, 3, 5 and 7).

An US device (Sonosite) was used with a 5- to 7.5-MHz linear probe. We took two muscles for evaluation the rectus femoris and anterior tibialis muscles. We used ultrasound for evaluation of both quantitative and qualitative changes of the muscles preoperative and follow up through a week postoperative.

For both muscles we placed the transducer perpendicular to the muscle at 3/5 the distance between the anterior superior iliac spine and the upper border of the patella for the rectus femoris muscle and 5 cm beneath the peroneal head for the anterior tibialis muscle.

We marked the measurement points to ensure day-to-day consistency. Measurement was done while the patient on his back with both legs extended. Excessive local gel applied to minimize underlying soft tissue distortion; Gain, focus and depth were the same for every patient in all measurements. The same side was used every time. AP, LL diameter and CSA were measured from the outer contour of the muscle section. Echogenicity was reported as qualitative parameter, normal muscle is relatively black, that was expressed according to Heckmatt scale [12], as follows: (1) normal,

(2) mild increase muscle echoes with normal bone reflection, (3) moderate increase muscle echoes with decrease bone reflection, (4) severe increase muscle echoes with disappear bone reflection, higher grade of echogenicity with reduced bone signal indicate severe myopathy.

2.1. Data collection

Demographic data, age, sex. Child score. SGA, anthropometry measurements weight, height, BMI, modified BMI, mid-arm circumference (MAC), triceps skin fold (TSF) and HGS. Laboratory data serum protein, albumin, Transferritin, BUN and serum phosphate. Ultrasonography on RF and AT muscles AP and LL diameters, CSA, Echogenicity. All measurements were at POD 0, 1, 3, 5 and 7. Then fined the correlation between the degree of changes in muscles and SGA A-B patients.

2.2. Sample size & power of study

Based on previous studies (Annetta et al., 2017) [13]. who reported that there was a increased loss of muscle mass up to 20 days after admission to ICU, the degree of RF loss was (45%) and for the AT (22%). Minimum calculated sample is 65 patients; according to the following formula:

$$p = \frac{p_1 + rp_2}{1 + r}$$

$$n \geq \frac{\left[z_{1-\alpha/2}\sqrt{(r+1)p(1-p)} + z_{1-\beta}\sqrt{rp_1(1-p_1) + p_2(1-p_2)} \right]^2}{r(p_2 - p_1)^2}$$

A total number of 78 patients is needed for this study after adding 13 patients for drop-out or withdrawal rate (drop-out rate = 10–20% of calculated sample size = 20% × 65 = 13 patients).

2.3. *Statistical analysis*

The results were presented in a tabulated manner and analysed using SPSS-21 for windows. Test of normality by using Kolmogorov-Smirnov which detects significance in the distribution of most variables, so that non-parametric statistics was used. Data were described using median and inter-quartile rang. Comparisons were carried out among related-samples by Friedman's test "alternative to the one-way ANOVA with repeated measures". Pair-wise comparison when Friedman's test was significant was carried out using Dunn-Sidak method.

3. Results

Seventy-eight patients scheduled for major abdominal surgery were involved. Six patients were excluded either due to severe malnutrition or a delay in starting oral feeding. (Figure 1)

Patients' demographic data were described; median of age was 51.5 with IQR (45.00–56.00)

Thirty-three patients were female, 39 patients were male and 62 patients (86.1%) were child score A and 10 patients (13.9%) were child score B. Fifty-two patients (72.2%) were SGA A and 20 patients (17.8%) were SGA B. About 25% of patients underwent resection. Intensive care unit stay, median IQR was 3.00 (2.00–4.50). Hospital stay, median IQR was 7 (5.00–10.00) (Table 1).

Weight and BMI were significantly increased in POD1, 3 and 5 compared to POD0 (p = 0.00) . It was also significantly decreased in POD7 compared to POD1, 3 and 5 p = 0.00. (Table 1)

Although MAC showed overall significance with chi square test (p = 0.00), there was no significance using pair wise comparison. TSF was significantly increased in POD5 and 7 compared to POD0 (p = 0.006, 0.024) respectively. While HGS showed significance decrees in POD1, 3, 5 and 7 compared to base line (Table 2).

