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VALIDITY OF CALCULATIONS OF BODY COMPOSITION BY MEANS OF VARIOUS REGRESSION EQUATIONS IN FOUR CZECH POPULATION GROUPS

Assessment of the body fat in live subjects is an important functional indicator, which is important not only with regard to the nutritional status but also for the prevention of some diseases. Thus e.g. an increase of the body fat ratio is associated with higher blood lipid levels which are risk factors of cardiovascular diseases (Barnes 1973, Kannel 1974, Lewis et al. 1974, Rosenman et al. 1975, and others).

Several methods were elaborated for the assessment of body composition in vivo. The most is very pretentious as regards equipment and time (densitometry, estimation of body potassium by means of ^{40}K, estimation of cyclopropane or ^{25}Kr output, assessment of creatinine in urine, estimation of total body water and others) and these methods are not suitable for surveys in large population groups.

Several authors therefore concentrated their attention to the anthropometric assessment of body composition. Based on the most closely correlating somatometric measurements indices or regression equations were prepared according to which the lean body mass (LBM) and percentage body fat (%F) or body density (D) of the investigated subjects can be calculated.

The results of these equations correlate as a rule very well with the densitometric estimation of body composition in the population group for which they were elaborated. Usually they are not so suitable for populations which differ as regards age, physical activity, height, weight or geographical position. Therefore we tried to compare the applicability of some regression equations in four different groups of the Czech urban population. The groups differed as to sex, age, and physical activity.

MATERIAL AND METHODS

The investigation was conducted in 223 subjects divided into the following four groups:

Ist group 81 men aged 18 to 35 years with a medium grade physical activity

IInd group 28 young physically active men aged 19—22 years

IIIrd group 75 women aged 18—35 years with a medium grade physical activity

IVth group 39 obese women, patients of the First Research Unit of Internal Medicine, aged 18 to 52 years.

More detailed physical characteristics of the groups are presented in *table 1.*

From data in the literature the following regression equations were selected:

A. Percentage of body fat:

1. Y u h a s z (1962):
%F = 5.783 + 0.153 [skinfold on triceps*) + subscapular*) + abdomen*) + suprailiac*)]

2. M ö h r (1969):
F% women = −20.9 + 17.305 × lg skinfold on triceps + 12.012 × lg (ssc + axillary) + 6.293 × lg skinfold on abdomen
F% men = −16.2 + 9.367 × lg triceps + 13.462 × lg (ssc + axillary) + 5.298 × lg skinfold on abdomen
skinfolds in mm

3. A l l e n et al. (1956):
total body fat in kg =

$$\frac{\text{body weight in kg} \times \frac{\text{sum of 10 skinfolds} - 40}{20} \times \text{body surface sq. m.} \times 0.739 - 0.0030}{\text{body weight in kg}}$$

x) our calculation was modified by reducing the number of skinfolds from 10 to 5: subscapular, abdominal, axillary, suprailiac and triceps.

B. Density:

1. G o w g i l l (1957):

$$D = 0.8 \times \frac{(\text{height in cm})^{0.242}}{(\text{weight in g})^{0.1}} + 0.162$$

2. S l o a n et al (1967):
D = 1.1043 — (0.001327 × skinfold on thigh) — (0.00131 × ssc)
3. K a t c h et al. (1973)
D women = 1.09246 — [0.00049 × ssc*)] — (0.00075 suprailiac skinfold) × [0.00710 × width of elbow**)] — (0.00121 × circumfer. of thigh)
D men = 1.10986 — (0.00083 × triceps) (0.00087 × ssc) — (0.00098 × abdominal circumference) + (0.00210 × circumference of forearm)

C. Lean body mass:

1. W i l m o r e, B e h n k e (1968):
LBM = 10.260 + (0.7927 × body weight) (0.3676 × skinfold on abdomen)
2. W i l m o r e, B e h n k e I (1969):
LBM = 10.138 + (0.9259 × body weight) — (0.1881 × skinfold on thigh) + (0.6370 × ic — ic) + (0.4888 × circumference of neck) — (0.5951 × circumference of abdomen across the navel)
3. W i l m o r e, B e h n k e II (1969):
LBM = 39.6520 + (1.0932 × body weight) + (0.8370 × ic—ic) + (0.3297 × max. abdom. circumference) — (0.6478 × knee circumference)
4. P i e t e r s (1972):
LBM = 12.546 + (0.781 × body weight) — (0.408 × skinfold on abdomen)

