이학석사 학위논문

단면 영상에서 복부 근육의 최적 정량화 방법: 표준화된 근감소증 바이오 마커

Optimal method of abdominal muscle mass quantification in cross-sectional imaging: toward a standardized sarcopenia biomarker

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Abstract (English)

Purpose: The quantification of abdominal muscle mass in cross-sectional imaging has been increasingly used to diagnose sarcopenia. We aimed to determine an optimal method with a focus on the measurement area and level.

Methods: Among 50 consecutive subjects who underwent abdominal CT and MRI simultaneously for possible liver donation, the total abdominal muscle area (TAMA) and total psoas muscle area (TPA) at the L3 inferior endplate level were measured by two blinded readers. The inter-scan agreement between CT and MRI and inter-reader agreement between the two readers were evaluated by intraclass correlation coefficient (ICC) and within-subject coefficient of variation (WSCV) analyses. To evaluate the effect of measurement level, one reader measured the TAMA and TPA at six levels from the L2 to L4 vertebral bodies.

Results: Based on the ICC and WSCV values, the reliability of the TAMA was better than that of the TPA in both inter-scan agreement (ICC, 0.928 vs. 0.788 for reader 1 and 0.853 vs. 0.821 for reader 2, respectively; WSCV, 8.3% vs. 23.4% for reader 1 and 10.4% vs. 22.3% for reader 2, respectively) and inter-reader agreement (ICC, 0.986 vs. 0.886 for CT and 0.865 vs. 0.669 for MRI, respectively; WSCV, 8.2% vs. 16.0% for CT and 11.6% vs. 29.7% for MRI, respectively). These results also indicated that the inter-reader agreement of CT was better than that of MRI. In terms of the measurement level, the TAMA did not differ from the L2inf to L4inf levels, whereas the TPA was increased as measurement levels went down.

Conclusions: In terms of reliability, the TAMA is better than the TPA, and CT is better than MRI. To use these sarcopenia biomarkers in clinical practice, the standardization of measurement methods is required with large-scale evidence and the consensus of academic communities.

Keywords: Sarcopenia; biomarker; reliability; computed tomography; magnetic resonance imaging

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Introduction

Sarcopenia is characterized by an age-related decline of muscle mass with low muscle strength and/or physical performance, and it has recently been classified by the International Classification of Diseases (ICD-10CM) code [M62.84] [1, 2, 3]. The assessment of muscle and fat tissues is essential in the management of patients with obesity, aging, and wasting diseases [4, 5]. Recent accumulating evidence strongly suggests that sarcopenia is predictive of certain clinical outcomes including postoperative complications, hospital stay, and final survival/mortality in various diseases [6-11]. Therefore, sarcopenia is regarded as a diagnostic and prognostic biomarker.

Cross-sectional imaging techniques such as magnetic resonance imaging (MRI) and computed tomography (CT) are the most reliable methods and thus regarded as gold standard methods for quantifying the muscle mass and visceral fat area (VFA) or volume. CT has been the most widely used cross-sectional imaging modality because it is readily available in most hospitals worldwide owing to its reasonable cost and fast scan speed. Currently, the use of MRI for the abdomen has been increasing because of radiation exposure concerns as well as the potential to achieve improved tissue contrast [12, 13].

However, the quantification of abdominal muscle mass by CT and MRI as a diagnostic biomarker for sarcopenia assessment has not been fully validated. The two main requirements for validating the abdominal muscle area as a quantitative biomarker for sarcopenia are as follows: (1) clinical validation, which is the evidentiary process of linking the abdominal muscle area with clinical endpoints such as survival or mortality, and (2) standardization, which is the process of implementing and developing technical standards [14]. In terms of clinical validation, increasing evidence has demonstrated a strong association of the abdominal muscle area measured by cross-sectional imaging with survival in patients with various diseases such as cancer, cardiovascular disease, or trauma [15-17]. However, the technical method of abdominal muscle mass quantification by CT/MRI has not been standardized because of several issues.

First, the area that should be segmented on abdominal CT/MRI for abdominal muscle mass quantification has not been standardized. Some studies have used the total abdominal muscle area (TAMA), whereas some have used the total psoas muscle area (TPA). Second, there has been insufficient evidence of reliability for abdominal muscle mass quantification by CT/MRI, including the inter-reader agreement and inter-scan agreement between CT and MRI. Third, the assessment of abdominal muscle mass has not been standardized from L2 to L4 [18, 19]. Thus far, only a few studies have examined these issues [20]. Therefore, we aimed to determine an optimal standardized method by focusing on the measurement area and level as well as to evaluate the reliability of abdominal muscle mass quantification by CT/MRI, including inter-scan and inter-reader agreements.

Methods

This retrospective study adhered to the guidelines established by the Declaration of Helsinki and was approved by the Institutional Review Board of Asan Medical Center, Seoul, Korea. The requirement for informed consent was waived.

Patients

We retrospectively searched our institution's computerized databases for a clinical cohort of liver transplantation and found 50 consecutive healthy subjects who underwent abdominal CT and MRI for possible liver donation from March 2016 to June 2016. All the 50 liver donors underwent CT and MRI within a 2-week interval as a preoperative work-up for liver transplantation.

CT and MR images were anonymized, coded, and transferred from our picture archiving and communication system (PetaVision; Hyundai Information Technology, Seoul, Korea) to the central imaging review system (AiCROTM; Asan Image Metrics, Seoul,

Korea). The central imaging core lab in our institution (Asan Image Metrics, www.aim-aicro.com) independently performed the imaging process following our request.