Total protein, albumin, both were significantly decreased in POD1, 3, 5 and 7 compared to POD0

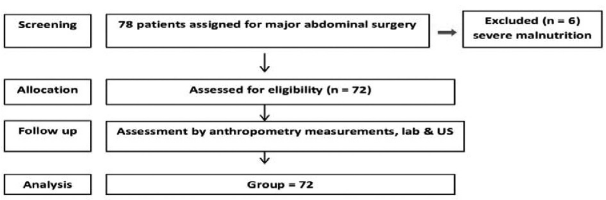

Figure 1. Flow chart of the study.

Table 1. Patient demographic, clinical data and outcome

Parameter N=72	N %
Age (Yrs.)	
Min-Max	18-60
Median (IQR)	51.5 (45-56)
Sex:	39(54.2%) / 33(45.8%)
Male / Female	
Height (m)	
Min-Max	1.6-1.9
Median (IQR)	1.7 (1.7-1.8)
Child score:	62(86.1%) / 10(13.9%)
A / B	
SGA:	52(72.2%) / 20(27.8%)
A / B	
Type of surgery:	18 25
Resection	14 19.4
Whipple	7 9.7
Splenectomy	4 5.6
Colectomy	4 5.6
CBD exploration	19 26.4
Bypass surgery	6 8.3
Distal pancreatectomy	
ICU stay (Days)	
Min-Max	0-11
Median (IQR)	3 (2-4.5)
Hospital stay (Days)	
Min-Max	3-16
Median (IQR)	7 (5-10)

N= Number of patients; SGA: subjective Global Assessment, CBD: Common Bile Duct, Min-Max: Minimum – Maximum, IQR: Inter-quartile range (25th – 75th percentile).

(p value = 0.000) . However, it was significantly increased in POD5 and 7 compared to POD1 (p value = 0.006, 0.000 respectively). Albumin was significantly increased in POD5 and 7 compared to POD3 (p value = 0.034, 0.000 respectively) and it was significantly increased in POD7 compared to POD5 (p value = 0.029). In addition, BUN was significantly decreased in POD7 compared to POD1

(p value = 0.048). While Ph. was significantly lower in POD3 and 5 compared to POD0 (p = 0.000) However, Ph was significantly greater in POD7 in comparison with POD3 (p = 0.041) (Table 2).

All measures of rectus femoris muscle with CSA, AP and LL diameters decreased progressively during ICU stay. All statistically significant decreases in POD3, 5 and 7 compared to POD0 and 1 (p = 0.000). Echogenicity score of RF was statistically significant increase in POD3, 5 and 7 compared to POD0 (p = 0.000) (Table 3). While the median (IQR) CSA, AP and LL of anterior tibialis muscle statistically significant decreased in POD3, 5 and 7 compared to POD0 and POD1 (p = 0.000). Echogenicity score of AT was statistically significant increase in POD3, 5 and 7 compared to POD0 (p = 0.000) (Table 3).

There was (0.56%) loss of CSA of the RF muscle at POD1. (2.05%) loss at POD3, (3.28%) loss at POD5 (3. 67%) loss at POD7. For AT muscle; there was (0.23%) loss of CSA at POD1. (1.03%) loss at POD3, (1.84%) loss at POD5, (2.49%) loss at POD7. For both muscles, there was no statistically significance difference between

Table 2. Anthropometry & laboratory data

Variable	POD0	POD1	POD3	POD5	POD7	*P value*
Weight (Kg).	76.2 (68.9-84.8)	76.8■ (69.8-86.2)	76.4■ (70.3-86.2)	76.6■ (69.4-86)	76 (69.6-85.3)	0.000*
BMI (kg/m²)	25.9 (23.8-29)	26.4■ (24.1-29.3)	26.2■ (24-29.3)	26.3■ (24-29.2)	26.2 (23.5-29.4)	0.000*
Modified BMI (BMIxalb.(g/L)	1030.9 (905.8-1121)	665.8■ (552-775.7)	692.8 (566.7-805.1)	736.4■ (598.2-839.3)	792.4■ (637.8-895.1)	0.000*
MAC (cm)	28 (24.5-32)	28 (25. -31.5)	28 (25 -32)	28 (25-32)	28 (25-32)	0.014*
TSF (mm)	21.5 (18.5-25)	22 (19.5-25)	22 (19.5-24)	22■ (20-24)	22■ (19.5-24.5)	0.000*
HGS (kg)	45 (38-50)	19■ (15-22)	24■ (18-28)	25■ (20-31)	30■ (25-35)	0.000*
Total protein (g/dl)	7.5 (6.9-7.9)	5.4■ (5.1-5.9)	5.5■ (5.2-6)	5.7■ (5.4-6.1)	5.9■ (5.5-6.3)	0.000*
Albumin (g/dl)	3.8 (3.6-4.2)	2.5■ (2.2-2.8)	2.5■ (2.3-2.9)	2.7■ (2.4-3.1)	3■ (2.6-3.3)	0.000*
Transferritin (µg/L)	39.65 (34.3-45.4)	19.50° (16.7-26.1)	15.35° (13.6-19.2)	13.50° (11-16.9)	11.90° (9.4-16)	0.000*
BUN (mg/dl)	16 (12-19.5)	18 (13-23.5)	17 (13.5-22)	17 (13.5-19)	16.8 (12-19)	**0.012***
PO_4 (mg/dl)	4 (3.6-4.4)	3.8 (3.3-4.2)	3.2 ■ (2.9-3.8)	3.2■ (3-3.7)	3.4 (3.1-3.9)	0.000*

