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Abdominal fat ratio estimation equation by abdominal type in elderly women

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Abstract

This study was conducted to define the abdomen types of Korean elderly women and to develop an abdominal fat ratio (AFR) estimation equation using key body measurements and indexes that well represented the body type characteristics of elderly women. An analysis was performed of the correlations between the individual obesity-related measurements and index items to explain the body shape characteristics and obesity trends in elderly women. To derive the equation for estimating the AFR of elderly women, the abdominal types of elderly women were classified, and then, the distribution of each type was investigated. Then, a simple regression analysis was performed in which the dependent variable is predicted by using a single predictor. The AFR and WHtR (Waist-Height Ratio) showed a higher correlation with the obesity-related measurement items and indexes; thus, an equation was derived that enables the estimation of the AFR using simple body measurements. Additionally, the morphological differences of the various abdomen types were analyzed to provide the trends of the abdomen types depending on the AFR in the elderly. This new model for estimating abdominal fat percentage developed in the present study is significant in that it uses relatively easy-to-obtain anthropometric measures like height and waist circumference. The results of the present study demonstrated the relationship between WHtR, which not only well reflects elderly obesity but is also closely related to the prevalence of obesity in the elderly. This finding suggests that the shape of the abdomen will serve as a potential health indicator in the future.

Keywords: Elderly women, Abdominal obesity, Abdominal fat ratio, Obesity index, Abdomen type

Introduction

The skeletal muscle decreases in the elderly with the increase of the age. While the growth of bones and muscles is harmonized with the change of the weight in young or healthy adults, the amount and strength of muscles are decreased significantly more in comparison with the body size in an aged body due to the damage of the physiological mechanism (Stenholm et al. 2008). The muscles in human body begin to decrease gradually from the age of 30, and the decrease is accelerated from the age of 60 (Ding et al. 2007). As a result, the elderly usually have less physical activities and a sedentary lifestyle, which in turn causes loss of muscles, decreases the basal metabolic rate (Stenholm et al. 2008), and increase the body weight. In this vicious cycle, the obesity of the elderly is exacerbated.

The obesity rate among the elderly is much higher than that among the general adults, and the obesity of elderly has features that are different from those of the obesity among the general adults. (Jung et al. 2012). Therefore, addressing the problems related to the health and clothing design caused by senile obesity require the understanding of the characteristics and forms of the obesity in the elderly. The most common change found in the elderly with the increase of the age is the decrease of the height by kyphosis. Because the body mass index (BMI), which is often used as an index of obesity, is based on the height, it cannot appropriately reflect the body fat in the elderly. Therefore, questions have been raised whether it is appropriate to use the BMI as a criterion of the obesity in the elderly (Lee 2015; Moon & Kim 2005; WHO 2000).

With regard to the senile obesity, which has features that are different from the obesity in the general adults, a new concept of 'sarcopenic obesity,' a compound word of 'sarcopenia' and 'obesity,' has been suggested to mean the loss of muscle content due to the advanced age (Baumgartner 2000). However, recent studies have shown that sarcopenic obesity is not a simple combination of 'sarcopenia' and 'obesity'; sarcopenia and obesity have a synergic effect and both have a negative effect on the body functions and the risk of diseases (Kohara 2014). Therefore, sarcopenic obesity found in the elderly has negative effects on the quality of life. Since the obesity in the elderly causes not only medical problems but also other problems such as depression in the elderly and difficulties in the choice of clothes, it is necessary to understand the characteristics and forms of the obese body in the elderly in order to appropriately evaluate and treat the obesity in the elderly and to apply the understanding to the ergonomic design of clothes. However, many recent studies have shown that the commonly used obesity indexes, including BMI, waist circumference (WC) and waist-hip ratio (WHR), may not be appropriately applied to the elderly (Jung et al. 2012; Stenholm et al. 2008). Although the conventional indexes of obesity contain the information about the body size and ratio, they do not provide the specific morphological information about obese bodies.

Indexes for determining obesity have high usability because they enable easy and prompt investigation of the body compositions of individuals, including the amount and distribution of visceral fat, based on only a few body measurements. However, despite the availability of various obesity indexes, each has pros and cons because different body measurements are used to determine obesity for each index. Therefore, questions have been raised as to whether individual obesity indexes are appropriate to define the degree of obesity in subjects with different physical characteristics (Kwon 2005). The most accurate methods for determining abdominal obesity are the measurements of visceral fat by bioelectrical impedance analysis (BIA) or computed tomography (CT). However, such a direct measurement of visceral fat requires specific instruments and requires a long time and a high cost. Therefore, abdominal obesity is determined indirectly using indexes that are calculated by direct measurements, including the WHR.

These indexes and items can be easily calculated by substituting several key body measurements to simple formulas. However, since most of them are the obesity indexes that are employed to determine the prevalence of the disease, they have limitations in describing the various morphological characteristics of obese bodies. In addition, Lee

(2013) conducted a study on the classification of the body shapes of obese males and the development of a prototype torso, and pointed out that an index that considers the correlations between the existing obesity indexes and the key body measurements is necessary to be used in the field of apparel study. An index for determining obesity is needed particularly for the elderly whose body shape is changed with the increase of the age and whose obesity is significantly different from that of the general adults from a morphological perspective.

Many previous studies have been conducted to identify upper body obesity factors as the key factors of body shapes in elderly women and to classify body types based on these factors (Lee & Kim 2004; Nam & Choi 1997). The obesity factors commonly include the circumference, width and thickness of the waist and abdomen, indicating that the obesity in the elderly is found mainly at the abdominal parts. According to Kim and Lee (2011), who comparatively analyzed the abdominal cross-section of obese women in the 40, 50 and 60 s, the waist and the waist cross-section (omphalion) of the obese women in their 60 s are characterized that the center of the posterior waist is flat and the overall abdomen is protruded. This may be due to the redistribution of the body fat from the subcutaneous fat to the visceral fat in the old age. These results are significant, considering that the abdominal obesity rate is highest (38.1%) in the old women between the ages of 75 and 79 years among all the age and gender groups, followed by the women in the age groups of 70–74 years (36.9%), 80–84 years (35.7%) and 65–69 years (32.3%) (Statistics Korea 2016).

