

The Skeleton Frame as a Crucial Part of Body Weight: Comparison to Metropolitan Life Insurance Data

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Abstract: Background: The study presents a new anthropometric model, Dahlmann-Body-Analysis (DBA), for the specific estimation of reference body weight (Ref-W) based on the individual structure of skeleton frame. Subjects/Methods: Estimation of the Ref-W is based on measurements of height (Ht), body weight (W) and hand circumference (HdC) in consideration of sex to classify the skeleton frame into small, medium and large (sSkFr, mSkFr, lSkFr). Calculations were performed in 90 obese German subjects (BMI ≥ 30 kg/m²), aged 18-65 years. Results were compared with the Metropolitan Life Insurance (MLI) body weight, skeleton frame adjusted (MLI-Ws). Results: The mean reference weight estimates of men (women) \pm standard deviation were 71.7 \pm 5.5 (60.7 \pm 4.5) kg for Ref-W and 71.2 \pm 6.8 (59.7 \pm 5.6) kg for MLI-Ws. Pearson correlation coefficients (r) and Lin's concordance correlation coefficient (CCC) were $r = 0.98$ and $CCC = 0.96$ for men and $r = 0.92$ and $CCC = 0.88$ for women, respectively. Bland-Altman plot showed limits of agreement between Ref-W and MLI-Ws of 4.1 kg to -3.1 kg (range: 7.2 kg) for men and 4.7 kg to -6.0 kg (range: 10.7 kg) for women. MLI-Ws exhibited an average positive bias of 0.49 kg for men and 0.95 kg for women. Over all, there is a strong concordance and reproducibility between the DBA and MLI data sets. Conclusions: The implementation of the hand circumference (HdC) into the DBA model as a proxy for skeleton frame is essential for the final body weight and resulted in a strong concordance with MLI data. These findings indicate that the DBA model may reflect the body shape of the white American population classified as "ideal" at that time.

Keywords: body composition analysis; reference weight; skeleton frame; public health

1. Introduction

There is a great deal of scientific evidence linking overweight to increased risk of morbidity and mortality [1, 2]. Due to their ease of computation and the availability of data on height (Ht) and weight (W), indices of relative weight are often used to assess overweight. These measures, in particular the body mass index (BMI), are used extensively in epidemiologic studies where only weight and height data are available [3, 4]. The rationale behind these studies is the assumption that in a normal unselected population the distribution of body weight at each level of height will reflect the distribution of obesity.

This assumption proved to be right in mass statistics [5, 6]. However, it is obvious that no formula relating weight to height can measure adiposity in an individual [7]. Any derived index cannot distinguish between heaviness due to body frame, muscularity or adiposity. In particular, the BMI cannot fully distinguish the fat-free mass from fat mass compartments. The BMI performance in severely obese patients is impaired by the large amount of subcutaneous adipose tissue.

The need for an index of normal relative body weight was recognized soon after the actuaries noted the increased death claims of their obese policyholders. Louis I. Dublin, a statistician and vicepresident of the Metropolitan Life Insurance (MLI) Company, was the first to lead the

development of tables of normal weights, based on the average weights recorded for a given height. However, as data accrued, he noted a rather wide range of weights for persons of the same sex and height, which he attributed to differences in body 'shape' or 'frame'. To resolve the problem, he divided the distribution curve of weight at a given height into thirds, and labelled them 'small', 'medium' and 'large' frames. The average weights of those thirds were then termed 'ideal' weights, later less presumptuously labelled 'desirable' weight, for each of the three frame types [8]. However, no instructions are given on how frame size should be determined in individuals. And, up to now, it is not yet clear if this fragmentation represents different forms of skeleton frame. In 1983 the tables were revised designating the determination of frame size now by the measurement of elbow breadth. At this point it is to emphasize that it is not the intention of the study to decide, which of the anthropometric measures - elbow breadth or hand circumference-is best, though this point will be discussed.