Image acquisition

Computed tomography

CT examinations were performed using a Somatom Definition AS+ scanner (Siemens Healthineers, Erlangen, Germany). CT were obtained with standard exposure parameters (200 effective mAs and 120 kVp; the actual radiation dose was adjusted according to the patient's body size and shape by automatically modulating the tube current [Care-Dose; Siemens Healthineers, Erlangen, Germany]), a detector configuration of 1.5 mm × 16 mm, a table feed of 24 mm per rotation, and a gantry rotation time of 0.5 s. Contrast-enhanced CT scans were performed in the supine position in the portal venous phase with a fixed delay of 70 s after contrast agent injection. By using an autoinjector, 120 mL of nonionic contrast material was intravenously administered at 3 mL/s. The images were reconstructed with a section thickness and interval of 5 mm.

Magnetic resonance imaging

Abdominal MRI was performed using a 1.5T scanner (Magnetom Avanto; Siemens Healthineers, Erlangen, Germany) with dedicated six-channel torso array coils. The maximum gradient strengths were 45 mT/m for the amplitude and 200 mT/m/s for the slew rate. The parameters for the transverse breath-hold T1-weighted gradient-echo images without fat-suppression were as follows: repetition time, 4.2 ms; echo time, 2.5 ms; flip angle, 7.0°; slice thickness, 3 mm; field of view, 341 × 420 mm; and matrix size, 208 × 256. These images were used for body morphometric analysis. The other imaging sequences of the abdominal MRI included transverse T2-weighted fast spin-echo imaging, MR

cholangiography, in-phase and opposed-phase chemical shift imaging, and contrast-enhanced multiphasic MRI.

Body morphometric analysis

The AsanJ-MorphometryTM software, which is provided to the public for non-profit research (http://datasharing.aim-aicro.com/tools/morphometry), was used for body morphometric analysis. This software was developed based on ImageJ (NIH, Bethesda, MD, USA).

The TAMA (cm2) including all muscles on the selected axial images, i.e., psoas, paraspinal, transversus abdominis, rectus abdominis, quadratus lumborum, and internal and external obliques, were demarcated using predetermined thresholds for the Hounsfield unit (HU) onCT and the signal intensity (SI) on precontrast T1-weighted MRI. The VFA (cm2) and the subcutaneous fat area (SFA) (cm2) were also demarcated using the fat tissue thresholds in CT/MRI (Fig 1). The time spent on measuring the TAMA, TPA, and VFA using the AsanJ-MorphometryTM software was recorded only by reader 1. The definition of the time spent was set to include opening the software, importing the prepared CT/MR images, finding the L3 inferior endplate level, and segmenting the abdominal muscle.

Level of body morphometric measurement

To evaluate the inter-reader and inter-scan agreements, we selected CT and MR images at the L3 inferior endplate level.

To evaluate the effect of measurement level on the results of body morphometric analysis, we measured the TAMA, TPA, and VFA at six levels from the L2 to L4 vertebral bodies. For each vertebral body level, we measured at the mid-body level (hereafter referred to as L2mid, L3mid, and L4mid) and inferior endplate level (hereafter referred to as L2inf,

L3inf, and L4inf).

Statistical analysis

Data are expressed as the mean ± standard deviation (SD). The mean values from body morphometric analysis were compared by Student's t-test or analysis of variance (ANOVA) and post-hoc multiple comparison tests.

The measurement agreements between CT and MRI (inter-scan agreement) and between readers 1 and 2 (inter-reader agreement) were assessed by the intraclass correlation coefficient (ICC) of a single measurement calculated according to the two-way random-effects model for consistency. The 95% confidence intervals (CIs) associated with the ICCs were also determined. The ICC estimates the overall correlation between all possible values within the variable taken by the same reader. The ICCs were interpreted as poor (0.00–0.49), fair (0.50–0.74), and good (0.75–1.00) [21].

To evaluate the inter-reader and inter-scan agreements, we used statistical tools recommended by the methodological guidelines of the Radiological Society of North America-Quantitative Imaging Biomarkers Alliance (RSNA-QIBA) (https://www.rsna.org/QIBA) and Park et al. [14-16]. By using these methods, the within-subject coefficient of variation (WSCV) and repeatability coefficient (RC) were calculated. Bland-Altman plots were also constructed. For statistical analysis, we used a web-calculator (available at http://datasharing.aim-aicro.com/reliability) and MedCalc version 13.1.2 (MedCalc Software, Ostend, Belgium).

To evaluate the difference between measurement levels, one-way ANOVA was performed with post-hoc Tukey-Kramer pairwise comparison tests. MedCalc version 13.1.2 (MedCalc Software, Ostend, Belgium) was used for statistical analysis.

Results

Patients

The average age (mean ± SD) of the 50 subjects was 29.9 ± 8.3 years (range: 17–57 years). They included 29 men (mean age: 29.03 years; range: 18–57 years) and 21 women (mean age: 31.05 years; range: 17–47 years).

Body morphometric analysis

The TAMA, TPA, and VFA measurement results are summarized in Table 1. There was no significant difference between reader 1 and reader 2 in TAMA measurement (t-test, P = 0.925 for CT, P = 0.121 for MRI), TPA measurement (P = 0.738 for CT, P = 0.223 for MRI), and VFA measurement (P = 0.919 for CT, P = 0.01). Similarly, no significant difference was observed between CT and MRI in TAMA measurement (t-test, P = 0.333 for reader 1, P = 0.636 for reader 2), TPA measurement (P = 0.520 for reader 1, P = 0.097 for reader 2), and VFA measurement (P = 0.154 for reader 1, P = 0.176 for reader 2).

