

Association between the Thickness or Area of the Temporal Muscle and Skeletal Muscle Mass in Bioimpedance Analysis

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Keywords

Bioimpedance analysis · Cerebrovascular disease · Sarcopenia · Skeletal muscle mass · Temporal muscle

Abstract

Introduction: Sarcopenia associated with stroke can significantly impact patient prognosis; however, the current standard diagnostic methods for sarcopenia are rarely used in stroke patients. Therefore, the aim of the current study was to investigate whether the temporal muscle thickness (TMT) or area (TMA) could serve as a surrogate marker for measuring skeletal muscle mass. **Methods:** This retrospective chart review study was conducted on 244 participants from March 2018 to February 2020. The TMT and TMA were measured at the supraorbital roof level using brain CT or T1-weighted MR imaging obtained from participants. The skeletal muscle mass and skeletal muscle index (SMI) and whole-body phase angle (WBPA) at 50 kHz were collected. Pearson correlation analysis was used to assess the relationship between the TMT or TMA and the results of the bioimpedance analysis. **Results:** The mean TMT showed significant positive correlations with skeletal muscle mass (male, $r = 0.520$; female, $r = 0.706$), SMI (male, $r = 0.426$; female, $r = 0.582$), and WBPA (male, $r = 0.295$; female, $r = 0.232$). The mean TMA showed significant positive correlations with skeletal muscle mass (male, $r = 0.490$; female, $r = 0.657$), SMI (male, $r = 0.289$; female, $r = 0.473$), and WBPA

(male, $r = 0.232$; female, $r = 0.243$). **Conclusion:** We observed moderate to strong positive correlations between body composition analysis measured by BIA and TMT or TMA, suggesting that TMT or TMA could serve as a reliable surrogate marker for identifying low skeletal muscle mass in cerebrovascular disease.

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Introduction

Sarcopenia is a skeletal muscle disorder characterized by muscle mass loss, muscle weakness, and decline in physical performance [1]. Sarcopenia is associated with the aging process and can lead to several adverse events in older individuals, including falls and associated fractures, disabilities in activities of daily living (ADL), and even death [2]. The prevalence of sarcopenia varies from 10% to 27% depending on the classification criteria and specific population studied [3]. Cerebrovascular diseases, such as ischemic or hemorrhagic strokes, are common conditions that can result in death or disability, particularly in the elderly population. In Korea, the incidence of stroke increased by 29.7% in 2019 due to an increasing proportion of elderly individuals in society [4]. Stroke patients are at an increased risk of muscle atrophy due to factors such as paralysis, lack of use, rigidity, inflammation, and nutritional deficiencies [2]. A previous study

reported that the prevalence of sarcopenia increased from 15.8% before stroke to 51.6% 1 month after a stroke diagnosis [5].

This finding suggests that preventing the development of sarcopenia in stroke patients is important to manage their condition, and identifying individuals with sarcopenia or pre-sarcopenia before a stroke diagnosis, may also be crucial for providing preventive or therapeutic interventions. Sarcopenia can affect the prognosis of stroke patients because it is associated with adverse outcomes such as dependent ADL, swallowing disorders, and decreased likelihood of being discharged home after rehabilitation [6, 7]. However, evaluating muscle mass in stroke patients is rarely performed due to the cost of tests or the absence of appropriate evaluating machines such as dual-energy X-ray absorptiometry (DXA) or bioelectrical impedance analysis (BIA). Additionally, measuring muscle strength or assessing functional ability is challenging in the acute stage of stroke and may not accurately reflect the pre-stroke functions of the patients. Therefore, there is a need for alternative indicators of pre-stroke skeletal muscle mass that can replace conventional measurements or serve as screening tests for decreased muscle mass in stroke patients.

Recently, there has been increasing interest in the thickness or area of the temporalis muscle, which has been found to be correlated with grip strength and the severity of swallowing disorders in stroke patients [8, 9]. However, the association between temporalis muscle parameters and measurements of skeletal muscle mass remains unclear, with limited previous research available. Cho et al. [10] reported a significant correlation between temporal muscle thickness (TMT) and muscle mass measured by DXA in patients with dementia. Moreover, Leitner et al. [11] found that TMT was correlated with the cross-sectional area of skeletal muscles at the level of the third lumbar vertebra on computed tomography (CT). However, to date, there have been no previous reports of an association between TMT and results from BIA or between the area of the temporalis muscle (TMA) and conventional measurements of skeletal muscle mass. Therefore, the objectives of this study were to determine the correlation between TMT, TMA, and various parameters measured using BIA, including skeletal muscle mass or skeletal muscle index, in patients with cerebrovascular diseases.

