Comparison of single- or multifrequency bioelectrical impedance analysis and spectroscopy for assessment of appendicular skeletal muscle in the elderly

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Bioelectrical impedance analysis (BIA) is an affordable, noninvasive, easy-to-operate, portable, and fast (assessments can be made within 5–10 min) alternative for assessing segmental or whole body SM (15, 19, 31, 38, 40) and so may be a practical method for assessing SM in the elderly, although the technique has not been fully validated in this age group.

Sarcopenia is defined as a loss of skeletal muscle mass (SM) and/or strength (MS) associated with aging (4, 5, 7, 14, 32, 35). The SM declines at approximately 1%/yr after the age of 30 yr. Severe muscle loss (defined as 2 SDs below that of healthy, young individuals) is evident in 11–50% of those 80 yr and older (8, 43). This loss of SM has been shown to be associated with disability (3, 17). Therefore, the assessment of SM is important in the elderly.

The SM can be assessed by magnetic resonance imaging (MRI) or computed tomography (CT) (5, 32). Alternatively, the nonbone fat mass or appendicular lean mass, as measured by 1H or 31P NMR (10, 11, 23, 26, 28, 29), and a relative measure of skeletal muscle mass, although its application in the elderly has not been fully established. Several BIA modalities are available: single-frequency BIA (SFBIA), multifrequency BIA (MFBI A), and bioelectrical impedance spectroscopy (BIS). The aim of this study was to examine the difference between SFBIA and RICW, and for BIS for assessment of appendicular skeletal muscle strength in the elderly. A total of 405 elderly (74.2 ± 5.0 yr) individuals were recruited. Grip strength and isometric knee extension strength were measured. Segmental SFBIA, MFBI A, and BIS were measured for the arms and upper legs.

Bioelectrical impedance indices were calculated by squared segment length divided by impedance (L2/Z). Impedance at 5 and 50 kHz (Z5 and Z50) was used for SFBIA. Impedance of the intracellular component was calculated from MFBI A (Z50,s) and BIS (RICW). Correlation coefficients between knee extension strength and L2/Z5, L2/Z50, L2/RICW; and L2/Z50.5 of the upper legs were 0.661, 0.705, 0.790, and 0.808, respectively (P < 0.001). Correlation coefficients were significantly greater for MFBI A and BIS than SFBIA. Receiver operating characteristic curves showed that L2/Z50.5 and L2/RICW had significantly larger areas under the curve for the diagnosis of muscle weakness compared with L2/Z5 and L2/Z50. Very similar results were observed for grip strength. Our findings suggest that MFBI A and BIS are better methods than SFBIA for assessing skeletal muscle strength in the elderly.

Bioelectrical impedance analysis; sarcopenia; muscle strength; elderly; skeletal muscle mass

Sarcopenia is defined as a loss of skeletal muscle mass (SM) and/or strength (MS) associated with aging (4, 5, 7, 14, 32, 35). The SM declines at approximately 1%/yr after the age of 30 yr. Severe muscle loss (defined as 2 SDs below that of healthy, young individuals) is evident in 11–50% of those 80 yr and older (8, 43). This loss of SM has been shown to be associated with disability (3, 17). Therefore, the assessment of SM is important in the elderly.

The SM can be assessed by magnetic resonance imaging (MRI) or computed tomography (CT) (5, 32). Alternatively, the nonbone fat mass or appendicular lean mass, as obtained by dual-energy X-ray absorptiometry (DXA), may be used (6, 21). However, as these instruments are often located in hospitals or research facilities, it may be difficult for frail, elderly individuals to have SM assessed using these techniques. Bioelectrical impedance analysis (BIA) is an affordable, noninvasive, easy-to-operate, portable, and fast (assessments can be made within 5–10 min) alternative for assessing segmental or whole body SM (15, 19, 31, 38, 40) and so may be a practical method for assessing SM in the elderly, although the technique has not been fully validated in this age group.