By using an ImageJ-based software (AsanJ-MorphometryTM), the mean time spent on measuring the TAMA, TPA, and VFA by reader 1 was 3.63 ± 0.57 min for CT and 5.65 ± 1.55 min for MRI (P < 0.001, t-test). The longer time for MRI may be attributed to a greater difficulty in identifying the L3 inferior endplate level on MR images and the need to adjust the semi-automatically drawn muscle boundaries.

Inter-scan and inter-reader agreements

The ICC, WSCV, and RC for inter-scan and inter-reader agreements are shown in Table 2. Bland-Altman plots for all pairs of comparison are illustrated in the supplementary material.

In the comparison of the inter-scan and inter-reader agreements for the TAMA, TPA, and VFA, ICC values were generally higher than 0.75. However, the ICC of the TAMA was higher than that of the TPA in both inter-scan agreement (0.928 vs. 0.788 for reader 1 and 0.853 vs. 0.821 for reader 2, respectively) and inter-reader agreement (0.986 vs. 0.886 for CT and 0.865 vs. 0.669 for MRI, respectively). Based on the WSCV, the reliability of the TAMA was better than that of the TPA in both inter-scan agreement (8.3% vs. 23.4% for reader 1 and 10.4% vs. 22.3% for reader 2, respectively) and inter-reader agreement (8.2% vs. 16.0% for CT and 11.6% vs. 29.7% for MRI, respectively). These findings suggest that TAMA measurement might be a more robust method for abdominal muscle mass quantification than TPA measurement.

A comparison of the inter-reader agreement between CT and MRI revealed that the ICC for CT was higher than that for MRI in the measurement of the TAMA (0.986 vs. 0.865), TPA (0.886 vs. 0.669), and VFA (0.989 vs. 0.954). The WSCV for CT was also lower (i.e., better reliability) than that for MRI in the measurement of the TAMA (0.082 vs. 0.116), TPA (0.160 vs. 0.297), and VFA (0.069 vs. 0.166). We evaluated all regions of interest (ROI) on CT and MR images in a side-by-side manner and found that the anatomical boundary of the muscles was degraded and less clear in some parts because of artifacts such as bowel gas susceptibility artifacts, motion artifacts, or chemical shift artifacts (14/50, 28%) (Fig 2).

Effect of measurement level on body morphometric analysis

One-way ANOVA revealed a significant difference between measurement levels in the TAMA ($P = 0.003$) and TPA ($P < 0.001$) but not in the VFA ($P = 0.525$). The post-hoc test results for the TAMA showed a significant difference only between L2mid and L3inf ($P < 0.05$) and between L2mid and L4mid ($P < 0.05$). The TAMA from L2inf to L4inf did not differ significantly, ranging from 122.5 to 139.6 cm2 (Fig 2A). In contrast, the TPA was increased as measurement levels were decreased from L2mid to L4inf with significant

differences between levels (Fig 2B). The VFA did not differ among the measurement levels (Fig 2C). According to the results, the measurement of the TAMA and VFA was robust from L2inf to L4inf (Fig 3).

Discussion

The study results provide evidence for a standardized method of abdominal mass quantification with CT/MRI by demonstrating that the TAMA is more reliable and robust than the TPA in terms of the inter-scan agreement and inter-reader agreement as well as the effect of measurement level. The results also indicated that TAMA assessment can be easily integrated into routine clinical care by using an open-source software to generate highly reliable measures of body composition with clinically acquired CT/MRI scans.

We investigated why the TAMA is more reliable than the TPA in terms of the inter-scan and inter-reader agreements and found that readers may have difficulty in manually drawing the posterior margin of the psoas muscle on both CT and MR images because the psoas muscle is closely attached posteriorly to the quadratus lumborum and erector spinae muscle. In contrast, the TAMA is generally calculated by a semi-automatic software based on predetermined thresholds of the HU in CT or the SI in MRI.

In terms of measurement level, the TAMA was different between the L2mid and L2inf–L4inf levels, and it was similar between the L2inf and L4inf levels. Therefore, the TAMA can be measured anywhere between the L2inf and L4inf levels. However, the TPA was generally larger with a lower measurement level; thus, the TPA was different between the L2, L3, and L4 levels. Therefore, when using the TPA as an index, it is important to select one level and measure at the same level consistently. As the TAMA is less affected by the measurement level, it is considered as a more robust index than the TPA.

Against our initial expectation, CT was more robust and reliable for abdominal muscle mass quantification than MRI based on the ICC and WSCV values. This may be

attributed to the clearer anatomical boundary of the muscles on CT images than on MR images. Bowel gas and motion artifacts caused the degradation of the image of the adjacent abdominal muscle; thus, the readers had difficulty in drawing the boundaries of the muscle (Fig 4). Based on the results, the measurement of the TAMA by CT might be the most robust method for sarcopenia evaluation compared with the measurement of the TAMA by MRI and that of the TPA by CT/MRI.

Recently, studies on sarcopenia have been rapidly increasing because of various potential clinical applications such as the mortality assessment of liver transplant patients [22], selective and non-abdominal aortic aneurysm repair [23, 24], pancreatic adenocarcinoma treatment [25], and emergency surgery for elderly patients [26, 27]. However, sarcopenia is not a condition restricted to patients with late-stage diseases but rather is highly prevalent among all patients [15].

