Annals of Clinical and Medical Case Reports

Research Article

ISSN 2639-8109 | Volume 14

Relative Composition of Body Fat Percentage to BMI Based on Height Differences

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Received: 16 July 2024
Accepted: 06 Aug 2024
Published: 12 Aug 2024
J Short Name: ACMCR

Citation:

Yuki Takeyama, Relative Composition of Body Fat Percentage to BMI Based on Height Differences. Ann Clin Med Case Rep. 2024; V14(1): 1-6

Keywords:

BMI; Height; Body fat percentage; Correlation; BMI fluctuation

1. Abstract

It has previously been pointed out that body mass index (BMI) may have a problem in overestimating obesity in people with taller heights and underestimating it in people with shorter heights. However, there are almost no reports in which BMI is actually calculated for tall and short heights and its relationship with body fat, the parameter most related to the definition of obesity, is examined. In this study, to confirm whether height differences affect determinations of physique from BMI, we constructed a linear regression equation of body fat percentage versus BMI in people with tall height (≥180 cm; 1,812 people), medium height (171 ± 1 cm; 4,204 people), and short height (≤161 cm; 1,106 people), respectively. We then performed covariance analysis on the regression equation for each of the constructed height groups, and by examining the differences in slope investigated whether differences exist in the relative composition of body fat percentage to BMI, depending of differences in height. The results showed no significant between-group differences in the tall, medium, and short height groups, and no difference in the relative composition of BMI and body fat percentage. For a more detailed examination, the wavelet interpolation model was applied to the behavior of the mean value for body fat percentage in BMI fluctuations (single unit changes in BMI). In this way, the differences were analyzed from the fluctuation trends of the calculated velocity values. Then, based on the fact that when judging from velocity values, critical points were also shown in the same period in analyses in BMI fluctuations, it was determined that the same behavior was seen in all height categories. Thus, it seems that the effect of height differences can be excluded when determining fatness level from BMI, and that BMI as a simple indicator of health level can be guaranteed to be reliably effective in all height categories.

2. Introduction

Body mass index (BMI) and bioelectric impedance analysis (BIA) are useful methods to easily assess level of obesity in recent years. BMI in particular is simple and has broad utility as a measure of level of fatness, and is widely used is various fields. Globally, it is considered one of the simplest indicators of health. It was originally devised as an index of physique by Quetelet [1], who found that body weight was proportional to the square of height, based on the results of height and weight measurements in French and Scottish soldiers. That index, known as the Quetelet index, is the BMI of today. It was in recent years that the possibility of BMI as an index of fatness level came to be recognized. The finding of a high correlation between BMI and body fat percentage derived in studies by Keys et al [2] and Garrow and Webster [3] was a big achievement. Thus, BMI came to hold a different meaning from that devised by Quetelet [1]. Since then, the relationship between BMI and various obesity-related diseases has been verified many times, and from these findings the effectiveness of BMI as an indicator of level of fatness has been established. A relationship between BMI and mortality rate has also been reported from epidemiological studies. In Japan, for example, Tokunaga et al [4] reported that in the results of health checkups of about 5,000 male and female Japanese people aged 30–59 years old, those with a BMI of 22 had the fewest problem findings. Tsugane [5] also reported from a similar epidemiological study that the mortality rate was the lowest in people with BMI of 23–24.9. BMI of around 22–23 has then been proposed as a standard body weight. Thus, while the criteria for determining obesity differ among races, one may say that there are many useful findings showing that BMI can be used as an indicator of health. However, it has also been pointed out that there are limitations to the accuracy of BMI. Judging from the calculation formula, obesity would seem to be overestimated in people with taller height. Trefethen thought it odd that since humans live in a three-dimensional world, height in the formula for calculating BMI (weight (kg) ÷ height2 (m)) has only two exponent portions. That is, if weight is thought of as volume, and BMI is calculated dependent on height (length), it would mean that the fatness assessment of BMI would change depending on differences in height. In fact, in the growth of fetuses living in amniotic fluid in which there is almost no effect from body weight, the law of similarity is nearly maintained morphologically in the relation between height and weight, and so it has been said that the Rohrer index would be a better fit (Hattori, [6]). However, Fujii et al [7] pointed out that obesity assessments from the changes with age in the Rohrer index in young children are unsuitable, and they conversely advocated the effectiveness of obesity assessments using BMI. From this, it was reported that in individual adults, weight corresponds closely with the square of height (Hattori, Sawaki, [8]), and it was recognized that BMI is valid in assessing obesity from adulthood. Keys et al [2] conducted a clear analysis of these things, and showed that the correlation between body fat percentage and BMI was significant. From the above, while much is still not comprehended about the essential meaning of BMI, the close relative composition between BMI and body fat percentage seems to have been made clear from an analysis of the sigmoid shape composition of BMI and body fat percentage, as indicated by Fujii et al [9]. However, as mentioned above, it is unknown whether the relative composition between BMI and body fat percentage remains the same with differences in height. In this study, therefore, to examine the sigmoid shape composition of body fat percentage with respect to BMI based on height differences, we analyzed the changing composition of body fat percentage versus BMI fluctuations in people of tall and short heights. If no change in the sigmoid shape composition of BMI and body fat percentage is seen with differences in height, the stability of BMI as an assessment of obesity is assured and the high validity of this index as a simple indicator of health would be suggested.