Several BIA modalities are in general use: single-frequency BIA (SFBIA), multifrequency BIA (MFBI A), and bioelectrical impedance spectroscopy (BIS). SFBIA is the most popular technique; it measures the impedance (Z) or the resistance (R) at 50 kHz. In BIA, reactance (Xc) is ~10% of R, so the magnitude of Z is similar to that of R, leading to their almost interchangeable use, although strictly Z = (R2 + Xc2)1/2. Because a 50-kHz current will not penetrate tissue completely, SFBIA cannot measure the entire muscle volume (MV). MFBI A uses several current frequencies, relying on the principle that the body’s R is dependent on the frequency of the alternating current applied. Total body water is distributed between the intracellular and extracellular compartments, separated by cell membranes. Cell membranes act as capacitors that insulate the intracellular water (ICW) at low frequencies so that predominantly extracellular water (ECW) is measured. At higher frequencies, in contrast, the membranes are permeable to the current so that ICW and ECW are both measured. BIS uses a series of frequencies according to the principle of the Cole-Cole model, which characterizes the measurement segment with parallel circuits for ECW and ICW and accounts for a capacitative effect introduced by the nonconducting membrane that separates the ICW and ECW. A plot of Xc vs. R at different frequencies results in a semicircular arc. Fitting the measured Z data to this model, R at infinity frequency (R∞) and at zero frequency (R0) are obtained by extrapolation.

Most recent studies that have sought to develop Z models for estimating SM have used SFBIA against MRI. In these studies, bioelectrical Z index (L2/Z50), calculated from the squared segment length (L) divided by Z (Z50) or R (R50) at 50 kHz, was found to be strongly correlated with SM (15, 19, 31, 36, 38, 40); however, the previous validation studies were performed on healthy young adults. Skeletal muscle quality changes with aging. Structural changes of the extracellular matrix include an increase in collagen concentration, changes in the elastic fiber system, and an increase in fat accumulation within skeletal muscle (10, 11, 23, 26, 28, 29), and a relative expansion of ECW to skeletal MV (45). These changes could be expected to affect the relationship between L2/Z50 and SM. Although BIA equations for SM may have been validated...
Sarcopenia in Older People (5).

Existing imaging methodologies for assessing muscle area, volume, or soft tissue lean mass (e.g., MRI, CT, DXA) and SFBIA are confounded by ECW, which is measured and calculated as lean mass or muscle. Although traditional SFBIA has been notoriously fraught with concerns about its reliability and has required various mathematical adjustments to determine fat and lean tissue more precisely, we speculated that MFBIA or BIS might prove to be more reliable.

### METHODS

**Subjects.** A total of 405 community-dwelling, healthy, Japanese individuals (aged 65–90 yr; 165 men and 240 women) participated in this study, having provided written, informed consent. Inclusion criteria were as follows: 1) reported ability to walk more than 10 m with or without a cane, 2) ability to provide informed consent with no indication of dementia, 3) no history of any joint arthroplasty or current use of an artificial pacemaker, 4) no medication for edema or lymphedema, and 5) absence of any definite kidney, digestive, or other acute disease. The study protocol was approved by the ethics committee of Kyoto Prefectural University of Medicine. Barefoot standing stature was measured to the nearest 0.1 cm using a wall-mounted stadiometer. The body mass of each subject was measured to the nearest 0.1 kg, with the subjects dressed in light clothing without shoes. Anthropometric measurements were obtained in the morning, and limb lengths were measured to the nearest 0.5 cm using a flexible tape (Flat rule, KDS, Kyoto, Japan) with the subjects in a standing position (31).