Great effort was made to create a universal index, that is to say a serious attention to the dimensions of the body and its biological and medical implications. The efforts started with indices based on body weight in proportion to height [9, 10] waist to height relationship [11, 12] and lead to more sophisticated ones like ABSI [13], BRI [14] or CUN-BAE [15]. But as yet there is no agreement on any particular index. The reason for that can be found at least in part in a

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lack of calibrating data, as A. Keys supposed [5]. The plasticity of the human body with regard to surface and composition in connection with a lack of a standard model might be responsible for it. This holds true for now and decades before and was the reason that Dahlmann et al were searching for a reference population, which was found in the “Schlegel” material with the opportunity of a systematic examination of wide-ranging samples of data analysed in parallel [16].

It is based on measurements taken by W. Schlegel and his assistant G. Hopfeld on 1749 young adults aged 18 to 30 for men and 17 to 30 for women, all living in Hamburg, Germany, and the surrounding area, being a random sample of the population. The measurements of gender, age, height (Ht), weight (W) and hand circumference (HdC) were carried out between 1955 and 1973, at a time when neither junk nor fast food and the corresponding restaurant chains existed in Germany. Since then, from 1975 to 2016, there was a trend in body-mass index that recently flattened in north-western Europe, albeit at high level [17]. Thus, the evaluated collective herewith fuses the two aspects of a low caloric lifestyle combined with the general fitness of young adults. It is a well-known fact that weight tends to increase with age and with that the prevalence of T2D [18]. For this reason, the British National Research Council proposed in 1958 that actuarial standards ideally should not increase above that which is “normal” at about age 25 [19]. Reflecting the situation nowadays this is, however, more a myth than a fact.

The hand circumference (HdC) was implemented into the DBA model as a proxy for skeleton frame and gave for the first time the chance to develop weight-height-frame tables and to scale the body frame [16]. In the meantime, it is common to use wrist breadth as a proxy for frame size [20]. With regard to skeleton phenotype, hand and wrist circumference are equally matched variables. Schlegel found a high correlation between wrist and hand circumference ($r = 0.75$). Of both parameters he decided in favour of the hand circumference because of a smaller relative error [21].

A measure of frame allows the discrimination between those, who are heavy because of large fat free mass from those whose overweight is largely fat. Deduced from this reference population and based on a multiple regression equation including the parameters height, weight and hand circumference the DBA system allowed for the first time and for each individual the calculation of a reference weight (Ref-W), which should replace the terms “desirable” or “ideal”. It is a standard independent of age and intends to be, so to speak, the blue print of body analysis.

The purpose of the present study is to compare the reference weight (Ref-W), derived by the Dahlmann-Body-Analysis (DBA) system from obese patients, with data of the Metropolitan-Life-Insurance (MLI) company. The two data sets are scaled to the same level of body frame to make them comparable and give an answer to the question, to what kind of magnitude the skeleton frame has an influence on the final body weight. Furthermore, the comparison of the two data sets may elucidate the assumption to which extend the

“Schlegel” material might represent the body shape of the white American population at that time

2. Subjects and Methods

Patients

For this study, data were collected between January 2019 and May 2021 including 96 severely obese German patients (57 female, 39 male), who were candidates for bariatric surgery and each of whom had a $BMI \geq 30 \text{ kg/m}^2$. They were recruited from the outpatients' clinic of the endocrinological department of the University Hospital, Bonn, Germany. Subjects between 18 to 65 years of age were asked to report to the study centre in the morning and 10 h after the last food intake. The exclusion criteria were: cancer patients; clinically detectable oedema; physical amputations; and acute diseases of the liver, lung, kidney, and heart. All study procedures were performed according to the ethical standards of the World Medical Association's Declaration of Helsinki, approved by the institutional ethics review board. Written informed consent was obtained from each patient prior to trial participation.