3. Methods

3.1. Subjects and Materials

The subjects were 26,653 healthy male university students during from period from 2008 to 2022. Height was measured using a Tanita digital stadiometer, and weight and body fat percentage were measured using a Tanita body composition analyzer (DC-320), which employes BIA (impedance method). BMI (weight (kg) ÷ height (m)2) was calculated and used in determining obesity from height and weight.

3.2. Analysis Procedures

1) People of tall height (≥180 cm), medium height (171 ± 1 cm), and short height (≤161 cm) were identified.

2) A simple regression analysis was performed for body fat percentage versus BMI, and a linear regression formula was constructed in each height group.

3) An analysis of covariance was performed for the regression formula of each of the constructed height groups, and whether or not there was a difference in the relative composition of body fat percentage to BMI depending on height differences was analyzed by examining differences in the slopes.

4) A fluctuation axis was established for each unit of BMI (BMI 16.5–30.5), and the mean and standard deviation of body fat percentage were calculated.

5) A polynomial regression analysis was performed for mean BMI and body fat percentage, and a least squares approximation polynomial was constructed.

6) The wavelet interpolation model was applied to the least squares approximation polynomial to calculate distance and velocity values, and the behavior of body fat percentage changes with respect to BMI changes was analyzed from those change trends.

3.3. Wavelet Interpolation Model (WIM)

The wavelet interpolation model (WIM) is a method to approximately describe the true growth curve in given growth data. Different data points are interpolated with a wavelet function, a growth distance curve is drawn, and a growth velocity curve is derived by differentiating the drawn growth curves. The WIM is used to investigate growth distance values during the pubertal peak or at the age of menarche.

4. Results

4.1. Selection of People of Tall, Medium, and Short Height

From among the 26,653 male university students who were the subjects in this study, those with heights of ≥180 cm were selected as tall height, those of 171 ± 1 cm as medium height, and those of ≤161 cm as short height. Basic statistics were calculated for all subjects and for each of the height groups (Figure 1). No significant differences were seen between the groups ($p<0.05$) in the results of a multiple comparison test with BMI and body fat percentage.

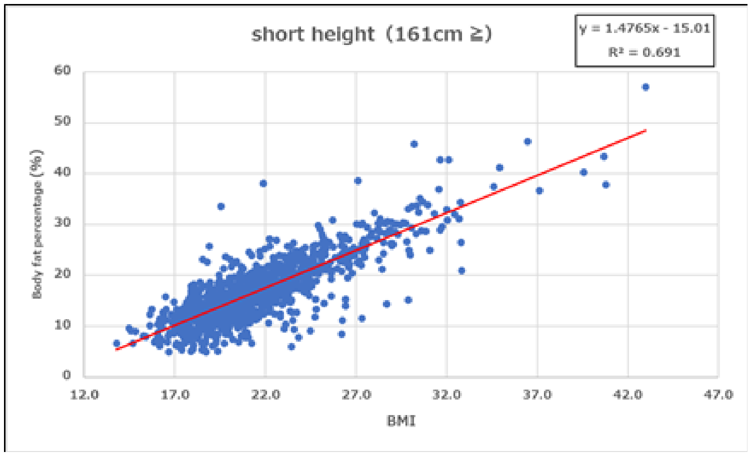

Figure 1. Regression analysis of body fat percentage versus BMI in short height.

