Development of Estimate Formulas for Waist Circumference Using Body Mass Index and Limb Circumferences in Hospitalized Older Adults

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ABSTRACT

Background: Little research has been conducted on the estimate formulas for waist circumference using body mass index and limb circumferences in hospitalized older adults. Thus, we conducted the present study to develop estimate formulas of waist circumference using body mass index and limb circumferences in hospitalized older adults. Methods: Forty hospitalized older patients were recruited in this cross-sectional study. We measured waist circumference, body mass index, upper arm circumference, forearm circumference, thigh circumference, and calf circumference. The estimate formulas for waist circumference were developed using simple and multiple regression analysis. Results: Simple regression analysis indicated that body mass index, upper arm circumference, forearm circumference, thigh circumference, and calf circumference were independent explanators for waist circumference (p < 0.05 for all). In addition, body mass index, upper arm circumference, and forearm circumference but not thigh circumference and calf circumference were extracted as independent explanators for waist circumference in multiple regression analysis (p < 0.05). We were able to develop the estimate formulas using body mass index, upper arm circumference, forearm circumference, thigh circumference, and calf circumference. Conclusion: The results suggest that the estimate formulas for waist circumference may provide an opportunity to easily evaluate waist circumference, even in hospitalized older adults with kyphosis posture. However, future studies should be conducted to develop the estimate formulas for waist circumference with a lower error value.

Keywords: Estimate formula, Waist circumference, Body mass index, Limb circumference, Hospitalized older adults

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Introduction

According to the World Health Organization’s 2016 report, ischemic heart disease and stroke are the main causes of death worldwide [1]. Metabolic syndrome results in an increased risk of onset of cardiovascular diseases and waist circumference (WC) as visceral fat is a required parameter for the diagnosis of metabolic syndrome in Japan [2,3]. WC has also been used as one measure of sarcopenic obesity related to metabolic syndrome [4,5]. Moreover, WC is positively associated with the homeostasis model assessment of insulin resistance (HOMA-IR), and patients with lacunar infarction and atherothrombotic infarction have been shown to have higher insulin resistance [6,7]. Thus, it is important to evaluate WC to prevent the emergence of ischemic heart disease or stroke.

As compared with younger individuals, a higher proportion of individuals aged 60–69 and older than 70 years have a stronger suspicion of metabolic syndrome and being likely to suffer from metabolic syndrome [2]. As kyphosis posture is a characteristic of old age [8], we often experience the inability to measure WC in older adults.

Body mass index (BMI) is an index of obesity and is calculated as the individual’s body weight in kilograms divided by the square of the height in meters [2]. BMI can be easily measured in the clinical setting because it requires the use of only height and weight. Circumference is also a simple measurement that requires only a tape measure. Circumference values reflect both muscle mass and fat mass [9-11]. Previous studies have reported that both BMI and circumferences at the upper and lower limbs are related to WC [12-14]. The estimate formula is a useful method for predicting WC without the dependence of posture. However, there have been few studies on the estimate formulas for WC using BMI or limb circumferences, which can be easily measured in older adults. Clarification of the estimate formulas using BMI and limb circumferences could provide an opportunity to use the values of WC in older adults and may consequently decrease the onset of ischemic heart disease or stroke.

We conducted the present investigation to develop estimate formulas of WC using BMI and limb circumferences in hospitalized older adults. We hypothesized that estimate formulas of WC using BMI and limb circumferences exist in hospitalized older adults.

Materials and Methods

Participants

For this cross-sectional study, we recruited 40 hospitalized older patients from Toyoda Eisei Hospital (average age ± standard deviation [SD]: 81.4 ± 7.4; range, 69–97 years). Exclusion criteria included 1) the inability to obtain consent and 2) incomplete measurements. The average duration from the onset of major diseases was 31.1 ± 31.6 days. Major diseases represented in the sample included cardiovascular diseases (stroke: 22.5% [n = 9/40]; total 22.5%), orthopedic diseases (femur fracture: 40.0% [n = 16/40]; vertebral fracture: 5.0% [n = 2/40]; patella or leg fracture: 5% [n = 2/40]; pelvic fracture: 7.5% [n = 3/40]; cervical fracture: 5.0%
[n = 2/40]; total 62.5%), and others (disuse syndrome: 10.0% [n = 4/40], Guillain-Barre syndrome: 2.5% [n = 1/40]; Parkinson syndrome: 2.5% [n = 1/40]; total 15.0%), respectively. The average Barthel index (BI) score, which indicates the ability to carry out activities of daily living (ADL), \[^{[15]}\] is 58.8 ± 18.1 points. Total score in BI is ranged from 0 to 100 points and the lower point values show more need for assistance in ADL \[^{[15]}\]. All participants read and signed an informed consent form, and this study was approved by the ethics committee of the Health Science University.