### Segmental MFBIA and BIS

Impedance measurements were obtained with the subjects in a relaxed supine position on a padded bed, arms slightly abducted from the body, forearms pronated, and legs slightly apart. Participants were instructed to refrain from vigorous exercise for 24 h, and to refrain from eating a meal or drinking more than 0.5 liter of water for 3 h before the experiments. Room temperature was adjusted to maintain a thermoneutral environment. Z was measured after 5–10 min of rest (2), to avoid the immediate (1–2 min) effect of the transition from a standing to a supine position on the shift in body fluid from the extremities to the thorax, as well as the slow phase of this shift that continues for up to 3–12 h (24, 37).

Bioelectrical impedance was measured using a logarithmic distribution of 256 frequencies, ranging from 4 to 1,000 kHz (SPB7, ImpediMed, Pinkenba, QLD, Australia), using disposable tab-type monitoring electrodes (2 cm × 2 cm, Red Dot, 3M, St. Paul, MN). Before the test, the system was checked against a series of precision resistors provided by the manufacturer. For arm measurement, two injecting electrodes were placed on both sides of the body on the dorsal surface of the feet proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints. Sensing electrodes were placed on both sides of the body on the dorsum of hands proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints. Sensing electrodes were placed on both sides of the body on the dorsal surface of the feet proximal to the metatarsal-phalangeal and metatarsal-phalangeal joints. Sensing electrodes were placed on both sides of the body on the articular crest between

### Table 2. Segment length, bioimpedance, and impedance indexes of the upper legs and arms

<table>
<thead>
<tr>
<th>Segment</th>
<th>Upper Legs</th>
<th>Arms</th>
</tr>
</thead>
<tbody>
<tr>
<td>L, cm</td>
<td>71.3 ± 4.4</td>
<td>146.4 ± 8.3</td>
</tr>
<tr>
<td>Zs, Ω</td>
<td>166 ± 27</td>
<td>609 ± 86</td>
</tr>
<tr>
<td>Zso, Ω</td>
<td>150 ± 25</td>
<td>553 ± 84</td>
</tr>
<tr>
<td>Z250, Ω</td>
<td>746 ± 213</td>
<td>2,939 ± 792</td>
</tr>
<tr>
<td>Rcwc, cm²/Ω</td>
<td>486 ± 134</td>
<td>1,915 ± 501</td>
</tr>
<tr>
<td>L2/Z250, cm²/Ω</td>
<td>31.6 ± 6.9</td>
<td>36.3 ± 8.1</td>
</tr>
<tr>
<td>L2/Zso, cm²/Ω</td>
<td>35.2 ± 8.0</td>
<td>40.1 ± 9.4</td>
</tr>
<tr>
<td>L2/Rcwc, cm²/Ω</td>
<td>11.4 ± 3.9</td>
<td>12.2 ± 4.0</td>
</tr>
<tr>
<td>SEE of Cole-Cole plot, %</td>
<td>0.547 ± 0.253</td>
<td>0.427 ± 0.350</td>
</tr>
</tbody>
</table>

Values are means ± SD; n = 405 subjects. L, segment length; Zs and Zso, impedance at 5 and 50 kHz frequencies, respectively; Z250, impedance of intracellular water (ICW) component calculated from MFBIA; multifrequency bioelectrical impedance analysis; Rcwc, resistance of ICW component calculated from bioelectrical impedance spectroscopy (BIS); SEE, standard error of the estimate.
the femoral and tibial condyles. Segment length (L) was measured as the sum of the upper leg lengths measured from the articular cleft between the femoral and tibial condyles and the greater trochanter of the femur. The R0 and R∞ for the arms and upper legs were determined by extrapolation after fitting the spectrum of bioimpedance data to the Cole-Cole model using specific software (ImpediMed, Pinkenba, QLD, Australia). The analysis parameters were as follows: minimum frequency, 5 kHz; maximum frequency, 500 kHz; rejection limit, 0%. For BIS, the RICW was calculated using 1/(1/Z250) for the arms and upper legs, respectively (1, 12, 20, 34).