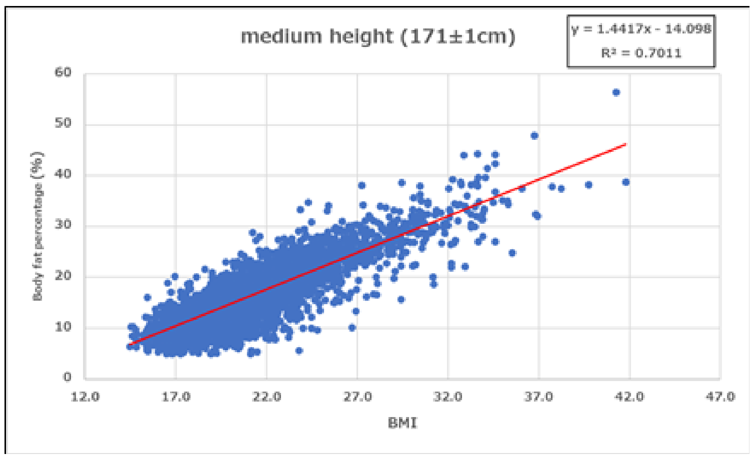

Figure 2. Regression analysis of body fat percentage versus BMI in medium height.

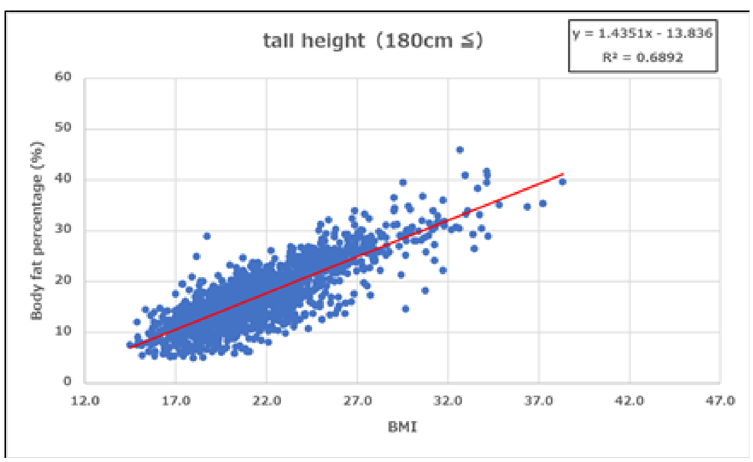

Figure 3. Regression analysis of body fat percentage versus BMI in tall height.

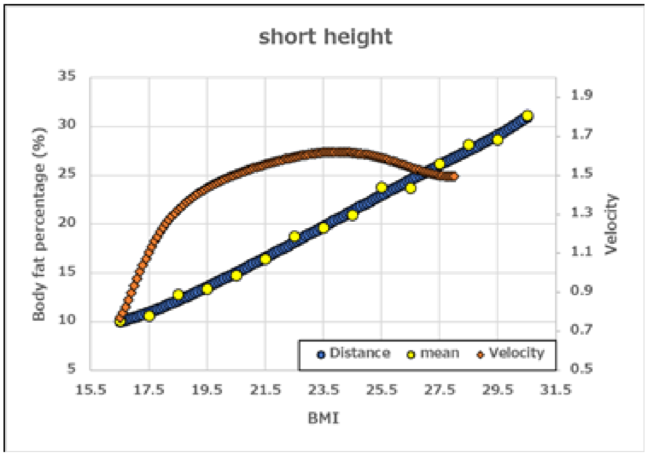

Figure 4. BMI fluctuation analysis in short height.

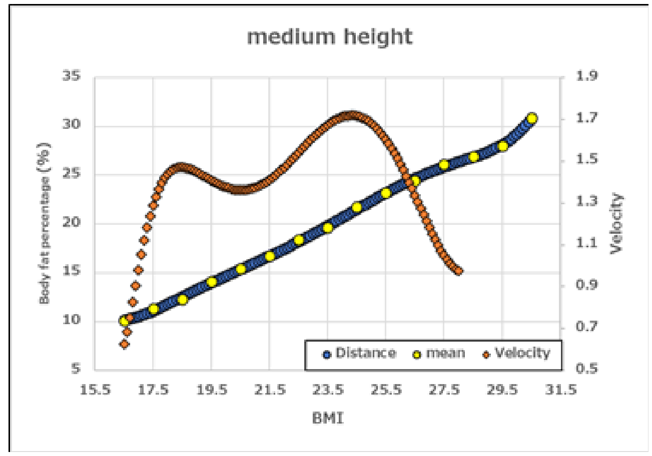

Figure 5. BMI fluctuation analysis in medium height.