**BMI and WC**

BMI was calculated as the individual’s body weight in kilograms divided by the square of the height in meters. WC was measured at the umbilicus with the subject in a standing posture at the end of mild expiration and was estimated to the nearest 0.1 cm using a tape measure. The average of two values of WC was analyzed as a representative value. The high reliability of WC has been observed, and intraclass correlation coefficients are greater than 0.90 \[^{[16-18]}\].

**Limb circumference**

Upper arm circumference (UC), forearm circumference (FC), thigh circumference (TC), and calf circumference (CC) were measured at the largest points to the nearest 0.1 cm. The measurements of each circumference were conducted twice using a tape measure. The intraobserver reliability of the circumference measurements ranged from good to perfect (0.65–0.99) \[^{[19]}\]. UC and FC measurements were carried out in a sitting position when the participant’s upper limbs were placed at the side of their body with their hands in a neutral position. For the TC values, participants were measured from a point 10 cm from the patella on the edge with the knee joint extension in the supine position. For CC measurements, participants were in a seated position with an approximate 90° flexion of the hip and knee joints. Higher values of each of the average values of both the right and left sides were used for the analysis.

**Statistical analysis**

Data were expressed as means ± SD. Statistical analysis was conducted using JMP 11 software (SAS Institute Inc., Cary, NC, USA). Relationships among age, height, weight, BMI, WC, UC, FC, TC, and CC were evaluated using Pearson’s product–moment correlation coefficient (both parametric data) or Spearman’s rank-correlation coefficient (either or both non-parametric data) according to the Shapiro–Wilk test. Differences in WC values between men and women were assessed using an unpaired t test. In addition, we used simple or multiple regression analysis to develop the estimate formulas for predicting WC. Statistical significance was set at p < 0.05.

**Results**

Table 1 presents the characteristics of the study patients. Using the Shapiro–Wilk test, age, weight, BMI, WC, UC, FC, TC, and CC were normally distributed, except for height. WC was significantly associated with height, weight, BMI, UC, FC, TC, and CC according to the Pearson’s product–moment correlation coefficient or Spearman’s rank-correlation coefficient,
respectively (age: \( r = -0.31, p = 0.055 \); height: \( r = 0.35, p = 0.026 \); weight: \( r = 0.78, p < .0001 \); BMI: \( r = 0.71, p < .0001 \); UC: \( r = 0.82, p < .0001 \); FC: \( r = 0.62, p < .0001 \); TC: \( r = 0.66, p < .0001 \); CC: \( r = 0.58, p < .0001 \); Table 2). Table 2 also shows the values of the correlation coefficients with other items. Moreover, no significant difference was observed in WC values between sexes using an unpaired t test (both parametric data, \( p = 0.65 \)).

**Table 1. Characteristics of the patients in this study**

<table>
<thead>
<tr>
<th>Characteristics (n = 40)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (n, male / female)</td>
<td>21 / 19</td>
</tr>
<tr>
<td>Age (years)</td>
<td>81.4 ± 7.4</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>150.2 ± 10.8</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>47.6 ± 9.8</td>
</tr>
<tr>
<td>BMI (kg / m(^2))</td>
<td>21.1 ± 3.1</td>
</tr>
<tr>
<td>WC (cm)</td>
<td>82.1 ± 8.7</td>
</tr>
<tr>
<td>UC (cm)</td>
<td>24.2 ± 3.4</td>
</tr>
<tr>
<td>FC (cm)</td>
<td>21.5 ± 2.5</td>
</tr>
<tr>
<td>TC (cm)</td>
<td>36.6 ± 4.6</td>
</tr>
<tr>
<td>CC (cm)</td>
<td>30.3 ± 3.9</td>
</tr>
</tbody>
</table>

Values were expressed mean ± standard deviation; BMI, body mass index; WC, waist circumference; UC, upper arm circumference; FC, forearm circumference; TC, thigh circumference; CC, calf circumference.