In particular, cancer patients are vulnerable to muscle wasting and easily fall into a cachectic state; thus, sarcopenia plays an important role. As the majority of cancer patients are followed up by CT/MRI, there are increasing efforts to evaluate the muscle mass using CT/MRI scans [27-29]. In many studies, the TPA was used mainly because it is easier and faster to measure than the TAMA [25, 30]. Nevertheless, the results in our study showed that the TAMA was more robust than the TPA; the TPA was larger at a lower level, and the posterior margin was not well distinguished, which is a disadvantage in terms of reliability. Indeed, our findings are consistent with those of several prior studies [6, 31]. In addition, the TAMA has been shown to be a valid surrogate marker of whole body muscle mass because it reflects all muscles of the abdomen [29, 32].

Only one study has compared imaging modalities for sarcopenia assessment, which demonstrated that the TAMA measured at the L3 level was comparable between CT and MRI for patients with liver cirrhosis [33]. In contrast to this prior study, our study showed that CT was more robust than MRI. Differences in the imaging protocol or measurement software may cause these inconsistencies; thus, further studies are required.

Currently, measurement methods and measurement levels have not been standardized. Based on our results, we propose that the TAMA rather than the TPA should be used to reliably quantify the abdominal muscle mass. If possible, CT should be the primary cross-sectional imaging modality. However, if only MRI is available, then measurement by MRI would be acceptable. Although there was no significant difference in the measurement between L2inf and L4inf, we recommend measuring the TAMA at the L3 inferior endplate level in order to standardize the method. The L3 inferior endplate level is easy to identify; it is in the center of the lumbar vertebrae.

Body morphometric analysis based on cross-sectional images can be easily integrated into routine clinical care by using a simple image processing software to perform reliable measures of the abdominal muscle and fat with clinically obtained scans. As increasing evidence supports cross-sectional imaging-based surveillance as an objective method for identifying sarcopenia in patients with various diseases, clinically acquired CT/MRI scans of patients with various diseases may be used concurrently to diagnose sarcopenia, identify patients at risk of poor survival, and contribute toward general health improvements [15].

There are several limitations in this study. First, this study was conducted in a retrospective manner with a relatively small number of subjects. A large-scale, prospective validation study is needed. Second, the subjects enrolled in this study were healthy subjects for liver donation, which might limit the generalizability of the study results. Nevertheless, it was the best approach to accumulate data for abdominal muscle area measurement while minimizing the confounding effects of pathologic conditions. This method should be further evaluated using patients with various diseases.

Conclusion

As a sarcopenia biomarker based on cross-sectional imaging, the TAMA was more

reliable than the TPA in terms of the inter-scan and inter-reader agreements and robustness in measurement. Furthermore, CT was a more reliable imaging modality than MRI. To use these sarcopenia biomarkers in clinical practice, the standardization of measurement methods is required with large-scale evidence and the consensus of academic communities.

Table 1. Mean values from body morphometric analysis

	TAMA			TPA			VFA		
	CT	**MRI**	**P-value***	**CT**	**MRI**	**P-value***	**CT**	**MRI**	**P-value***
Reader 1	47.2 ± 10.1	50.0 ± 11.3	0.199	6.4 ± 2.7	6.0 ± 3.1	0.550	23.1 ± 13.9	21.1 ± 13.3	0.476
Reader 2	47.0 ± 10.3	46.1 ± 10.1	0.654	6.1 ± 2.7	5.3 ± 2.1	0.083	23.3 ± 14.3	19.3 ± 13.1	0.140
P-value[§]	0.914	0.071		0.697	0.180		0.926	0.480	

*Derived from a *t*-test comparison of CT and MRI
[§]Derived from a *t*-test comparison of reader 1 and reader 2
Abbreviations: total abdominal muscle area (TAMA), total psoas muscle area (TPA), visceral fat area (VFA)

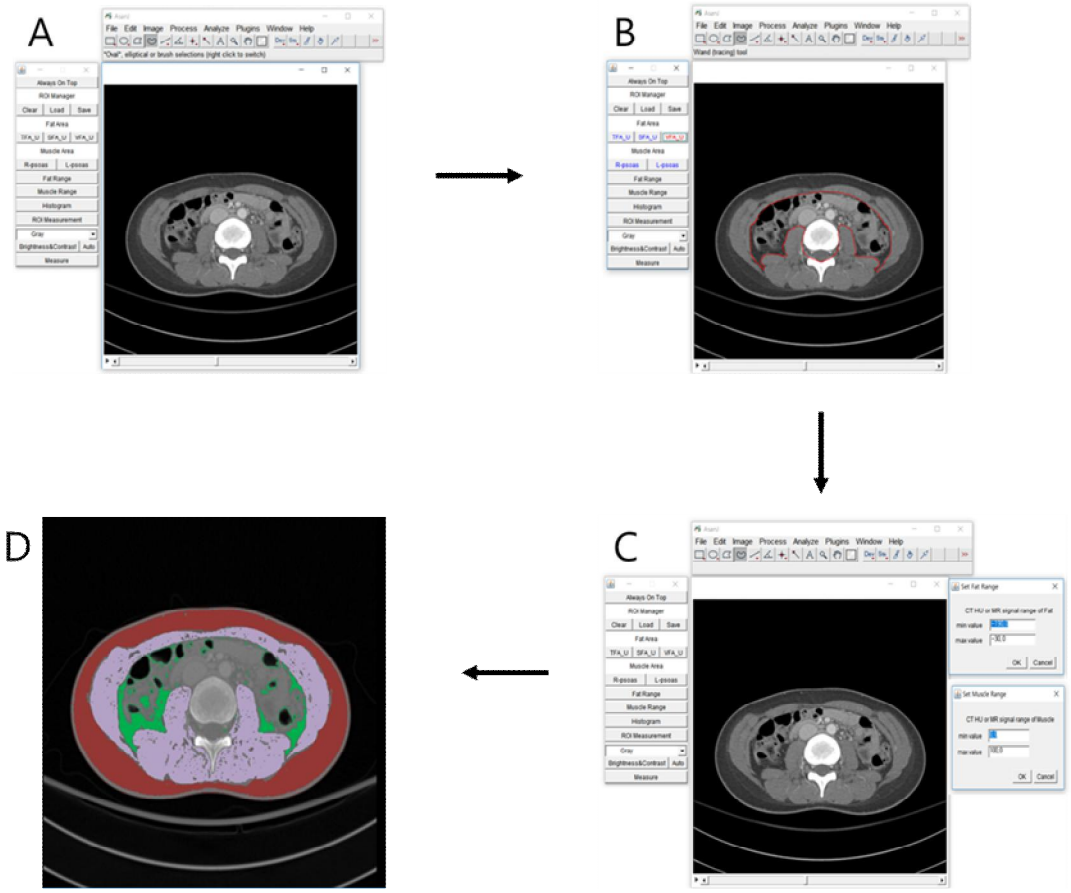
Table 2. Inter-scan and inter-reader agreements for the TAMA, TPA, and VFA