Table 3. Ultrasonography results of both RF & AT muscles:

Variable	POD0	POD1	POD3	POD5	POD7	P value
RF CSA (cm²)	3.6 (3-4.5)	3.6 (3.1-4.4)	3.5■ (2.9-4.3)	3.5■ (2.9-4.4)	3.5■ (2.9-4.4)	0.000*
RF AP diam. (cm)	1.6 (1.3-1.9)	1.6 (1.4-1.9)	1.5■ (1.3-1.9)	1.5■ (1.2-1.8)	1.4■ (1.2-1.8)	0.000*
RF LL diam. (cm)	3.4 (2.8-4.3)	3.4 (2.7-4.2)	3.3■ (2.6-4.2)	3.3■ (2.5-4.2)	3.3■ (2.6-4.1)	0.000*
RF echo.	1 (1-2)	1 (1-2)	2■ (1-2)	2■ (2-3)	2■ (2-3)	0.000*
AT CSA (cm²)	6.9 (6.2-7.9)	7.2 (6.2-8.1)	7■ (6.1-7.89)	7■ (6.1-7.8)	6.9■ (6.1-7.8)	0.000*
AT AP diam. (cm)	2.2 (1.9-2.7)	2.2 (1.9-2.6)	2.1■ (1.8-2.5)	2■ (1.7-2.5)	2■ (1.7-2.51)	0.000*
AT LL diam. (cm)	4.7 (4.4-5.3)	4.7 (4.4-5.3)	4.6■ (4.3-5.3)	4.6■ (4.3-5.2)	4.6■ (4.2-5.2)	0.000*
AT echo	1 (1-2)	2 (1-2)	2■ (2-3)	2■ (2-3)	3■ (2-3)	0.000*

N= number of patients (N=72), RF = rectus femoris muscle, AP diam. =Anteroposterior diameter, CSA cross sectional area LL diam. = laterolateral diameter, Echo. = echogenicity; AT anterior tibialis muscle; data expressed as Median, IQR: Inter-quartile range (25^{th} – 75^{th} percentile) *= statistically significant ($p<0.05$) ■ significant compared to baseline

SGA A and SGA B regarding the percentage of muscle wasting estimated by CSA (Table 4).

4. Discussion

In our study, we used ultrasonography for the measurement of quantitative and qualitative changes of skeletal muscles in a homogenous group of patients with liver cirrhosis undergoing major abdominal surgery. We reported a significant loss of RF and AT muscle mass started early after ICU admission up to 7 days. As well as the echogenicity score of these muscles were statistically significant increase in POD3, 5 and 7 compared to POD0 and we concluded that the ultrasound can be used as a nutritional assessment tool in LC patients.

Sarcopenia ranges from about 20% in compensated liver disease to 65–100%.In decompensated liver cirrhosis sarcopenia has been reported in up to 100% of the patients on the liver transplant waiting list [14]. It is considered to be risk factor for pour outcome among those patients.

It's so important to study the effect of the operative stress on muscle mass, find a new tool for the assessment of muscle in hepatic patient which can be used easily.

Seymour et al study the relationship of US measurement of RF CSA with quadriceps strength in COPD patients and concluded that ultrasound measurement of RF CSA is a radiation-free and an effort-independent method of measuring quadriceps muscle CSA that correlates to strength. Also

Table 4. comparison between SGA group A & group B regarding the percentage of muscle wasting.