In each of the 223 subjects the following characteristic were assessed:

1. height — by means of an anthropometer with an accuracy of 0.5 cm
2. body weight on a lever balance with an accuracy of 0.1 kg
3. skinfolds on the triceps — above the m. triceps brachii, half-way the acromion and olecranon;
on the subscapulare — beneath the lower angle of the scapula;
on the suprailiac — above the iliocristale, on the right side on the axillary line;
on the abdomen — horizontally on the right from the navel;
on the axillary — vertically in the centre of the axillary line at the level of the 9th rib;
on the thigh — above the m. quadriceps femoris, half-way between the hip and knee.

The skinfolds were measured on the dominant side of the body (on the right in right-handed subjects and on the left in left-handed ones) by means of an Allen-Best caliper with a constant spring tension of 10 g/1 mm^2 and a contact surface of 7 sqmm. The data are given in mm.

4. Bodily circumferences were measured by a tape measure with an accuracy of 0.5 cm:
on the arm with the biceps relaxed at the site of the maximum bulge of the m. biceps brachii, at the right angle to the axis of the arm;
on the forearm — at the site of the maximum circumference with the arm stretched and supine;
on the thigh — with the legs slightly apart at the site of maximum development of the thigh, at a right angle to the axis of the lower extremity;
on the leg — across the maximal bulge of the m. gastrocnemius, at a right angle to the axis of the burdened lower extremity;
gluetal — dorsally across the maximum bulge of the m. gluteus maximus, ventrally across the symphysis ossis pubis;
abdomen min. — laterally between the lowest process of the costal arch and the iliocristale;
abdomen max. — laterally across the iliocristale, ventrally ocross the navel;
neck — horizontally — closely below the larynx;

*) *skinfolds in mm*

*) *subscapulare*

**) *our calculation was modified by replacing width of elbow by circumference of forearm*

TABLE 1

Physical characteristics of four population groups

Parameter	Group — men				Group — women			
	I. n = 81		II. n = 28		III. n = 75		IV. n = 39	
	x̄	s.d.	x̄	s.d.	x̄	s.d.	x̄	s.d.
age	24,8	3,96	20,8	1.01	22.9	3.23	36.1	8.98
weight in kg	73.28	9.11	72.44	7.38	61.99	8.37	107.57	23.03
height in cm	185.83	18.77	176.47	5.48	164.91	6.13	163.80	6.63
density g/ml	1.095	0.010	1.070	0.000	1.030	0.011	0.9913	0.014
% fat	16.66	6.52	13.78	3.59	28.22	7.82	42.80	6.48
LBM in kg	63.10	9.08	62.45	7.11	44.28	6.12	60.93	10.28
body surface	1.89	0.16	1.87	0.11	1.68	0.12	2.08	0.21
skinfolds in mm								
triceps	8.50	3.75	8.96	3.13	16.43	5.03	23.23	5.60
subscapular	10.91	3.37	10.29	3.10	13.82	10.52	28.21	7.56
suprailiac	14.59	6.77	13.82	4.64	15.35	7.08	27.83	6.73
abdomen	13.30	8.00	14.36	4.72	20.91	10.01	34.28	9.29
axillary	5.21	3.15	4.75	2.13	8.67	4.75	16.53	5.83
thigh	13.50	4.30	11.78	3.92	19.24	7.11	30.20	10.59
circumference in cm								
forearm	27.60	1.68	27.11	1.50	24.55	1.73	27.27	2.47
arm	29.21	2.33	28.13	1.51	27.06	2.34	36.01	4.39
calf	37.85	3.21	38.11	2.80	36.86	2.56	42.93	4.05
thigh	53.91	4.28	51.47	3.00	57.35	3.96	72.65	7.22
gluteal	95.53	5.53	93.21	4.92	97.86	6.27	128.59	16.06
abdomen min.	79.36	6.94	81.25	4.41	71.92	7.34	110.57	16.24
abdomen max.	94.65	7.86	83.39	3.62	99.28	8.24	138.55	18.35
neck	38.33	2.19	36.57	1.91	34.23	2.08	39.24	4.21
knee	37.25	1.95	35.13	1.50	35.78	2.01	43.11	5.05
ic — ic	28.11	1.82	27.59	1.80	27.61	2.16	34.49	3.22

knee — across the centre of the patella with the lower extremity slightly flexed, not burdened.