Materials and Methods

Participants

This retrospective cross-sectional study was conducted at a single tertiary urban medical hospital, where patients from March 2018 to February 2020 were screened. The inclusion criteria were

as follows: (1) Patients who were admitted to rehabilitation units due to cerebrovascular diseases such as ischemic or hemorrhagic stroke or subarachnoid hemorrhage (SAH) and (2) patients who had magnetic resonance imaging (MRI) or CT examination of the brain and BIA tests within 1 month of brain imaging. The exclusion criteria were as follows: (1) history of craniectomy or cranioplasty; (2) inability to analyze the TMT or TMA due to image quality; and (3) traumatic brain injury, which could cause edematous changes in the temporalis muscle. Detailed information of the participants was collected by a retrospective review of the patients' medical charts. The ethical validity of this retrospective study was approved by the Institutional Review Board of the Chung-Ang University Hospital (IRB No. 2312-010-19500). The requirement for written informed consent was waived due to the retrospective nature of the study.

TMT and TMA

The TMT and TMA were assessed using CT images or T1-weighted MRI images obtained from participants during their admission period. The evaluation followed previously described methods [12, 13]. TMT and TMA measurements were performed at the slice corresponding to the orbital roof level, with the sylvian fissure serving as a reference point (Fig. 1). The TMT and TMA were measured using a picture archiving and communication system. TMT values were determined by measuring perpendicular to the long axis of the temporalis muscle, while TMA values were obtained by manually tracing the outline of the temporalis muscle on the same slice. Both the TMT and TMA were evaluated on both sides of the brain and then summed the values and divided by two to provide the mean values for each patient.

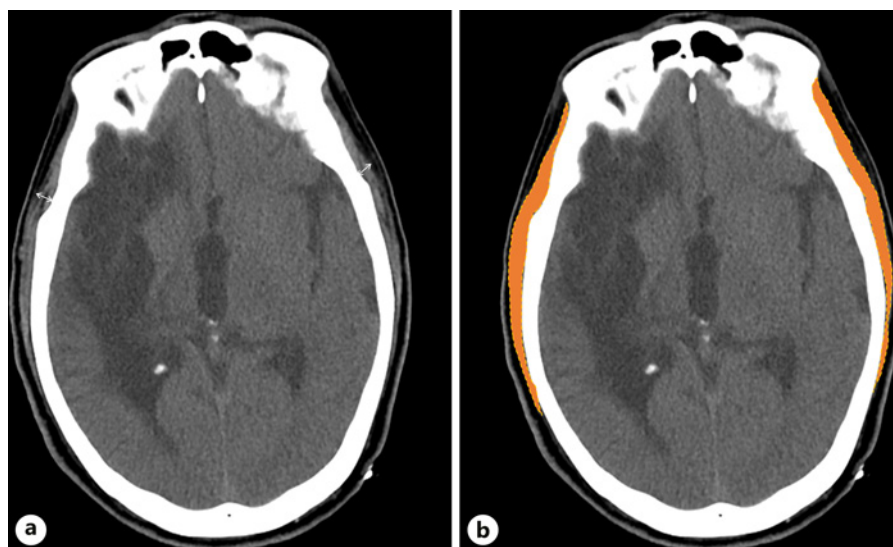
Bioimpedance Analysis

The body composition of the participants, including skeletal muscle mass, percent body fat (PBF), skeletal muscle index (SMI), and whole-body phase angle (WBPA), was analyzed using multi-frequency BIA (Inbody S10, Seoul, South Korea). The WBPA, which was calculated from the resistance and reactance at a frequency of 50 kHz, is a parameter associated with muscle strength and physical fitness in older populations [14, 15]. BIA was conducted on patients after their transfer to the rehabilitation medicine department, and the CT/MRI scans used for analysis were either taken at the time of the initial admission or, for the purpose of follow-up according to the decision of neurologists, the image scans closest in timing to the BIA procedure were utilized. Only the values that were measured within 1 month before and after brain imaging were used for body composition analysis. The detailed measurement procedures were conducted in accordance with the instructions provided by the device manufacturer.

