Utility of the simplified measurements of muscle mass in patients with gastrointestinal and chronic liver diseases

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Sarcopenia is an important prognostic factor in patients with gastrointestinal and chronic liver diseases. Computed tomography and bioelectrical impedance analysis are the gold standards for measuring skeletal muscle mass for the diagnosis of decreased muscle mass, but there are some institutions where BIA and CT cannot be carried out. We evaluated the utility of simplified methods for measuring muscle mass; the psoas muscle mass index (PMI) method, simple PMI method, and arm muscle area (AMA) method. This retrospective study included 331 patients with gastrointestinal diseases and 81 patients with chronic liver diseases who were admitted from June 2018 to December 2019 at Municipal Hospital of Kofu. The skeletal muscle mass was measured using the PMI via the volume analyzer SYNAPSE VInCEnt ver3.0, simple PMI based on CT imaging, and AMA method. Positive correlations were found between muscle mass measured by PMI and simple PMI, PMI and AMA, and simple PMI and AMA in patients with gastrointestinal diseases (correlation coefficients = 0.76, 0.57, 0.47, respectively, p < 0.001). Positive correlations were observed between muscle mass measured by PMI and simple PMI, PMI and AMA, and simple PMI and AMA in chronic liver diseases (correlation coefficients = 0.77, 0.53, 0.45, respectively, p < 0.001). Measurement of muscle mass by the AMA method showed some correlation with the PMI method. Measurement of muscle mass by the simple PMI method showed correlation with the PMI method. These simplified methods can be alternative methods of evaluating muscle mass in patients with gastrointestinal and chronic liver disease.

Sarcopenia is a syndrome characterized by a decrease in skeletal muscle mass, skeletal muscle strength, and physical function. There are several diagnostic criteria for sarcopenia, including the European Working Group on Sarcopenia in Older People (EWGSOP), the International Working Group on Sarcopenia (IWGS), the Asian Working Group for Sarcopenia (AWGS) criteria, and the Japanese Society of Hepatology (JSH). All definitions are based on decreased skeletal muscle mass and decreased function, and decreased skeletal muscle mass is defined as myopenia. In the JSH criteria, patients with chronic liver disease are diagnosed with sarcopenia if they have “decreased grip strength” and “decreased muscle mass” (as determined by computed tomography (CT) or bioelectrical impedance analysis (BIA)-guided skeletal muscle mass index). CT and BIA are the gold standards for measuring skeletal muscle mass available at present. Performing these examinations is difficult in some institutions with no special software or equipment. Simplified methods for measuring muscle mass have attracted attention in such clinical settings.

One of the simplified methods is the psoas muscle mass index (PMI) using CT images. This method is mentioned as an alternative method in the criteria from the JSH. In particular, simple PMI can be obtained from CT images immediately and easily. The second method uses anthropometric measurements to estimate the area of the brachial muscle. Arm circumference (AC) and triceps skinfold thickness (TSF) are used to estimate muscle mass.

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mass by calculating the arm muscle area (AMA) of the brachial muscle\(^8,9\). In this study, the utility of the AMA method and the simple PMI method as simplified methods was verified.

**Methods**

**Patients.** This study targets 331 patients with gastrointestinal diseases who were admitted to our department between June 2018 and December 2019 and whose muscle mass was measured using three methods: the psoas muscle mass index (PMI) method, the simple PMI method, and the arm muscle area (AMA) method. The patients with comorbidity malignancies other than gastrointestinal cancers were excluded. All patients provided informed consent for this study, which was in compliance with the Declaration of Helsinki and was approved by the ethics committee for clinical studies of Municipal Hospital of Kofu: Rinshoukenkyu-Rinrishinsa-linkai (in Japanese), approval number 31–2).

**Measurement of muscle mass and diagnosis using the PMI method and simple PMI method.** CT images taken during hospitalization or within one month before admission were used. SYNAPSE Vincent volume analyzer version 3.0 was used in the PMI method as the sum of the areas of the ilioiopsoas muscles on both sides at the level of the L3 vertebral body divided by the square of the height. The simple PMI was obtained as the sum of the product of the long axis and the short axis of the iliopsoas muscles on both sides at the level of the L3 vertebral body divided by the square of the height. According to the diagnostic criteria for sarcopenia in patients with liver disease from the JSH, the cut-off value for myopenia was a PMI of 6.36 cm\(^2\)/m\(^2\) in males and 3.92 cm\(^2\)/m\(^2\) in females, and a simple PMI of 6.0 cm\(^2\)/m\(^2\) in males and 3.4 cm\(^2\)/m\(^2\) in females\(^7\).