Abdominal obesity is one of the critical factors to the body shape of the elderly women and considered as one of the factors to the entire body shape of the elderly women. Therefore, it can be seen that an analysis of the shape and size of the abdomen should be required, especially when producing clothing suitable for the body type of older women. However, few studies have been conducted to analyze the abdominal part only from the perspectives of body measurements and body shape. In addition, despite the importance of considering two-dimensional measurements, information relative to the three-dimensional abdominal shape to improve the fit of clothing for elderly women has not been analyzed sufficiently, and thus, more studies are required in this regard. Considering that the abdominal obesity ratio is particularly high in elderly women, investigation of the correlation between the degree of abdominal obesity and body type will provide considerable help in the manufacturing of clothing by the clothing industry and in grading medical devices and clothing for elderly women.

Thus, the present study was conducted to investigate the body shape and obesity characteristics of Korean elderly women between the ages of 70 and 85 years. Because it is difficult to investigate the various aspects of the body shape characteristics of elderly women using only one or two obesity indexes, the validity of applying various obesity indexes to elderly women and their mutual correlations was analyzed in the present study. Moreover, the morphology of the abdomen of elderly women based on their AFRs was analyzed to provide a trend relative to the abdominal shape in the elderly as a function of the degree of abdominal obesity.

Table 1 Direct measurement items and three-dimensional indirect measurement items

No	Measurement items		Measurement methods
Direct measurement items			
1	Height item	Stature	Vertical distance from floor to vertex
2		Waist height	The vertical distance from the natural waist level (the natural waistline between the top of the hip bones and the lower ribs) to the ground with the subject standing upright
3	Circumference item	Chest circumference	The maximum horizontal circumference measured during normal breathing with the subject standing upright and the tape-measure passed over the shoulder blades (scapulae), under the armpits (axillae), and across the chest nipples
4		Bust circumference	The maximum horizontal circumference measured during normal breathing with the subject standing upright and the tape-measure passed over the shoulder blades (scapulae), under the armpits (axillae), and across the nipples
5		Underbust circumference	The horizontal circumference of the body just below the breasts
6		Waist circumference	The circumference of the natural waistline between the top of the hip bones (iliac crests) and the lower ribs, measured with the subject breathing normally and standing upright with the abdomen relaxed
7		Waist circumference (Omphalion)	Horizontal circumference passing anterior waist (omphalion), both lateral waists (omphalion), and posterior waist (omphalion), measured during natural breathing
8		Hip circumference	Horizontal circumference at the level of buttock protrusion
9	Weight item	Body weight	Weight of body
10	Body composition measurement item	Body fat (kg)	Measured by InBody 230
11		Abdominal fat ratio of Inbody	Measured by InBody 230
3D indirect measurement items			
1	Circumference item	Abdomen circumference	The maximum horizontal abdomaen measured during normal breathing
2	Width item	Waist width	Horizontal distance between lateral waists
3		Abdomen width	Horizontal distance at the level of abdominal protrusion
4		Hip width	Horizontal distance between the most protrudent parts of the right and left hips in sitting posture
5	Thickness item	Waist thickness	Lateral trunk thickness at the level of anterior waist
6		Abdomen thickness	Lateral trunk thickness at the level of abdominal protrusion
7		Hip thickness	Lateral trunk thickness at the level of buttock protrusion

Methods

Data

The present study used direct measurements, three-dimensional scan automatic measurement size data, and three-dimensional indirect measurement data obtained from 378 elderly women between the ages of 70 and 85 years (127 subjects between 70–74 years, 119 subjects between 75–79 years, and 132 subjects between 80–85 years) in Size Korea (Korean Agency for Technology and Standards 2014). All statistical analyses for this

Table 2 Obesity indexes, index value items, and measurement methods

Measurement item		Definition
Calculated item	BMI (body mass index)	Weight (kg)/height (m)
Circumference index	WHR (Waist-Hip Ratio)	Waist circumference/Hip circumference
	WHtR (Waist-Height Ratio)	Waist circumference/Height
	AHR (Abdomen-Hip Ratio)	Abdomen circumference/Hip circumference
	WAR (Waist-Abdomen Ratio)	Waist circumference/Abdomen circumference
Flatness index	Waist flatness	Waist thickness/Waist width
	Abdomen flatness	Abdomen thickness/ Abdomen width
	Hip flatness	Hip thickness/ Hip width

study were performed using IBM SPSS 22.0. Eleven direct measurement items analyzed. Table 1 shows all the measurement items and their measurement methods.

Body fat measurements were obtained with a body composition analyzer, InBody230. In addition, 7 measurement items were analyzed by obtaining data through indirect measurement from the three-dimensional data using the Geomagic Design X 2014 program. The BMI, WHR, and WHtR (Waist-Height Ratio) were used because they are the most commonly applied clinical obesity indexes (Gallagher et al. 1996; Garrow & Webster 1984; Ko & Kim 2007; Larsson et al. 1984; Lee 2013; WHO 2000; WHO 2011). Additionally, the AHR (Abdomen-Hip Ratio) and WAR (Waist-Abdomen Ratio) indexes were developed and used in the present study. Flatness, defined as the ratio of the thickness to the width, was introduced as an index to investigate the change of the cross-sectional shapes of the abdomen. Table 2 shows the obesity indexes used in the present study.

Identification of measurement and index items correlated to the obesity of elderly women

To investigate the correlations between the measurements and index items and to explain the body shape characteristics and obesity trends in elderly women, a correlation analysis comparing the measurement and index items and analysis of variance (ANOVA) were performed. The correlations between the measurement items and the indexes were analyzed with reference to the statistical significance of $p < 0.01$ and the Pearson's product moment correlation coefficient of $r = 0.40$. In addition, a one-way analysis of variance of the measured items was conducted by dividing the age group between 70 and 85 years of age into five years of age to analyze whether each Obesity index reflects the difference between groups of older women.

