

Method for estimating body weight in persons with lower-limb amputation and its implication for their nutritional assessment¹⁻³

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ABSTRACT

Background: Body weight is a good indicator of a person's size and is widely used in clinical assessment. However, health-status assessment based on observed body weight (W_O) is incorrect for persons with limb amputation.

Objectives: The objectives were 1) to develop a more accurate and generalized method for estimating body weight in persons with limb amputation, 2) to determine whether corrected body weight can be used to assess nutritional status in persons with limb amputation, and 3) to test the validity of the estimation by using empirical data.

Design: Anthropometric data were collected from men from Calcutta and adjoining areas with unilateral lower-extremity amputation ($n = 102$). Mathematic formulas were developed for determining estimated body weight (W_E) and body mass index (BMI) calculated from both W_O and W_E (ie, BMI_O and BMI_E , respectively). We assessed nutritional status by using BMI_O and BMI_E and tested the validity of each by considering the result of nutritional assessment from midupper arm circumference as the gold standard. We also compared the nutritional status results for the subjects with limb amputation with those for a similar sample size of healthy control subjects.

Results: BMI_E had a stronger association with midupper arm circumference and a higher efficiency (ie, proportion of correct results given by any test method) than did BMI_O . Moreover, the results obtained with BMI_E were similar to those obtained with BMI in healthy control subjects. However, the nutritional assessments made with BMI_O and BMI_E did not differ significantly from one another.

Conclusion: For persons with limb amputation, W_E provides a better basis for appropriate nutritional evaluation than does W_O . *Am J Clin Nutr* 2004;80:868-75.

KEY WORDS Body weight, body proportions, persons with lower-limb amputation, anthropometry, body mass index, nutritional assessment

INTRODUCTION

Body weight generally reflects many physical attributes (size and shape) of the human body. Despite significant variation attributable to sex, stature, age, and socioeconomic conditions, body weight is often used as an indicator of the nutritional status and morbid condition of a person because of its sensitivity to environmental conditions. Therefore, body weight is an important physical characteristic that can be helpful in making clinical assessments, including determining the appropriate dosage of medicine and appropriate food supplements.

For healthy persons, body weight can be estimated very easily and accurately. However, body-weight estimation becomes critical and sometimes complicated in the case of persons who are devoid of a limb or a part of a limb usually due to amputation or congenital defects. For persons with limb amputation, body weight obtained by using the standard method is generally an underestimate and does not properly reflect their body shape and size. There are 2 alternatives for estimating the body weight of a person with an amputated limb: 1) weigh the amputated portion of the body (at the time of the amputation) and then add the extra weight, which is hardly practical; or 2) estimate the weight of the amputated portion of the body from the observed body weight (postamputation) by using body-weight proportions.

Past studies on body-weight proportions were based on measurements of the weight of separated body segments from human cadavers (1-3). In 1964 Hanavan (4) developed a computerized segment model of the human body with the use of 25 anthropometric measurements. Several limitations of the earlier studies have been pointed out. These limitations include the fact that generalization of the results may be difficult because of variation in body-weight proportions due to sex (5, 6), age (7-10), and ethnicity (11, 12). However, Wilson and Loesch (13) showed that the shape variables of trunks and limbs in both sexes are similar. Martorell et al (14) found that although length measurements are affected by socioeconomic status such that poor persons are likely to be short, socioeconomic factors do not affect relative body proportions, and this finding has been confirmed in other studies (15). Tanner (15) also opined that the body proportions of European and Asiatic populations are similar but differ from those of African populations. However, all these studies were based on assessment of the relative size of the body segments, not of the actual weights of the body segments.

Therefore, the need for a simple method for estimating body-weight proportions in persons with limb amputation was felt, although the exact assessment of the ideal proportion of the body weight when all possible varying factors are considered is very

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complex. An attempt was recently made to generalize the findings of published studies based on the actual assessment of segmental body weight, coupled with trends in generational change, which also supported the utility of that generalization of the results for the assessment of nutritional status (16). In the course of reviewing the work of Osterkamp (16), an additional application of nutritional assessment by formulating the body mass index (BMI; in kg/m^2) of persons with limb amputation was pointed out. An effort was also made to estimate total body weight (ie, before amputation) by using a mathematic model for persons with amputation through the knee only (17). However, in reality the frequency of amputation through the knee is much lower than that of amputation above or below the knee, in which the limb loss is transfemoral or transtibial. Tzamaloukas et al (18, 19) also developed a mathematic model for predicting the estimated (preamputation) weight of persons with limb amputation and attempted to estimate the body mass index and nutritional status of persons with limb amputation. However, the studies by Tzamaloukas et al had some limitations, such as the following: 1) they used an outdated method (20) for estimating the preamputation weight of the persons with limb amputation, and 2) their sample sizes were very small and heterogeneous.