**Measurement of muscle mass and diagnosis using the AMA method.** Measurements were performed on the non-paralytic or non-dominant upper arm using an insert tape and an adipometer (ABBOTT JAPAN). Arm circumference (AC) and triceps skinfold thickness (TSF) were measured at the level of the mid-point between the acromial process of the scapula and the olecranon process of the ulna. All measurements were performed three times, and mean values were used. Arm muscle circumference (AMC) and AMA were calculated using the following equations. There are no standard values recommended as cut-offs for myopenia, and 21.4 cm\(^2\) was used for males and 21.6 cm\(^2\) for females in this study as these are the cut-offs for undernutrition in the general elderly population\(^6,8,9\). The percentage notation was calculated with reference to the Japanese Anthropometric Reference Data (JARD2001).

\[
AMC = AC - \pi \times TSF.
\]

\[
AMA = \frac{AMC (cm^2)}{4\pi} - \text{bone area} \quad \text{males } 10 \text{ cm}^2, \quad \text{females } 6.5 \text{ cm}^2.
\]

**Statistical analyses.** Values were shown as means ± standard deviation (SD). Categorical variables were subjected to Fisher’s test. Continuous variables were using unpaired Student’s t-tests. Pearson’s product rate correlation was used to assess the correlation of continuous variables. The best cut-off values in receiver operating characteristic (ROC) analyses were determined by the Youden index. P value <0.05 was considered statistically significant. All statistical analyses were performed using EZR (Saitama Medical Center, Iichi Medical University, Saitama, Japan), a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). More precisely, it is a modified version of the R commander designed to include statistical functions frequently used in biostatistics.

**Results**

**Background characteristics of gastrointestinal disease patients.** The background characteristics of the 331 patients with gastrointestinal diseases who underwent muscle mass measurements are shown in Table 1. The primary diseases included liver cirrhosis in 81 patients [including 54 patients with hepatocellular carcinoma (HCC)], gastric or esophageal cancer in 34 patients, biliary or pancreatic cancer in 47 patients, colorectal cancer in 29 patients, and benign disease in 140 patients. Benign diseases included colorectal adenomas in 15 patients, gastrointestinal bleeding in 17 patients, enteritis and intestinal obstruction in 28 patients, cholecystolithiasis in 38 patients, acute pancreatitis in 14 patients, and other benign diseases in 28 patients. The median age was 74 ± 13 years old, with 206 (62%) males. Myopenia in patients with gastrointestinal diseases was observed in 115 (35%) patients by PMI, 102 (31%) by simple PMI, and 123 (37%) by AMA. The frequency of myopenia was significantly higher in patients with malignant tumors than in those without (24 vs. 5.7% by PMI, p < 0.001, 37 vs. 25% by simple PMI, p = 0.017, 49 vs. 26% by AMA, p < 0.001). The frequency of myopenia did not differ by BMI, blood test findings, or presence of comorbidities in this study.

**Comparisons between muscle mass measurement methods in patients with gastrointestinal diseases.** Positive correlations were found between muscle mass measured by PMI and simple PMI, PMI and AMA, and simple PMI and AMA (correlation coefficients = 0.76, 0.57, 0.47, respectively, p < 0.001) (Fig. 1). Similarly, in males (correlation coefficients = 0.73, 0.39, 0.48, p < 0.001) and females (correlation coefficients = 0.71, 0.43, 0.35, p < 0.001), a positive correlation between the three methods was observed (Fig. 2).

**Background characteristics of chronic liver disease patients.** The characteristics of chronic liver disease patients are shown in Table 2. All patients had liver cirrhosis, and 54 patients also had HCC. The median age was 75 ± 11 years old, with 54 (67%) males. Etiology of chronic liver disease was hepatitis B, hepatitis C, alco-
hol, non-alcoholic steatohepatitis, and others in 5, 39, 16, 19, and 2 patients. Hepatic function was Child–Pugh A, B, and C in 39, 32, and 10 patients. Myopenia was observed in patients with chronic liver disease in 29 (36%) patients by PMI, 23 (28%) by simple PMI, and 29 (36%) by AMA.