Measurements

Body weight was measured to the nearest 0.1 kg using the body weight scale (Omron BF511, Kyoto, Japan) with the patient standing in the centre of the scale platform, barefoot, wearing underwear. During the measuring period batteries were replaced once. The weight is restricted to 150 kg because of the limited capacity of the scale. Body height ($\pm 0.1 \text{ cm}$) was obtained with a stadiometer (seca, Hamburg, Germany) with the patient standing barefoot with the heels together, back upright, and arms stretched next to the body. Hand circumference ($\pm 0.1 \text{ cm}$) was measured in the non-dominant arm by positioning a non-stretchable measuring tape in the horizontal plane over the base joints of the 2nd to 5th finger. The hand should be strained and the thumb splayed. The measurement was taken by fitting the tape tightly. Readings of both measurements were taken to the nearest mm.

Statistical methods

Descriptive statistics are presented as means and standard deviation ($\pm SD$). The Student's t-test for two means was performed for the bivariate hypothesis contrast to compare the means of Ref-W and MLI-Ws for both genders. Relative agreement between the variables DBA-and MLI-weight were analysed by linear regression analysis. Pearson's correlation coefficient (r) was calculated by square root of the determination coefficient R^2 for relationships between variables. Lin's concordance correlation coefficient (CCC) was used to assess the reproducibility between the two methods [22]. Analysis according to the Bland-Altman method was created to determine absolute agreement between the body weight assessed by DBA-and MLI-system [23]. The limits of agreement (LOAs), calculated as bias ± 2 SD error hereby express 95% confidence interval of the individual difference. Bias was calculated as result obtained from the difference of the two methods. All statistics were performed in Excel (Office 2019, Microsoft Corporation, USA). Tests not available in Excel were calculated by hand. Ap-value < 0.05 was considered statistically significant.

Data Processing

Details of material and formulas were previously described [16]. The following algorithms are implemented in Excel for calculation of:

Reference Weight (Ref-W)

Men

$$=IF(\text{Sex}="m";-68.46+0.535*\text{Ht}+2.09*\text{HdC})(1)$$

Women

$$=IF(\text{Sex}="f";-64.53+0.439*\text{Ht}+2.69*\text{HdC})(2)$$

Skeleton Frame (SkFr)

Men

$$=IF(\text{HdC}>21.9;"l";IF(\text{HdC}<19.9;"s";"m"))(3)$$

Women

$$=IF(\text{HdC}>19.2;"l";IF(\text{HdC}<17.4;"s";"m"))(4)$$

Plausibility

Men

$$=IF(\text{AND}(\text{Age}>=18;\text{Age}<=65;\text{Ht}>=150;\text{Ht}<=200;\text{W}>=50;\text{W}<=150;\text{HdC}>=17;\text{HC}<24);"ok";"neg")(5)$$

Women

$$=IF(\text{AND}(\text{Age}>=17;\text{Age}<=65;\text{Ht}>=145;\text{Ht}<=195;\text{W}>=40;\text{W}<=150;\text{HdC}>=15;\text{HdC}<=22);"ok";"neg")(6)$$

The classification of the skeleton frame according to the DBA model is based on measurements of the hand circumference (HdC), where the "medium" category covers the range of 20.9±1.0 cm for men and 18.2 ±0.82 cm for women, respectively [16]. Values for men (women) below 19.9 (17.4) cm are classified as "small", values greater than 21.9 (19.2) "large".

After the input of gender, age and the measurements for height (Ht), weight (W) and hand circumference (HdC) calculations were automatically performed by the system software (DBA). The result is the reference weight (Ref-W) addressed to individual skeletal frame (small, medium and large).

Metropolitan Life Insurance (MLI) Data:

The following Metropolitan Life Insurance (MLI) data are taken from the Geigy Table [24]. It is a reprint of the 1959 Metropolitan Desirable Weight Table. The tables` endorsed weights are based on the Build and Blood Pressure Study, 1959, and covered the weights of insured lives aged 25-59 years during the years 1935-1953 [25]. People who were included were predominantly white and middle-classed. The tables do not call for an increase in weight with increasing age [26].

All values are the average of the given range. Subjects were measured clothed and wearing shoes. The distribution of weight at a given height was divided into thirds. No further definition of "small", "medium" or "large" frame is given. The "average" frame is the frame of all subjects aged 20-24 years old.