BMI is often used as an indicator of nutritional status in human populations (21). However, BMI has rarely been used for the assessment of nutritional status in persons with limb amputation. BMI was used in a study in Israel as one of the obesity indexes to assess cardiovascular health in persons with limb amputation due to trauma (22). Some studies of physically disabled persons have also used BMI, although data from persons with limb amputation have not been analyzed separately; for example, few studies have included both aged and disabled persons (23, 24), and studies have also calculated BMI in disabled children (25). The reason behind the limited number of studies may be the problem in measuring body weight and stature in persons with limb amputation. Although stature measurement is possible to some extent in the case of persons with unilateral amputation, the correct body weight (proportional to body shape and size) is difficult to measure because of the loss of proportion of body weight due to limb amputation. This ultimately leads to an underestimation of BMI as well as an underestimation in nutritional assessment. In view of the need for efficient estimation of body weight in persons with limb amputation and the limitations of earlier studies as stated above, the purposes of the present study were 1) to develop an accurate method for estimating body weight in persons with limb amputation, 2) to determine whether corrected body weight can be used to assess nutritional status in persons with limb amputation, and 3) to test the validity of the estimation procedure by using empirical data from persons with lower-extremity amputation from Calcutta and its adjoining areas.

SUBJECTS AND METHODS

Population and area

The data used in the present study were collected as part of a larger biomedical program involving persons with lower-extremity amputation from Calcutta and its adjoining areas. Two national-level rehabilitation centers, the National Institute for the Orthopedically Handicapped and Mahavir Seva Sadan, were contacted for a list of addresses of persons with lower-extremity amputation. A statement of purpose of the present research and

a consent form were mailed to these persons. Respondents, who provided written informed consent, were included in the study. The study was performed according to the responsible committee on human experimentation (Scientific Ethical Committee for Protection of Research Risks to Humans, Indian Statistical Institute). Data were collected from a total of 102 men with unilateral lower extremity amputation; 32 of these men had amputations above the knee, and 70 had amputations below the knee.

The mean (\pm SD) age of the subjects was 43.54 ± 15.37 y. A large proportion (82.6%) of the subjects had amputation due to trauma, only 11.0% had amputation due to degenerative disease, and the remaining 6.4% had a reported history of cancer. All the subjects had prostheses, and all of them had been amputated ≥ 2 y before this study. All data were collected by a single investigator (AM) through multiple home visits. In addition, data were collected from a control group made up of 105 healthy men who were matched to the subjects with limb amputation by age and socioeconomic status. All the subjects with limb amputation and all the healthy control subjects were Bengali-speaking Hindus.

Anthropometric measurements

All anthropometric measurements were performed with the use of standard techniques (26). The subjects with limb amputation were requested to wear a prosthesis before having their stature and body weight measured (if required, the subjects were supported against a wall with adequate precautions to guard against bending of the trunk and knees). The weight of the prosthesis was then taken and subtracted from the previous weight with the prosthesis to get the actual weight (postamputation) of the body. To our knowledge, there is no standard method for measuring the stature of persons with limb amputation. Therefore, the stature measurements of the person with limb amputation were cross-checked for consistency by calculating body proportions (sitting height/stature) (27) and comparing them with those of persons without limb amputation.

Analysis

Theoretical considerations

If the present body weight of a person with limb amputation (postamputation) is W_O , estimated (preamputation) total body weight is W_E , and the reduction of the body weight due to the amputation is ΔW , then the following formula can be developed.

$$W_O = W_E - \Delta W \quad (1)$$

or, dividing both sides by W_E

$$W_O/W_E = 1 - \Delta W/W_E \quad (2)$$

or

$$W_E = W_O/(1 - \Delta W/W_E) \quad (3)$$

Now $\Delta W/W_E$ is the proportion of the body weight lost due to amputation from the total body weight.