Comparisons between muscle mass measurement methods in patients with chronic liver disease.

Patients diagnosed with myopenia by the AMA method had significantly lower muscle mass by the PMI method compared to patients without myopenia (males 5.6 ± 1.8 vs. 7.3 ± 1.0 cm²/m², p = 0.001, females 4.2 ± 0.97 vs. 6.5 ± 1.9 cm²/m², p < 0.001) and the simple PMI method (males 5.1 ± 2.1 vs. 7.4 ± 2.2 cm²/m², p = 0.001, females 3.8 ± 1.6 vs. 6.1 ± 1.5 cm²/m², p < 0.001) (Fig. 3). Positive correlations were observed between muscle mass measured by PMI and simple PMI, PMI and AMA, and simple PMI and AMA (correlation coefficients = 0.77, 0.53, 0.45, respectively, p < 0.001) (Fig. 4). A positive correlation was also found among the three methods, in males (correlation coefficient = 0.76 p < 0.001, 0.49 p < 0.001, 0.42, p = 0.0015) and females (correlation coefficient = 0.70 p < 0.001, 0.65 p < 0.001, 0.53, p = 0.004), (Fig. 5).

Accuracy in identifying myopenia using simple PMI and AMA in chronic liver disease patients.

The reliability of simplified methods was as follows when the PMI method was assumed as the

| Table 1. Backgrounds of patients with gastrointestinal diseases. Continuous values are expressed as mean ± standard deviation. BMI body mass index, AC Arm circumference, AMC Arm muscle circumference, AMA Arm muscle area, PMI Psoas muscle mass index. |
|-----------------|-----------------|-----------------|
| **BMI** (body mass index) | **AC** (Arm circumference) | **AMC** (Arm muscle circumference) |
| **N=331** | **331** | **331** |
| **Age: years, mean ± SD** | 74 ± 13 | |
| **Men: n (%)** | 206 (62%) | |
| **BMI, mean ± SD** | 22 ± 4.2 | |
| **Performance status: n (%)** | 0/1/2/3/4 | 105/110/74/35/7 (32/33/22/11/3%) |
| **%AC: %, mean ± SD** | 89 ± 13 | |
| **%AMC: %, mean ± SD** | 95 ± 13 | |
| **%AMA: %, mean ± SD** | 69 ± 26 | |
| **Primary disease: n (%)** | | |
| Chronic liver disease | 81 (24%) | |
| Gastroesophageal cancer | 34 (10%) | |
| Biliary pancreatic cancer | 47 (14%) | |
| Colorectal cancer | 29 (9%) | |
| Benign disease | 140 (43%) | |
| **Comorbidities: n (%)** | | |
| Heart disease | 54 (17%) | |
| Chronic lung disease | 24 (7.3%) | |
| Cerebrovascular disease | 44 (13%) | |
| Chronic renal disease | 17 (5.2%) | |
| Diabetes | 68 (21%) | |
| **Myopenia: n (%)** | | |
| By PMI method | 115 (35%) | |
| By simple PMI method | 102 (31%) | |
| By AMA method | 123 (37%) | |
gold standard method: the sensitivity of the simple PMI method was 62% (95% CI 42–79%), specificity was 90% (95% CI 79–97%), the positive predictive value was 78% (95% CI 56–93%), and negative predictive value was 81% (95% CI 69–90%), while the sensitivity of the AMA method was 62% (95% CI 42–79%), specificity was 79% (95% CI 65–89%), the positive predictive value was 62% (95% CI 42–79%), and negative predictive value was 79% (95% CI 65–89%). The cut-off values for predicting PMI-induced myopenia were 21.4 cm² (AUROC 0.74, 95% CI 0.61–0.88) in males and 21.4 cm² (AUROC 0.81, 95% CI 0.65–0.98) in females, respectively.

Discussion
Sarcopenia was proposed in 1989 by Rosenberg and, to date, there have been several diagnostic criteria. Skeletal muscle mass index (SMI) measured by BIA and CT is the current standard for skeletal muscle mass, and sarcopenia is diagnosed in patients with chronic liver disease who have decreased grip strength (26 kg for males and 18 kg for females) and myopenia with SMI measured by CT (42 cm²/m² in males and 38 cm²/m² in females) or BIA (7.0 kg/m² in males and 5.7 kg/m² in females) in the JSH criteria. In this study, we investigated the utility of simplified methods that did not require special equipment or software for measuring muscle mass. There was a positive correlation between muscle mass measured by the PMI method, simple PMI, and AMA method in patients with gastrointestinal diseases and chronic liver disease. In particular, the reliability of AMA method in diagnosing myopenia is not equal to PMI, but in institutions where CT cannot be done, we have thought that the AMA method was alternative method for evaluating muscle mass.

