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Anthropometric fractionation of body mass: Matiegka revisited

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In a group of 699 Belgian nursing professionals, we estimated body composition using the four-component anthropometric model, relying on the equations originally formulated by Matiegka in 1921 and later revised by Drinkwater and colleagues. We estimated muscle mass using the more recent formula proposed by Martin and co-workers. A discrepancy was noted between estimated total body mass and 'assessed' mass, suggesting erroneous estimations of the components.

Keywords: body composition, muscle mass, remainder mass, skeletal mass, skin and adipose tissue mass.

Introduction

Fractionation of body mass for the estimation of body composition is done by one of two methods. The chemically based approach estimates the amounts of water, fat, protein and mineral components in different body segments. The anatomical approach separates the different body segments into their constituent parts of skin, muscle, adipose tissue, bone and organs. These two approaches are fundamentally different and hence their results are not interchangeable.

The Czechoslovakian anthropologist Matiegka (1921) developed a series of formulae for the anthropometric fractionation of body mass into its anatomical components using surface anthropometric measurements. These formulae were revised by Drinkwater *et al.* (1986) and validated on cadaver data. Based on the data from the Brussels Cadaver Study (Clarys *et al.*, 1987), Martin *et al.* (1990) proposed a new approach to estimate muscle mass. Since the formulae were based on *in vitro* data, to what extent can they be used *in vivo*? To address this question, we evaluated the formulae of Drinkwater *et al.* (1986) and of Martin *et al.* (1990) in an *in vivo* anthropometric study of Belgian nursing professionals.

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Matiegka's original formulae

Matiegka (1921) developed a series of equations using groups of surface anthropometric measurements that closely relate to specific tissues. Using estimates of tissue mass inferred from cadaver data available to him at the time (Vierordt, 1906), Matiegka derived a series of coefficients for his equations which related these tissue mass estimates to surface measurements. The formulae are as follows and are expressed in grams and centimetres:

- Estimation of skeletal mass = (sum of the transverse diameters of the humeral and femoral condyles, wrist and ankle widths measured on one side of the body/4)^2 * height * k_1
- Estimation of skin + subcutaneous adipose tissue mass = 1/2 (sum of skinfolds at: upper arm above biceps, anterior side of the forearm at maximal width, thigh above the quadriceps muscle half-way between the inguinal fold and the knee, calf of the leg, thorax on the costal margin half-way between the nipples and the umbilicus, and on the abdomen half-way between the umbilicus and the superior anterior iliac spine/6) * surface area * k_2

- Estimation of muscle mass = (sum of the average radii of the extremities corrected for the thickness of the skin and subcutaneous adipose tissue, as determined from circumferences measured on the flexed arm above the belly of the triceps, the forearm at the maximum girth, the thigh half-way between the trochanter and lateral epicondyle and the leg at the maximal circumference of the calf/4)^2 * height * k_3
- Estimation of remainder mass = measured body mass * k_4

In these formulae, the coefficients were calculated to be as follows: $k_1 = 1.2$, $k_2 = 0.13$, $k_3 = 6.5$ and $k_4 = 0.206$. Based on Dubois and Dubois (1916), the surface area used in the equation for estimating skin and subcutaneous adipose tissue mass was calculated using the following formula:

$$\text{surface area} = 71.84 * \text{mass}^{0.425} * \text{height}^{0.725}$$

To verify the accuracy of the formulae, total body mass was calculated by the summation of the four components: skin plus subcutaneous adipose tissue mass + muscle mass + skeletal mass + residual mass of viscera, organs and other tissues and fluids.

Recent revisions of the formulae

Drinkwater *et al.* (1986) proposed a revision of Matiegka's (1921) formulae based on the data available from 25 cadavers aged 55–94 years. Their formulae added to the existing data on the quantities of tissues and organs in the adult human body by relating the quantities of these tissues and organs to external body measurements. They also yielded data that could be used both for validating various *in vivo* methods for the estimation of human body composition and for developing new anthropometric methods.