To extract the obesity-related characteristics constituting the body shape of elderly women, a factor analysis was performed with respect to the horizontal size items and weight associated with the obesity and body size factors, body composition measurement items associated with fat, obesity determining indexes and index values. The factor analysis was performed as a principal component analysis by varimax rotation to eliminate the items having a high factor loading in many factors or those having a too low factor loading from the derivation of an abdominal fat ratio (AFR) estimation equation.

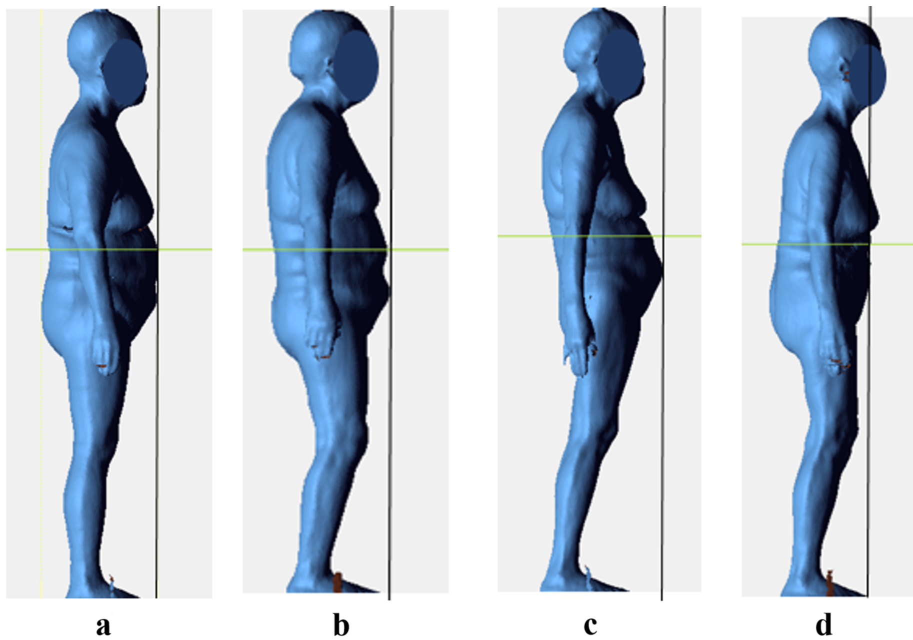


Fig. 1 Representative silhouettes of abdomen types used in the visual evaluation. **a** overall protrusion type, **b** top and bottom protrusion type, **c** bottom protrusion type, **d** flat type

Classification of the abdomen type of elderly women

To classify the abdomen type of elderly women and to investigate the distribution in each type, a visual evaluation was performed by seven body shape experts. Based on the report by Park (2009) (Fig. 1), the visual evaluation in the present study used a modification of a previous classification and provided four types of protrusion assessments (overall protrusion, top and bottom protrusion, bottom protrusion, and flat protrusion). In relation to the horizontal line of the waist, if the abdomen above and below is protruding globally, the distribution type is classified as an overall protrusion. If the protruding feature is extruded separated up and down, the type is classified as top and bottom protrusion. If only the lower part is extruded, the type is classified as bottom protrusion, and if not protruding, classified as flat protrusion. The visual evaluation method is presented by marking the reference line perpendicular to the floor surface at the point of departure from the boat, and the reference line drawn horizontally on the floor surface at the level of the waist, above the image of the right side of the 3D image. Out of the four abdominal types presented, experts were asked to choose the type that they believe is the subject of evaluation. Each of the subjects was classified into one abdomen type for which five or more of the experts, out of the seven experts, agreed upon. For the visual evaluation, after presenting 30 new lateral body shapes of elderly women to experts, asked for a response with 5-points Likert scale (1 point = very agree/2 points = almost agree/3 points = normal/4 points = almost disagree/5 points = very disagree).

In the equation for calculating the degree of agreement (Eq. (1)), N is the number of subjects whose abdomen type was agreed on by five or more experts, and a, b, and c represent the number of subjects whose abdomen type was agreed on by 7, 6, and 5 experts.

To verify the trend of the abdomen types based on the degree of obesity, the significance of the difference was tested between the classified abdomen types in the AFR and the obesity-related indexes.

$$\text{Degree of agreement (\%)} = \frac{7 \times a + 6 \times b + 5 \times c}{7 \times N} \times 100 \tag{1}$$

Derivation and verification of the equation for estimating the AFR of elderly women

An equation for estimating the AFR from the body measurements of elderly women was derived. In order to define items that reflect the body type of elderly women well, items with high correlation coefficient with indexes in Table 2 were selected from in Table 1. After setting the selected items as predictors, a regression equation was constructed in which the AFR was a dependent variable. The analysis was performed by a simple regression analysis in which the dependent variable is predicted using a single predictor. The derived regression equation was tested by a paired t-test to find out the presence of a significant difference between the actual AFR measurements and the predicted values.

A visual evaluation was performed with 30 new randomly extracted subjects to estimate the abdomen types using the AFR estimated by the regression equation and to examine if the estimated abdomen types are consistent with the trend of abdominal obesity. Seven experts in the study of body shape were shown the body shapes of other 30 elderly women and asked to respond in a five-point Liker scale the degree of agreement of each of the four abdomen types. The range of the trend for each abdomen type was established by considering the mean and standard deviation of the AFR of the abdomen types and the degree of agreement between the abdomen types, which were highly agreed on in the visual evaluation. Furthermore, the AFR ranges estimated by the regression equation were tested to verify the validity of the estimation equation. A paired t-test was performed to see if there is a significant difference between the AFR values of the other 30 elderly women calculated by using the regression equation and the actual AFR values measured by using the body composition analyzer.

Results

Identification of the measurement and index items correlated to the obesity of elderly women

First, with regard to the Height items, a significant correlation was found with none of the circumference, width, thickness, body composition, index value and calculation items, except the 'height-hip width' pair (Pearson correlation coefficient: 0.447, $p < 0.01$). The result means that the height is correlated with the measurements representing the height and size of the skeleton, such as the waist height and hip width, while it is not significantly correlated with the items that are increased by the effect of the visceral fat deposition, rather than the skeleton, including the circumference items and the abdomen width and thickness. This shows that in elderly women, the circumference, width, thickness, BMI, and obesity indexes were increased depending on the obesity trend regardless of the height.