Table 3. Correlation coefficients (r) between knee extension strength and physical characteristics or impedance indexes of the upper legs

<table>
<thead>
<tr>
<th>No.</th>
<th>r</th>
<th>95% CI</th>
<th>Statistical Comparison (P &lt; 0.001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Age, yr</td>
<td>-0.205</td>
<td>-0.296 to -0.109</td>
</tr>
<tr>
<td>2</td>
<td>FFM, kg</td>
<td>0.720</td>
<td>0.669–0.764</td>
</tr>
<tr>
<td>3</td>
<td>SM, kg</td>
<td>0.749</td>
<td>0.702–0.789</td>
</tr>
<tr>
<td>4</td>
<td>SMI, kg/m²</td>
<td>0.646</td>
<td>0.585–0.699</td>
</tr>
<tr>
<td>5</td>
<td>L²/Z5, cm²Ω</td>
<td>0.661</td>
<td>0.603–0.713</td>
</tr>
<tr>
<td>6</td>
<td>L²/Z50, cm²Ω</td>
<td>0.705</td>
<td>0.652–0.751</td>
</tr>
<tr>
<td>7</td>
<td>L²/RICW, cm²Ω</td>
<td>0.790</td>
<td>0.750–0.824</td>
</tr>
<tr>
<td>8</td>
<td>L²/Z250-5, cm²Ω</td>
<td>0.808</td>
<td>0.772–0.840</td>
</tr>
</tbody>
</table>

n = 405 Subjects. CI, confidence interval; L, distance between the knees; All r values were statistically significant (P < 0.001). Statistical comparison of correlation coefficients was performed using Meng’s z-test (27) with an α of 0.001 was used to denote statistical significance in order to avoid type I error as a result of multiple testing.

Grip strength and isometric knee extension strength. Grip strength and isometric KES tests were conducted after BIA measurements. Maximal GS was measured using a Smedley Hand Dynamometer (Grip-D, TKK5401; Takei Scientific Instruments, Niigata, Japan), as described elsewhere (22). When performing the measurement, subjects were instructed to maintain a standard bipedal position for the duration of the test. The involved arm was placed in complete extension with the dynamometer not touching any other part of the body, except the hand being measured. The width of the handle was adjusted to ensure that, when the subject held the dynamometer, the second phalanx was against the inner stirrup. Two trials, separated by a brief rest, were allowed for each hand alternately, and the highest value was recorded as the result. Subjects were encouraged to exert themselves maximally during each effort. The sum of the maximum GS recordings for each side was used to calculate the mean. The cutoff point of weakness of GS was set at 30 kg for men and 20 kg for women, in accordance with previous studies (5, 25).

Maximal KES at a knee angle of 90° was measured in a sitting position on a custom-made dynamometer chair, as described elsewhere (22, 45). The ankle was attached to a strain-gauge system (TKK5710e; Takei Scientific Instruments,). After familiarization with the test, subjects were encouraged to produce maximal knee extension force. The test consisted of two maximal efforts, each separated by a 1-min rest period, with the highest value recorded. The length between the lateral epicondyle of the humerus and the ankle attachment was measured. Knee extension torque (Nm) was calculated as the strength multiplied by the length, and the mean was calculated. A cutoff point for weakness of KES was set at 25 kg for men and 15 kg for women. In accordance with previous studies (5, 25), this seemed reasonable because the lower quartile of GS in our cohort was 30.1 kg for men and 19.5 kg for women.

Fig. 1. Relationship between knee extension strength (KES) and impedance (Z) indexes of squared segment length (L²) divided by Z at 5 kHz (L²/Z5; A), L²/Z50 (Z at 50 kHz; B), L²/RICW [resistance of intracellular water component calculated from bioelectrical impedance spectroscopy (BIS); (C), and L²/Z250-5 (Z of the intracellular component calculated from multifrequency bioelectrical impedance analysis (MFBIA); (D)] in the upper legs. ×, Women; •, men. The relationships between KES and BIS (L²/RICW) or MFBIA (L²/Z250-5) were significantly stronger than the relationship between KES and single-frequency bioelectrical impedance analysis (SFBIA) (L²/Z5 and L²/Z50).
comparison closely to the cutoff point for GS weakness in the literature (5, 25).