Table 1

Metropolitan Life Insurance Data				
Age				
Men	≥ 25 years			20-24 y
Height (cm)	Weight (kg)			
	s SkFr	m SkFr	l SkFr	a SkFr
160	54.0*	57.6	61.9	59.9
165	56.7	60.3	65.1	63
170	60	63.7	68.6	65.7
175	63.6	67.4	72.6	69.2
180	67.4	71.2	76.4	72.8
185	70.9	75.2	80.7	76.8
190	74.7	79.4	85.1	80.4
Women	Weight (kg)			
Height (cm)	s SkFr	m SkFr	l SkFr	a SkFr
150	44.3	47.3	51.8	47.7
155	46.8	49.9	45.5	50.8
160	49.4	51.8	57.2	53.5
165	52.1	55.8	60.6	56.6
170	55.5	59.5	64.1	59.8
175	59	63.1	67.7	63.3
180	62.8	66.7	71.6	67.3

Table 1: s, m, l, a SkFr: small, medium, large, average skeleton frame; * all values are the average of the given range, taken from Geigy Tables [24]

These values are the basis to calculate the regression equations between y = W (weight) and x = Ht (height). The results are the following equations:

Men

$$\text{sSkFr: } y = 0.699x - 58.48 (7)$$

$$\text{mSkFr: } y = 0.733x - 60.55 (8)$$

$$\text{lSkFr: } y = 0.776x - 62.84 (9)$$

$$\text{aSkFr: } y = 0.687x - 50.56 (10)$$

Women

$$\text{sSkFr: } y = 0.614x - 48.51 (11)$$

$$\text{mSkFr: } y = 0.659x - 52.48 (12)$$

$$\text{lSkFr: } y = 0.791x - 70.68 (13)$$

$$\text{aSkFr: } y = 0.644x - 49.19 (14)$$

If a person was identified by the DBA system to have a "small", "medium", or "large" skeleton frame, the corresponding SkFr-equation of the MLI system was addressed to calculate the corresponding MLI-weight (MLI-W). The systematic link of the two data sets, based on the same individual level of skeleton frame, makes the two models comparable.

The study was performed in a double-blind form. Measurements were taken in Bonn, send to the author, processed by the DBA system and send back. Values outside the plausibility range and/or values >3kg for men and >4kg for women, respectively, between the differences of DBA and MLI body weight were recommended for a re-measurement.

94 data sets were generated. 10 were recommended for re-examination. One was excluded because of age over 65 years, two because of weight > 150 kg, one was diagnosed with acromegaly. Four anthropometric measurements had to

be corrected, two were confirmed. At the end a data set of 90subjects remained.

3. Results

A group of severely obese persons were analysed with regard to their bone structure and their body weight. The anthropometric data were processed by the DBA system to generate information about the skeleton frame (small, medium, large) and the reference weight (Ref-W). The results were taken to calculate the MLI-weight (MLI-W), skeleton frame adjusted (s) and not (a), referred to the corresponding regression equation. Results and descriptive characteristics of the study group are displayed in Table 2.

From the entire sample, most of the patients were women (61%), the BMI ranged from 30 to 52 kg/m², with 32% of patients having BMI > 40 kg / m²; age ranged from 18 to 65 years old. The mean estimates of body weight calculated by DBA-system (Ref-W)and the MLI-system (MLI-Ws and MLI-Wa) were 71.7kg, 71.2 and 72.0 kg for men and 60.7kg, 59.7 and 58.1 for women, respectively (Tab. 2). The mean estimates for Ref-W and MLI-Ws of each sex analysed by t-test, revealed no statistically significant differences for both genders on the 5% level.

Table 2

Anthropometric and body composition characteristics of severely obese German adults.