BMI, UC, FC, TC, and CC were used to develop the estimate formulas for predicting WC. Simple regression analysis identified BMI, UC, FC, TC, and CC as significant independent explanators for WC, respectively (BMI: \( \beta = 0.71 \); UC: \( \beta = 0.82 \); FC: \( \beta = 0.62 \); TC: \( \beta = 0.66 \); CC: \( \beta = 0.58 \), all \( p < .0001 \)). For BMI and UC, and for BMI and FC as predictor variables by multiple regression analysis, BMI, UC, and FC were all extracted as significant independent explanators for WC (BMI and UC BMI: \( \beta = 0.27, p = 0.032 \); UC: \( \beta = 0.64, p < .0001 \); BMI and FC BMI: \( \beta = 0.54, p < .0001 \); FC: \( \beta = 0.35, p = 0.0054 \)) but not TC and CC in BMI and TC, and BMI and CC (BMI and TC BMI: \( \beta = 0.52, p = 0.014 \); TC: \( \beta = 0.23, p = 0.253 \); BMI and CC BMI: \( \beta = 0.65, p = 0.0009 \); CC: \( \beta = 0.08, p = 0.643 \)). Table 3 shows the estimate formulas for WC in the simple and multiple regression analyses. Furthermore, \( R^2 \) (coefficient of determination) and \( \beta \) of the regression of the measured WC and estimated WC using the estimate formulas of UC, FC, TC, CC, BMI; BMI and UC; BMI and FC; BMI and TC; and BMI and CC were 0.68 and 0.83 (UC), 0.38 and 0.62 (FC), 0.44 and 0.66 (TC), 0.34 and 0.58 (CC), 0.51 and 0.71 (BMI), 0.72 and 0.85 (BMI and UC),
0.60 and 0.78 (BMI and FC), 0.53 and 0.73 (BMI and TC), and 0.51 and 0.71 (BMI and CC), respectively (p < .0001; Figure 1-1, 1-2, 1-3, 1-4, and 1-5, 1-6, 1-7, 1-8, 1-9).

**Table 2. Correlation coefficients among age, height, weight, BMI, WC, and limb circumference (n = 40)**

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
<th>BMI</th>
<th>WC</th>
<th>UC</th>
<th>FC</th>
<th>TC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>-0.27</td>
<td></td>
<td>-0.29</td>
<td>-0.10</td>
<td>-0.31</td>
<td>-0.39</td>
<td>-0.28</td>
<td>-0.11</td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td>0.65**</td>
<td></td>
<td>0.73**</td>
<td>0.78**</td>
<td>0.81**</td>
<td>0.49**</td>
<td>0.62**</td>
</tr>
<tr>
<td>BMI</td>
<td>-0.31</td>
<td>0.35*</td>
<td>-0.03</td>
<td>-0.03</td>
<td>-0.78**</td>
<td>0.69**</td>
<td>0.62**</td>
<td>0.69**</td>
</tr>
<tr>
<td>WC</td>
<td></td>
<td></td>
<td>0.35*</td>
<td></td>
<td></td>
<td>0.38*</td>
<td>0.69**</td>
<td>0.49**</td>
</tr>
<tr>
<td>UC</td>
<td>-0.39*</td>
<td></td>
<td>0.81**</td>
<td>0.69**</td>
<td>0.71**</td>
<td>0.82**</td>
<td>0.71**</td>
<td>0.71**</td>
</tr>
<tr>
<td>FC</td>
<td>-0.28</td>
<td>0.69**</td>
<td>0.86**</td>
<td>0.49**</td>
<td>0.62**</td>
<td>0.69**</td>
<td>0.71**</td>
<td>0.71**</td>
</tr>
<tr>
<td>TC</td>
<td>-0.11</td>
<td>0.17</td>
<td>0.76**</td>
<td>0.83**</td>
<td>0.58**</td>
<td>0.61**</td>
<td>0.52**</td>
<td>0.80**</td>
</tr>
<tr>
<td>CC</td>
<td>-0.02</td>
<td>0.15</td>
<td>0.69**</td>
<td>0.77**</td>
<td>0.58**</td>
<td>0.61**</td>
<td>0.52**</td>
<td>0.80**</td>
</tr>
</tbody>
</table>

* p < 0.05 ** p < 0.01. Relationship between height and age, weight, BMI, WC, UC, FC, TC, and CC were evaluated using Spearman’s rank-correlation coefficient and others with Pearson’s product–moment correlation coefficient. BMI, body mass index; WC, waist circumference; UC, upper arm circumference; FC, forearm circumference; TC, thigh circumference; CC, calf circumference.