Using data from 13 unembalmed cadavers, the coefficients in Matiegka's (1921) formulae were substituted as follows:

- for skeletal mass: $k_1 = 0.92$
- for skin + subcutaneous adipose tissue mass: $k_2 = 0.17$
- for muscle mass: $k_3 = 7.11$
- for remainder mass: $k_4 = 0.235$

More recently, based on the results of the dissection of another 12 cadavers in the Brussels Cadaver Study, Martin *et al.* (1990) revised the formula to estimate muscle mass:

- Muscle mass = height * (0.0553 (thigh circumference corrected for the front thigh skinfold)^2 + 0.0987 (uncorrected forearm circumference)^2 + 0.0331 (calf circumference corrected for the medial calf skinfold thickness)^2) − 2445

Methods

Participants

Altogether, 784 nursing professionals were measured in four different regional and academic hospitals in Belgium. With 85 persons excluded because of incomplete data or assumed errors, 699 individuals (159 men, 540 women) were retained for statistical analysis. The age, body mass and height of the participants were as follows: men, 32.2 ± 6.5 years, 73.2 ± 11.2 kg, 1.77 ± 0.07 m (mean ±*s*); women, 32.4 ± 8.3 years, 62.1 ± 9.6 kg, 1.65 ± 0.07 m (see Table 1).

In vivo data for the four-component anthropometric model

Skinfolds were measured by means of Holtain® and John Bull® calipers. Height was measured using a Harpenden® anthropometer and circumferences by means of a metal GPM® tape. All widths were measured using recurved outside calipers (GPM®) except for the wrist (sliding caliper GPM®). All participants were weighed on a Seca® balance.

Four trained examiners took all measurements in separate rooms. All measures were taken twice. The upper extremities were measured on the right side and the lower extremities on both sides. The data were entered immediately onto the computer by four assistants, using a double-check procedure. Following Borms *et al.* (1977), the two measurements were compared with a tolerance of 10% for fat measures, 1% for height and 5% for all other measures. In the case of a discrepancy, a third measurement was taken and, using the same tolerances, compared with the first and then the second measurement. The two measures that remained within the pre-set tolerance were used for statistical analysis. Results with unacceptable discrepancy were to be excluded from all calculations. This eventuality, however, did not occur.

Body composition was estimated using the formulae of Drinkwater *et al.* (1986) for skeletal mass, skin + subcutaneous adipose tissue mass, and mass of viscera and remainder, while the formula of Martin *et al.* (1990) was used for estimating muscle mass. In this paper, the term 'assessed' is used to refer to the *in vivo* measurement of total mass, whereas the term 'estimated' is used to refer to the calculated body component mass using anthropometric formulae. Estimated total body mass, which was calculated from the sum of the four estimated body components, served as a control method.

Table 1. Physical characteristics of the participants (mean ± *s*)

	Age (years)	Height (m)	Total body mass (kg)	Body mass index
Males ($n = 159$)	32.2 ± 6.5	1.77 ± 0.07	73.2 ± 11.2	23.4 ± 3.0
Females ($n = 540$)	32.4 ± 8.3	1.65 ± 0.07	62.1 ± 9.6	22.8 ± 3.4

To demonstrate the representativeness of the population studied, somatotype was assessed using the anthropometric method of Carter and Heath (1990). Endomorphy was determined by comparing the sum of the triceps, subscapular and suprailiac skinfolds to Carter's (1975) tables. Mesomorphy was calculated by the following formula:

(0.858 * bicondylar humerus width) +
(0.601 * bicondylar femoral width) +
(0.188 * (arm circumference contracted –
(triceps skinfold/10))) +
(0.161 * (calf circumference –
(calf skinfold/10))) – (0.131 * height) + 4.5

Ectomorphy was determined by comparing the reciprocal ponderal index (RPI) to Carter's (1975) tables. The RPI was defined as (height/(mass)$^{1/3}$). The body mass index (BMI) was also calculated (see Table 1).