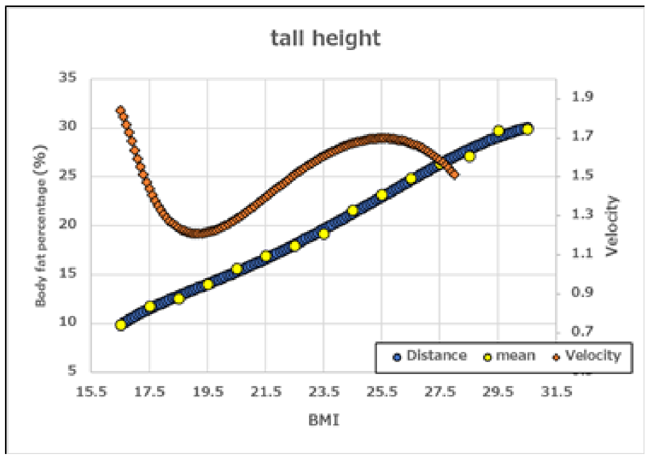

Figure 6. BMI fluctuation analysis in tall height.

4.2. Test of Differences in Regression Equation Slope in Each Height Group

From the results of the regression analyses of body fat percentage versus BMI in the tall, medium, and short height groups, regression equations were obtained for tall height (slope: 1.4351, intercept: -13.836), medium height (slope: 1.4417, intercept: -14.098), and short height (slope: 1.4765, intercept: -15.01). The respective coefficients of determination were 0.69 for tall height, 0.70 for medium height, and 0.69 for short height.

Next, no significant differences were seen in any of the groups in the results of analyses of covariance performed as tests of differences in the slopes of the regression equations obtained between groups in the tall, medium, and short height.

4.3. Behavior Analysis of Changes in Body Weight Percentage Versus Changes in BMI

A fluctuation axis was established with each unit of BMI (BMI 16.5–30.5), and the mean and standard deviation of body fat percentage were calculated (Table 2).

Least squares approximation polynomials were constructed with mean values for BMI and body fat percentage in each of the different height groups, and the wavelet interpolation model was applied. Distance and velocity values were then calculated. The results showed a behavior in which critical points were detected at a BMI of 25.5 for tall height, 24.3 for medium height, and 24.0 for short height.

Table 1: Basic statistics of subjects.

	No. of people	Height (cm)	Weight (kg)	BMI (kg/m²)	Body fat percentage (%)
Total	26577	171.00±5.86	62.41±10.90	21.32±3.43	16.62±5.91
Short height	1148	158.76±2.32	54.22±9.19	21.51±3.58	16.75±6.37
Medium height	4308	170.91±0.65	62.17±9.74	21.28±3.34	16.59±5.74
Tall height	1869	182.43±2.54	71.12±11.35	21.37±3.37	16.83±5.82

Table 2. Basic statistics of BMI values for body fat percentages in groups classified by height.

BMI	*Short height mean±SD (N)*	*Medium height mean±SD (N)*	*Tall height mean±SD (N)*
16.5	10.12±2.36 (36)	10.13±2.58 (150)	9.88±2.36 (71)
17.5	10.66±2.86 (89)	11.34±2.56 (336)	11.78±2.89 (145)
18.5	12.81±3.36 (130)	12.31±2.59 (537)	12.58±2.74 (237)
19.5	13.38±2.85 (178)	14.12±2.82 (645)	14.03±2.80 (262)
20.5	14.80±3.08 (170)	15.41±3.09 (648)	15.61±3.18 (265)
21.5	16.47±3.28 (126)	16.72±3.24 (509)	16.94±3.35 (216)
22.5	18.80±3.16 (103)	18.37±3.48 (421)	17.96±2.99 (177)
23.5	19.64±3.41 (79)	19.66±3.49 (327)	19.18±3.58 (132)
24.5	20.95±3.19 (60)	21.75±3.54 (198)	21.60±3.89 (96)
25.5	23.79±3.59 (31)	23.21±3.31 (140)	23.21±4.02 (68)
26.5	23.77±2.86 (33)	24.46±3.71 (80)	24.87±3.83 (45)
27.5	26.23±2.51 (22)	26.12±3.76 (55)	26.45±3.12 (43)
28.5	28.15±2.72 (21)	26.95±3.18 (55)	27.15±2.50 (14)
29.5	28.71±2.37 (13)	28.04±2.82 (43)	29.73±3.16 (18)
30.5	31.12±3.51 (10)	30.87±3.56 (35)	29.90±2.89 (10)