Body composition measurement. The proportion of body fat and fat-free mass was estimated using segmental BIA at 50 kHz. This method has previously been validated for use in the elderly (9, 44). The analysis was based on Ohm’s law and used impedance indexes and a recently developed correction factor for water distribution within the body (44). The segmental BIA calculation was not influenced by age, sex, or weight (44), and it estimated body composition with a higher accuracy than traditional methods (16, 40).

SM was calculated using the BIA equation of Janssen et al. (18, 19):

\[
SM (\text{kg}) = \frac{[\text{height}/R_{50} \times 0.401] + (\text{sex} \times 3.825) + (\text{age} \times -0.071)] + 5.102}{\text{height between the right wrist and ankle in a supine position for sex, men = 1 and women = 0; and age is measured in years. This BIA equation was developed against MRI measures of whole body MV in a sample of 269 men and women who varied widely in age (18–86 yr) and adiposity (body mass index, 16–48 kg/m²). MRI is a measure of MV, and the volume units were converted to mass units in that study by multiplying the volumes by the assumed constant density for adipose tissue-free SM (1.04 kg/l). In that study, the correlation between BIA-predicted and MRI-measured muscle mass was 0.93, with a SE of the estimate of 9% (19). Absolute muscle mass (kg) was normalized for height [muscle mass (kg)/height (m)] and termed the skeletal muscle index (17, 18). The muscle quality was calculated by dividing KES or GS by SM to examine the existence of a sex difference.

Statistical analysis. Results are presented as the mean ± SD. Muscle quality (KES/SM and GS/SM) was compared between sexes using one-way ANOVA. All variables were judged to be distributed normally according to the Kolmogorov-Smirnov test (P > 0.1), and thus Pearson’s correlation coefficients were calculated between MS and impedance indexes. Correlation coefficients were compared using the methods described by Meng et al. (27). The sensitivity and specificity of the impedance indexes for the diagnosis of muscle weakness were calculated using receiver operating characteristic (ROC) curves. All analyses were performed using SPSS 12.0 for Windows (SPSS, Chicago, IL). For all analyses, an α of 0.001 was used to denote statistical significance to avoid type I error as a result of multiple testing.

RESULTS

Table 1 shows the participants’ physical characteristics, KES, and GS. Table 2 shows the segment lengths, bioimpedance, and Z indexes for the upper legs and the arms. The KES/SM was not

### Table 4. Correlation coefficients between grip strength and physical characteristics or impedance indexes of the arms

<table>
<thead>
<tr>
<th>No.</th>
<th>Characteristic</th>
<th>r</th>
<th>95% CI</th>
<th>Statistical Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Age, yr</td>
<td>−0.179</td>
<td>−0.272 to −0.083</td>
<td>2 &gt; 1, 4</td>
</tr>
<tr>
<td>2</td>
<td>FFM, kg</td>
<td>0.794</td>
<td>0.755–0.827</td>
<td>2 &gt; 1, 2, 4, 5</td>
</tr>
<tr>
<td>3</td>
<td>SM, kg</td>
<td>0.825</td>
<td>0.792–0.854</td>
<td>3 &gt; 1, 2, 4, 5</td>
</tr>
<tr>
<td>4</td>
<td>SMI, kg/m²</td>
<td>0.718</td>
<td>0.667–0.762</td>
<td>4 &gt; 1</td>
</tr>
<tr>
<td>5</td>
<td>L²/Z₅₀, cm²/Ω</td>
<td>0.783</td>
<td>0.743–0.818</td>
<td>5 &gt; 1, 4</td>
</tr>
<tr>
<td>6</td>
<td>L²/Z₅₀₆, cm²/Ω</td>
<td>0.804</td>
<td>0.767–0.836</td>
<td>6 &gt; 1, 4, 5</td>
</tr>
<tr>
<td>7</td>
<td>L²/Rcw, cm²/Ω</td>
<td>0.839</td>
<td>0.808–0.866</td>
<td>7 &gt; 1, 2, 4, 5, 6</td>
</tr>
<tr>
<td>8</td>
<td>L²/Z₅₀₆, cm²/Ω</td>
<td>0.845</td>
<td>0.815–0.871</td>
<td>8 &gt; 1, 2, 4, 5</td>
</tr>
</tbody>
</table>