Statistical analysis

The mean, standard deviation (*s*) and minimum and maximum values were calculated for the assessed and estimated total body mass, for the estimated mass of the four body components and for the differences between estimated and assessed total body mass. Pearson correlation coefficients and *P*-values were calculated between assessed and estimated total body mass, and between estimated body component mass and the differences between assessed and estimated total body mass. Paired *t*-tests were performed and two-tailed *P*-values were calculated for the differences between assessed and estimated total body mass. All statistical calculations were performed using the Statistical Package for Social Sciences release 6.1 software (SPPS-6.1).

Results

Table 2 presents the results of body composition estimation using the formula of Martin *et al.* (1990) for muscle mass and the formulae of Drinkwater *et al.* (1986) for skeletal mass, skin + subcutaneous adipose tissue mass, and mass of viscera + remainder. The results indicate a substantial difference in total body mass between males and females, as expected. Mean assessed body mass in men was 73.2 kg and in women 62.1 kg. All estimations of body composition were calculated separately for men and women because of the differences in assessed body mass and the expected differences in percentages of estimated body components.

There were clear differences between men and women for the percentages of muscle mass and of skin + subcutaneous adipose tissue mass. Muscle mass estimated by the method of Martin *et al.* (1990) accounted for up to 49% of estimated total body mass in men and for 41% of estimated total body mass in women. In men, the estimated skin + adipose tissue mass was about 20% of estimated total body mass, whereas in women it accounted for more than 30% of total body mass. There were small differences between the sexes in the proportion of estimated skeletal mass, which approached 10%, and of estimated mass of viscera + remainder, which was somewhat less than 20%.

Although the correlation between assessed and estimated total body mass reached 0.96 ($P < 0.001$), there was a considerable discrepancy between estimated and assessed total body mass. Summing the different estimations of partial masses overestimates the assessed total body mass by 16.2 kg in men and 17.6 kg in women. These differences were significant ($t = -27.6$, $P < 0.001$ for men; $t = -59.7$, $P < 0.001$ for women).

Because of these discrepancies, in the next step the formula of Martin *et al.* (1990) for estimating muscle mass was replaced with the original formula of Drinkwater *et al.* (1986), and the resulting estimation of total body mass was calculated. The results were compared with the method used in this study (Table 3). The mean total body mass estimated with Drinkwater and colleagues' formulae showed even larger overestimations than those found with the combined method. Hence, it is preferable to use the formula recently proposed by Martin *et al.* (1990).

Although the use of skinfolds is controversial (Clarys *et al.*, 1987), they cannot be regarded as the only possible source of overestimation of body mass shown in this study. Even when subtracting estimated skin and adipose tissue mass from estimated total body mass as calculated by the formulae of Drinkwater *et al.*

Table 2. Body composition estimations of 669 Belgian nursing professionals, according to the methods of Drinkwater *et al.* (1986) and Martin *et al.* (1990)

	Males ($n = 159$) (somatotype 3.5–4.5–2.5)		Females ($n = 540$) (somatotype 5.0–4.0–2.0)	
	Mass (kg)*	% of total body mass	Mass (kg)*	% of total body mass
Estimated skeletal mass (Drinkwater *et al.*, 1986)	8.8 ± 1.1	9.8	6.6 + 7.2	8.3
Estimated skin + adipose tissue mass (Drinkwater *et al.*, 1986)	19.9 ± 9.7	22.3	25.9 ± 10.5	32.4
Estimated muscle mass (Martin *et al.*, 1990)	43.4 ± 6.7	48.6	32.6 ± 4.9	41.0
Estimated mass of viscera and remainder (Drinkwater *et al.*, 1986)	17.2 ± 2.6	19.3	14.6 ± 2.3	18.3
Estimated total body mass (sum of four components)	89.4 ± 17.5	100.0	79.7 ± 18.9	100.0
Assessed body mass	73.2 ± 11.2	81.9	62.1 ± 9.6	77.9

* Mean ± standard deviation.