The PMI method is an evaluation method using CT imaging, and is easy to use in patients with HCC in whom CT scans are frequently performed in the follow-up. In the present study, PMI was calculated using the manual trace method proposed by Vincent ver3.0. PMI has been reported to correlate with SMI using muscle mass measuring software (r = 0.57, P < 0.01) and SMI measured by BIA (r = 0.74, P < 0.01). Additionally, simple PMI is one of the simplified methods referred to in the JSH criteria. A positive correlation between simple PMI and SMI has been reported (r = 0.57, P < 0.01).

The second simplified method of evaluating muscle mass is the AMA method; the method for estimating the cross-sectional area of the brachial muscle using anthropometric measurements. It has been reported to be strongly correlated with whole body skeletal muscle mass measured by dual energy X-ray absorptiometry and AMA in the elderly. Moreover, there is reportedly a good correlation between AMA and grip strength in patients waiting for liver transplantation (Spearman correlation 0.49, p < 0.01). Among elderly individuals over 70 years and older, the mortality rate was reported to be higher in males with AMA ≤ 21.4 cm² and ≤ 21.6 cm² in females. However, overestimation of the AMA method has been reported as 15–25% over actual muscle mass, and a large difference particularly in patients with thick subcutaneous fats was reported in the 1980–1990s. A subsequent 2010 research reported that anthropometric AMA correlated well with CT-based AMA (r = 0.85, P < 0.001 in
males and r = 0.90, p < 0.001 in females). Reproducibility and difficulty in establishing uniform cut-off values across races have been reported15. As a simplified anthropometric method other than the AMA method, a yubiwakka test in Japanese patients has been reported; however, it is largely affected by leg edema and obesity16–19. In patients with chronic liver disease in whom edema of the lower legs is common, a determination based on measurements of the lower legs would likely be difficult. Thus, anthropometric AMA measurements that can be performed as a primary screening at any time and any place are helpful.

In this study, myopenia in patients with gastrointestinal diseases was found in 35% of patients with PMI, 31% with simple PMI, and 37% with AMA. Myopenia in patients with chronic liver disease was found in 36% of patients with PMI, 28% with simple PMI, and 36% with AMA. In a large survey of the general Japanese population, the incidence of sarcopenia was approximately 8% compared to 20% in individuals aged 65 years and older20,21. The prevalence of sarcopenia in the field of gastrointestinal cancers has been reported to be high at 26–65% for gastric and esophageal cancer22–26, 19–39% for colorectal cancer27,28, 21–63% for biliary and pancreatic cancer29,30, 11–65% for HCC31–34. In esophagectomy cases, postoperative cardiovascular-related complications, pulmonary complications, and mortality were significantly higher in patients with myopenia22,23. Sarcopenia in gastric cancer patients was associated with infection after surgery (odds ratio 9.0), independent