With regard to the flatness indexes, the 'waist flatness -waist width' pair did not show a significant correlation but the 'waist flatness-waist thickness' showed a significant correlation ($r = 0.755$, $p < 0.01$). The result showed that the increase of the flatness of the waist, is correlated to the increase of the waist thickness rather than the increase of the waist width. The AFR showed a considerably high correlation with the items that are affected by the visceral fat deposition, including the waist circumference ($r = 0.883$, $p < 0.01$), abdomen circumference ($r = 0.852$, $p < 0.01$), waist circumference (Omphalion) ($r = 0.836$, $p < 0.01$), hip circumference ($r = 0.787$, $p < 0.01$), waist width ($r = 0.807$, $p < 0.01$), abdomen width ($r = 0.670$, $p < 0.01$), waist thickness ($r = 0.861$, $p < 0.01$) and hip thickness ($r = 0.768$, $p < 0.01$), but a relatively low correlation with the items that are affected by the skeletal size, such as hip width ($r = 0.493$, $p < 0.01$).

In order to determine whether the measurements vary from age group (70–74, 75–79, 80–85 year), a one-way analysis of the measured items and index values was conducted. The results showed statistically significant differences among age groups in Waist flatness and Hip flatness, excluding the Abdomen flatness index. For the Waist flatness, the early 80 s (80–85 year) had a statistically significant compared to the 70 s. For circumference indexes, no significant differences between age groups were found in WHR, AHR and WAR except WHtR. For WHtR, groups in their late 70 s (75–79 year) and early 80 s showed significantly greater values than those in their early 70 s (70–74 year). This shows that in the case of elderly women, the proportion of the abdomen to height increases in the older group. Particularly, considering that WHR, which represents the ratio of waist circumference to hip circumference, does not reflect the difference between age groups, the ratio of abdomen to hip circumference, which is greatly affected by fat and muscle, in analyzing the abdomen of elderly women. This indicates that it is more useful to use a key that reflects the skeleton than to use an exponent value representing. In addition, since the main body shape

Table 3 Comparison of one-way analysis of variance of indexes among the age groups of elderly women

Index values	Early 70 s (70–74 year) N = 127	late 70 s (75–79 year) N = 119	Early 80 s (80–785 year) N = 132	F
Calculated item				
BMI (Body Mass Index)	24.88 (3.05)	25.01 (3.12)	24.92 (3.39)	0.05
Circumference index				
WHR (Waist-Hip Ratio)	0.96 (0.06)	0.97 (0.06)	0.97 (0.06)	41.99
WHtR (Waist-Height Ratio)	0.58 (0.06) a	0.60 (0.05) b	0.61 (0.06)	5.29**
AHR (Abdomen-Hip Ratio)	1.03 (0.05)	1.04 (0.04)	1.04 (0.04)	2.62
WAR (Waist-Abdomen Ratio)	0.92 (0.04)	0.94 (0.04)	0.93 (0.04)	3.04
Flatness index				
Waist flatness	0.82 (0.06) a	0.84 (0.06)	0.86 (0.06) b	9.30***
Abdomen flatness	0.80 (0.07)	0.82 (0.07)	0.82 (0.06)	3.14
Hip flatness	0.73 (0.09) a	0.76 (0.09) b	0.77 (0.10)	4.77**

**$p < 0.01$. ***$p < 0.001$, Scheffe test results a < b < c

Table 4 Correlations of trunk-related items with the WHR, WHtR and BMI

Item	WHR	WHtR	BMI
Chest circumference	0.591**	0.755**	0.855**
Bust circumference	0.691**	0.842**	0.878**
Underbust circumference	0.686**	0.836**	0.870**
Waist circumference	–	–	0.898**
Waist circumference (Omphalion)	0.704**	0.855**	0.863**
Abdomen circumference	0.577**	0.810**	0.862**
Waist thickness	0.766**	0.896**	0.848**
Abdomen thickness	0.647**	0.831**	0.867**
Waist width	0.668**	0.828**	0.840**
Abdomen width	0.357	0.593**	0.706**
Waist flatness	0.546**	0.579**	0.494**

WHR-waist circumference and WHtR-waist circumference were excluded for their self-correlation

**$p < 0.01$

characteristic of elderly women is the decrease in height with increasing age, it can be seen that WHtR is more useful than WHR as an index indicating the abdominal shape of elderly women in that it reflects height. In the case of BMI, there was no significant difference between the age groups of elderly women. Although many body type studies use BMI as a classification criterion for obese body type, in the case of the elderly female group, BMI cannot reflect the difference according to age, so it should be used together with various obesity indices indicating central obesity (Table 3).

With regard to the index values and calculation items, the BMI and WHtR showed a high correlation with the trunk circumferences (Table 4). In the case of BMI, the difference between age groups was not reflected. Regarding the WHR and WHtR, the indexes representing the abdominal obesity, the WHtR had a higher correlation with the abdomen-related circumference measurement items, such as the waist circumference (omphalion) and the abdomen circumference, compared with the WHR. This shows that the WHtR is more useful than the WHR as a shape index reflecting the abdominal obesity trend of elderly women.

Identification of factors to obesity in elderly women

A factor analysis is performed on the basic assumption that there exists a correlation between variables. Therefore, the 'thigh flatness' and 'abdominal protrusion hip thickness' were excluded from the factor analysis, because the two variables showed no correlation or a too low correlation in the correlation analysis. In addition, the WAR was also eliminated from the factor analysis, because it showed a too high factor loading on various factors or a too low factor loading.

The factor analysis (Table 5) derived three factors, and the total explanatory power was 82.42%. Factor 1 has an eigenvalue of 10.75 and a total variance explained of 66.16%. Considering the characteristics of the included items, Factor 1 was named as 'BMI and body fat-related trunk circumference.' Factor 2 has an eigenvalue of 6.18 and a total variance explained of 11.71%. Considering the characteristics of the included items, Factor 2 was named as 'circumference index values and waist-underbust circumference factor.'