Table 3. Total body mass estimations of 669 Belgian nursing professionals, according to the methods of Drinkwater *et al.* (1986) and Martin *et al.* (1990) (mean ± *s*)

	Males ($n = 159$)	Females ($n = 540$)
Estimated total body mass (kg)		
Drinkwater *et al.* (1986)	122 ± 20.2	103 ± 17.1
Martin *et al.* (1990)	89.4 ± 17.5	79.7 ± 15.6
Assessed total body mass (kg)	73.2 ± 11.2	62.1 ± 9.6
Estimated – assessed (kg)		
Drinkwater *et al.* (1986)	48.8 ± 9.0	40.9 ± 7.5
Martin *et al.* (1990)	16.2 ± 6.3	17.6 ± 6.0

(1986), a considerable overestimation still existed. A summation of different estimation errors probably accounts for this discrepancy. Therefore, in the next step, to ascertain which of the four fractional mass estimations is related to the overestimation of the total mass, correlations were calculated between each fractionated mass and the amount of overestimation of the total mass. The correlations between assessed total body mass and the difference between assessed and estimated total body mass were 0.77 ($P < 0.001$) in men and 0.79 ($P < 0.001$) in women (Table 4). This indicates that the individual overestimation is proportional to body mass. Furthermore, for both methods all individual values of the differences between the estimated and the assessed total body mass were positive.

The sum of the masses of the four components estimated using the formulae of Drinkwater *et al.* (1986) overestimated total body mass by 49.0 ± 9.5 kg in men and by 41.0 ± 8.0 kg in women, which is about 66% of the assessed total body mass. With the combination method, the assessed total body mass was 82% of the estimated total body mass in men and 78% in women. The correlations of the difference between assessed and estimated total body mass with the four separate body components were all significant except for skeletal mass, which ranged from moderate to high (Table 4). These correlations suggest a substantial positive association with skin and adipose tissue mass, muscle mass and remainder mass.

The mean somatotype of the males was 3.5–4.5–2.5; that of the females was 5.0–4.0–2.0. Most males were mesomorphic, with a minority of mesomorphic–endomorphs and mesomorphic–ectomorphs (see Fig. 1). The females were mainly mesomorphic–endomorphs (see Fig. 2).

Discussion

In the recent literature, hydrodensitometry, bioelectrical impedance analysis, ultrasonic measurement, near infrared interactance, computer tomography, magnetic resonance imaging and air displacement plethysmography have been used to estimate fat mass, lean body mass and other aspects of human body composition (Vansant *et al.*, 1994; Dempster and Aitkens, 1995; Reilly *et al.*, 1996; Roche *et al.*, 1996;

Table 4. Pearson correlation coefficients for different components of body composition in 669 Belgian nursing professionals

	Males ($n = 159$)	Females ($n = 540$)
Assessed TBM/estimated TBM	0.96*	0.96*
Assessed TBM/estimated − assessed TBM	0.77*	0.79*
Estimated − assessed TBM/estimated skeletal mass	0.39*	0.37*
Estimated − assessed TBM/estimated muscle mass	0.68*	0.52*
Estimated − assessed TBM/estimated skin + adipose tissue mass	0.93*	0.94*
Estimated − assessed TBM/visceral + remainder mass	0.77*	0.79*

Note: TBM = total body mass. *$P < 0.001$.