		Inter-scan agreement		
		ICC	**WSCV**	**RC**
TAMA	**Reader 1**	0.894	0.419	47.439
	Reader 2	0.775	0.403	44.121
TPA	**Reader 1**	0.783	1.122	39.240
	Reader 2	0.782	1.160	39.571
VFA	**Reader 1**	0.943	0.159	28.576
	Reader 2	0.883	0.259	44.850
		Inter-reader agreement		
TAMA	**CT**	0.980	0.405	44.789
	MRI	0.815	0.415	46.577
TPA	**CT**	0.870	1.111	38.994

	MRI	0.637	1.172	39.820
VFA	**CT**	0.987	0.452	29.092
	MRI	0.993	0.497	31.275

Abbreviations: total abdominal muscle area (TAMA), total psoas muscle area (TPA), visceral fat area (VFA)

Figure 1. Semi-automatic segmentation for body morphometric analysis.



(A) ImageJ after program run and CT or MR image upload.

(B) Adjustment of the total abdominal muscle area (TAMA), total psoas muscle area (TPA), and visceral fat area (VFA) threshold.

(C) Measurement of the semi-automatic regions of interest (ROI).

(D) Segmentation and color mapping.

Figure 2. Quality of CT and MR images for TAMA measurement.

(A) In the CT image, the abdominal muscle boundary was clear. (B) In the MR image, there were susceptibility and motion artifacts due to bowel gas (arrows), which caused the degradation of the image of the adjacent left rectus muscle and left psoas muscle.