Table 5 Results of factor analysis for identifying the obesity factors in elderly women

Factor	Item	Factor loading	Eigenvalue	Total variance explained (%)
Factor 1 BMI and body fat-related trunk circumference and upper limb circumference factor	Hip circumference	0.833	10.75	66.16%
	Hip width	0.820		
	Abdomen width	0.776		
	Weight	0.728		
	Body fat	0.715		
	Waist width	0.675		
	BMI	0.670		
	AFR	0.648		
	Chest circumference	0.636		
	Abdomen circumference	0.625		
	Bust circumference	0.585		
Factor 2 Circumference index values and waist-underbust circumference factor	WHR	0.895	6.18	11.71%
	AHR	0.805		
	WHtR	0.644		
	Waist circumference	0.638		
	Waist thickness	0.634		
	Waist circumference (Omphalion)	0.604		
	Underbust circumference	0.587		
Factor 3 Flatness indexes and abdomen and hip thickness factor	Hip flatness	0.860	5.96	4.55%
	Abdomen flatness	0.842		
	Hip thickness	0.714		
	Waist flatness	0.645		
	Abdomen thickness	0.613		

Factor 3 has an eigenvalue of 5.96 and a total variance explained of 4.55%. Considering the characteristics of the included items, Factor 3 was named as 'flatness indexes and abdomen and hip thickness items'.

The fact that Factor 1 explains the largest number of variables indicates that the principal characteristics of the obesity in elderly women are the increase of the body fat, due to the increased visceral fat, and the resulting increase of the circumference of the trunk. Factors 1 to 3 included one or two of the BMI, AFR, body fat, WHtR, and waist flatness, which are the items that showed a high correlation with the obesity-related factors or reflected the difference between the age groups of elderly women, indicating that they are the key obesity factors that explain the body shape of elderly women.

Classification of abdomen types of elderly women by visual evaluation

According to the visual evaluation of the abdomen types of the elderly women, 295 out of the 365 subjects (80.8%) were those whose abdomen type was agreed on by five or more experts. Among them, 181 were classified as the overall protrusion type, 14 as the top and bottom protrusion type, 89 as the bottom protrusion type and 11 as the flat type. The abdomen type of 129 subjects was agreed by seven experts, that of 95 subjects by six experts, and that of 71 subjects by five experts. Therefore, the total degree of agreement, calculated by the equation, was 88.52%.

Table 6 Distribution of the abdomen types in elderly women and distribution of the experts' degree of agreement in each abdomen type

	Agreed by 7 experts	Agreed by 6 experts	Agreed by 5 experts	Sum	Ratio (%)	Degree of agreement (%)
Overall protrusion type	83 (45.9%)	56 (30.9%)	42 (23.2%)	181 (100%)	61.4	88.95
Top and bottom protrusion type	2 (14.3%)	5 (35.7%)	7 (50.0%)	14 (100%)	4.7	80.61
Bottom protrusion type	40 (44.9%)	29 (32.6%)	20 (22.5%)	89 (100%)	30.2	88.9
Flat type	4 (36.4%)	5 (45.5%)	2 (18.2%)	11 (100%)	3.7	83.31
Sum	129 (43.7%)	95 (32.2%)	71 (24.1%)	295 (100%)	100	

Table 7 Comparison of the AFR and obesity indexes between the abdomen types of elderly women

	Overall protrusion type (n = 181)	Top and bottom protrusion type (n = 14)	Bottom protrusion type (n = 89)	Flat type (n = 11)	F
Waist flatness (Waist thickness/Waist width)	0.86 (0.05) b	0.83 (0.06)	0.80 (0.06) a	0.77 (0.05)	32.392***
WHtR	0.62 (0.05) c	0.58 (0.05) b	0.56 (0.05)	0.50 (0.04) a	46.071***
WHR	0.99 (0.04) c	0.95 (0.05) b	0.93 (0.06)	0.87 (0.04) a	52.304***
BMI	26.10 (2.79) c	24.16 (2.47) b	23.20 (2.84)	20.24 (2.25) a	33.094***
AFR	0.91 (0.04) c	0.88 (0.04) b	0.86 (0.05)	0.81 (0.01) a	35.861***

**p < 0.01. ***p < 0.001, Scheffe test results a < b < c

Table 6 shows the number of subjects and the degree of expert agreement of each abdomen type. The distribution of the 295 subjects in the four abdomen types shows that 61.4% (181 subjects) was classified as the overall protrusion type, 30.2% (89 subjects) as the bottom protrusion type, 4.7% (14 subjects) as the top and bottom protrusion type, and 3.7% (11 subjects) as the flat type. Therefore, among the elderly women in Korea, the ratio of the overall protrusion type was the highest, followed by the bottom protrusion type, the top and bottom protrusion type, and the flat type. The ratios of the top and bottom protrusion type and the flat type were relatively low.

The analytical results to analyze the difference of the AFR and the obesity-related indexes depending on the classified abdomen types show that the AFR and all the obesity-related indexes were significantly different between the abdomen types (Table 7). In addition, as the values of the AFR and the obesity-related indexes increased, the ratio of the abdomen type was high in the order of the flat type, the bottom protrusion type, the top and bottom protrusion type, and the overall protrusion type, indicating that the abdomen type changes in the above sequence as obesity progresses in elderly women.