Amputation may be of different components of the limbs (including partial amputation of limbs), and the weight loss due to these components (a, b, c, \dots, n) can be denoted as $\Delta W_a, \Delta W_b,$

$\Delta W_c, \dots, \Delta W_n$. Therefore, the total weight loss of the body (ie, ΔW) is

$$\Delta W = \Delta W_a + \Delta W_b + \Delta W_c + \dots + \Delta W_n \quad (4)$$

or

$$\Delta W/W_E = \Delta W_a/W_E + \Delta W_b/W_E + \Delta W_c/W_E + \dots + \Delta W_n/W_E \quad (5)$$

The value of ΔW (ie, the weight loss due to amputation) is not uniform among most persons with limb amputation. For example, an amputation below the knee results in a partial loss of the leg and a complete loss of the foot. In the case of an amputation above the knee, the weight loss is due not only to the complete loss of the lower leg and the foot but also to a partial loss of the thigh. Similarly, an amputation through the knee results in a weight loss of the lower leg and the foot but no partial loss of any other segment of the lower extremity. Lower-extremity amputations and loss of weight, therefore, may broadly be classified into the following types:

$$\text{Ankle disarticulation amputation, } \Delta W = \Delta W_s \quad (6)$$

$$\text{Amputation below the knee (transtibial), } \Delta W = \Delta W_s + \Delta_p W_T \quad (7)$$

$$\text{Amputation through the knee, } \Delta W = \Delta W_s + \Delta W_T \quad (8)$$

$$\text{Amputation above the knee (transfemoral), } \Delta W = \Delta W_s + \Delta W_T + \Delta_p W_F \quad (9)$$

$$\text{Hip disarticulation amputation, } \Delta W = \Delta W_s + \Delta W_T + \Delta W_F \quad (10)$$

where ΔW = total weight loss, ΔW_s = weight loss due to the loss of a foot, ΔW_T = weight loss due to the loss of a leg (tibial region), $\Delta_p W_T$ = partial weight loss due to the partial loss of a leg, ΔW_F = weight loss due to the loss of a thigh (femoral region), and $\Delta_p W_F$ = partial weight loss due to the partial loss of a thigh.

According to Osterkamp (16), the proportions of ΔW_s , ΔW_T , and ΔW_F to total body weight (ie, W_E) are 1.5%, 4.4%, and 10.1%, respectively. Therefore, the proportion of weight loss (lower-limb amputation) for ankle and hip disarticulation amputations and amputations through the knee are easier to estimate with the use of these proportions from Osterkamp (16). However, in real life, amputations below or above the knee (ie, transtibial or transfemoral), which involve the partial loss of the tibial or femoral region, respectively, are more common. However, no method to estimate the proportion of weight (lost or retained) of the tibial or femoral region is available. It is not feasible to weigh the amputated portion (unless the weighing is done at the time of the amputation), and it is also difficult to know the weight of the stump (ie, the remaining portion of the limb from its nearest distal bone joint). Thus, one has to rely on the proportional estimation of the size of the stump relative to that of the total region (ie, the tibial region in the case of amputations below the knee and the femoral region in the case of amputations above the knee). However, such estimation procedures require additional anthropometric measurements of the persons with limb amputation. The

measurements are 1) length of the stump, and 2) knee height for persons with amputation below the knee and buttock-knee length for persons with amputation above the knee (see reference 26 for technical details). These measurements have been used widely in many ergonomics studies (28, 29) of subjects with amputated limbs. Although, measurement of knee height or buttock-knee length is obviously not possible for the amputated limb, in the case of persons with unilateral limb amputation, these measures may be replaced by those of the available limb, with the assumption of bilateral symmetry. Thereafter, estimation of the remaining proportion of the limb may be made by calculating the proportion of the length of the stump to the knee height or buttock-knee length as follows:

$$\Delta_p W_T = \Delta W_T - \Delta W_T \times L_{Sip}/L_{Kn} = \Delta W_T(1 - L_{Sip}/L_{Kn}) \quad (11)$$

$$\Delta_p W_F = \Delta W_F - \Delta W_F \times L_{Sip}/L_{Btk} = \Delta W_F(1 - L_{Sip}/L_{Btk}) \quad (12)$$

where L_{Sip} = length of the stump, L_{Kn} = knee height, and L_{Btk} = buttock-knee length.