n = 405 Subjects. All r values were statistically significant (P < 0.001). Statistical comparison between correlation coefficients was performed using Meng’s z-test (27) with an α of 0.001 was used to denote statistical significance in order to avoid type I error as a result of multiple testing.
significantly different between men and women (5.37 ± 1.26 and 5.19 ± 1.27 Nm/kg, respectively, P = 0.17). The GS/SM was also not significantly different between men and women (1.25 ± 0.20 and 1.30 ± 0.20, respectively, P = 0.12). The SE of estimate of curve fitting for Cole-Cole plot was below 1% (Table 2).

Table 3 shows the correlation coefficients between KES and impedance indexes in the upper legs. Knee extension strength was strongly correlated with \( L^2/Z_{250.5} \) and \( L^2/R_{ICW} \) of the upper legs (\( r = 0.808 \) and 0.790, respectively, \( P < 0.001 \)). The correlation coefficients between KES and \( L^2/Z_5 \) or \( L^2/Z_{50} \) of the upper legs were 0.661 and 0.705, respectively (\( P < 0.001 \)). The correlation coefficients were significantly larger in \( L^2/Z_{250.5} \) or \( L^2/R_{ICW} \) than in SFBIA (\( L^2/Z_5 \) or \( L^2/Z_{50} \)). The correlation with MFBIA was slightly but significantly greater than that of BIS. Figure 1 shows the relationship between KES and impedance indexes in the upper legs.

Table 4 shows the correlation coefficients between GS and impedance indexes in the arms. The GS was strongly correlated with \( L^2/Z_{250.5} \) and \( L^2/R_{ICW} \) (\( r = 0.845 \) and 0.839, respectively, \( P < 0.001 \)). The correlation coefficients between GS and \( L^2/Z_5 \) or \( L^2/Z_{50} \) of the arms were 0.783 and 0.804, respectively (\( P < 0.001 \)). The correlation coefficients were significantly greater in \( L^2/Z_{250.5} \) or \( L^2/R_{ICW} \) than SFBIA. Figure 2 shows the relationship between GS and impedance indexes in the arms.

Figure 3 shows ROC curves for KES and GS. The intracellular component impedance indexes (\( L^2/Z_{250.5} \) of MFBIA and \( L^2/R_{ICW} \) of BIS) had significantly larger areas under the curve compared with single frequency impedance index for SFBIA (5 and 50 kHz).

**DISCUSSION**

The main findings of the study were that the relationships between MS and BIS (\( L^2/R_{ICW} \)) or MFBIA (\( L^2/Z_{250.5} \)) were significantly stronger than the relationship between MS and SFBIA (\( L^2/Z_5 \) and \( L^2/Z_{50} \)). The ROC curves show \( L^2/Z_{250.5} \) and \( L^2/R_{ICW} \) had larger areas under the curve for the diagnosis of muscle weakness compared with \( L^2/Z_5 \) and \( L^2/Z_{50} \).