	Men		Women		All	
	n = 34		n = 56		n = 90	
	Mean	±SD	Mean	±SD	Mean	±SD
Age, years	45.2	11.9	42.5	12.5	43.5	12.3
Height, cm	178.4	7.7	166.7	6.5	171.1	7.0
Weight, kg	114.5	15.4	108.3	17	110.6	16.4
BMI, kg/m ²	36.0	4.3	38.9	5.1	37.8	4.8
HC, cm	21.4	1.4	19.4	1.1	20.2	1.2
Ref-W, kg	71.7	5.5	60.7	4.5	64.9	4.9
MLI-Ws, kg	71.2	6.8	59.7	5.6	64.0	6.1
MLI-Wa, kg	72.0	5.3	58.1	4.2	63.4	4.6

Abbreviations: BMI, body mass index; HC, hand circumference; Ref-W, reference weight; MLI, Metropolitan Life Insurance; (s) skeleton frame adjusted; (a) average frame adjusted.

The association of the Ref-W, calculated according to the DBA-System and the corresponding MLI-W, are depicted in Fig. 1 a-d.

Association between Ref-Weight and MLI-Weight with and without skeleton frame adjusted, for men and women

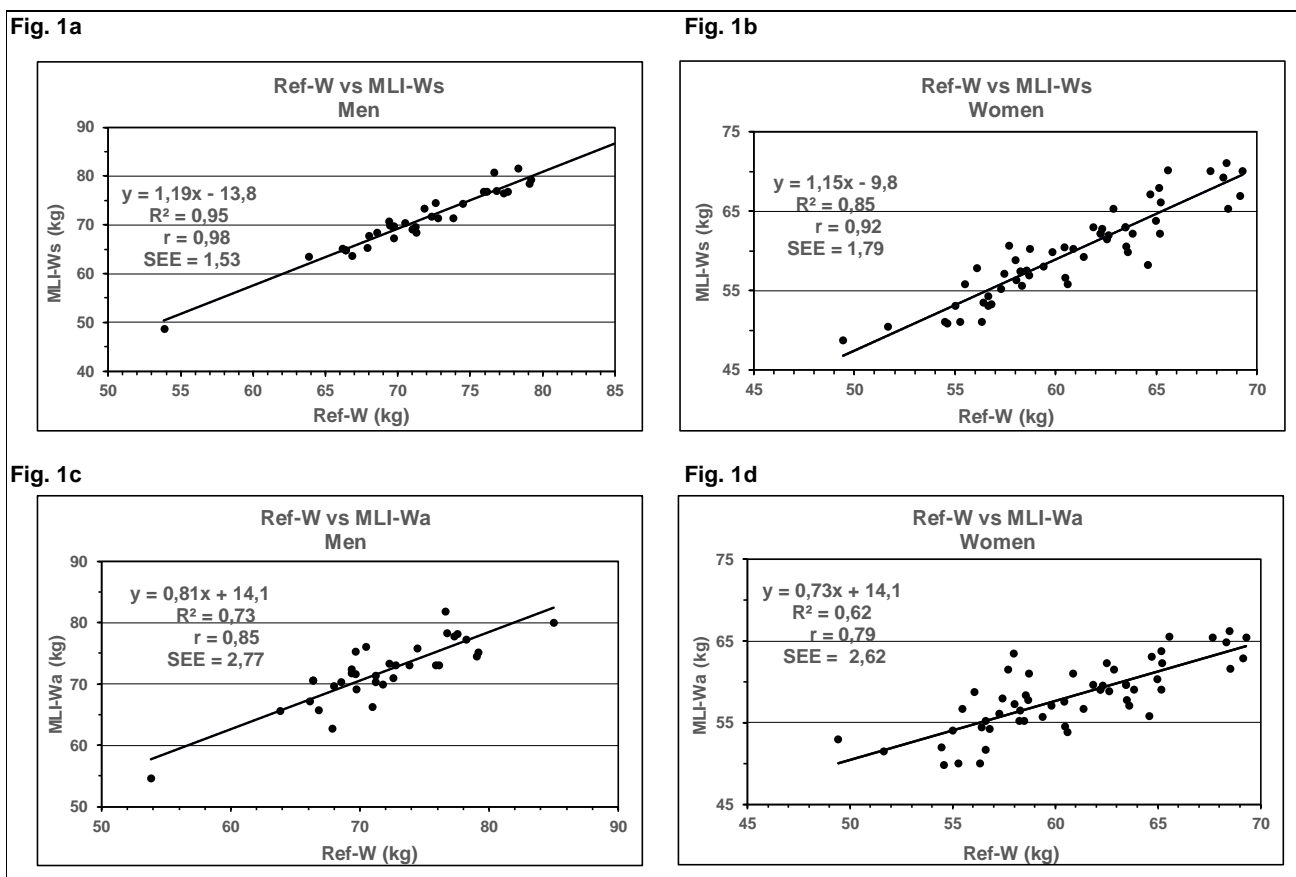


Figure 1 (a-d): Relationship between Ref-W vs. MLI-W, (s), skeleton adjusted; (a), not skeleton adjusted; for men (Fig. 1a and 1c) and for women (Fig. 1b and 1d). Solid line, regression line; (R²) determination coefficient; (r) Pearson`s correlation coefficient; (SEE) standard error of estimate.

The Ref-W is compared to the MLI-W, adjusted to the body frame (MLI-Ws) and compared to the MLI-W of the 20-24

years old participants without considering the skeleton frame (MLI-Wa). The results are plotted and analysed by