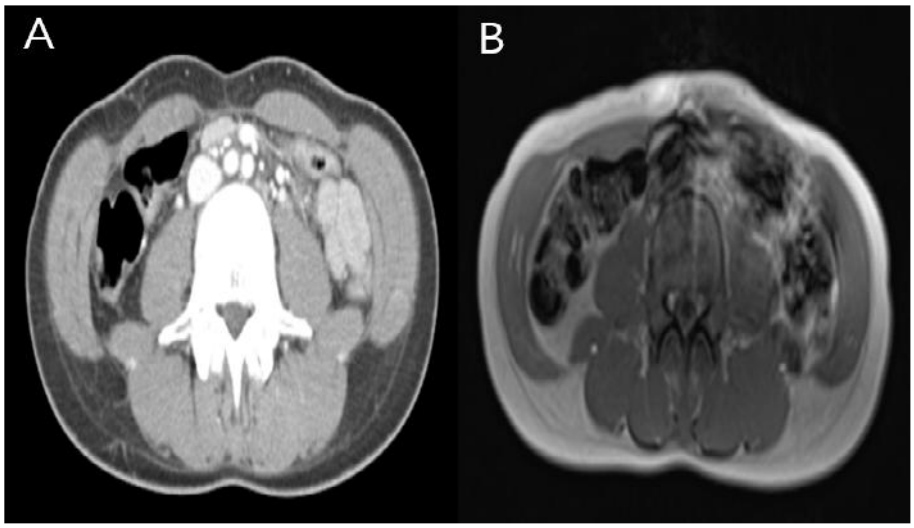
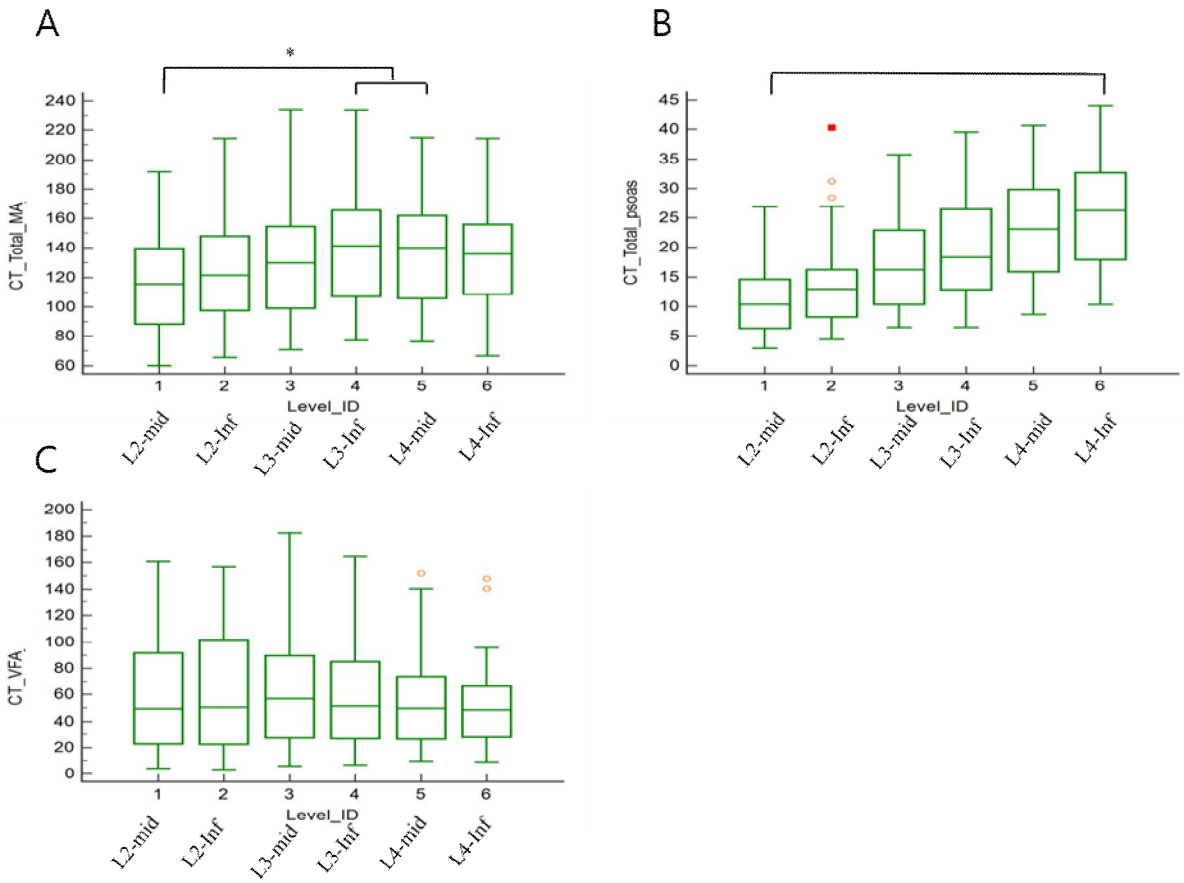


Figure 3. Effect of measurement level on the TAMA, TPA, and VFA.

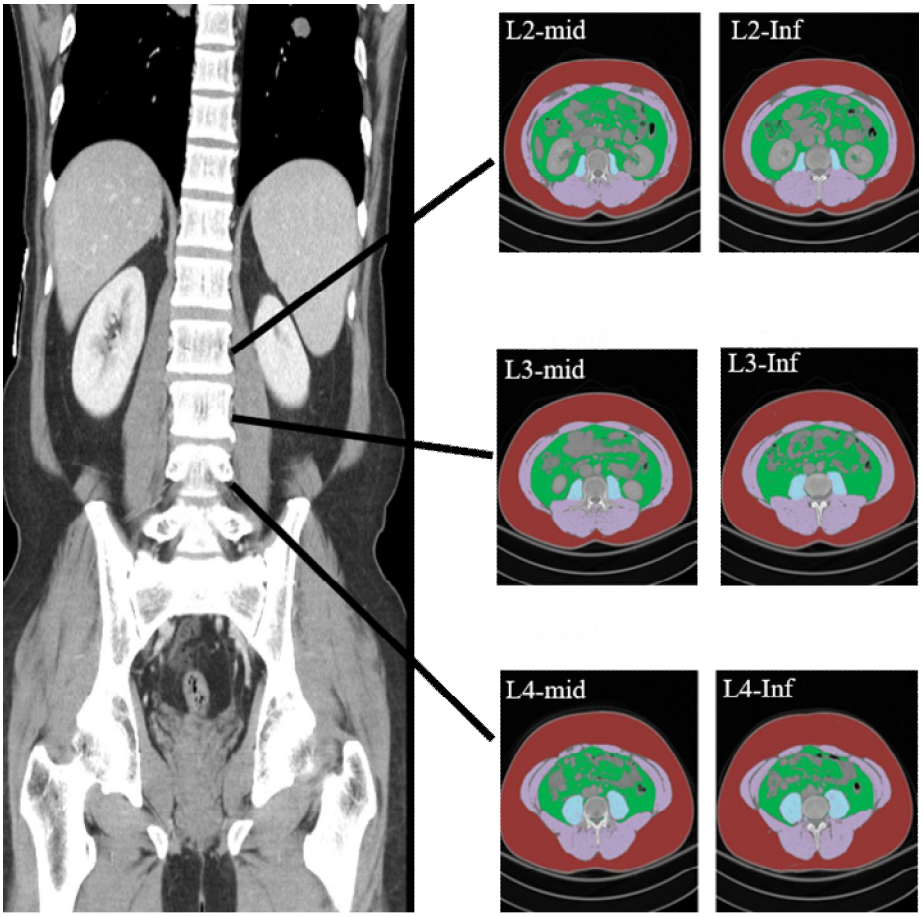


(A) The TAMA at $L2_{mid}$ was different from that between $L2_{inf}$ and $L4_{inf}$, and it was similar at other levels.