The increase in the proportion of the world’s population that is ≥65 yr old has led to several international working groups attempting to establish an accepted definition of sarcopenia (5, 32). The primary definition of sarcopenia should be based on the measurement of SM (14). However, there are several limitations associated with the use of SM to define sarcopenia. One reason is that the measurement of SM using MRI and CT is costly and time consuming and is limited to populations that are mobile. BIA analysis is recognized as an alternative method to estimate SM, although its use in the elderly has been questioned (32). Commercially available BIA instruments often use multiple regression models that include age, mass, and sex as independent variables to estimate body composition, but the use of such instruments is not appropriate for research purposes, where the aim may be to examine the relationship between age and muscle atrophy. Raw bioelectrical impedance data can be used in research; however, these data have not been reported from cohorts of elderly individuals.

In healthy, young adults, the \( L^2/Z_{50} \) is strongly correlated with SM and MS (30, 31, 36). Miyatani et al. (31) demonstrated the \( L^2/Z_{50} \) of the upper leg was strongly correlated with MV (\( r = 0.937, P < 0.001 \)) and KES (\( r = 0.897, P < 0.001 \)).

The correlation coefficient between KES and the \( L^2/Z_{50} \) of the upper leg was the same as the correlation coefficient between KES and MV, measured using MRI (\( r = 0.816, P < 0.001 \)) (31). In contrast, the \( L^2/Z_{50} \) of the upper leg was only moderately correlated with KES (\( r = 0.661 \)) in our study. A possible explanation for this result could be that skeletal muscle quality changes with aging. Specifically, there are structural changes of the extracellular matrix, including an increase in collagen concentration, a change in the elastic fiber system, an increase in fat accumulation within skeletal muscle, and the expansion of ECW relative to MV (10, 11, 23, 26, 28, 29, 45). The R at low frequencies (<100 kHz) reflects mainly ECW, and, therefore, the correlation between KES and \( L^2/Z_{50} \) might be attenuated with aging. However, there is no direct evidence of this in our study, and thus the further studies are needed.

However, the impedance indexes for the ICW component in the upper legs, \( L^2/Z_{250.5} \) of segmental MFBIA and \( L^2/R_{ICW} \) of segmental BIS, were strongly correlated with KES (\( r = 0.808 \) and 0.790, respectively \( P < 0.001 \)). A previous study has reported the correlation coefficient between KES and MV measured by MRI to be 0.816 in healthy young adults (31). The upper and lower extremities consist of adipose tissue, skeletal muscle, and bone. There is a higher proportion of water in...
skeletal muscle compared with adipose tissue and bone. Therefore, when ICW is assessed in the extremities, it primarily reflects muscle cell volume. Our findings suggest that the $L^2/IZ_{250.5}$ of SFBI A and $L^2/RICW$ of BIS are good indicators of MS in the elderly.

Although several previous studies have indicated that SM is a strong independent predictor of physical disability or mortality (3, 17, 42), other studies have shown that SM measured using imaging methods, such as MRI, CT, and DXA, were poorly associated with physical function and mortality (25, 33, 41). The SM, measured using imaging methods, contains an ECW component (1), even if intramuscular adipose tissue is eliminated. One previous study demonstrated that SM was strongly correlated with physical function when the ECW volume was excluded from the SM, and our results support this finding (45). Simultaneous measurement using both segmental BIS and imaging methods may be effective means of assessing actual muscle tissue changes. Furthermore, the portability and the relatively low level of cooperation required may enable the segmental BIS measurements to be made in elderly patients who might not tolerate other techniques. For the future, it is important to validate BIS based on multiple imaging techniques; Y.Y. prepared figures; Y.Y., Y.W., M.I., K.Y., T.M., and M.K. edited and revised manuscript; Y.Y., Y.W., M.I., K.Y., T.Y., and M.K. approved final version of manuscript.

DISCLOSURES
No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS
Author contributions: Y.Y., K.Y., T.M., and M.K. conception and design of the study; Y.Y., K.Y., and T.M. statistical analysis and data interpretation; Y.Y., K.Y., and T.M. performed experiments; Y.Y., K.Y., and T.M. wrote the manuscript.

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