Therefore, new corrected formulas for estimating the lost proportions of total body weight in the case of persons with amputations below or above the knee may be written as follows:

$$\text{Amputation below the knee (transtibial), } \Delta W = \Delta W_s + \Delta W_T(1 - L_{Sip}/L_{Kn}) \quad (13)$$

or

$$\Delta W/W_E = \Delta W_s/W_E + \Delta W_T/W_E \times (1 - L_{Sip}/L_{Kn}) \quad (14)$$

$$\text{Amputation above the knee (transfemoral), } \Delta W = \Delta W_s + \Delta W_T + \Delta W_F(1 - L_{Sip}/L_{Btk}) \quad (15)$$

or

$$\Delta W/W_E = \Delta W_s/W_E + \Delta W_T/W_E + \Delta W_F/W_E \times (1 - L_{Sip}/L_{Btk}) \quad (16)$$

The proportions $\Delta W_s/W_E$, $\Delta W_T/W_E$, and $\Delta W_F/W_E$ can easily be obtained from the findings of Osterkamp (16) as mentioned before. Moreover, from the subsequent calculation of $\Delta W/W_E$, it is possible to estimate W_E by using Equation 3.

This method of estimating total body weight obviously pertains to persons with unilateral limb amputation only. For persons with bilateral amputation, there is no scope for using the measurement of the normal limb to predict the proportion of weight loss from the amputated limb. Stature measurement is generally used to predict the length proportion of limb segments. However, it is impossible to obtain stature measurements of persons with bilateral limb amputation because of the absence of both lower limbs. Several efforts have been made to develop some methods for measuring the stature of persons with bilateral locomotor disability (28), but these could not be adequately standardized. Therefore, we did not consider stature measurement of persons with bilateral limb amputation. Many studies of persons with limb amputation show that a linear body measurement that is strongly correlated with stature, such as sitting height (27) and

arm span (30), can be considered instead of stature. In the present study, sitting height measurement was considered for calculating body proportions; such measurement may be obtained even from persons with bilateral lower-limb amputation with the use of standard techniques and instruments. Drillis and Contini (31) developed a schematic diagram of human body proportions by using linear measurements. The sitting height proportion obtained by dividing the sitting height by stature is estimated to be 0.52 (31), although there is slight variation across ethnic groups.

From the above, if L_{St} is stature and L_{Sst} is the sitting height of a person, then

$$L_{St} = L_{Sst}/P_{Sst:St} \quad (17)$$

where $P_{Sst:St}$ is the proportion of sitting height to stature (ie, 0.52). We recommend that this proportion be estimated independently for the specific ethnic group being studied by taking measurements in a group of healthy persons without limb amputation from that population.)

Estimation of total weight loss in persons with bilateral limb amputation can thus be done in the following way. Suppose a person has undergone amputation below the knee in the left leg and above the knee in the right leg. In such a case, total weight loss can be represented by the following equation:

$$\Delta W = \Delta W_L + \Delta W_R \quad (18)$$

where ΔW_L is the weight loss from the loss of the left leg, and ΔW_R is the weight loss from the loss of the right leg.

From Equation 14, the following formula can be derived:

$$\Delta W_L = \Delta W_L + \Delta W_L(1 - L_{Sp}/L_{Kn}) = \Delta W_L + \Delta W_L[1 - L_{Sp}/(P_{Kn:St} \times L_{St})] \quad (19)$$

where $P_{Kn:St}$ is the proportion of knee height to stature, and L_{St} is the preamputation stature. From Equation 16, the following formulas can be derived:

$$\Delta W_B = \Delta W_B + \Delta W_B + \Delta W_B(1 - L_{Sp}/L_{Bk}) \quad (20)$$

$$\Delta W_B = \Delta W_B + \Delta W_B + \Delta W_B[1 - L_{Sp}/(P_{Bk:St} \times L_{St})] \quad (21)$$

where $P_{Bk:St}$ is the proportion of buttock-knee length to stature. As a note of caution, only in cases in which it is impossible to measure the buttock-knee length or knee height from other limb measurements, such as in persons with bilateral limb amputation, should those measurements be estimated from stature.