(B) The TPA was different at every level.

(C) The VFA was not significantly different between levels.

Figure 4. Representative images of the TAMA, TPA, and VFA at different measurement levels.



Images measurements by different vertebral levels. The axial CT images were segmented into the TAMA (purple), TPA (blue), and VFA (green).

Supplementary material

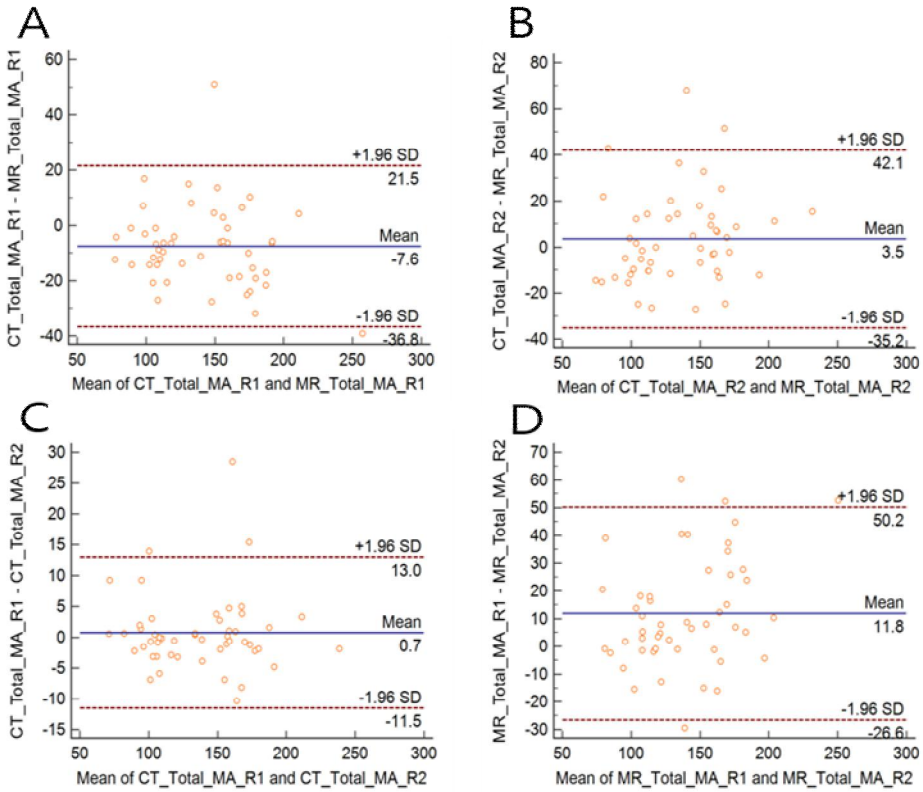
1. Bland-Altman plots for the TAMA

A. CT vs. MRI for reader 1 (Inter-scan agreement)

B. CT vs. MRI for reader 2 (Inter-scan agreement)

C. Reader 1 vs. Reader 2 for CT (Inter-reader agreement)

D. Reader 1 vs. Reader 2 for MRI (Inter-reader agreement)



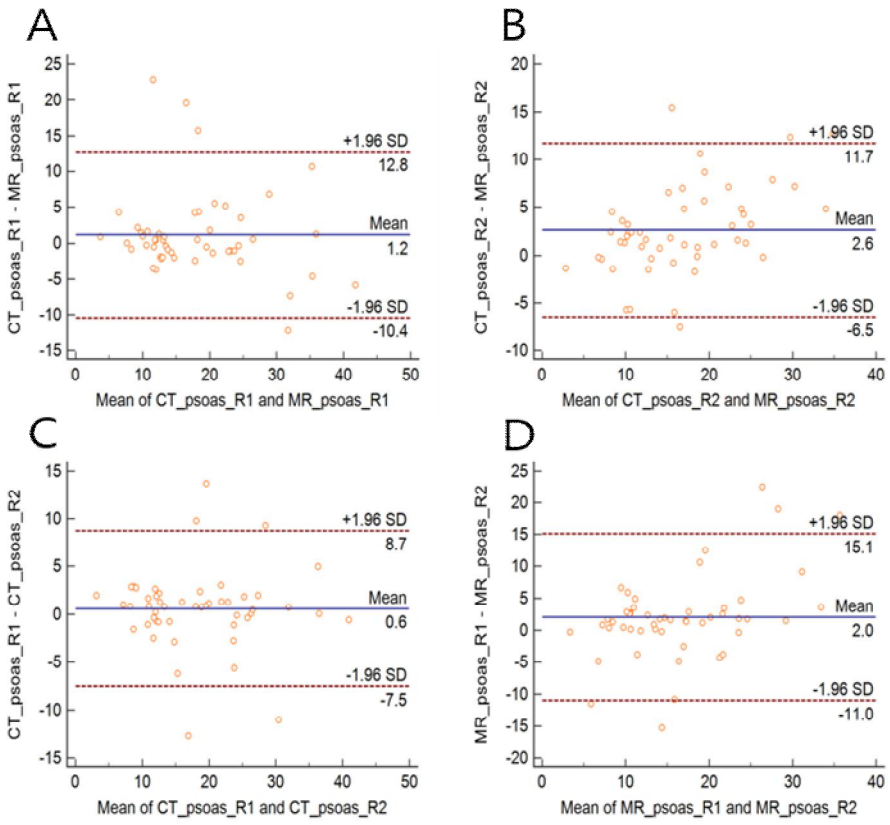
2. Bland-Altman plots for the TPA

A. CT vs. MRI for reader 1 (Inter-scan agreement)

B. CT vs. MRI for reader 2 (Inter-scan agreement)

C. Reader 1 vs. Reader 2 for CT (Inter-reader agreement)

D. Reader 1 vs. Reader 2 for MRI (Inter-reader agreement)



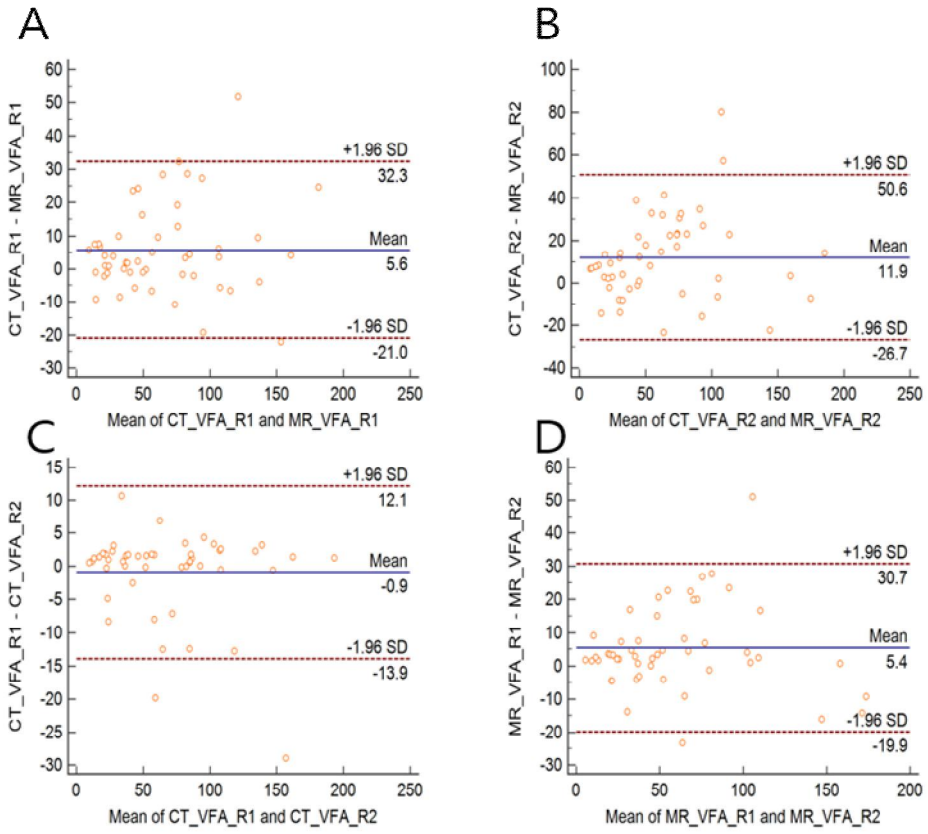
3. Bland-Altman plots for the VFA

A. CT vs. MRI for reader 1 (Inter-scan agreement)

B. CT vs. MRI for reader 2 (Inter-scan agreement)