	SGA		
	A (N=52)	B (N=20)	
	Min-Max Median (IQR)	Min-Max Median (IQR)	Statistical significance
CSA percentage change RF (POD1 vs baseline)	-19.4 – 4 0.6 (-0.6 – 1.1)	-2.6 – 3.9 0.4 (-0.8 – 1.1)	$Z_{(MW)}$=0.390 *p*=0.697 NS
CSA percentage change RF (POD3 vs baseline)	-59.9 – 1.5 -1.9 (-3.5 – -0.9)	-7.1 – 1.8 -2.5 (-3.9 – -1)	$Z_{(MW)}$=0.742 *p*=0.458 NS
CSA percentage change RF (POD5 vs baseline)	-59.4 – 1.2 -3.4 (-4.4 – -1.9)	-8.7 – 3 -2.9 (-5.6 – -1.7)	$Z_{(MW)}$=0.101 *p*=0.920 NS
CSA percentage change RF (POD7 vs baseline)	-56.2 – 1.4 -3.4 (-5.6 – -2.7)	-9.8 – 2.3 -4.6 (-5.8 – -1.8)	$Z_{(MW)}$=0.138 *p*=0.890 NS
CSA percentage change AT (POD1 vs baseline)	-2.9 – 31.1 0.2 (-0.3 – 0.5)	-2.5 – 2.2 0.1 (-1 – 0.5)	$Z_{(MW)}$=0.779 *p*=0.436 NS
CSA percentage change AT (POD3 vs baseline)	-6.1 – 6.8 -1 (-2.1 – -0.5)	-6.40 – 2.75 -1.2 (-2.8 – -0.7)	$Z_{(MW)}$=0.641 *p*=0.521 NS
CSA percentage change AT (POD5 vs baseline)	-5.8 – 6.3 -1.8 (-2.9 – -1)	-8.2 – 1.7 -2.5 (-3.2 – -1.3)	$Z_{(MW)}$=1.097 *p*=0.274 NS
CSA percentage change AT (POD7 vs baseline)	-6.1 – 3.7 -2.3 (-3.3 – -1.2)	-9.1 – -0.1 -3 (-3.7 – -2.1)	$Z_{(MW)}$=1.521 *p*=0.128 NS

SGA= Subjective Global Assessment, CSA cross sectional area, N number of patients, RF= Rectus Femoris muscle, AT= Anterior Tibialis muscle, Min-Max= Minimum – Maximum, IQR: Inter-quartile range (25th – 75th percentile), *: Statistically significant (p<0.05), NS: Statistically not significant (p>0.05)

ultrasound has been used to quantify the loss of skeletal muscles in patients with, malignancy and Pillen et al evaluate muscle US in neuromuscular disorders and review its value and limitations as a diagnostic tool in neuromuscular disorders [11,15,16]. Paris et al assess the validity of the US of muscle layer thickness of the quadriceps QMLT in critically ill patient and suggested that QMLT not accurate in patients with low muscle mass. Reeves reported that ultrasonography is shown to be more accurate than anthropometric measurements and has closely correlated with the data collected from MRI and CT scan [17,18]

In our study MAC not found to be affected by postoperative sarcopenia (p value 1.000) perhaps the duration of the study was short to detect such gross muscular changes. That was in contrary with the authors of Hübneret al and Sanchez et al. [19,20], who noted that MAC and TSF are accurate with presence of salt and water retention.

In the current study HGS showed a massive decline in POD1 (P value 0.000), followed by increase in subsequent readings, but unable to reach the preoperative value, the massive decline in POD1 may be contributed to other factors than muscle power as analgesia with opioids & psychic condition of the patients . Griffith CD et al. have found the same findings in patients undergoing major vascular surgery & it was associated with postoperative complications [21]

In the current study, about quantitative muscular changes there was a decline in the RF and AT muscles mass representing as CSA, AP and LL diameters in POD3, 5 and 7 compared to POD0 (p value = 0.000) In particular POD5 and 7, there was an overall reduction of 3.67% of CSA of RF muscle and 2.49% of CSA of AT muscle in POD7 .