Table 8 Regression equations for estimating the AFR

Predictor (X)	B	t—value	R^2	Regression equation	F
WHtR	0.742	36.09***	0.776	Y = 0.446 + 0.742X	1302.41***
Waist flatness	0.443	12.33***	0.288	Y = 0.515 + 0.443X	152.79***
Weight	0.005	26.46***	0.651	Y = 0.617 + 0.005X	700.22***
Waist circumference	0.001	36.54***	0.780	Y = 0.443 + 0.001X	1335.35***
BMI	0.014	52.98***	0.878	Y = 0.527 + 0.014X	2702.80***
WHR	0.508	15.09***	0.377	Y = 0.395 + 0.508X	227.726***

Dependent variable (Y):AFR, ***p < 0.001

Table 9 Mean and standard deviation of the AFR values and trend range of individual abdomen types

Abdomen type	AFR		Trend of the abdomen type according to AFR range
	Mean	Standard deviation	
Overall protrusion type	0.91	0.04	0.87 ~ 0.95
Top and bottom protrusion type	0.88	0.03	0.85 ~ 0.91
Bottom protrusion type	0.86	0.05	0.81 ~ 0.91
Flat type	0.81	0.01	0.80 ~ 0.82

In the post-hoc analysis, with reference to waist flatness, the overall protrusion type and the top and bottom protrusion type were combined into one group, and the bottom protrusion type and the flat type were combined into another group, suggesting that the four abdomen types may be divided into two groups. Therefore, compared with the other indexes, the abdomen type classification with reference to the waist flatness is less clear. By contrast, the WHtR, WHR, BMI, and AFR classified the abdomen types into three groups: the overall protrusion type group, the top and bottom protrusion type and the bottom protrusion type group, and the flat type group. Therefore, these indexes classified the abdomen types more clearly than the waist flatness.

Derivation of the equation for estimating the AFR of elderly women

The analytical results (Tables 8, 9) showed that the F-value of all the regression equations was significant, and the t-value of the regression coefficient of the individual regression equations was also significant at the level of $p < 0.001$. However, the explanation power (R^2) of the regression equations was low when derived with the waist flatness (28.8%,$R^2 = .288$), WHR (37.7%,$R^2 = .377$) as the predictors. The regression coefficients of the predictors of weight, BMI, and waist circumference as the predictors was relatively high at 65.1% ($R^2 = .651$) 87.8% ($R^2 = .878$) and 78.0% ($R^2 = .780$), respectively; however, the regression coefficients of the predictors, BMI, and waist circumference were extremely small at 0.005, 0.014 and 0.001, respectively, indicating that they have almost no explanatory power.

By contrast, the explanation power of the regression equation derived with the WHtR as the predictor was 77.6% ($R^2 = .776$), and the regression coefficient of the predictor was 0.742 without causing the problem of an extremely small regression coefficient.

Table 10 Analysis of the difference between the AFR values of new subjects obtained by body composition measurement and those estimated from the regression equation

	Number of subjects	Mean	Standard deviation	Degree of freedom	t-value
InBody AFR	378	0.88	0.05	377	− 0.024 (p = 0.981)
Y-value of AFR estimation regression equation	378	0.88	0.04		
(InBody AFR)—(Y-value of AFR estimation regression equation)	378	− 0.00	0.02		

Y-value of AFR = Dependent variable (Y)

In a regression analysis, even if a regression equation and a regression coefficient are significant, an extremely small regression coefficient may lack the explanation power. Considering this problem, the WHtR-based regression equation was derived as an AFR estimation model (Eq. (2)).

$$\text{Abdominal fat ratio (AFR)} = 0.446 + 0.742W, \quad W = WHtR \tag{2}$$

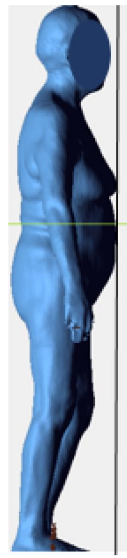
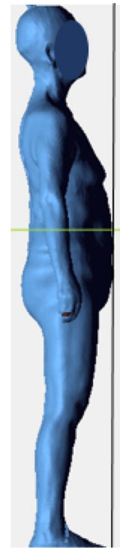
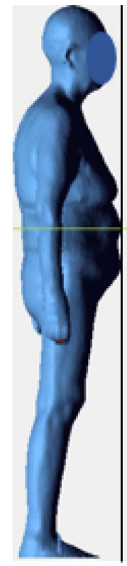
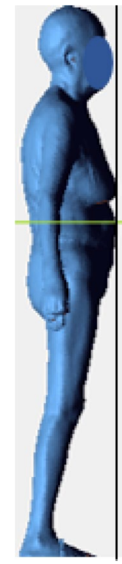
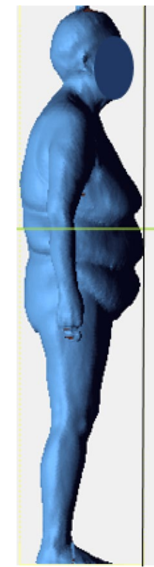
To verify if the finally derived AFR estimation regression equation reflects the actual AFR of elderly women, an analysis was performed to see if there is a significant difference between the actual AFR values obtained from 378 elderly women by using a body composition analyzer and the AFR values estimated by using the regression equation. The analytical result (Table 10) shows that the t-value was − 0.024, and the significance level was 0.981, indicating that the actually measured AFR values were not significantly different from the values estimated with the AFR estimation equation. Therefore, the WHtR-based AFR estimation equation well reflects the actual AFR.

Abdominal obesity trend in elderly women with new subjects

The trend of the abdomen types, according to the AFR of the elderly women, was also verified with the new 30 subjects. The abdomen type classification data from the 378 elderly women, who were the subjects of the previous visual evaluation, were used, and the AFR ranges for the trend of the abdomen types were determined by considering the mean and standard deviation of the AFR in each abdomen type (Table 11). The result shows that the range of the AFR for the trend of the abdomen type was 0.87–0.95 in the overall protrusion type, 0.85–0.91 in the top and bottom protrusion type, 0.81–0.91 in the bottom protrusion type, and 0.80–0.82 in the flat type.