**Table 3. Estimate formulas of WC using BMI, UC, FC, TC, and CC (n = 40)**

<table>
<thead>
<tr>
<th>Model</th>
<th>Estimate formulas</th>
<th>R²</th>
<th>SDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WC = 42.303 + 1.314 × CC</td>
<td>0.34</td>
<td>7.2</td>
</tr>
<tr>
<td>2</td>
<td>WC = 35.241 + 2.180 × FC</td>
<td>0.38</td>
<td>7.0</td>
</tr>
<tr>
<td>3</td>
<td>WC = 35.897 + 1.262 × TC</td>
<td>0.44</td>
<td>6.6</td>
</tr>
<tr>
<td>4</td>
<td>WC = 40.436 + 1.979 × BMI</td>
<td>0.51</td>
<td>6.2</td>
</tr>
<tr>
<td>5</td>
<td>WC = 31.592 + 2.088 × UC</td>
<td>0.68</td>
<td>5.0</td>
</tr>
<tr>
<td>6</td>
<td>WC = 38.450 + 1.801 × BMI + 0.189 × CC</td>
<td>0.51</td>
<td>6.3</td>
</tr>
<tr>
<td>7</td>
<td>WC = 35.438 + 1.444 × BMI + 0.444 × TC</td>
<td>0.53</td>
<td>6.2</td>
</tr>
<tr>
<td>8</td>
<td>WC = 23.935 + 1.495 × BMI + 1.242 × FC</td>
<td>0.60</td>
<td>5.7</td>
</tr>
<tr>
<td>9</td>
<td>WC = 27.287 + 0.754 × BMI + 1.610 × UC</td>
<td>0.72</td>
<td>4.8</td>
</tr>
</tbody>
</table>

SDE, standard deviation of error; $R^2$, coefficient of determination. Units are given as cm for WC, kg/m² for BMI, cm for UC, cm for FC, cm for TC, cm for CC. BMI, body mass index; WC, waist circumference; UC, upper arm circumference; FC, forearm circumference; TC, thigh circumference; CC, calf circumference.
Figure 1-1. Measured WC and estimated WC (UC)

Figure 1-2. Measured WC and estimated WC (FC)

Figure 1-3. Measured WC and estimated WC (TC)

Figure 1-4. Measured WC and estimated WC (CC)

Figure 1-5. Measured WC and estimated WC (BMI)

Figure 1-6. Measured WC and estimated WC (BMI+UC)

Figure 1-7. Measured WC and estimated WC (BMI+FC)

Figure 1-8. Measured WC and estimated WC (BMI+TC)
Figure 1-1, 1-2, 1-3, 1-4, 1-5, 1-6, 1-7, 1-8, 1-9. Relationship between the measured WC and estimated WC by estimate formulas. BMI, body mass index; WC, waist circumference; UC, upper arm circumference; FC, forearm circumference; TC, thigh circumference; CC, calf circumference.

Discussion

In this study, we found that WC was significantly associated with height, weight, BMI, UC, FC, TC, and CC. BMI, UC, and FC were also independent explainers for WC in multiple regression analysis. We were able to develop the estimate formulas of WC using BMI, UC, FC, TC, and CC in hospitalized older adults. The results suggest that the estimate formulas may provide an opportunity to use the values of the WC in hospitalized older adults.

We observed significant correlations between WC and BMI, UC, FC, TC, and CC. A previous study reported that WC is related to BMI and the circumferences of the upper and lower limbs [12-14]. In addition, BMI, UC, and FC were extracted as independent explainers for WC but not for TC or CC in the multiple regression analysis. UC and FC are generally classified as upper bodies as with WC. Therefore, UC and FC might reflect WC more easily than TC and CC. Moreover, the circumference values reflect both muscle mass and fat mass [9-11]. During the aging process, the muscle mass of the lower body tends to decrease compared with that of other parts of the body, and the antigravity muscles are easily influenced by immobilization [20-22]. Thus, TC and CC in BMI and TC, and BMI and CC in the multiple regression analysis may not be independent explainers of WC in this study. Furthermore, the estimate formula using BMI and UC has the highest values of $R^2$, which is an index used to evaluate the suitability of multiple regression analysis. It has been reported that the mid upper arm circumference is associated with WC as central obesity [23]. Therefore, the estimate formula using BMI and UC may have the highest values of suitability from the multiple regression analysis in this study.

Typically, for estimate formulas, $R^2$ values greater than 0.5 are desirable. In this study, the calculated $R^2$ values for each of the estimate
formulas ranged from 0.34 to 0.72 (Table 3), and the values for the estimate formulas using BMI, UC, BMI and UC, BMI and FC, BMI and TC, and BMI and CC could be greater than 0.5. On the other hand, in this study, the standard deviation of the error indicates that the error of the estimated WCs was ±4.8–7.2 cm. Thus, to use the WC predicted the estimate formulas of this study should be considered the errors, and future studies should develop the estimate formulas with a lower error value.

This study has some limitations. This research included only a small number of participants, and future studies should include a greater sample size. Moreover, we did not clarify the reasons for the error in the multiple regression analysis. Future studies should develop estimate formulas for WC using a lower standard deviation of error by clarifying the reasons for the error.

**Abbreviations:**

ADL, Activities of daily living  
BI, Barthel index  
BMI, Body mass index  
HOMA-IR, Homeostasis model assessment of insulin resistance  
SD, Standard deviation  
UC, Upper arm circumference  
FC, Forearm circumference  
TC, Thigh circumference  
CC, Calf circumference  
WC, Waist circumference

**References**