The underlying mechanisms of this different amount of losses between the two muscle groups are unclear. In rodent and human models, the extend of muscle loss vary according to muscle type and degree of use of this muscle [22,23]. Lower limb muscle loss is greater in the extensor muscles. This is can explain more RF muscle loss as compared to AT. Also, type 11 fast twitch fibers present in RF this make it more liable to loss than type 1 fiber that present in AT muscle [24, 25 and 26]. Krawiec et al concluded that a predominant loss of type II fibers and conversion of fiber typing from type I to type II in lower limb muscles [27].

Morphological changes that occur in the muscle myofibril including muscle edema then fibrosis and fatty degeneration these changes affect muscle echogenicity as these changes represent a signal to myofibril damage and derangement of the muscle contour which closely related to muscle dysfunction [28]. These derangement in the muscle morphology are seen and detected with muscle biopsies [29] or with magnetic resonance imaging [30]. Increased echogenicity has strong relationship with function and muscle strength [30]. Also its associated with decrease bone signal and advanced myopathy [12]. Heckmatt Scale in contrast to objective, algorithms for image analysis as computer-assisted quantitative gray scale may show inter-observer variation and technical misinterpretation [31]. But, it has the merit of being a rapid and inexpensive.

In our study, there was also progressive increase in echogenicity by Heckmatt Scale which was more relevant in AT muscle than RF muscle this is similar to results obtained by Annetta et al who evaluate US of the muscles in young trauma patients and concluded that this method is costless, noninvasive and easily in trauma patient. They were able to follow the morphological changes of skeletal muscle in those types of patients [13].

Our results can be justified by the incidence of sarcopenia due to defect in the intake or absorption due to paralytic ileus magnified by the need of higher calories as the patient in severe stress and the presence of chronic hepatic illness which diminishes the stores of the body needed to face the patient's requirements. Other factors like inflammation, neuroendocrine stress response, immobilization, impaired microcirculation and denervation.

4.1. The conclusion and the limitation of our study

Ultrasonography is a promising tool to be used for nutrition assessment in hepatic patients we used it easily for skeletal muscle assessments as well as it helped us to observe the qualitative changes of these muscles and subsequently it can be used as a nutritional assessment tool in LC patients. Muscle US is an emerging tool can be used in nutritional assessment and nutritional guided protocol on malnourished hepatic patient in the future.

Disclosure statement

There was no conflict of interest and It was self funded.