With regard to the degree of agreement between the abdomen types estimated from the AFR ranges of the abdomen type trend and those determined by the agreement scores of the visual evaluation, the abdomen types of 24 subjects (80%) out of a total of 30 subjects were classified according to the trend ranges, and disagreement was found in 6 subjects (20%). Consistency scores by experts were investigated on a five-point Likert scale and the average value was presented in Table 10. Subjects 5,6,14,16 showed a high agreement of over 4 points, whereas subjects 26,30 showed a three-point agreement score. Subject 26 is a mixture of two types, overall and flat, and subject 30 is top and bottom. In addition to the subjects presented on Table 11, three abdomen types overlapped in the AFR range from 0.87 to 0.91, which corresponded

Table 11 Lateral silhouettes of the subjects whose adbomen type was not agreed on by experts

Lateral silhouettes							
Subject		Subject 5	Subject 6	Subject 14	Subject 16	Subject 26	Subject 30
Actual AFR		0.89	0.86	0.82	0.85	0.88	0.96
AFR estimated by regression equation		0.86	0.83	0.85	0.93	0.86	0.97
Estimated abdomen type	Overall				O		O
	Top and bottom	O		O		O	
	Bottom	O	O	O		O	
	Flat						
Abdomen type agreed on by experts	Overall	**4.43**	**4.71**	3.14	1.86	**3.71**	3.43
	Top and bottom	1.14	1.14	1.14	**4.71**	1.00	**3.86**
	Bottom	2.14	1.57	1.71	2.14	1.00	1.86
	Flat	1.57	1.57	**4.00**	1.14	2.57	1.00

to 15 subjects (50%). Therefore, the abdomen type of the subjects with an AFR value within this range may first be determined according to the trend range, but it should be further specified by considering the actual body measurements and body shape silhouette from various viewpoints. Although it is somewhat unreasonable to accurately predict the form of abdominal obesity using AFR, it is possible to predict the approximate shape of the abdomen of an elderly woman through the AFR value.

In the cases of Subjects 5, 6 and 26, the AFR estimated by the regression equation was lower than the actual AFR. Hence, although the actual range of the AFR corresponded to the overall protrusion type, the estimated range corresponded to the top and bottom protrusion type and the bottom protrusion type. The highest degree of agreement in the expert evaluation was found in the overall protrusion type. On the contrary, in the cases of Subjects 14 and 16, the AFR estimated by the regression equation was higher than the actual AFR. The actual range of the AFR of Subject 14 corresponded to the flat type, but the type estimated by the regression equation was the top and bottom protrusion type and the bottom protrusion type. The actual range of the AFR of Subject 16 corresponded to the top and bottom protrusion type and the bottom protrusion type, but the type estimated by the regression equation was the overall protrusion type. In the case of Subject 30, the abdomen type estimated by the actual AFR and the one estimated by the regression equation were both the overall protrusion type, but the highest degree of agreement in the expert evaluation was found in the top and bottom protrusion type. The comparison with the lateral body shape silhouette of Subject 30 showed that the actual top and bottom protrusion type is hardly differentiated from the shape having a dent at the abdomen due to the compression of the measurement gown by the elastic waist belt. The same effect of the measurement gown was also found in the case of Subject 16.

In summary, the disagreement of the abdomen type between the estimation and the expert evaluation may have two main reasons. First, Since the explanatory power of the regression equation for estimating the AFR ($Y=0.446+0.742X$, $X=\text{WHtR}$) is 77.6%, there is a limit to clearly distinguishing the abdominal shape only with the regression equation. Second, in the elderly women, the abdomen shape of the subjects whose waist was compressed by the elastic waist belt of the measurement gown was confused with other types.

The abdomen type, affected more by fat than by the skeleton, is easily changed by the degree or pattern of fat distribution. Therefore, some subjects showed intermediate characteristics between different abdomen types. For this reason, this paper does not provide the detailed ranges of AFR clearly differentiated according to the abdomen type. However, the results of the present study showed the trend of the abdomen types depending on the increase of the AFR as well as the correlations of the abdomen types with the WHtR and FAR, which are the indexes that are conventionally used to determine obesity. Therefore, for the subjects whose abdomen types are difficult to determine, the abdomen types should be determined by considering various aspects, including the abdomen type estimated by the trend range, the lateral body shape, and body measurements. Based on the results acquired from the present study, the reference FAR ranges may be further divided according to the abdomen types.

Discussion

Physical health is the most critical concern in improving the quality of life in elderly people, and therefore the association between health and abdominal obesity in the elderly is being actively investigated. Most of these studies investigating the link between abdominal obesity in the elderly and health indicators have used InBody body composition analyzer (BCA), computed tomography (CT), and dual energy X-ray absorptiometry (DXA) to determine abdominal fat and distribution (Kang et al. 2011; Turcato et al. 2000). However, BCA machines like InBody work by applying microcurrents to the body and are thus not viable for older adults with medical implants like artificial joints or artificial heart. The predictive model developed in this study can be used as an alternative for gauging abdominal fat levels in elderly patients that cannot be obtained with a typical BCA.

The present study demonstrated the pattern of change in abdomen shape with increasing abdominal fat percentage. However, the present study has a limitation in that it did not provide the precise range of abdominal fat percentage that is clearly distinguished for each abdomen shape category. To overcome this limitation, future research should expand the number of subjects, which was only 30 in this study, and employ quantitative criteria for size and shape along with expert visual assessment in the classification step. If the results of this study are used as basic information and supplemented with sufficient validation samples and quantitative criteria, a more defined reference range for abdominal fat percentage can thus be determined.

The results of classifying the abdomen shape of elderly women using expert visual assessment in this study showed that there are some subjects who could not be identified definitively as one type in the verification process. These were women with a mixed-type silhouette. Park (2009), in a research project to generate a parametric virtual lower body for elderly women, selected 9 parameters pertaining to abdomen shape that showed statistical differences among visually classified shape categories, and indicated that the parameters included abdomen- and hip-related circumference, back thickness, and angle of the abdominal silhouette in the XY-plane. Future studies may attempt to use such quantitative parameters that reflect abdomen shape as well as visual assessment for a better classification of the mixed-type subjects.

In addition, ambiguation in abdomen type classification might occur due to skin aging characteristics of elderly subjects that caused an apparent deformation of the abdomen when wearing a body-measurement suit. Since abdomen shape is affected by fat tissue rather than skeletal structure and easily fluctuates with the degree and pattern of fat distribution, distinguishing the different types using individually measured virtual shape data was somewhat difficult. Additional research is required to determine anthropometric indexes and evaluation criteria other than silhouette that can be used on individuals that are not readily classifiable. Moreover, since the abdomen deformation caused by the measurement suit made it difficult to analyze, discussion on how to improve the measurement suit and deal with the bodily deformation caused by it will be necessary for future anthropometric measurement projects targeting elderly women.