5. Bone measurements:
   ic—ic — by means of a pelvimeter with an accuracy of 0.5 cm as the minimal distance of the iliocristal points.
6. The body surface was calculated according to Du Bois equation (Vandervael 1964):
   body surface in sqm = 0.425 log body weight in kg + 0.725 log height in cm + log 71.84
7. The density was assessed by the method of hydrostatic weighing according to Keys and Brožek et al. (1963) and the percentage of body fat (%F) according to equations of Brožek et al. (1963) ($\%F = 100 \times \frac{4.57}{D} - 4.142$). The calculation of LBM was made according to the equation of Brožek et al. (1963):

$$LBM = \text{body weight} - \frac{\text{body weight} \times \%\ \text{body fat}}{100}$$

RESULTS

Detailed physical characteristics of the four investigated groups are presented in *table 1.*

The lowest percentage of body fat (13.78 %) was, as expected, found in the group of physically active men, the highest percentage (42.80 %) in obese women. The men with medium physical activity had 16.66 % body fat, women 28.22 %.

If these results are compared with some groups in other countries, it is apparent that the percentage of fat in both groups of men is similar as mean values assessed by Behnke (1963), Damon et al. (1964), Wright et al. (1972), Katch et al. (1973), Krziwicki et al. (1974) and Wang et al. (1974) where the percentage of body fat is within a range of 13.5—17.8 %. Our values in both groups of men were lower than the mean values published by Howell et al. (1962) — 18.8 % and higher than 10.9—10.8 assesed by Brožek et al. (1951) and Sloan (1967) respectively.

Our results in normal women with medium physical activity are somewhat higher than the mean findings of Katch et al. (1973), who found 25.6 ±6.4 % fat, Hampton et al. (1966) 19.03 %, Durnin et al. (1967) 24.2 % and Hauchuc (Krziwicki 1974): 5.0—39.2 %.

These discrepancies are probably due to inborn differences between the investigated groups.

It is also worth attention that the difference in the subcutaneous fat between the two groups of men studied was small, although the difference in total body fat was 3 %.

In every subject in these four groups according to the above regression equations values of the percentage of body fat, density and LBM were calculated. These theoretical values were compared by

TABLE 2

Correlation of the percentage of body fat assessed densitometrically and anthropometrically according to different authors

AUTHOR	Initial parameter	GROUP I. men	n = 81	II. men	n = 28	III. women	n = 75	IV. women	n = 39
		r	P	r	P	r	P	r	P
Yuhasz (1962)	skinfolds: triceps subscapular suprailiac abdomen	0.324	0.01	0.410	0.05	0.498	0.001	0.525	0.001
Möhr (1969)	skinfolds: triceps subscapular axillary abdomen	0.283	0.01	0.421	0.05	0.388	0.001	0.542	0.001
Allen (1956)	10 skinfolds: body surface body weight	0.329	0.01	0.383	0.05	0.511	0.001	0.619	0.001

TABLE 3

Correlation of density assessed by hydrostatic weighing and anthropometrically accordig to different authors

AUTHOR	Initial parameters	GROUP I. men	n = 81	II. men	n = 28	III. women	n = 75	IV. women	n = 39
		r	P	r	P	r	P	r	P
Gowgill (1957)	body weight height	0.175	NS	—0.004	NS	0.300	0.01	0.641	0.001
Sloan (1967)	skinfolds: subscapular thigh	0.344	0.01	0.334	NS	0.403	0.001	0.505	0.01
Katch (1973)	skinfolds: subscapular triceps suprailiac abdominal circumference circumference forearm circumference of thigh	0.302	0.01	0.229	NS	(0.079)*	(NS)	(0.126)*	(NS)

* *Unsuitable modification of Katch's equation for wome, NS not significant*

correlation analysis with actual values. The results are summarized in the following three tables.

Table 2

From the table 2 it is apparent that the percentage of body fat calculated from anthropometric data correlates more closely in women than in men of our groups. The highest correlation coefficients for all three equations were found in obese women, the lowest ones in physically active young men. From the table, it is also apparent that for obese women of our groups Allen's equation is best for the calculation of body fat. The same applies to the group of men and women with a normal habitus and medium grade physical activity. For physically active young men the relatively most suitable index is Möhr's which, however, correlates only at the 95 % level of significance.