ORCID

Eman Sayed Ibrahim http://orcid.org/0000-0002-6850-1931

References

[1] Weimann A, Braga M, Carli F, et al. ESPEN guideline: clinical nutrition in surgery. Clin Nutr. 2017;36 (3):623–650.
[2] Trethewey SP, Brown N, Gao F, et al. Interventions for the management and prevention of sarcopenia in the critically ill: A systematic review. J Crit Care. 2019;50:287–295.
[3] Chang W-T, Ker C-G, Hung H-C, et al. Albumin and prealbumin may predict retinol status in patients with liver cirrhosis. Hepato-gastroenterology. 2008;55 (86–87):1681–1685.
[4] De Jonghe B, Bastuji-Garin S, Durand M-C, et al. Respiratory weakness is associated with limb weakness and delayed weaning in critical illness. Crit Care Med. 2007;35(9):9.
[5] Maharshi S, Sharma BC, Srivastava S. Malnutrition in cirrhosis increases morbidity and mortality. J Gastroenterol Hepatol. 2015;30(10):1507–1513.
[6] Gattermann Pereira T, da Silva Fink J, Tosatti JAG, et al. Subjective global assessment can Be performed in critically ill surgical patients as a predictor of poor clinical outcomes. Nutr Clin Pract. 2019;34(1):131–136.
[7] Cichoż-Lach H, Michalak A. A comprehensive review of bioelectrical impedance analysis and other methods in the assessment of nutritional status in patients with liver cirrhosis. Gastroenterol Res Pract. 2017;2017: 1–10.
[8] Hirsch S, Bunout D, De La Maza P, et al. Controlled trial on nutrition supplementation in outpatients with symptomatic alcoholic cirrhosis. J Parenteral Enteral Nutr. 1993;17(2):119–124.
[9] Fernandes SA, Bassani L, Nunes FF, et al. Nutritional assessment in patients with cirrhosis. Arq Gastroenterol. 2012;49(1):19–27.
[10] Masuda T, Shirabe K, Ikegami T, et al. Sarcopenia is a prognostic factor in living donor liver transplantation. Liver Transpl. 2014;20(4):401–407.
[11] Seymour JM, Ward K, Sidhu PS, et al. Ultrasound measurement of rectus femoris cross-sectional area and the relationship with quadriceps strength in COPD. Thorax. 2009;64(5):418–423.
[12] Heckmatt J, Pier N, Dubowitz V. Real-time ultrasound imaging of muscles. Muscle Nerve. 1988;11(1):56–65.
[13] Annetta MG, Pittiruti M, Silvestri D, et al. Ultrasound assessment of rectus femoris and anterior tibialis muscles in young trauma patients. Ann Intensive Care. 2017;7 (1):104.
[14] Cheng PC Hand grip strength as a nutritional assessment tool. University of Saskatchewan; 2014.
[15] Campbell SE, Adler R, Sofka CM. Ultrasound of muscle abnormalities. Ultrasound Q. 2005;21(2):87–94.
[16] Pillen S, Arts IM, Zwarts MJ. Muscle ultrasound in neuromuscular disorders. Muscle Nerve. 2008;37 (6):679–693.
[17] Paris MT, Mourtzakis M, Day A, Leung R, Watharkar S, Kozar R, et al. Validation of bedside ultrasound of muscle layer thickness of the quadriceps in the critically ill patient (VALIDUM study) a prospective multicenter study. J Parenteral Enteral Nutr. 2017;41(2):171–180.
[18] Reeves ND, Maganaris CN, Narici MV. Ultrasonographic assessment of human skeletal muscle size. Eur J Appl Physiol. 2004;91(1):116–118.
[19] Hübner M, Mantziari S, Demartines N, et al. Postoperative albumin drop is a marker for surgical stress and a predictor for clinical outcome: a pilot study. Gastroenterol Res Pract. 2016;2016: 1–8.
[20] Sanchez F, Faganello M, Tanni S, et al. Anthropometric midarm measurements can detect systemic fat-free mass depletion in patients with chronic obstructive pulmonary disease. Braz J Med Biol Res. 2011;44(5):453–459.
[21] Griffith C, Whyman M, Bassey E, et al. Delayed recovery of hand grip strength predicts postoperative morbidity following major vascular surgery. Br J Surg. 1989;76 (7):704–705.
[22] Zhong H, Roy RR, Siengthai B, et al. Effects of inactivity on fiber size and myonuclear number in rat soleus muscle. J Appl Physiol. 2005;99(4):1494–1499.
[23] Psatha M, Wu Z, Gammie FM, et al. A longitudinal MRI study of muscle atrophy during lower leg immobilization following ankle fracture. J Magn Reson Imaging. 2012;35(3):686–695.
[24] Henriksson-Larsén KB, Lexell J, Sjöström M. Distribution of different fibre types in human skeletal muscles. I. Method for the preparation and analysis of

cross-sections of whole tibialis anterior. Histochem J. 1983;15(2):167–178.
[25] De Jonghe B, Sharshar T, Lefaucheur J-P, et al. Paresis acquired in the intensive care unit: a prospective multicenter study. Jama. 2002;288(22):2859–2867.
[26] Petrasek PF, Homer-Vanniasinkam S, Walker PM. Determinants of ischemic injury to skeletal muscle. J Vasc Surg. 1994;19(4):623–631.
[27] Krawiec BJ, Frost RA, Vary TC, et al. Hindlimb casting decreases muscle mass in part by proteasome-dependent proteolysis but independent of protein synthesis. Am J Physiol Endocrinol Metab. 2005;289(6):E969–E80.
[28] Grimm A, Teschner U, Porzelius C, et al. Muscle ultrasound for early assessment of critical illness neuromyopathy in severe sepsis. Crit Care. 2013;17(5):R227.
[29] Puthucheary ZA, Rawal J, McPhail M, et al. Acute skeletal muscle wasting in critical illness. Jama. 2013;310(15):1591–1600.
[30] Parry SM, El-Ansary D, Cartwright MS, et al. Ultrasonography in the intensive care setting can be used to detect changes in the quality and quantity of muscle and is related to muscle strength and function. J Crit Care. 2015;30(5):1151.e9-. e14.
[31] Pillen S, van Alfen N. Skeletal muscle ultrasound. Neurol Res. 2011;33(10):1016–1024.