Skeletal Muscle Mass Measurement

The participants' skeletal muscle mass was measured using BIA. The participants were classified into two groups: low skeletal muscle mass (LMM) and without-LMM groups. The classification of low skeletal muscle mass followed the guidelines set by the Asian Working Group of Sarcopenia, defined as a SMI (calculated by dividing the appendicular muscle mass by the square of the participant's height) of $<7.0 \text{ kg/m}^2$ in males and $<5.7 \text{ kg/m}^2$ in females [16].

Fig. 1. Method used to measure the temporal muscle thickness (TMT) and temporal muscle area (TMA). The measurements were conducted at the level of the orbital roof slice, with the sylvian fissures as reference points. TMT values were obtained by measuring perpendicularly to the long axis of the temporalis muscle (**a**), while TMA values were obtained by manually tracing the outline of the temporalis muscle on the same slice (**b**).



Statistical Analysis

Descriptive statistics were used to present the mean and standard deviation for continuous variables, while categorical data are reported as frequencies and percentages. After the Kolmogorov-Smirnov test to test the normality of data, Pearson correlation analysis or Spearman's correlation analysis was employed to examine the correlation coefficients between parameters obtained from images (e.g., TMT and TMA) and the results of body composition analysis using BIA. Authors also conducted partial correlation analysis to examine the relationship between TMT/TMA and BIA parameters while controlling for the influence of age. Correlation coefficients were interpreted as follows: <0.10, negligible; 0.10–0.39, weak; 0.40–0.69, moderate; 0.70–0.89, strong; and >0.90 very strong correlation [17]. Independent *t* tests were conducted to compare the TMT/TMA and results of body composition between LMM group and without LMM group. IBM SPSS Statistics (version 26.0, Armonk, NY, USA) was used for all statistical analyses, and a significance level of 5% was set with a 95% confidence interval.

Results

Among the 513 patients who had been transferred to the department of rehabilitation medicine from September 2018 to March 2020, 317 patients affected with ischemic or hemorrhagic stroke or subarachnoid hemorrhage who had undergone BIA and had either brain MRI or CT within 1 month before and after the BIA measurement were included.

Exclusion criteria were applied in cases where surgical interventions (e.g., craniectomy or cranioplasty) made TMT or TMA measurements unreliable ($n = 32$). Additionally, patients with traumatic brain injury ($n = 41$)

Table 1. General characteristics of the study participants

	Male ($n = 140$)	Female ($n = 104$)
Age, years	65.2±14.3	69.0±14.7
Height, cm	168.8±6.6	156.7±6.0
Weight, kg	66.0±11.3	54.9±9.7
BMI, kg/m ²	23.1±3.4	22.3±3.4
Initial NIHSS	10.0±9.2	11.3±9.5
Grip power, kg ^a	20.7±11.1	10.2±7.0
Modified Rankin Score ^a	3.5±1.5	3.4±1.5
Berg Balance Score ^a	26.9±19.3	21.4±18.0
Etiology, n (%)		
Ischemic stroke	76 (54.3)	52 (40.6)
Hemorrhagic stroke	70 (50.0)	40 (38.5)
SAH	9 (6.4)	19 (18.3)
Comorbidities, n (%)		
DM	37 (26.4)	24 (23.1)
HTN	90 (64.3)	66 (63.5)
CKD (dialysis) ^b	3 (2.1)	1 (1.0)
Dyslipidemia	12 (8.6)	13 (12.5)
LMM	21 (15.0)	29 (27.9)

NIHSS, National Institutes of Health Stroke Scale; SAH, sub-arachnoid Hemorrhage; DM, diabetes mellitus; HTN, hypertension; CKD, chronic kidney disease; LMM, low skeletal muscle mass. ^aThe reported functional assessment was based on the those for whom data were available in the charts (Grip power: male 123/140, female 90/104; MRS: male 134/140, female 97/104; BBS: male 97/140, female 71/104). ^bThe number of patients with CKD currently receiving hemodialysis or peritoneal dialysis was reported.

were excluded because of the potential occurrence of temporal muscle edema. Finally, a total of 244 patients (140 males and 104 females) were included in the

Table 2. Parameters measured by temporal muscle evaluation and bioelectrical impedance analysis

	Male (n = 140)	Female (n = 104)
Mean TMT, mm	6.1±1.5	4.7±1.3
Mean TMA, mm ²	4.76±1.6	2.9±1.1
Skeletal muscle mass, kg	28.3±4.8	19.8±4.2
Percent body fat, %	19.9±9.9	29.8±10.9
Whole-body phase angle, degrees	5.1±1.3	4.2±1.3
Skeletal muscle index, kg/m ²	8.7±2.1	6.8±2.3

TMT, temporal muscle thickness; TMA, temporal muscle area.

analysis. The TMT and TMA were assessed using brain CT or T1-weighted images in all included 244 patients. The mean time interval between brain image and BIA assessment was 12.5 ± 8.6 days in male patients, 12.4 ± 8.6 days in female patients.