C. Reader 1 vs. Reader 2 for CT (Inter-reader agreement)

D. Reader 1 vs. Reader 2 for MRI (Inter-reader agreement)



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국문 요약

목적: 본 논문은 단면 영상 촬영에서 복부 근육의 정량화는 근감소증 진단에 점점 더 많이 사용되어 왔다. 우리는 측정 영역과 수준에 초점을 맞춘 최적의 방법을 결정하는 것을 서술하고자 한다.

방법: 간 공여자 50명에게 복부 CT와 MRI 영상을 받았다. 두명의 영상 분석원은 총 복부 근육 면적(TAMA), 총 허리 근육 영역(TPA)을 L3 레벨에서 측정하였다. CT와 MRI간의 일치도 및 두명의 영상분석원 간의 일치도는 ICC, WSCV에 의해 평가되었다. 측정 수준의 효과를 평가하기 위하여, 한 명의 영상분석원이 L2에서 L4 척추까지 6 단계로 TAMA와 TPA를 측정하였다.

결과: 본 논문에서 ICC와 WSCV 값에 기초하여, TAMA의 신뢰도는 TPA의 신뢰도보다 우수했다. (ICC, 분석원 1의 경우 0.928 vs. 0.788, 분석원 2의 경우 0.853 vs. 0.821; WSCV, 분석원 1의 경우 8.3 % vs. 23.4 %, 분석원 2의 경우 10.4 % vs. 22.3 %), 분석자 간 일치도 (ICC, CT의 경우 0.986 vs. 0.886, MRI의 경우 0.865 vs. 0.669; WSCV CT의 경우 8.2% vs. 16.0%, MRI의 경우 11.6% vs. 29.7%). 이결과는 CT가 MRI보다 더 나은 것으로 나타났다. 측정 수준 측면에서 TAMA는 L2inf 수준에서 L4inf 수준과 다르지 않지만, 측정 수준이 낮아짐에 따라 TPA가 증가하였다.

결론: 신뢰성 측면에서 TAMA가 TPA보다 우수하며, CT가 MRI보다 우수하다. 임상에서 이러한 근감소증 바이오 마커를 사용하기 위해서는 측정 방법의 표준화가 대규모의 증거와 학계의 합의에 의해 우선적으로 이뤄져야 한다.

중심단어: 근감소증, 바이오 마커, 신뢰성, 컴퓨터 단층 촬영, 자기 공명 영상