5. Discussion

The findings of Keys et al [2], Garrow and Webster [3], and Hattori and Sawaki [8] are behind the establishment of BMI as an index for the determination of obesity in recent years. From these findings BMI was considered effective as an index fort the determination of obesity in adults, while the Kaup index or Rohrer index have been considered more effective for early childhood to school age children. However, BMI is currently applied to all age groups. Reasons for this are the good fit of BMI to each age category and its stability as an index of obesity. Conversely, the grounds for this background are not well comprehended. This is because there are no findings on whether BMI is appropriate for school age children. The only report is one by Fujii et al [7] that indicated the effectiveness of BMI from the Rohrer index and changes with age in BMI, but other than that no much is known. The Kaup index has been used in early childhood, but the calculation formula is fundamentally the same as for BMI, and so BMI has been applied. Thus, while BMI is applied to all age categories today, there are no findings on the stability of BMI as an index with differences in height. Ozawa [10] compared the changes in the indices of BMI, body-weight ratio (height/weight), Ponderal index (height/3√body weight), and Broca-Katsura index (body weight/[height – 100] × 0.9), for heights classified every 5 cm for subjects in their 20s. Since BMI was shown to be the most stable value, it was advocated for its stability. In this study, the three groups of tall, medium, and short height were compared, and the results showed that BMI was stable as an index. Since a similar significant difference was not shown even in body fat percentage, the validity of BMI in determining obesity was shown.

Next, to examine whether there are differences in the relative composition of body fat percentage to BMI depending on differences in height, a linear regression equation of body fat percentage versus BMI was constructed in each height group. Covariance analyses were then performed for the regression equations constructed for each group, and differences in the slope were examined. The results showed no significant differences between any of the height groups, and body fat percentage did not tend to increase depending on differences in height. In judging obesity with BMI as an index, no differences were seen due to differences in height. However, as mentioned in the Introduction, while some people have suggested that obesity determinations would be affected by differences in height, there are no findings that have actually verified the correlation between BMI and body fat percentage in tall, medium, and short heights. Trefethen suggested that with the BMI calculation formula obesity may be overestimated in tall people and proposed a new BMI calculation formula that considers height. Ultimately this proposal is based on a mathematical formula, and it has not been verified from actual data. In the only examination of this in Asians (Filipinos) (Haute, [11]), the relationships between body fat percentage versus BMI calculated from the formula of Trefethen and body fat percentage versus BMI calculated from the formula of Keys were compared and examined. The result was that body fat percentage was significantly predicted and the effectiveness of BMI as a health indicator was reconfirmed. Lopez-Alvarenga [12] also pointed out an effect due to height differences in a comparison of BMI in Italians of tall and short height. However, data were collected from under 40 people in each height category, and so this finding cannot be said to be statistically significant. About 26,000 subjects were available in this study, from which more than 1,000 were extracted in each height category. Subjects with a wide range of BMI of 13–40 were also included, and so the statistical significance of this study can be ensured. To examine the sigmoid shape composition of body fat percentage versus BMI for different heights conducted by Fujii et al [9], we analyzed the changing composition of body fat percentage versus BMI fluctuations in people of tall and short heights. The results, judging from the calculated velocity values (change rate), showed a critical point around BMI of 24 to 25 in all age groups. A similar critical point to this was also confirmed in Fujii et al [9], and is thought to be evidence that the sigmoid shape composition of body fat percentage versus BMI is the same in all height groups. Hence, no change was seen in the sigmoid shape composition of BMI and body fat percentage with differences in height. The stability of BMI as an obesity assessment is ensured, and the high validity of the index as a simple health indicator has been reconfirmed.

In this study, by ensuring a statistically significant amount of data, we can say that the stability of BMI as an index unrelated to height differences has been ensured. In particular, the sigmoid shape composition of body fat percentage versus BMI could be examined separately for tall, medium, and short heights, which may be a finding shows there is no clear effects on obesity determinations from height differences. Therefore, the stability of BMI as a simple health indicator would seem to have been ensured in all height categories.

6. Conclusion

In this study, to confirm whether the relative composition of body fat percentage to BMI is affected based on height differences, people of tall height (≥180 cm; 1,812 people), medium height (171 ± 1 cm; 4,204 people), and short height (≤161 cm; 1,106 people) were selected from among 26,653 healthy male university students. A linear regression equation of body fat percentage versus BMI was then constructed in each of the height categories. An analysis of covariance was performed on the constructed regression equation for each height group, and by examining differences in the slope we examined whether there are differences in the relative composition of body fat percentage to BMI depending on height differences. For a more detailed examination, the wavelet interpolation model was applied to the behavior of the mean values for body fat percentage in BMI fluctuations (single unit changes BMI), from which an analysis was done from the fluctuation trends in the calculated velocity values. The results showed no significant differences between any of the groups in the constructed regression equations in each height group. In addition, since a critical point was shown in the same period when judging from velocity values in the BMI fluctuation analysis as well, similar behaviors were taken to be shown in all height categories. From this, the effect of height differences can be excluded when judging level of fatness from BMI, and the validity of BMI as a simple health indicator in all height groups may be considered to have been firmly demonstrated.

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