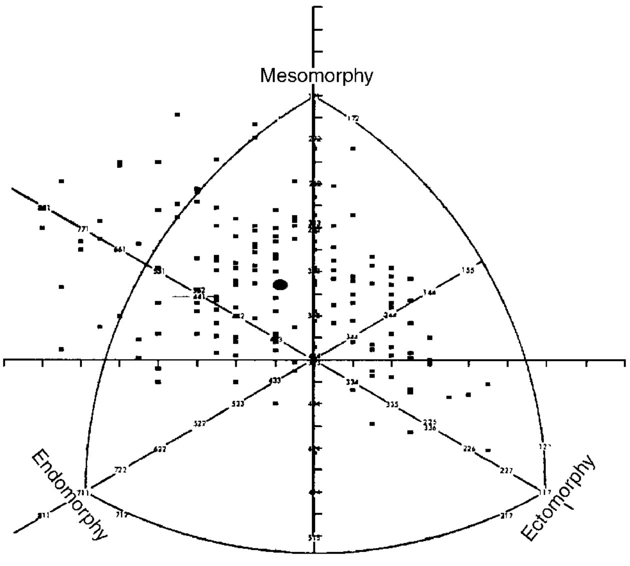

Fig. 1. Distribution of male somatotypes ($n = 159$). ●, mean somatotype (3.5–4.5–2.5).

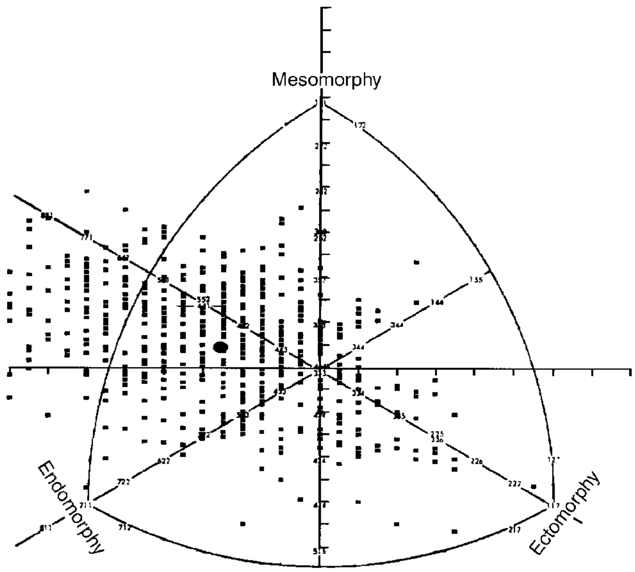

Fig. 2. Distribution of female somatotypes ($n = 540$). ●, mean somatotype (5.0–4.0–2.0).

Sutcliffe, 1996). Skinfolds have proved to be a useful measure in clinical settings and in research on body composition (Brodie *et al.*, 1998). They are often used because of their uncomplicated collection (Orphanidou *et al.*, 1994; Bonora *et al.*, 1995; Han *et al.*, 1996; Lean *et al.*, 1996; Gualdi-Russo *et al.*, 1997; Leslie and Mikanowicz, 1997; Oosthuizen *et al.*, 1997; Rolland-Cachera *et al.*, 1997).

The formulae proposed by Matiegka (1921), Drinkwater *et al.* (1986) and Martin *et al.* (1990) for the assessment of body composition were derived and validated from cadaver studies. Application of the formulae of Drinkwater *et al.* (1986) and Martin *et al.* (1990) to an *in vivo* sample of Belgian nursing professionals showed a significant discrepancy between estimated and assessed body mass: 22% (16 kg) in men and 28% (18 kg) in women. These huge discrepancies are caused by a combination of different errors that cannot be assessed accurately using this approach. One source of error may be the difference in mean age of the study sample (32 years) compared with that of the cadavers analysed by Drinkwater (1984), Drinkwater *et al.* (1986) and Martin *et al.* (1990) (all older than 50 years). Differences in skinfold compressibility, subcutaneous fat patterning and visceral fat due to age may be another source of error. Another source may be related to the use of the upper thigh girth in the present study compared with the mid-thigh girth in the original formulae of Matiegka (1921). Therefore, part of the estimation error may be related to an overestimation of the muscle mass component but it cannot, however, explain the overestimation in full. This might also explain way the use of the original muscle mass formula of Drinkwater *et al.* (1986) leads to an even larger over-estimation, although it is not clear which thigh girth was used by these authors. Another source of error may be due to the present study being performed *in vivo*. All formulae used in the anatomical approach to human body composition were derived from cadavers and were shown to be valid *in vitro*. They had never been validated *in vivo*, but they are the only method available at present in an anatomical *in vivo* approach.