Table 3

Also the density assessed by calculation from regression equations correlates more closely with the density assessed by hydrostatic weighing in both groups of women. For physically active young men no of the selected regression equations was suitable. For men with a medium grade physical activity in our group Gowgill's equation did not prove suitable. The latter equation was most suitable for obese women, despite the fact that it was elaborated and used for American normal men. The results of Katch's equation cannot be compared in any group

TABLE 4

Correlation of LBM assessed densitometrically and anthropometrically according to different authors

AUTHOR	Initial parameters	GROUP I. men r	I. n = 81 P	II. men r	II. n = 28 P	III. women r	III. n = 75 P	IV. women r	IV. n = 39 P
Wilmore + Behnke (1968)	body weight skinfold abdomen	0.582	0.001	0.988	0.001	0.750	0.001	0.888	0.001
Wilmore + Behnke (1969) I.	body weight skinfold thigh ic — ic circumfer. neck circumfer. thigh circumfer. abdomen max.	0.234	0.05	0.838	0.001	0.522	0.001	0.762	0.001
Wilmore + Behnke (1969) II.	body weight ic — ic circumfer. knee circumfer. abdomen min. circumfer. abdomen max.	0.304	0.01	0.884	0.001	0.397	0.001	0.723	0.001
Pieters (1972)	body weight skinfold abdomen	0.280	0.025	0.989	0.001	0.5351	0.001	0.886	0.001

of women, as our modification of the equation replacing the width of the elbow by the circumference of the forearm was not suitable.

Table 4

The densitometrically assessed amount of lean body mass correlates with the theoretical calculation very closely in all four investigated groups. The correlation coefficients are highest as compared with the density or the percentage of fat. Rather surprising were the high correlations in groups of physically active men where the actual density did not correlate with the calculated one.

For the calculation of LBM based on anthropometric measurements according to our results the regression equation of Wilmore et al. (1968) was most suitable. The latter is based on body weight and the abdominal skinfold. These two dimensions are, as it seems, good indicators of LBM. Similar results are obtained also with Pieter's (1972) regression equation which is also based on body weight and the abdominal skinfold.

Wilmore's equations I and II (1969) based on body weight, the skinfold on the thigh the bicristal width and the circumference of the neck, thigh and abdomen correlate relatively least in the group of men with a medium grade physical activity (n = 81).

DISCUSSION

Among the regression equations used for the calculation of body composition the equation for the calculation of LBM appears most suitable. We find that, as compared with density and the percentage of body fat, the correlation coefficients are highest, regardless of the type of populations group.

For the calculation of the percentage of body fat according to our results Allan's equation is most suitable. For the calculation of density the highest regression coefficients were obtained with Sloan's equation, for the calculation of LBM with Behnke's equation. In all selected indices we find more significant correlation in women, in particular in obese women.

If we compare mean values of body fat assessed by densitometry with values calculated from anthropometric measurements, we can see that Yuhasz' equation is suited best for the group of physically active young men ($\bar{x}$ density assessed $= 13.78 \pm 3.50$, $\bar{x}$ density calculated $= 13.04 \pm 2.09$; r = 0.4101). Möhr's equation gives the closest mean value in both groups of women: women n = 75 : $\bar{x}$ dens. $= 28.22 \pm 7.82$, $\bar{x}$ calc. $= 29.61 \pm 8.57$; r = 0.388; obese women n = 39 : $\bar{x}$ dens. $= 42.80 \pm 6.48$, $\bar{x}$ calc. $= 45.95 \pm 10.02$; r = 0.5418.

Allen's equation displays, while the correlation coefficients are relatively high, great differences in the mean values of the percentage of fat assessed densitometrically and by calculation (see *table 5*).

As regards density, all values obtained densitometrically are lower than the values obtained by calculation. The relatively highest correlation coefficient was recorded with Gowgill's equation for obese woman and Sloan's equation for men with a medium grade physical activity (see *table 6*).