regression analysis. The determination coefficient R^2 and the standard error of estimate (SEE) are 0.95 (1.53) vs. 0.73 (2.77) for men (Fig. 1a and 1c) and 0.92 (1.79) vs. 0.62 (2.62) for women (Fig. 1b and 1d), skeleton and not skeleton adjusted, respectively. The goodness of fit is much higher and the bias much lower for the skeleton frame adjusted data indicating that the adjustment for skeleton frame improves the accuracy for the determination of the Ref-weight.

The comparison between the Ref-W and the MLI-Ws with regard to Pearson's correlation coefficient (r) and Lin's concordance correlation coefficient (CCC) revealed the

following results: $r = 0.98$ and $CCC = 0.96$ for men (Fig. 1a and Fig. 2a) and $r = 0.92$ and $CCC = 0.88$ for women (Fig. 1b and Fig. 2b), respectively. The results underline the strong concordance and reproducibility between the two data sets. Analysis according to the Bland-Altman method was created to determine absolute agreement between the body weight assessed by DBA-and MLI-system, skeleton adjusted. The limits of agreement (LOA) between DBA and MLI weight were 4.1 kg to -3.1kg (range: 7.2kg) for men and 4.7 kg to - 6.0 kg (range: 10.7 kg) for women, respectively, as shown in Fig. 2a and 2b, representing a 95% interval.

Bland-Altman Plot, comparing the Ref-Weight vs. MLI-Weight, skeleton frame adjusted, for men and women