Statistical analysis

Descriptive statistics were calculated for all anthropometric measurements from the subjects with limb amputation (below the knee, above the knee, and pooled) and from the healthy control subjects without limb amputation. The total body weights (preamputation) of the subjects with limb amputation were estimated according to Equations 14 and 16, and descriptive statistics were calculated.

The ratio of sitting height to stature was calculated for all the subjects with limb amputation and for the control subjects, and descriptive statistics were calculated. Furthermore, one-way analysis of variance was performed to test whether the difference in mean values for the ratio of sitting height to stature between the

subjects with limb amputation and the control subjects were statistically significant.

BMI was calculated by using both W_O (BMI_O) and W_E (BMI_E). The terms BMI_O and BMI_E have been used consistently throughout the article.

Correlation coefficients between midupper arm circumference (MUAC) and the 2 BMI values (ie, both BMI_O and BMI_E) were calculated for the subjects with limb amputation. It is worth mentioning that MUAC generally has a strong positive correlation with BMI in healthy adult populations and can therefore be used as a measure of nutritional status in adult populations (32).

The nutritional status of the subjects with limb amputation was classified by using cutoffs (33). An MUAC ≥ 24.3 cm was considered normal, and an MUAC < 24.3 cm was considered indicative of the presence of chronic energy deficiency (CED). Similarly, a BMI ≥ 18.5 was considered normal, and a BMI < 18.5 was considered indicative of the presence of CED.

The test of sensitivity and specificity is a way of examining the effectiveness of the prediction protocols. A good predictor is one that has high sensitivity and high specificity, but one must sometimes choose a balance between the 2 because it is very difficult to determine which one is more important than the other. Sometimes, a test with high sensitivity is desired. For example, when a blood bank tests blood for HIV, a test with 100% sensitivity is desired, although some false-positive test results will occur. Conversely, before doing an autopsy, a pathologist tests for the presence of death; this test requires high specificity to avoid autopsying someone who is not dead. However, measuring the effectiveness of a test method that has been developed is always necessary. To test effectiveness, a statistical tool called "efficiency" has been calculated; it is the proportion of correct test results given by any test method (ie, true positives + true negatives/total number of cases) (34).

It is not always possible to identify a true condition, which is biologically independent of the test method under investigation. Therefore, a reference test (gold standard) was used to examine the performance of a new test. In such a circumstance, the result of the reference test is considered to be indicative of the true condition, and the efficiency of the new test method is tested accordingly.

MUAC is a good predictor of nutritional status in adults and for screening populations (32, 33). In many instances, MUAC has been used as the first screening method in a crisis setting (35, 36) and has been shown to be a good predictor of morbidity and mortality as well (37). MUAC also has a good correlation with BMI (32, 33). Therefore, MUAC was used in the present study as the gold standard against which the estimated method was calibrated.

Agreement statistics (Cohen's κ) between MUAC and BMI_O and between MUAC and BMI_E were calculated in the subjects with limb amputation (below the knee, above the knee, and pooled), and agreement statistics between MUAC and BMI were calculated in the control subjects. The κ value indicates the degree of association, which varies from -1 to 1 , and a κ value close to 1 indicates a very strong association.

In the present analysis, the sensitivity, specificity, positive predictive value, negative predictive value, and efficiency of both BMI values were calculated for persons with limb amputation and control subjects by using MUAC as the gold standard to determine the validity of the calculated BMI values for the

TABLE 1

Descriptive statistics for anthropometric variables in the subjects with limb amputation (below the knee, above the knee, and pooled) and in the control subjects¹

Anthropometric variable	Subjects with limb amputation			Control subjects (n = 105)
	Below knee (n = 70)	Above knee (n = 32)	Pooled (n = 102)	
Stature (cm)	160.85 ± 7.15	164.42 ± 6.83	161.97 ± 7.21	163.79 ± 6.52
Weight (kg)	54.49 ± 11.36	59.97 ± 12.41	56.21 ± 11.92 ²	59.71 ± 11.28
Sitting height (cm)	83.22 ± 3.83	84.66 ± 3.74	83.67 ± 3.84 ³	85.15 ± 3.75
MUAC (cm)	26.40 ± 3.37	29.14 ± 3.24	27.26 ± 3.55	27.13 ± 3.29
Knee height (cm)	50.14 ± 3.07	51.97 ± 2.92	50.72 ± 3.13	50.85 ± 2.77
Buttock-knee length (cm)	54.57 ± 3.53	55.75 ± 3.49	54.94 ± 3.54	54.62 ± 3.00

¹ All values are $\bar{x} \pm$ SD. MUAC, midupper arm circumference.

