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BODY MASS-TO-STATURE AND CHEST CIRCUMFERENCE INDICES AND THE ADEQUATE BODY MASS

ABSTRACT — To evaluate adequate human body mass is first of all a problem of health and welfare, overweight and obesity being taken as the important factors responsible for the increased risk of morbidity and mortality.

In the paper body mass adequacy is considered as its adequacy to the dimensions of skeleton, represented by the stature and chest circumference. As an alternative approach to the well-known procedure of linear regression a set of procedures has been evaluated through which body mass was estimated by means of a suitably chosen index. Prediction efficiency of all these procedures has been evaluated by means of the least squares principle which made it possible to recognize the relatively best one. Theoretical formulas have been applied in the set of 540 adult males.

KEY WORDS: Body mass — Stature — Chest circumference — Body mass index — Adequate body mass — Prediction — Prediction efficiency.

INTRODUCTION

In the recent years overweight has been under consideration in the epidemiological research among the factors responsible for the increased risk of morbidity and mortality. That is the reason why the objective criteria for the assessment of overweight are being searched for; among others also through the indices relating body mass to stature or some suitable function of stature (Stavig at al. 1984). The data on stature having been available easily, these indices are to be computed without any complications.

Let us imagine that the statistics of such an index is well-known in some reference population. Then its suitably chosen value can be taken as adequate and used in the procedure by which the adequate body mass is to be estimated of a subject whose stature value is known (Komenda, 1986 a, b).

The purpose of the study is to generalize this procedure for the set of body mass-to-stature and chest circumference indices (body mass adequacy being considered as its adequacy to the dimensions of the skeleton); information efficiency of the respective prediction functions being evaluated systematically by means of the least squares method (Komenda 1986d). In such a way the best one among the indices under study has been found able to estimate the adequate body mass for the subject of the given stature and chest circumference values, with the highest possible accuracy. This optimum accuracy itself could have been reached by means of the well-known methods of linear regression of the data or of the log-transformed data (Komenda, 1986c).

The results of theoretical analysis have been applied on the data obtained in the anthropometrical measurement of the set of 540 adults males, Ostrava miners; the data was a part of the material yielded by the research staff of the Institute of Normal Anatomy, Medical Faculty of the Palacký University in Olomouc (Head of the Institute: Doc. MUDr. Vladimír Holibka, CSc) in 1984 (Komenda et al. 1985).

BODY MASS-TO-STATURE AND CHEST CIRCUMFERENCE INDICES

In the following let us denote stature, chest circumference and body mass by the symbols X, Y and W, respectively, so that the respective indices could be introduced in a most concise formal way. X and Y are measured in cm, W in kg.

Body mass-to-stature and chest circumference indices under consideration are defined as follows (see also Martin and Saller, 1957):

$Q = \frac{W}{X}$ ... index of Quetelet-Bouchard gives the mean body mass related to one unit of stature, physical dimension of it being kg . cm^{-1}

$G = \frac{W}{X^2} 10^3$ ... index of Quetelet-Kaup-Gould measures the human body density corresponding to one cm^2 of the square the side of which equals the value of stature; physical dimension of it being g . cm^{-2}

$R = \frac{W}{X^3} 10^6$ ... index of Rohrer-Buffon-Bardeen is the mean density human body has in the cube the side of which equals the stature; physical dimension of it being mg . cm^{-3}

$C = \frac{W}{XY} 10^3$ ... by this index mean human body density is measured corresponding to one square centimeter of the cylinder surface the height and circumference of which are the same as those of stature and chest circumference; physical dimension of it being g . cm^{-2}

$K = \frac{W}{XY^2} 4\pi 10^3$ ... Mean human body density is evaluated by the index in the unit volume of the cylinder with the height equal to stature and the circumference identical with the chest circumference; physical dimension of the index being g . cm^{-3}

$D = \frac{W}{Y}$ ... index indicates the human body density on the chest circumference, i. e. body mass corresponding to one centimeter of the circle of the same circumference as that of the chest; physical dimension of the index D is kg . cm^{-1}

$E = \frac{W}{Y^2} 4\pi 10^3$ ... index indicates the human body density on the surface unit of the circle the circumference of which is the same as that of the chest Y; the surface of the circle being $Y^2/4\pi$, physical dimension of the index E is g . cm^{-2}

$F = \frac{W}{Y^3} 6\pi^2 10^3$ ... index is indicating the human body density in the unit volume of the sphere the main circle of which coincides with the chest circumference; the volume of the sphere being $Y^3/6\pi^2$, physical dimension of the index F is g . cm^{-3}