In terms of baseline demographics, the mean age of males was 65.2 ± 14.3 years, while that of females was 69.0 ± 14.7 years. Males had a mean height of 168.8 ± 6.6 cm, while females had a mean height of 156.7 ± 6.0 cm. Males had a mean weight of 66.0 ± 11.3 kg, while females had a mean weight of 54.9 ± 9.7 kg. The body mass index (BMI) was not significantly different between males (23.1 ± 3.4 kg/m²) and females (22.3 ± 3.4 kg/m²). Regarding comorbidities, the presence of diabetes mellitus, hypertension, chronic kidney disease, dyslipidemia, and LMM was assessed (Table 1).

Table 2 displays the measured values of TMT and TMA. The mean TMT was 6.1 ± 1.5 mm in males and 4.7 ± 1.3 mm in females, while the mean TMA was 4.76 ± 1.6 mm² in males and 2.9 ± 1.1 mm² in females. Additionally, the measured skeletal muscle mass was 28.3 ± 4.8 kg in males and 19.8 ± 4.2 kg in females, while the PBF was 19.9 ± 9.9% in male, and 29.8 ± 10.9% in females. The WBPA was 5.1 ± 1.3° in males and 4.2 ± 1.3° in female. The SMI was 8.7 ± 2.1 kg/m² in males and 6.8 ± 2.3 kg/m² in female.

Table 3 presents the results of Pearson correlation analysis between the measured TMT and TMA and the parameters measured in BIA. The mean TMT showed significant positive correlations with skeletal muscle mass (male, $r = 0.520$, moderate; female, $r = 0.706$, strong), SMI (male, $r = 0.426$, moderate; female, $r = 0.619$, moderate), and WBPA (male, $r = 0.295$, weak; female, $r = 0.232$, weak). The mean TMA showed significant positive correlations with skeletal muscle mass (male, $r = 0.490$, moderate; female, $r = 0.697$, moderate), SMI (male, $r = 0.289$, weak; female, $r = 0.561$, moderate), and WBPA (male, $r = 0.232$, weak; female, $r = 0.243$, weak). However, there was no sig-

Table 3. Correlation analysis between parameters of temporal muscle evaluation and bioelectrical impedance analysis

	PBF	SMM	SMI	WB-PA
Male				
Mean TMT, mm	-0.054	0.520**	0.426**	0.295**
Mean TMA, mm ²	-0.002	0.490**	0.289**	0.232**
Male – Adjusted by age ^a				
Mean TMT, mm	-0.044	0.419**	0.392**	0.160
Mean TMA, mm ²	-0.011	0.386**	0.237*	0.086
Female ^b				
Mean TMT, mm	-0.206*	0.706**	0.619**	0.423**
Mean TMA, mm ²	-0.226*	0.697**	0.561**	0.243*
Female – Adjusted by age ^a				
Mean TMT, mm	-0.193	0.687**	0.534**	0.400**
Mean TMA, mm ²	-0.213*	0.625**	0.402**	0.207*

The correlation between two parameters was analyzed using Pearson's correlation analysis (* $p < 0.05$, ** $p < 0.001$). TMT, temporal muscle thickness; TMA, temporal muscle area. ^aPartial correlation analysis was conducted while controlling for the influence of age. ^bThe correlation between mean TMT/TMA and SMM/SMI in female participants were analyzed using Spearman's non-parametric correlation analysis due to the normality of the data.

nificant correlation between temporal muscle and PBF in males (Table 3). After controlling the age, similar tendency between mean TMT/TMA and SMM/SMI were noted. However, correlation between WB-PA and mean TMT/TMA in male participants, correlation between PBF and mean TMT in female participants were not statistically significant after adjusted by age (Table 3).