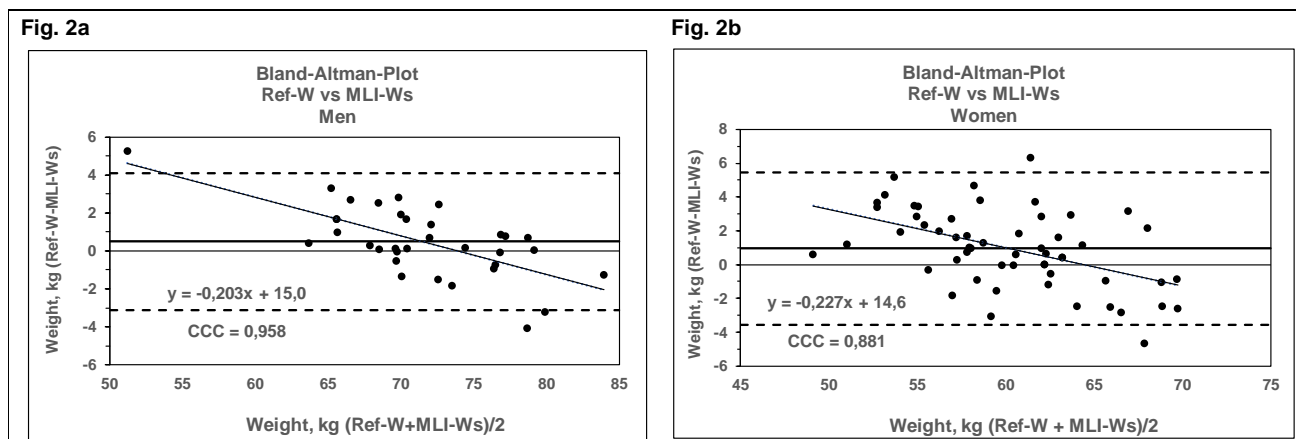


Figure 2 (a), 2 (b): Bland-Altman plot for men (a) and women (b) showing limits of agreement between the values of Ref-Weight estimated by DBA-System vs. those derived from the MLI data, (s) skeleton adjusted. Data were obtained from 90 severely obese patients. Bold continuous lines indicate the observed average agreement. Continuous lines indicate the line of perfect average agreement. Dashed lines indicate 95% limits of agreement. Equations for trend line one and Lin's concordance correlation coefficients (CCC) are shown.

MLI data underestimated body weight by 0.49 kg for men and 0.95 kg for women, respectively, compared with Ref-W data. Systematic errors were observed for the assessment of body weight using the DBA-and the MLI-method. MLI data tended to overestimate weight compared to the DBA method with increasing body weight for men and women, respectively. The reason for the systematic error is not yet clear, but MLI-measurements of participants being fully dressed and wearing shoes might be an explanation. In any case, the demonstrated error is of little clinical relevance as the bias of the two systems proves a negligible order of magnitude.

4. Discussion

This study aimed to understand, how far the "Schlegel" material might be representative for the white population and to what extent has the implementation of the hand circumference as a proxy for skeleton frame an influence on the final body weight.

Using weight-height tables based on frame size assumes that the measure of frame size provides an estimate of fat free mass intending that the result extends beyond that provided by height alone. Several authors worked out a high correlation between anthropometric diameters and circumferences, respectively, to be representative for the body frame, in particular wrist breadth [27]. Of 54 measured

sites Wilmore identified the wrist circumference to have the highest correlation with lean body weight of $r = 0.78$ for men [28] and $r = 0.70$ for women [29], respectively. Himes investigated six body breadths to be considered as frame size variables including shoulder, elbow, wrist, hip, knee and ankle [30]. He found that there is considerable variation in frame-size associations with body fat. Wrist and ankle breadths emerged as the frame measures that best satisfied the assumption of little or no associations with body fat. In contrast, breadths of shoulder, elbow, hip and knee all had partial correlations with per cent body fat and fat mass [30]. The reason for this might be the fact that the thickness of the overlaying skin and subcutaneous fat at these sites of measurements increase while subjects getting more and more overweight. These results are confirmed by an actual study working out that wrist and elbow breadth are equal with regard to lean body mass, however, wrist breadth has the lower association considering body fat percent [20]. A study of Petrofsky [31] assessed the thickness of subcutaneous fat in overweight subjects. The fat thickness on the back of the hand near the wrist between the second and third metacarpal was 0.05 cm compared to 1.09 cm on the umbilicus. The comparison of control (BMI: 23.7) and overweight (BMI: 36.4) subjects, respectively, revealed no increase of fat on the hand whilst the region of the umbilicus augmented to a level of 149 %. Seen from the point of accuracy and reproducibility of measurements, this is an important fact that even under conditions of severe obesity

in some parts of the body the subcutaneous fat tissue remains constant. The hand circumference turned out to best satisfy the assumption of little association with body fat, what is crucial in subjects developing obesity. And, because of its anatomical location, it is convenient to measure without any disrobing.

Furthermore, it is of interest how far beside the skeleton frame the other anatomical body compartments like skeleton muscle mass (SMM), lean body weight (LBW), fat mass (FM) and the organs liver and brain scale to height? Cause if a component scales differently to height, short and tall subjects will not have the same body composition. This question was elaborated by Heymsfield [32] using the traditional allometric model, which became known in its population specific form as the Benn Index (weight/height^β, with β population specific) [33]. For the same population under study, β for example equals to 2 when body weight is scaled to height and is therefore identical to the formula of BMI (weight/height²).