TABLE 1. *Principal statistical characteristics (mean values, variances, percentiles) of the body dimensions* X *(stature),* Y *(chest circumference),* W *(body mass) and their indices, as computed in the set of 540 adult males*

Dimension Index	Mean value	Standard deviation	Percentil				
			5	25	50	75	95
Stature X	174.90	6.72	164.5	170.0	175.0	179.5	186.0
Chest circumference Y	96.63	7.17	85.9	91.5	96.0	101.6	108.4
Body mass W	78.52	12.17	60.0	70.0	77.3	86.0	100.0
Index Q	0.4486	0.065	0.352	0.402	0.443	0.488	0.563
Index G	2.566	0.371	2.051	2.299	2.520	2.802	3.251
Index R	14.70	2.27	11.51	13.12	14.40	15.97	18.86
Index C	4.623	0.382	4.141	4.365	4.606	4.882	5.247
Index K	0.6021	0.039	0.553	0.577	0.602	0.626	0.661
Index D	0.8088	0.0763	0.682	0.757	0.806	0..856	0.932
Index E	105.3	7.61	93.0	100.3	105.1	109.8	118.0
Index F	5.166	0.573	4.30	4.75	5.16	5.50	6.18

TABLE 2. *Prediction formulas and their information efficiency in the body mass estimation. The set of* n = *540 adult males is being considered. The symbol* P *is for the respective parameter,* P ∈ {Q, G, C, R, K, D, E, F}

Prediction formula	P	$S(P)_{\min}$	$\frac{S(P)_{\min}}{n-1}$	$100\left(1 - \frac{S(P)_{\min}}{(n-1)\, s_W^2}\right)$
$w(x) = Qx$	0.4493	69 157.29	128.307	13.42 %
$w(x) = Gx^2\, 10^{-3}$	2.560	68 283.45	126.685	14.52 %
$w(x, y) = Cxy\, 10^{-3}$	4.664	23 165.85	42.979	71.00 %
$w(x) = Rx^3\, 10^{-6}$	14.521	77 327.00	143.464	3.19 %
$w(x, y) = Kxy^2\, (4\pi\, 10^3)^{-1}$	0.5983	13 969.62	25.918	82.51 %
$w(y) = Dy$	0.8164	30 059.96	55.770	62.37 %
$w(y) = Ey^2\, (4\pi\, 10^3)^{-1}$	104.90	17 496.85	32.462	78.10 %
$w(y) = Fy^3\, (6\pi^2\, 10^3)^{-1}$	4.968	43 240.85	80.224	45.87 %

Statistical characteristics (mean values, standard deviations and five most important percentiles) of the basic body dimensions X, Y, W as well as of the indices derived from them, are summarized in *Table 1.*

PREDICTION FORMULAS AND THEIR EFFICIENCY

By means of any index as introduced in the preceding section body mass can be estimated for each subject i whose values (x_i, y_i) of stature and chest circumference are being known. In the set of $n = 540$ adult males the values estimated in such a way have been compared with those measured directly, i.e. with the values w_i, $i = 1, 2, \ldots, n$. Sum of square deviations has been taken as a criterion of the estimation accuracy. Relative advantage or disadvantage of anyone among the indices under consideration can be evaluated by the results given in *Table 2.*

In the following, prediction formulas as well as formulas of their predictive efficiencies are introduced, in case of each body mass-to-stature and chest circumference index.

$\boxed{Q - \text{index}}$

Body mass W is to be estimated by means of the formula

$$w(x) = Qx \tag{1}$$

where

$$Q = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} x_i^2}, \tag{2}$$

least sum of square deviations being

$$S(Q)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i x_i)^2}{\sum_{i=1}^{n} x_i^2}. \tag{3}$$

$\boxed{G - \text{index}}$

Body mass W is to be estimated by means of the function

$$w(x) = Gx^2\, 10^{-3} \tag{4}$$

where

$$G = 10^3 \frac{\sum_{i=1}^{n} w_i x_i^2}{\sum_{i=1}^{n} x_i^4}, \tag{5}$$

least sum of square deviations being

$$S(G)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i x_i^2)^2}{\sum_{i=1}^{n} x_i^4}. \tag{6}$$

$\boxed{R - \text{index}}$

Body mass W is estimated by means of the Rohrer's index by the formula

$$w(x) = Rx^3\, 10^{-6} \tag{7}$$

where

$$R = 10^6 \frac{\sum_{i=1}^{n} w_i x_i^3}{\sum_{i=1}^{n} x_i^6}, \tag{8}$$

least sum of square deviations being

$$S(R)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i x_i^3)^2}{\sum_{i=1}^{n} x_i^6}. \tag{9}$$