In subgroup analysis presented with or without LMM, males in the LMM group had lower mean TMT and TMA values of 4.7 mm and 3.5 mm², respectively, and significantly lower values in both parameters compared to the without-LMM group. Females in the LMM group showed lower mean TMT and TMA values of 3.6 mm and

Table 4. Measured values of the TMT, TMA and results of bioelectrical impedance analysis in the normal and low muscle mass groups

	Normal muscle mass	Low muscle mass	<i>p</i> value
Male	<i>n</i> = 119	<i>n</i> = 21	
Mean TMT, mm	6.4±1.5	4.7±1.3	<0.001
Mean TMA, mm ²	5.0±1.5	3.5±1.3	<0.001
Skeletal muscle mass, kg	29.2±4.4	22.8±2.9	<0.001
Percent body fat, %	19.1±9.9	24.3±8.9	0.028
Whole-body phase angle, degrees	5.4±1.1	3.9±1.3	<0.001
Female	<i>n</i> = 75	<i>n</i> = 29	
Mean TMT, mm	5.1±1.2	3.6±0.8	<0.001
Mean TMA, mm ²	3.2±1.1	2.2±0.8	<0.001
Skeletal muscle mass, kg	21.4±3.6	15.6±2.3	<0.001
Percent body fat, %	27.4±10.6	36.0±9.1	<0.001
Whole-body phase angle, degrees	4.5±1.4	3.4±0.6	<0.001

TMT, temporal muscle thickness; TMA, temporal muscle area.

2.2 mm², respectively, and a similar tendency of decreased values in temporal muscle parameters compared to the without-LMM group (Table 4).

Discussion

Our findings indicate that the mean TMT and TMA values in patients with cerebrovascular disease showed significant correlations with body composition analysis using BIA. Specifically, the skeletal muscle mass and index were moderate to strongly correlate with the values of TMT and TMA in both male and female patients, except the correlation between TMA and SMI in male patients. Moreover, the WBPA was weakly correlated with the TMT and TMA values. Interestingly, in female patients only, we observed a negative weak correlation between PBF and the values of TMT and TMA. Additionally, in subgroup analysis, we identified significant differences in the values of TMT and TMA between groups with low and normal muscle mass in both male and female patients.

Stroke increases the risk of skeletal muscle loss, and stroke-related sarcopenia has been shown to be significantly associated with poor functional outcomes [18–20]. There has been debate whether the TMT observed in brain CT or MRI can serve as a surrogate marker to evaluate muscle mass or functional outcomes in patients with stroke, brain tumor, or other neurodegenerative diseases. In 2019, Katsuki et al. [21] reported TMT as a prognostic factor in SAH and suggested that a thick TMT is associated with favorable 6-month outcomes in elderly patients with

SAH. Furthermore, Nozoe et al. [22] investigated whether the TMT on CT images could be used as a sarcopenia risk indicator in 289 elderly stroke patients and reported that sarcopenia risk was independently associated with TMT. The utility of TMT as a prognostic factor has also been discussed in diseases other than stroke. Indeed, in a study of 128 patients newly diagnosed with primary central nervous system lymphoma, a low TMT value was reported as an independent adverse marker [23]. Additionally, in a study involving 755 ambulatory patients newly diagnosed with glioblastoma, TMT was reported as an effective surrogate marker for predicting progressive sarcopenia and poor disease outcomes [24]. Therefore, thin temporalis muscles may be associated with poor prognosis in patients with cerebrovascular diseases or brain tumors, possibly because the parameters of the temporalis muscle are associated with skeletal muscle mass. Masko et al. [25] conducted a study on 40 patients admitted to a neuro-intensive care unit, and reported a significant correlation between rectus femoris muscle thickness and TMT in relation to the progression of muscle wasting. Furthermore, TMT has been investigated as a valid index for estimating the appendicular skeletal muscle mass (ASMM) in patients with dementia. Indeed, a study conducted on 68 patients with probable Alzheimer's disease between November 2014 and December 2020 demonstrated a correlation between TMT and ASMM and cognitive function in patients with dementia [10].

Recently, 50-kHz WBPA has been utilized as a valuable indicator of cellular health, reflecting cell membrane integrity and cell function [14]. Low WBPA were known

to be associated with inactive physical activity [26], poor nutrition status [27] or sarcopenia [28]. Moreover, several recent studies indicate a correlation between muscle quality and WBPA. Tomeleri et al. [29] identified a small-to-moderate relationship between WBPA and muscle quality (total muscular strength per kilogram of appendicular lean soft tissue) in 125 older female participants. Similarly, Akamatsu et al. [30] found an association between muscle quality (hand grip strength/upper limb muscle mass) and WBPA, noting that participants with sarcopenia exhibited significantly lower WBPA compared to those without sarcopenia. Hence, as suggested by this research, the correlation between TMT/TMA and 50-kHz WBPA could serve TMT/TMA as a valuable clinical indicator in the early stages of stroke patients.