| Table 2. Backgrounds of patients with chronic liver diseases. Continuous values are expressed as mean ± standard deviation. BMI body mass index, AC Arm circumference, AMC Arm muscle circumference, AMA Arm muscle area, HCC hepatocellular carcinoma, NASH nonalcoholic steatohepatitis, AIH autoimmune hepatitis, PBC Primary biliary cholangitis, BCAA branched-chain amino acid, PMI Psoas muscle mass index, γ-GTP gamma-glutamyltransferase. |
| --- | --- |
| **Age:** years, mean ± SD | 75 ± 11 |
| **Men:** n (%) | 54 (67%) |
| **BMI:** mean ± SD | 22 ± 3.7 |
| **Performance status:** n (%) | 0/1/2/3/4 (21/31/28/23/38/26/10/3%) |
| %AC: %, mean ± SD | 90 ± 13 |
| %AMC: %, mean ± SD | 95 ± 14 |
| %AMA: %, mean ± SD | 70 ± 28 |
| **HCC:** n (%) | 54 (67%) |
| **Performance status:** n (%) | 0/1/2/3/4 (21/31/28/23/38/26/10/3%) |
| **Albumin:** g/dl, mean ± SD | 3.4 ± 0.75 |
| **Total cholesterol:** mg/dl, mean ± SD | 179 ± 59 |
| **Total bilirubin:** g/dl, mean ± SD | 1.5 ± 1.5 |
| **γ-GTP:** U/l, mean ± SD | 140 ± 231 |
| **White blood cell:** 10⁹/μl, mean ± SD | 5.9 ± 2.8 |
| **Hemoglobin:** g/dl, mean ± SD | 12 ± 2.2 |
| **Platelet:** × 10⁹/μl, mean ± SD | 157 ± 103 |
| **Neutrophil:** %, mean ± SD | 23 ± 11 |
| **Lymphophil:** %, mean ± SD | 80 ± 16 |
| **Prothrombin time:** %, mean ± SD | 67 ± 13 |
factors for death within 1 year after surgery (hazard ratio 3.6), and factors related to long-term hospitalization\textsuperscript{24,26}. In colorectal cancer patients treated with chemotherapy, the frequency of grade 3–4 toxicity was high in patients with sarcopenia, and the survival rate was significantly worse\textsuperscript{27,28}. Myopenia in biliary and pancreatic cancer was an independent risk factor for survival and recurrence, independent of cancer progression\textsuperscript{29,30}. Myopenia has been reported to be a prognostic factor independent of liver function in patients with compensated and early decompensated cirrhosis\textsuperscript{31,35,36}. In patients with HCC, myopenia has been reported to correlate with prognoses in patients undergoing hepatectomy, liver transplantation, percutaneous radiofrequency ablation, or hepatic artery embolization. In particular, the association between myopenia and dose intensity in patients taking molecular-targeted drugs is of interest\textsuperscript{32,37}. Screening myopenia is important for predicting prognoses and selecting treatments for patients with gastrointestinal diseases and chronic liver disease. The number of patients with chronic liver disease was small in our hospital, and sufficient statistical power was not obtained in this study. Assessment in more patients and detailed evaluations are necessary in the future.

**Figure 3.** Muscle mass by the PMI/simple PMI method depending on the presence or absence of myopenia diagnosed by the AMA method in 81 patients with chronic liver diseases. (a) men and PMI, (b) men and simple PMI, (c) women and PMI, (d) women and simple PMI.

**Figure 4.** Comparison between muscle mass measurement methods in 81 patients with chronic liver diseases. (a) PMI and simple PMI, (b) PMI and AMA, (c) simple PMI and AMA.
Limitations of this study include its retrospective nature, the small sample size, and the lack of grip strength measurements. The significance of myopenia has also been reported to vary by sex, but there were few female patients and sufficient evaluation by sex could not be carried out in this study. The relationship between myopenia and presence of comorbidities and malignant tumors has not been adequately studied, and additional searching is needed.

Muscle mass measured by the AMA method and simple PMI method showed some correlation with muscle mass measured using the PMI method. In particular, the AMA method is a non-invasive muscle mass measurement method that can be performed without radiation exposure, and can be performed conveniently at any institution.

**Conclusion**

Measurements of muscle mass by the AMA method and simple PMI method are correlated with measurement by the PMI method, and these methods can be simplified alternative methods of evaluating muscle mass in patients with gastrointestinal diseases and chronic liver disease.