^{2,3} Significantly different from control subjects (*t* test): ²*P* < 0.05, ³*P* < 0.01.

present purpose. All statistical analyses were performed by using SPSS for WINDOWS (version 7.5; SPSS, Chicago).

RESULTS

Descriptive statistics for anthropometric traits in the subjects with limb amputation (below the knee, above the knee, and pooled) and in the control subjects are shown in Table 1. When pooled data from the subjects with limb amputation were compared with the data from the control subjects, the subjects with limb amputation were found to have significantly lower weight (*P* < 0.05) and sitting height (*P* < 0.01). The mean values for all the anthropometric variables were higher in the subjects with an amputation above the knee than in those with an amputation below the knee.

Descriptive statistics for W_O and W_E , the ratio of sitting height to stature, and body mass index in the subjects with limb amputation and in the control subjects are shown in Table 2. The estimated weight of the subjects with limb amputation was calculated by using Equations 14 and 16 (described earlier). The difference between W_O and W_E in the subjects with an amputation above the knee was larger than that in the subjects with an amputation below the knee, because this difference includes the weight loss due to amputation, which is greater for the subjects with an amputation above the knee. An attempt to determine the possible effect of age on the calculated ratio (proportion) of sitting height to stature was also made; however, the effect of age

on the variable was found to be negligible. In one-way analysis of variance, the ratio of sitting height to stature did not differ significantly between the subjects with limb amputation and the control subjects. The mean value of BMI_E was higher than that of BMI_O in each group of subjects with limb amputation because W_E is always higher than W_O .

MUAC was significantly positively correlated with both BMI_O (*r* = 0.846, *P* < 0.01) and BMI_E (*r* = 0.872, *P* < 0.01). Moreover, in the present control population, a very strong positive correlation was found between MUAC and BMI as well.

The frequency distribution of nutritional status in the subjects with limb amputation (below the knee, above the knee, and pooled) and in the control subjects is shown in Table 3. Classifications were made by using MUAC and BMI cutoffs for CED. Individual values of both estimates of BMI (ie, BMI_O and BMI_E) and of MUAC were considered for cross-tabulation, and frequencies of subjects were calculated accordingly. For MUAC pooled (total) data, 26 and 76 subjects had CED and normal nutritional status, respectively, according to BMI_O , and 16 and 86 subjects had CED and normal nutritional status, respectively, according to BMI_E . Thus, more subjects had normal BMI if BMI_E was considered instead of BMI_O (because of the compensation for weight loss in the BMI_E calculation); however, some of the subjects classified as having normal nutritional status are instead classified as having CED if BMI_O is considered. There were no significant differences in BMI distribution between the control

TABLE 2

Descriptive statistics for observed and estimated body weight (W_O and W_E , respectively), the ratio of sitting height to stature, and BMI calculated from W_O and W_E (BMI_O and BMI_E , respectively) in the subjects with limb amputation (below the knee, above the knee, and pooled) and in the control subjects¹

	Subjects with limb amputation			Control subjects (n = 105)
	Below knee (n = 70)	Above knee (n = 32)	Pooled (n = 102)	
W_O (kg) ²	54.49 ± 11.36	59.97 ± 12.41	56.21 ± 11.92	59.71 ± 11.28
W_E (kg)	56.62 ± 11.82	66.30 ± 13.66	59.65 ± 13.15	—
Sitting height/stature ³	0.5175 ± 0.014	0.5149 ± 0.011	0.5167 ± 0.0135	0.5199 ± 0.013
BMI_O (kg/m ²) ⁴	20.96 ± 3.54	22.00 ± 3.82	21.29 ± 3.89	22.20 ± 3.60
BMI_E (kg/m ²)	21.78 ± 3.67	24.36 ± 3.43	22.58 ± 3.52	—

¹ All values are $\bar{x} \pm$ SD.