$\boxed{C - \text{index}}$

Body mass W should be estimated by means of the two-variable function

$$w(x, y) = Cxy\, 10^{-3} \tag{10}$$

where

$$C = 10^3 \frac{\sum_{i=1}^{n} w_i x_i y_i}{\sum_{i=1}^{n} x_i^2 y_i^2}, \tag{11}$$

least sum of square deviations being

$$S(C)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i x_i y_i)^2}{\sum_{i=1}^{n} x_i^2 y_i^2}. \tag{12}$$

$\boxed{K - \text{index}}$

The following two-variable function is to be used in the body mass W prediction

$$w(x, y) = Kxy^2 (4\pi\, 10^3)^{-1} \tag{13}$$

where

$$K = 4\pi\, 10^3 \frac{\sum_{i=1}^{n} w_i x_i y_i^2}{\sum_{i=1}^{n} x_i^2 y_i^4}; \tag{14}$$

least sum of square deviations is

$$S(K)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i x_i y_i^2)^2}{\sum_{i=1}^{n} x_i^2 y_i^4}, \tag{15}$$

$\boxed{D - \text{index}}$

Body mass W is to be estimated from the formula

$$w(y) = Dy \tag{16}$$

where

$$D = \frac{\sum_{i=1}^{n} w_i y_i}{\sum_{i=1}^{n} y_i^2}; \tag{17}$$

least sum of square deviations between the predicted body mass values and those measured ones is

$$S(D)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i y_i)^2}{\sum_{i=1}^{n} y_i^2}, \tag{18}$$

$\boxed{E - \text{index}}$

Body mass W can be estimated by means of the formula

$$w(y) = Ey^2(4\pi\ 10^3)^{-1} \tag{19}$$

where

$$E = 4\pi\ 10^3 \frac{\sum_{i=1}^{n} w_i y_i^2}{\sum_{i=1}^{n} y_i^4}; \tag{20}$$

least sum of square deviations can be obtained as follows

$$S(E)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i y_i^2)^2}{\sum_{i=1}^{n} y_i^4}. \tag{21}$$

$\boxed{F - \text{index}}$

Body mass W is to be predicted from the formula

$$w(y) = Fy^3(6\pi^2\ 10^3)^{-1} \tag{22}$$

where

$$F = 6\pi^2\ 10^3 \frac{\sum_{i=1}^{n} w_i y_i^3}{\sum_{i=1}^{n} y_i^6}; \tag{23}$$

which yields the following for the least sum of square deviations

$$S(F)_{\min} = \sum_{i=1}^{n} w_i^2 - \frac{(\sum_{i=1}^{n} w_i y_i^3)^2}{\sum_{i=1}^{n} y_i^6}. \tag{24}$$

LINEAR REGRESSION AS A METHOD OF BODY MASS PREDICTION

By the well-known method of three-dimensional linear regression of W (body mass) on X (stature) and Y (chest circumference) the following regression function

$$w(x, y) = -132.27 + 0.4133x + 1.4333y \tag{25}$$

has been derived, by means of which body mass W is to be estimated from the known values of stature X and chest circumference Y. Residual variance of W — X and Y having been known — was found to be 23.503 so that prediction efficiency has been evaluated to reach 84.14 %. Comparison with the last column of *Table 2* shows that this value is only little over the respective efficiency of the procedure based on K-index (this efficiency being 82.51 %). Of course, in such a comparison it should be taken into account that there are three parameters in the linear regression model against only one engaged in the prediction based on the K-index. That is the reason why this last procedure is to be estimated as a very successful one.

To explain this relatively high efficiency K-index has in the body mass prediction, an optimum formula of the kind

$$w(x, y) = Ax^B y^C \tag{26}$$

has been searched for; this optimum being considered in the meaning of the "least square" criterion.

By the method of linear regression of the dependent variable log W on the independent variables log X and log Y the predictor (26) has been proved to be optimum in the case of $B = 1$, $C = 1.75$, which turns (26) into the form

$$w(x, y) = 0.185\,477 \,.\, 10^{-3} x^{0.9611} y^{1.7472}. \tag{27}$$

Prediction efficiency of the formula (27) was found to be 83.77 %.

By this finding the relatively high efficiency in the body mass prediction through the procedure based on the K-index can be explained; the powers of X and Y are very close each other in both these cases (Komenda, 1986c).

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