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**References**

1. Rosenberg, I. H. Sarcopenia: Origins and clinical relevance. *J. Nutr.* **127**(5 Suppl), 990S-991 (1997).
2. Chen, L. K. *et al.* Sarcopenia in Asia: Consensus report of the Asian Working Group for Sarcopenia. *J. Am. Med. Dir. Assoc.* **15**(2), 95–101 (2014).
3. Fielding, R. A. *et al.* Sarcopenia: an undiagnosed condition in older adults. Current consensus definition; prevalence, etiology, and consequences. International working group on sarcopenia. *J. Am. Med. Dir. Assoc.* **12**(4), 249–56 (2011).
4. McLean, R. R. *et al.* Criteria for clinically relevant weakness and low lean mass and their longitudinal association with incident mobility impairment and mortality: the foundation for the National Institutes of Health (FNHI) sarcopenia project. *J. Gerontol. A Biol. Sci. Med. Sci.* **69**(5), 576–583 (2014).
5. Morley, J. E. *et al.* Sarcopenia with limited mobility: An international consensus. *J. Am. Med. Dir. Assoc.* **12**(6), 403–409 (2011).
6. Muscaritoli, M. *et al.* Consensus definition of sarcopenia, cachexia and pre-cachexia: Joint document elaborated by Special Interest Groups (SIG) “cachexia-anorexia in chronic wasting diseases” and “nutrition in geriatrics”. *Clin. Nutr.* **29**(2), 154–159 (2010).
7. Nishikawa, H. *et al.* Japan Society of Hepatology guidelines for sarcopenia in liver disease (1st edition): Recommendation from the working group for creation of sarcopenia assessment criteria. *Hepatol. Res.* **46**(10), 951–963 (2016).
8. Saito, R. *et al.* Validity of mid-arm muscular area measured by anthropometry in nonobese patients with increased muscle atrophy and variation of subcutaneous fat thickness. *Eur. J. Clin. Nutr.* **64**(8), 899–904 (2010).
9. Miller, M. D. *et al.* Corrected arm muscle area: an independent predictor of long-term mortality in community-dwelling older adults? *J. Am. Geriatr. Soc.* **50**(7), 1272–1277 (2002).
10. Cruz-Jentoft, A. J. et al. Sarcopenia: European consensus on definition and diagnosis: Report of the European Working Group on Sarcopenia in Older People. Age Ageing. 39(4), 412–423 (2010).

11. Hamaguchi, Y. et al. Proposal for new diagnostic criteria for low skeletal muscle mass based on computed tomography imaging in Asian adults. Nutrition. 32(11–12), 1200–1205 (2016).

12. Yuri, Y. et al. Implication of psoas muscle index on survival for hepatocellular carcinoma undergoing radiofrequency ablation therapy. J. Cancer. 8(9), 1507–1516 (2017).

13. Shirai, H. et al. Preoperative low muscle mass and low muscle quality negatively impact on pulmonary function in patients undergoing hepatectomy for hepatocellular carcinoma. Liver Cancer. 7(1), 76–89 (2018).

14. Marr, K. J. et al. Nutritional status and the performance of multiple bedside tools for nutrition assessment among patients waiting for liver transplantation: A Canadian experience. Clin. Nutr. ESPEN. 17, 68–74 (2017).

15. Kim, M., Jeong, M. J., Yoo, J., Song, D. Y. & Won, C. W. Calf circumference as a screening tool for cognitive frailty in community-dwelling older adults: The Korean Frailty and Aging Cohort Study (KEACS). J. Clin. Med. 7, 10 (2018).

16. Ishii, S. et al. Development of a simple screening test for sarcopenia in older adults. Geriatr. Gerontol. Int. 14(Suppl 1), 93–101 (2014).

17. Tanaka, T., Takahashi, K., Akishita, M., Tsuji, T. & Iijima, K. “Yubi-wakka” (finger-ring) test: A practical self-screening method for sarcopenia, and a predictor of disability and mortality among Japanese community-dwelling older adults. Geriatr. Gerontol. Int. 18(2), 224–232 (2018).

18. Hiraoka, A. et al. Easy surveillance of muscle volume decline in chronic liver disease patients using finger-circle (yubi-wakka) test. J. Cachexia Sarcopenia Muscle. 10(2), 347–354 (2019).

19. Onishi, S. et al. Prevalence of sarcopenia and its relationship with nutritional state and quality of life in patients with digestive diseases. J. Nutr. Sci. Vitaminol. (Tokyo). 64(6), 445–453 (2018).

20. Yoshida, D. et al. Using two different algorithms to determine the prevalence of sarcopenia. Geriatr. Gerontol. Int. 14(Suppl 1), 46–51 (2014).

21. Yoshimura, N. et al. Is osteoporosis a predictor for future sarcopenia or vice versa? Four-year observations between the second and third ROAD study surveys. Osteoporos. Int. 28(1), 189–199 (2017).

22. Hodari, A., Hammoud, Z. T., Borgi, J. E., Tsiouris, A. & Rubinfeld, I. S. Assessment of morbidity and mortality after esophagectomy using a modified frailty index, Ann. Thorac. Surg. 96(4), 1240–1245 (2013).

23. Nishigori, T. et al. Sarcopenia as a predictor of pulmonary complications after esophagectomy for thoracic esophageal cancer. J. Surg. Oncol. 113(6), 678–684 (2016).