² Observed body weight of the subjects with limb amputation and actual body weight of the control subjects.

³ No significant difference between groups (ANOVA).

⁴ BMI_O = BMI in the control subjects.

TABLE 3

Contingency table for distribution of the subjects with limb amputation (below the knee, above the knee, and pooled) and of the control subjects according to their nutritional status as assessed by using midupper arm circumference (MUAC) and BMI (in kg/m²)¹

	MUAC											
	Below knee			Above knee			Pooled			Control subjects		
	CED ²	Normal ³	Total	CED	Normal	Total	CED	Normal	Total	CED	Normal	Total
	<i>n</i>			<i>n</i>			<i>n</i>			<i>n</i>		
BMI _O												
CED ²	14	7	21	1	4	5	15	11	26	15	5	20
Normal ³	4	45	49	—	27	27	4	72	76	4	81	85
Total	18	52	70	1	31	32	19	83	102	19	86	105
BMI _E												
CED ²	12	3	15	1	—	1	13	3	16			
Normal ³	6	49	55	—	31	31	6	80	86			
Total	18	52	70	1	31	32	19	83	102			

CED, chronic energy deficiency; BMI_O, BMI calculated from observed body weight (BMI_O = BMI in the control subjects); BMI_E, BMI calculated from estimated body weight in the subjects with limb amputation. Agreement statistics between MUAC and BMI_O were as follows: $\kappa = 0.610$ (in subjects with an amputation below the knee), 0.297 (in subjects with an amputation above the knee), and 0.575 (in pooled subjects with limb amputation). Agreement statistics between MUAC and BMI_E were as follows: $\kappa = 0.644$ (in subjects with an amputation below the knee), 1.000 (in subjects with an amputation above the knee), and 0.690 (in pooled subjects with limb amputation). Agreement statistics between MUAC and BMI were as follows: $\kappa = 0.717$ (in control subjects).

¹ MUAC < 24.3 cm.

² MUAC ≥ 24.3 cm.

³ BMI < 18.5.

⁴ BMI ≥ 18.5.

subjects and the subjects with limb amputation (either by BMI_E or BMI_O).

The sensitivity, specificity, positive predictive value, negative predictive value, and efficiency of BMI_O and BMI_E are shown in Table 4. To test the validity of BMI for assessment of nutritional status, MUAC was used as the gold standard. The sensitivity of BMI_O was ≈ 10% higher than that of BMI_E, whereas for specificity, the result was reversed. Although the sensitivity of BMI_E was lower than that of BMI_O, BMI_E had a much higher positive predictive value than did BMI_O; however, negative predictive value did not differ significantly between BMI_O and BMI_E. The value of the efficiency statistic for BMI_E tended to be higher than that of the efficiency statistic for BMI_O, but this difference was not significant. The efficiency of BMI_E in the subjects with limb amputation was not significantly different from that of BMI in the control subjects. The binomial test for equality of proportions of sensitivity, specificity, and efficiency between MUAC and BMI in the control subjects and between MUAC and both BMI_O

and BMI_E in the subjects with limb amputation (pooled) did not show any significant differences.

DISCUSSION

The aim of this study was to develop a method for estimating the total body weight of a person with limb amputation from current (postamputation) body weight by using anthropometric measurements and body weight proportions of different limb segments according to Osterkamp (16). This method will ultimately help in assessing the nutritional status of persons with limb amputation. In the present study, the method was applied to an empirical data set collected from subjects with unilateral amputation from Calcutta and adjoining areas, and the validity of the method was tested statistically.

It has been argued that stature is an important measurement for evaluating nutritional status. However, although measurement of stature is possible for persons with unilateral amputation who

TABLE 4

Validity of BMI calculated from observed body weight (BMI_O) and of BMI calculated from estimated body weight (BMI_E) for assessment of nutritional status in subjects with limb amputation and in control subjects with the use of midupper arm circumference (MUAC) classification as the gold standard