The results of the study [32] suggest that weight, SMM, LBW and FM all scale to height with powers of 2. A significant deviation of the β=2 rule is the scaling of bone to height with values of 2.42 and 2.48 for men and women, respectively. The consequences for the DBA-model are that lean tissue compartments need no adaption to greater stature in contrast to bone mass. The results underline the necessity that any model assessing body composition needs the implementation of a bone mass measurement.

At the end, the question remains to which extend skeleton frame shares in body weight? To estimate the range of body weight influenced by skeleton frame, the ±2s values of hand circumference (20.9±2.0 cm for men and 18.2±1.6 cm for women, respectively) are inserted into the formula (1) for men and (2) for women. The values are taken from the study of Dahlmann [16]. Based on a stature of 176.0 cm for men and 165.0 cm for women, the RefW covers a range of 65.2 kg to 73.6 kg for men and 52.6 kg to 61.2 kg for women. That means, adjusted for sex and height, a range of about 8.5 kg can be expected for both genders. The results underline the influence of the skeleton frame with regard to the final body weight and confirm the notice of L. Durmin that the wide range of weights for persons of the same sex and height is attributed to differences in body shape, at least at that time.

Already in a former study, the “Schlegel” material was compared with conscripts of the German Armed Forces and with school girls measured by the Hamburg Department of Health, respectively, indicating that the DBA model seems to reflect the body shape of the German population at that time [16]. Here the question remains open to which extend the “Schlegel” sample fits with the MLI data. The results figure out that the goodness of fit for both data sets is excellent, supporting the assumption that the “Schlegel” material represents the white American population, too. Inasmuch as the MLI weight-height tables were classified as “ideal” it means that the “Schlegel” population corresponds to this standard.

Taken together, the present data provide good evidence for the choice of hand circumference as a guiding measurement to be representative for skeleton frame. The implementation of the hand circumference as a marker for skeleton frame gave for the first time the chance to develop weight-height-frame tables. Derived from a reference population, the DBA system allows the calculation of a reference weight, which should replace the terms “desirable” or “ideal”. It should be noted that for some purposes it is immaterial whether a proposed table of ‘standard’ weights accurately portrays the average of the reference population. So long as the standard is accepted and all sets of data on individuals are referred to it, the validity of comparisons between individuals or groups will be independent of the ‘quality’ of the table [5].

Limitation to the present findings is that the model in its present form cannot distinguish between muscularity and fat tissue. In the meantime, this challenge could be resolved [34]. Efforts have to be made to subject the proposed method with relevant data others than those of obese persons of white ethnicity.

5. Conclusions

The implementation of the hand circumference into the DBA model as a proxy for skeleton frame is essential for the final body weight and resulted in a strong concordance with MLI data indicating that the DBA model may reflect the body shape of the white European and American population at that time.

Abbreviations

BMI, body mass index; Ht, height; HdC, hand circumference; W, weight; Ref-W, reference weight;

DBA, Dahlmann-Body-Analysis; MLI, Metropolitan Life Insurance;

s, m, l, a SkFr: “small”, “medium”, “large”, “average” skeleton frame;

r, Pearson correlation coefficient; CCC, Lin’s concordance correlation coefficient;

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Availability of data and materials

The datasets used during the current study are available from the corresponding author on reasonable request.

Authors’ contributions

ND is responsible for the conception and design of the study, drafted the manuscript and performed statistical analyses and visualization. DK is responsible for consultation and all measurements on patients and documentation of datasets. Both authors were engaged in interpretation and discussion of data. All authors read and approved the final manuscript.

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Ethics approval and consent to participate

All study procedures were performed according to the ethical standards of the World Medical Association's Declaration of Helsinki and was approved by the medical ethics committee of the Rheinische-Friedrich-Wilhelms-Universität, Bonn, Germany (197/19). Written informed consent was obtained from each patient prior to trial participation.

Consent for publication

Not applicable.

Competing interests

ND is the owner of the website: www.dahlmann-body-analysis.de

For scientific work, the system is free of charge.

Contact: info@dahlmann-body-analysis.de

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