The results of the current study also demonstrated significant correlations between temporal muscle parameters, SMI, and the 50-kHz WBPA. These correlations align with the trends observed in previous studies, suggesting that temporal muscle parameters can be employed in the assessment of both muscle quantity and quality in populations that require brain imaging, such as patients with cerebrovascular disease. Additionally, to the best of our knowledge, our study is the first to explore the association with the WBPA, which holds significance as a potential biomarker reflecting muscle strength and physical performance [15].

Sarcopenia, a skeletal muscle disease associated with aging, is defined as decreased skeletal muscle mass, decreased muscle strength, and loss of functional performance [1]. Sarcopenia is common in older people and is known to cause various functional impairments, even in healthy older individuals [2]. Additionally, as mentioned earlier, sarcopenia is known to contribute to poor prognosis in conditions such as stroke or other neurological diseases [18–20]. Therefore, screening and management of sarcopenia in patients with neurological diseases, including stroke and other neurodegenerative diseases, is considered important. However, in patients with acute cerebrovascular disease, various obstacles, such as neurologic deficit, cognitive function, and altered consciousness, prevent the evaluation of muscle strength and functional performance to diagnose sarcopenia. Therefore, the skeletal muscle mass in the early stages of these diseases could play an important role in their management.

Nagano et al. [31] conducted a study in 2022 to determine the cut-off value of TMT for identifying sarcopenia in patients aged ≥ 65 years after acute stroke, and suggested that a temporal muscle thickness of 3.83 mm for men and 2.78 mm for women can be used for diagnosing sarcopenia and low skeletal muscle mass. However, more prospective multicenter studies are necessary to establish an association be-

tween temporal muscle parameters and sarcopenia. In this process, the findings of our study indicating the association of TMT or TMA with SMI and WBPA will likely contribute to the establishment of guidelines for such patients. Although there are currently no specific guidelines for patients with neurological diseases affected by sarcopenia, it appears necessary to emphasize protein supplementation and resistance exercise, as suggested in previous sarcopenia guidelines [16, 32, 33].

Despite its strengths, our study also has several limitations that warrant discussion. First, because of the retrospective nature of the study, we were unable to analyze the relationship between TMT or TMA and pre-existing muscle strength or functional assessments. Although we collected information on functional assessments, such as hand grip strength, BBS, and NIHSS, these may not accurately reflect the pre-stroke functional level or be used to diagnose sarcopenia. Therefore, our focus was solely on the relationship between the TMT or TMA and the results of BIA. Second, our study had a relatively small sample size of 244 patients from a single institution, which may limit the generalizability of our findings. Third, there is a possibility in which common errors in measuring body composition analysis using BIA due to fluid status changes such as edema or dehydration in stroke patients may have affected the results. Patients with dialysis were surveyed during the data collection, only 4 patients (3 in men, 1 in women) were on dialysis which is small portion in this retrospective cohort. However, those common errors in measuring BIA could be potential confounding factors of this retrospective study. Fourth, there were variations in the duration between BIA and brain imaging, which ranged up to 1 month, among participants. Considering the findings of previous reports showing that progressive muscle atrophy could occur in the early stages of cerebrovascular disease, these variations in duration may have introduced bias when interpreting the study results [5]. Therefore, a prospective, large-scale study investigating the association between TMT or TMA and muscle mass or functional status would be beneficial.

Conclusion

Our study revealed a significant correlation between TMT or TMA and the results of BIA. Skeletal muscle mass and SMI and WBPA showed significant correlations with TMT or TMA in both sexes. These findings may be useful to identify individuals with pre-stroke low muscle mass among patients with cerebrovascular diseases.

However, further large-scale prospective studies are needed to establish appropriate cutoff values for diagnosing low muscle mass or sarcopenia.

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Statement of Ethics

This study was approved by the Institutional Review Board of the Chung-Ang University Hospital (IRB No. 2312-010-19500) and was conducted in accordance with the Declaration of Helsinki. The requirement for written informed consent was waived due to the retrospective nature of the study.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

B.C.L. conceptualized the study. B.C.L., D.H.K., and J.M.H. analyzed the survey data and interpreted the results of the analysis. J.M.H. prepared the original draft. B.C.L. and D.H.K. reviewed and edited the draft. All authors have read and approved the final manuscript.

Data Availability Statement

The data that support the findings of this study are not publicly available as it contains information that could compromise the privacy of research participants but are available from the corresponding author upon reasonable request.

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