	Sensitivity	Specificity	Positive predictive value	Negative predictive value	Efficiency
MUAC compared with BMI _O					
Below knee	77.78	86.54	66.67	91.84	84.29
Above knee	100.00	87.10	20.00	100.00	87.50
Pooled	78.95 ¹	86.75 ¹	57.69	94.74	85.29 ¹
MUAC compared with BMI _E					
Below knee	66.67	94.23	80.00	89.09	87.14
Above knee	100.00	100.00	100.00	100.00	100.00
Pooled	68.42 ¹	96.39 ¹	81.25	93.02	91.18 ¹
MUAC compared with BMI					
Control subjects	78.95	94.19	75.00	95.29	91.43

¹ Not significantly different from the corresponding value in the control subjects (binomial test for equality).

wear a prosthesis, it is difficult for persons with bilateral amputation. In the present study, stature measurements of the subjects with unilateral amputation were cross-checked by using the ratio of sitting height to stature, and these ratios were compared with those in healthy subjects without limb amputation. The ratio of sitting height to stature observed in the population in the present study corroborates the value found by Drillis and Contini (31).

As shown in Table 2, estimated weight was higher than observed weight because estimated weight compensates for the weight loss due to amputation. Testing the validity of the estimate was not possible because no such test, especially for living subjects, exists; however, the logic by which the method was developed is in agreement with that of Himes (17).

For assessing the nutritional status of the subjects with limb amputation, BMI was calculated. In the present study, BMI was calculated from both the W_O and the W_E of the subjects with limb amputation. The BMI calculated from W_O was less than that calculated from W_E . BMI values in subjects with limb amputation are less than those in healthy control subjects without limb amputation because the lost weight of the limbs is not considered in calculating BMI (22). Therefore, to reduce the underestimation of nutritional status in persons with limb amputation, estimation of body weight is necessary so that BMI can be reliably estimated for persons with limb amputation. In the present study, a method for estimating body weight was developed, and its validity was tested. Estimated body weight was then used to reliably estimate BMI in subjects with limb amputation.

With classification of the subjects on the basis of MUAC and either BMI_O or BMI_E (Table 3), there was a fair chance of underestimating the nutritional status (ie, CED or normal) of subjects with unilateral amputation if BMI_O was used for screening because of the weight loss due to limb amputation. Screening with BMI_O also mismatched the classification based on MUAC. However, if W_E was used for calculating BMI_E , then the chances of underestimation were eliminated, and the BMI screening for CED and normal nutritional status corresponded with the classification based on MUAC. The agreement statistics showed a stronger association between MUAC and BMI_E than between MUAC and BMI_O . In addition, the agreement statistics showed a stronger association between MUAC and BMI in the control subjects and between MUAC and BMI_E in the subjects with limb amputation than between MUAC and BMI_O in the subjects with limb amputation.

The validity of BMI_O and BMI_E were tested by calculating the statistics of sensitivity, specificity, positive predictive value, negative predictive value, and efficiency by using MUAC as the gold standard. Although the sensitivity of BMI_O was higher than that of BMI_E , the specificity of BMI_E was higher, and the highest value for specificity of BMI_E was for the subjects with amputation above the knee (perhaps because of the small sample size). Furthermore, the positive predictive value of BMI_E was higher than that of BMI_O , whereas negative predictive value did not differ significantly between BMI_O and BMI_E . However, the efficiency of BMI_E was higher than that of BMI_O . Binomial tests for equality of proportions failed to show any significant differences in sensitivity, specificity, or efficiency between BMI_O in the subjects with limb amputation and BMI in the control subjects or between BMI_E in the subjects with limb amputation and BMI in the control subjects.

In sum, the agreement statistics suggest that BMI_E is a better estimator of BMI than is BMI_O for persons with limb amputation

and that nutritional status can be assessed on the basis of BMI_E . However, the specificity of the estimation is greater than its sensitivity for nutritional assessment.

The present study had some limitations, and thus some further research is required. The proportional weight estimation of the stump was performed by considering the length proportion although the compositions of the different segments of the body are not uniform. Therefore, a more elaborate study considering the three-dimensional structure and composition of different limb segments is necessary. For persons with bilateral amputations, accurate measurement of stature is difficult. However, the lengths of other segments of the body are generally estimated from stature. Therefore, population-specific data are required to calculate ratios of different body segments. Finally, further studies are necessary to cross-validate the present estimating method. Although the method of weight estimation may be valid for persons with bilateral amputations, because of the absence of empirical data, the validity of the method could not be assessed; thus, empirical studies are required. □

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