Conclusion

This new model for estimating abdominal fat percentage developed in the present study is significant in that it uses relatively easy-to-obtain anthropometric measures like height and waist circumference. Through the results of this study, it is possible to predict the overall shape of the abdomen in elderly women by using the value of AFR. In addition, the present study explored the relationship between the conventional obesity index in the medical field, which is based on obesity prevalence, and body shape. It then extrapolated an anthropometric index focused on shape and form to examine the body types of elderly women, and investigated the relationship between waist-height ratio (WHtR) and abdominal fat percentage as the obesity index, along with abdomen shape.

If the abdominal shape is further subdivided by further analysis of the results of this study and the range of AFR is further subdivided, the abdominal type will be possible with a simple formula without recruiting experts to classify and organize the shape. In the case of clothes that have to be made to reflect the shape of the abdomen, such as pants and skirts, currently, only the same size as the difference between the waist and hips is used for the pattern. By predicting the type of abdomen with only these size items and reflecting it on the clothing, it is possible to transform the pattern and make the clothing better suited to the wearer.

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References

Baumgartner, R. N. (2000). Body composition in healthy aging. *Annals of the New York Academy of Sciences, 904*(1), 437–448.

Ding, J., Kritchevsky, S. B., Newman, A. B., Taaffe, D. R., Nicklas, B. J., Visser, M., et al. (2007). Effects of birth cohort and age on body composition in a sample of community-based elderly. *The American Journal of Clinical Nutrition, 85*(2), 405–410.

Gallagher, D., Visser, M., Sepúlveda, D., Pierson, R. N., Harris, T., & Heymsfield, S. B. (1996). How useful is body mass index for comparison of body fatness across age, sex, and ethnic groups? *American Journal of Epidemiology, 143*(3), 228–239. https://doi.org/10.1093/oxfordjournals.aje.a008733.

Garrow, J. S., & Webster, J. (1984). Quetelet's index (W/H2) as a measure of fatness. *International Journal of Obesity, 9*(2), 147–153.

Jung, D. W., Cho, Y. H., & Lee, S. Y. (2012). Evaluation, Co-morbidity and Management of Obesity in the Elderly. *Journal of Obesity & Metabolic Syndrome, 21*(2), 77–83.

Kang, S. T., Yoon, J. W., Ahn, H. Y., Kim, S. Y., Lee, K. H., Shin, H., et al. (2011). Android fat depot is more closely associated with metabolic syndrome than abdominal visceral fat in elderly people. *PLoS ONE*, *6*(11), e27694. https://doi.org/10.1371/journal.pone.0027694.

Kim, H. S., & Lee, S. Y. (2011). A Study on the Body Shapes of 40–60s' obese women. *Journal of Korea Design Forum, 31*, 7–16.

Ko, J., & Kim, K. (2007). Comparison of Body Composition According to the Obesity Types Based Upon Percent Body Fat, BMI and Waist Circumference in Women. *The Korean Journal of Growth and Development, 15*(1), 1–7.

Kohara, K. (2014). Sarcopenic obesity in aging population: current status and future directions for research. *Endocrine, 45*(1), 15–25.

Korean Agency for Technology and Standards. (2014). *Report of a research on 3D human body shape measurement and development for elderly people*. Jincheon: Author.

Kwon, Y.-G. (2005). *Validity of Indices on Obesity and Overweight for the Body Composition Assessment in Women* [Unpublished doctoral dissertation]. Seoul: Sookmyung Women's University.

Larsson, B., Svärdsudd, K., Welin, L., Wilhelmsen, L., Björntorp, P., & Tibblin, G. (1984). Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 year follow up of participants in the study of men born in 1913. *British Medical Journal, 288,* 1401–1404.

Lee, S. Y., & Kim, H. S. (2004). A Study on Torso Shape Classification of Women in 60s. *Journal of the Korean Society of Clothing and Textiles*, *28*(11), 1426–1437.

Lee, J.-H. (2015). Obesity in the Elderly and Bariatric Surgery. *Journal of Metabolic and Bariatric Surgery, 4*(1), 6–10.

Lee, S. J. (2013). *Classification of obese male's body types and development of torso pattern* [Unpublished doctoral dissertation]. Seoul: Seoul National University.

Moon, H. K., & Kim, Y. J. (2005). Comparing Validity of Body Mass Index, Waist to Hip Ratio, and Waist Circumference to Cardiovascular Disease Risk Factors in Korean Elderly. *Journal of Nutrition and Health, 38*(6), 445–454.

Nam, Y. J., & Choi, I. S. (1997). An analysis of the somatotype of elderly women. *Journal of the Korean Society of Costume, 34,* 19–36.

Park, S. M. (2009). *A Study on the creation of virtual parametric lower body for elderly women for the apparel industry* [Unpublished doctoral dissertation]. Seoul: Seoul National University.

Statistics Korea. (2016). [Prevalence by age and gender metabolic syndrome risk factors]. Korean Statistical Information Service. Retrieved from https://kosis.kr/statHtml/statHtml.do?orgId=350&tblId=DT_35007_N139

Stenholm, S., Harris, T. B., Rantanen, T., Visser, M., Kritchevsky, S. B., & Ferrucci, L. (2008). Sarcopenic obesity-definition, etiology and consequences. *Current Opinion in Clinical Nutrition and Metabolic Care, 11*(6), 693.

Turcato, E., BoSello, O., Francesco, V., Harris, T., Zoice, E., Bissoli, L., et al. (2000). Waist circumference and abdominal sagittal diameter as surrogate of body fat distribution in the elderly: their relation with cardiovascular risk factors. *International Journal of Obesity*, *24*, 1005–1010. https://doi.org/10.1038/sj.ijo.0801352

World Health Organization. Regional Office for the Western Pacific. (2000). The Asia-Pacific perspective: Redefining obesity and its treatment. Geneva: World Health Organization. https://iris.wpro.who.int/handle/10665.1/5379

World Health Organization. (2011). Waist circumference and waist-hip ratio: Report of a WHO expert consultation, Geneva, 8–11 December 2008. Geneva: World Health Organization. https://apps.who.int/iris/handle/10665/44583

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