To understand the problem more fully, the relationships between the four components and the overestimation of total body mass were examined. The overestimations differed between the sexes. The relatively high standard deviations of the overestimations show that these are not constant (Table 3), and the correlations in Table 4 show that the overestimations are proportionate to each individual component mass estimation, except for the estimation of skeletal mass.

A correction to compensate for the overall overestimation in total body mass does not imply that each separate component estimation is to be corrected. It may not be necessary to correct the estimation of skeletal mass based on the low correlation with the overestimation. Skeletal mass is estimated from anthropometric bony measures that were correlated with cadaver data. When dissection techniques are considered, skeletal mass can be estimated accurately, as bone is easily separated from other tissues. Therefore, cadaver analysis provides very accurate data to refer to when correlating anthropometric bony measures to skeletal mass. Young bones are also more dense than older bones. Therefore, when using cadavers, a relative underestimation is to be expected rather than an overestimation. As for the other components, it cannot be concluded that one should be overestimated or even underestimated more than the other. Hence, a similar reduction for each of the three components appears to be the most appropriate approach. It is unclear, however, whether the use of formulae derived from cadaver material is the best way to estimate body components *in vivo*.

Another way of validating adaptations to the formulae based on the present findings would be to study the concurrent validity of the alternative methods of measuring body composition; this was beyond the scope of the present study. Furthermore, differences in the anatomical and chemically based approaches to body composition, such as hydrodensitometry and bioelectrical impedance, are sometimes difficult to overcome, and both approaches rely on several basic assumptions that are often questioned (Clarys *et al.*, 1984, 1987; Drinkwater, 1984). To date, there is no 'gold standard' for the accurate measurement of body composition.

The external validity for the revision of the formulae can be supported by the somatotype distributions of the sample (Figs 1 and 2). The mean somatotype and the somatotype distributions compare well with those of other national samples of Western and North American populations (Carter *et al.*, 1973; Carter, 1980; Carter and Heath, 1990). This suggests that, after validation, new formulae may be applicable to other populations.

Conclusion

The formulae of Drinkwater *et al.* (1986) and Martin *et al.* (1990) for estimating body composition components are unsatisfactory for use *in vivo*. The formula of Martin *et al.* (1990) to estimate muscle mass gives a better estimation of total body mass than the original formula of Drinkwater *et al.* (1986).

Estimating total body mass as the sum of the masses of four body components, relying on the combined formulae of Drinkwater *et al.* (1986) and of Martin *et al.* (1990), leads to a significant overestimation of assessed body mass *in vivo*. Analysis of the correlations between the overestimation of total body mass and the sum of the estimated masses of the four body components indicates that skeletal mass is not substantially related to the overestimation. The formula for estimation of skeletal mass proposed by Drinkwater *et al.* (1986) should therefore not be altered. For the other three body components, a proportional correction can be considered.

Adaptations to equations for estimating anatomical body composition should be validated in *in vivo* anthropometric studies and compared with the findings of alternative methods for the *in vivo* estimation of body composition. Nevertheless, the findings of the present study demonstate the inappropriateness of the original formulae of Drinkwater *et al.* (1986) and Martin *et al.* (1990) for *in vivo* populations. After further validation, corrected formulae may provide an appropriate classification tool for *in vivo* occupational anthropometry, sport science, medicine and ergonomics.

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