The equations for the calculation of LBM gave the best results; the mean values assessed densitometrically were almost identical with values calculated according to Wilmore's equation for both groups of men (see *table 7*). The regression equation of results according to Wilmore's equation reads as

TABLE 5

Comparison of values obtained by using regression equations for the calculation of the percentage of fat with assessed values

AUTHOR	Variables used	Group		n	Values assessed		Values calculated		Correlation		
					$\bar{x}$	s.d.	$\bar{x}$	s.d.	Original invest. r	Our invest. r	P
Yuhasz (1962)	skinfold: triceps	young		81	16.66	5.52	13.02	3.39	0.788	0.324	0.01
	subscapular	sportsmen	men	28	13,78	3.59	13.04	2.09		0.410	0.05
	abdomen	USA		75	28.22	7.82	15.96	4.00		0.498	0.001
	suprailiac		women	39	42.80	6.48	22.99	3.14		0.525	0.001
Möhr (1969)	skinfold: triceps	workers GDR	men	81			18.45	15.45	?	0.283	0.01
	subscapular	16—65 yrs.		28			18.95	5.76		0.421	0.05
	abdomen	n = 603 men	women	75			29.61	8.57		0.388	0.001
	axillary	378 women		39			45.95	10.02		0.542	0.001
Allen (1956)	body weight			81			7.84	5.80	?	0.329	0.01
	body surface	inhab. of	men	28			7.10	3.62		0.383	0.05
	sum of skinfolds	Formosa		75			10.53	5.53		0.511	0.001
			women	39			26.33	6.79		0.619	0.001

TABLE 6

Comparison of values obtained by using regression equations for the calculation of density with assessed values

AUTHOR	Variables used	Group		n	Values assessed		Values calculated		Correlation		
					$\bar{x}$	s.d.	$\bar{x}$	s.d.	Original invest. r	Our invest. r	P
Gowgill (1957)	body weight	normal adult		81	1.059	0.010	1.075	0.011	Wilmore	0.175	NS
	height		MEN	28	1.070	0.009	1.075	0.004	+	—0.004	NS
		males USA		75	1.030	0.011	0.074	0.013	Behnke	0.300	0.01
			WOMEN	39	0.991	0.014	1.026	0.018	0.519	0.641	0.001
Sloan (1967)	skinfold: thigh	young men	MEN	81			1.072	0.014	Wilmore	0.344	0.01
	subscapular	Capetown		28			1.072	0.008	+	0.334	NS
			WOMEN	75			1.062	0.036	Behnke	0.403	0.001
				39			1.022	0.018	0.845	0.505	0.01
Katch (1973)	skinfold: triceps	physically	MEN	81			1.074	0.009	Men: 0.86	0.302	0.01
	subscapular	active college		28			1.188	0.108	Women: 0.84	0.229	NS
	suprailiac	students									
	circumference: forearm	men = 53	WOMEN	75			1.179	0.193		(0.079)	
	abdomen	women = 69		39			1.164	0.011		(0.127)	
	thigh	New York									
	width of elbow										

compared to the results obtained by densitometry, as follows:

$$\text{men } n = 81 : y = 33.36 + 0.4712\,x$$
$$\text{men } n = 28 : y = 10.71 + 0.8277\,x$$
$$\text{women } n = 75 : y = 25.55 + 0.5910\,x$$
$$\text{women } n = 39 : y = 3.705 + 1.4204\,x$$

The applicability of the published regression equations for the calculation of body composition based on anthropometric data depends among others also on the type of population for which the regression equations were elaborated.

Yuhasz' (1962) regression equation for the calculation of the percentage of body fat was prepared for young sportsmen in the USA, Möhr's (1969) group was formed by men and women workers living in the GDR. Allen et al. (1956) prepared their equations for the population (men and women) of Formosa.