24. Fukuda, Y. et al. Prevalence of malnutrition among gastric cancer patients undergoing gastrectomy and optimal preoperative nutritional support for preventing surgical site infections. Ann. Surg. Oncol. 22(3), S778–85 (2015).

25. Huang, D. D. et al. Sarcopenia predicts 1-year mortality in elderly patients undergoing curative gastrectomy for gastric cancer: A prospective study. J. Cancer Res. Clin. Oncol. 142(11), 2347–2356 (2016).

26. Huang, D. D. et al. Impact of different sarcopenia stages on the postoperative outcomes after radical gastrectomy for gastric cancer. Surgery. 161(3), 680–693 (2017).

27. Liefers, J. R., Bathe, O. F., Fassbender, K., Winget, M. & Baracos, V. E. Sarcopenia is associated with postoperative infection and delayed recovery from colorectal cancer resection surgery. Br. J. Cancer. 107(6), 931–936 (2012).

28. Jung, H. W. et al. Effect of muscle mass on toxicity and survival in patients with colon cancer undergoing adjuvant chemotherapy. Support Care Cancer. 23(3), 687–694 (2015).

29. Okumura, S. et al. Visceral adiposity and sarcopenic visceral obesity are associated with poor prognosis after resection of pancreatic cancer. Ann. Surg. Oncol. 24(12), 3732–3740 (2017).

30. Peng, P. et al. Impact of sarcopenia on outcomes following resection of pancreatic adenocarcinoma. J. Gastrointest. Surg. 16(8), 1478–1486 (2012).

31. Hanai, T. et al. Sarcopenia impairs prognosis of patients with liver cirrhosis. Nutrition. 31(1), 193–199 (2015).

32. Takada, H. et al. Impact of pre-sarcopenia in sorafenib treatment for advanced hepatocellular carcinoma. PLoS ONE 13(6), e0198812 (2018).

33. Harimoto, N. et al. Sarcopenia is a poor prognostic factor following hepatic resection in patients aged 70 years and older with hepatocellular carcinoma. Hepatol. Res. 46(12), 1247–1255 (2016).

34. Iritani, S. et al. Skeletal muscle depletion is an independent prognostic factor for hepatocellular carcinoma. J. Gastroenterol. 50(3), 323–332 (2015).

35. Ebadi, M. et al. Poor performance of psoas muscle index for identification of patients with higher waitlist mortality risk in cirrhosis. J. Cachexia Sarcopenia Muscle. 9(6), 1053–1062 (2018).

36. Kang, S. H., Jeong, W. K., Baik, S. K., Cha, S. H. & Kim, M. Y. Impact of sarcopenia on prognostic value of cirrhosis: going beyond the hepatic venous pressure gradient and MELD score. J. Cachexia Sarcopenia Muscle. 9(5), 860–870 (2018).

37. Hiraoka, A. et al. Muscle volume loss as a prognostic marker in hepatocellular carcinoma patients treated with sorafenib. Hepatol. Res. 1(10), 12780 (2016).

38. Peng, S. et al. Body composition, muscle function, and energy expenditure in patients with liver cirrhosis: A comprehensive study. Am. J. Clin. Nutr. 85(5), 1257–1266 (2007).

39. Riggio, O. et al. Malnutrition is not related to alterations in energy balance in patients with stable liver cirrhosis. Clin. Nutr. 22(6), 553–559 (2003).

40. Merli, M., Giusto, M., Giannelli, V., Lucidi, C. & Riggio, O. Nutritional status and liver transplantation. J. Clin. Exp. Hepatol. 1(3), 190–198 (2011).

41. Alberino, E. et al. Nutrition and survival in patients with liver cirrhosis. Nutrition. 17(6), 445–450 (2001).

42. Merli, M., Riggio, O. & Dally, L. Does malnutrition affect survival in cirrhosis? PING (Politenica Italiana Nutrizione Ciriosi). Hepatology 23(5), 1041–1046 (1996).

43. Wu, L. W. et al. Mid-arm muscle circumference as a significant predictor of all-cause mortality in male individuals. PLoS ONE 12(2), e0171707 (2017).

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Study concept and design: H.T. Acquisition of data: H.T., F.A., H.Y., T.O., K.T., M.K. Analysis and interpretation of data: H.T. Drafting of the manuscript: H.T. Critical revision: F.A., M.K., N.E. Study supervision: F.A., M.K., N.E. All authors reviewed the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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