TABLE 7 *Comparison of values obtained by using regression equations for the calculation of LBM with assessed values*

AUTHOR	Variables used	Group		n	Values assessed		Values calculated		Correlation		
					$\bar{x}$	s.d.	$\bar{x}$	s.d.	Original invest. r	Our invest. r	Our invest. P
Wilmore (1968)	body weight skinfold abdomen	men USA	MEN	81	63.10	9.08	63.09	7.36	0.886	0.582	0.001
				28	62.45	7.10	62.40	5.96		0.988	0.001
			WOMEN	75	44.28	6.12	51.71	4.80		0.750	0.001
				39	60.93	10.28	82.84	16.44		0.888	0.001
Wilmore (1969) I	body weight ic — ic circumfer. neck circumfer. abdomen max. skinfold thigh	young men USA n = 133		81			64.67	6.87		0.234	0.05
			MEN	28			57.83	11.38	0.958	0.838	0.001
				75			56.40	5.74		0.522	0.001
			WOMEN	39			79.73	14.75		0.762	0.001
Wilmore (1969) II.	body weight ic — ic circumfer. knee circumfer. abdomen max. circumfer. abdomen min.	young men USA n = 133	MEN	81			77.50	7.18		0.304	0.01
				28			72.43	10.63	0.953	0.884	0.001
			WOMEN	75			74.91	7.06		0.397	0.001
				39			99.12	16.58		0.723	0.001
Pieters (1972)	body weight skinfold abdomen	physically active young men n = 48	MEN	81			64.35	5.59		0.280	0.05
				28			63.26	5.90	0.809	0.989	0.001
				75			52.43	4.63		0.535	0.001
			WOMEN	39			82.46	16.05		0.886	0.001

Sloan's (1967) equation for the calculation of density was elaborated for normal young men in Capetown, while Gowgill's (1957) equation was prepared for adult men in the USA. Katch' et al. (1973) calculated the regression equation for physically active university male and female students in New York.

Pieters' (1972) equation for the calculation of LBM is based on the population of physically active young men and Wilmore's and Behnke's equations (1968, 1969) were prepared for young university students from California (see *tables 5, 6, 7*).

From our results it is obvious that relatively most reliable are all the equations for the group of obese women aged 18—52 years and least useful they are for the group of physically active young men.

Despite the fact that the majority of the selected equations was based on measurements of the male population, the values assessed by densitometry- (percentage of body fat, density and LBM) correlate better in women than in men.

Several studies revealed that the density in men can be calculated from several skinfolds with an accuracy which varies for junior and senior men between r = 0.74 to 0.87 (Durnin et al. 1967, Pascale et al. 1956, Siri 1956). Similarly other studies provide evidence that the LBM can be assessed from bodily circumference and bone measurements with an accuracy of r = 0.71 to 0.92 (von Döblen 1959, Wilmore et al. 1968). Wilmore et al. (1969) compared the applicability of Yuhasz (1962), Gowgill's (1957), Sloan's (1967) and Wilmore's (1969) equations in 135 male students of California University. They obtained correlation coefficients varying between r = 0.519 (for Gowgill's equation) to r = 0.788 (for Yuhasz' equation).

Our correlation coefficients for young physically active men were in Yuhasz' equation 0.4101 ($P < 0.01$), Gowgill's — 0.0041 (NS) and Sloan's r = 0.3337 (NS). Gowgill's and Sloan's equations were not suitable for the calculation of density in our group of physically active young men.

The majority of tested regression equations is suitable in cross- sectional field studies when a rough estimate of body composition is required in large population groups. In clinical studies where a greater accuracy of individual evaluation is needed, the regression equations based on anthropometric measurements are applicable with an accuracy of ± 2 to 4 % fat (± 1 s.d.). From this variability it is obvious that the use of regression equations should be limited only to individuals with similar physical characteristics.

SUMMARY

In a group of 223 subjects divided by sex and physical activity into four groups the authors compared the body composition assessed densitometrically with values obtained by calculation based on anthropometric measurements, using regression equations of various authors.

For the group of 18—35-year-old men with a medium grade physical activity Yuhasz' (1962) equation for the calculation of body fat was most suitable. For the calculation of density in this group Sloan's (1967) equation was best. For LBM Wilmore's (1969) equation was most satisfactory.

In the group of physically active men for the calculation of the percentage of body fat Möhr's (1969) equation was suited best, for the calculation of density no of the selected regression equations proved useful and for the calculation of LBM Wilmore's (1968) equation was best.

In women aged 18—35 years with a medium physical activity for the calculation of the percentage of body fat Allen's equation (1956) was best, for the calculation of density Sloan's (1967) equation and for LBM the equation of Wilmore et al. (1968).

In the group of obese women aged 18—52 years for the calculation of body fat Allen's equation (1956) was suited best, for the calculation of density Gowgill's (1957) equation and for LBM that of Wilmore et al. (1968).

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