THE SPECIFIC GRAVITY OF HEALTHY MEN

BODY WEIGHT ÷ VOLUME AS AN INDEX OF OBESITY

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The fundamental biologic determination of corporeal specific gravity, essentially a relationship between weight and unit volume, has been neglected in the modern classification of healthy persons. Stern (1) and Spivak (2) emphasized the value of the measurement of corporeal density, but their experimental data are not conclusive. Of especial interest is the relationship between gravity and the fat content of the body.

The presence of an indeterminate amount of excess adipose tissue renders difficult any precise computation, for example, of metabolic rate or dosage of drugs in terms of total body weight. The important consideration should be the weight of the lean body representing the active mass of protoplasm.

In this paper the data support the concept that the comparatively low specific gravity of fat makes the measurement of the specific gravity of the body mass valid for the estimation of fat content.

The comprehensive, statistical analysis of Boyd (3), however, covering seven hundred and eighty-seven values reported since 1906 does not permit a classification of individuals with respect to obesity. The analyzed results (3), moreover, obtained by different investigators elude comparison by reason of the unknown quantity of air present in the lungs when the measurements were made.

In the present investigation the values of specific gravity obtained on ninety-nine healthy naval men in the 20 to 40 year age group were corrected by determining the residual air volume. The results obtained permit the classification of individuals as to degree of obesity and serve as a single index of physical fitness to supplement the standard age-height-weight tables which frequently lead to a designation of overweight for well developed men in contrast with a designation of normal weight for more obese individuals who fall into a lower weight group.

METHOD OF PROCEDURE

The essential measurement is that of body volume, which, based on Archimedes' principle, can be conve-

Behnke AR, Feen BG, Welham WC. The specific gravity of healthy men. *JAMA*. 1942;118:495-498.

Special thanks to Judy Roberts of the Pennington Information Center for help in acquiring this and reference documents.

The material in this article should be construed only as the personal opinion of the writers and not as representing the opinion of the writers and not as representing the opinion of the Navy Department officially.

1. Stern, H.: Investigations on Corporeal Specific Gravity and on the Value of This Factor in Physical Diagnosis, M. Rec. 59: 204-207, 1901.
2. Spivak, C. D.: The Specific Gravity of the Human Body, Arch. Int. Med. 15: 628-642 (April) 1915.
3. Boyd, Edith: The Specific Gravity of the Human Body, Human Biology 5: 646-672 (Dec.) 1933.

TABLE 1.–*Example Illustrating the Method of Computing Specific Gravity*

	Pounds	Kilograms
Weight of the body in air	183.00	83.20
Weight in water, full inspiration	14.20	6.45
Weight in water, complete expiration	23.20	10.55
Vital capacity computed from the volume of water displaced ... 4,090 cc.		
Vital capacity by spirometric measurements ... 4,150 cc.		
Volume of residual air ... 1,200 cc.		
Weight of abdominal belt	13.75	6.25
Corrections		
Gross weight in water	23.20	10.55
Weight of belt	13.75	6.25
Weight in water, not corrected for residual air	9.45	4.30
Correction for residual air (1,200/453)	2.65	1.20
Net weight in water	12.10	5.50

$$\text{Specific gravity} = \frac{\text{Weight}}{\text{Volume}} = \frac{183}{170.9} = 1.071$$

niently determined by the method of hydrostatic weighing, i.e. equivalent volume = weight in air – weight in water. The weight in water is determined by suspending a subject below the surface of the water on a line leading up to a spring scale graduated in ounces. A weighted lead belt maintains negative buoyancy for all types of persons.

Two weighings in water serve to check the accuracy of the procedure: one at the completion of maximum inspiration and the other at the end of maximum expiration.

The difference in weight obtained record hydrostatic displacement, which serves as a measure of vital capacity. This determination of vital capacity when corrected for the effect of the mean hydrostatic pressure on thoracic volume gives values comparable to those obtained by the standard method employing spirometry.

In the determination of residual air, the inhalation of a helium-oxygen mixture for a period of three minutes following maximal expiration brought about a removal of the residual nitrogen. The subsequent washing out during normal respiration of the previously inhaled helium with 50 liters of air or oxygen permitted an accurate computation of residual pulmonary volume comparable to unpublished results obtained by Willmon and Behnke using the nitrogen dilution method. Duplicate determinations usually gave values which dif-

TABLE 2.–*Residual Air and Vital Capacity Values*

Specific Gravity	Number of Men	Average Residual Air, Liters	Residual Air, Range	Average Vital Capacity, Liters	Vital Capacity, Range
1.020-1.029	2	1.315	1.312-1.317	4.350	4.100-4.600
1.030-1.039	2	1.357	1.200-1.513	4.125	4.100-4.150
1.040-1.049	4	1.131	0.850-1.486	4.575	3.700-5.000
1.050-1.059	20	1.525	1.060-2.398	4.888	3.575-6.000
1.060-1.069	23	1.179	0.707-1.643	4.757	3.975-6.095
1.070-1.079	27	1.504	0.858-2.650	4.820	3.875-6.200
1.080-1.089	14	1.379	0.706-2.126	5.003	4.400-5.750
1.090-1.099	7	1.730	1.098-2.204	5.085	4.250-5.970

TABLE 3.–*Individual Loss of Weight in Relation to Specific Gravity*

		Weight				Circumference			
		In Air		In Water (Net)		Chest		Abdomen	
Date	Gravity	Pounds	Kg.	Pounds	Kg.	Inches	Cm.	Inches	Cm.
3/12	1.056	202.5	92.0	10.8	4.9	38.5	97.8	35.2	89.4
7/ 1	1.060	194.5	88.4	11.0	5.0	...	...	...	...
8/13	1.066	187.0	85.0	11.6	5.3	38.7	98.3	33.0	83.8
10/9	1.071	183.0	83.2	12.1	5.5	39.1	99.3	31.4	79.7

fered by not more than 150 cc.

CIRCUMFERENTIAL MEASUREMENTS OF CHEST AND ABDOMEN

The circumferential measurements of the chest and the abdomen are subject to considerable variation unless special care is exercised. The values recorded were obtained usually in the midmorning, during quiet respiration and with the arms of the subject extended vertically. Under these circumstances errors arising from altered muscular tonus or voluntary retraction of the abdomen were minimized. The chest measurement was made at the level of the nipples, the abdominal measurement at the level of the umbilicus.

SOURCES OF ERROR

The greatest error arises from the determination of residual lung volume. If the variation in this measurement is of the order of 200 cc., values for specific gravity will be subject to an error of ± 0.003.

Repeated determinations on the same individual permitting the use of a constant volume for residual air give values that agree to within 0.003.

A second error may arise from the presence of gas in the abdominal viscera. In an attempt to minimize this error, determinations were made in the morning on the fasting individual.

RESULTS OBTAINED

In table 4 are listed values obtained on ninety-nine healthy men in military service. From analysis of the data, two facts are apparent: 1. Specific gravity increases inversely in relation to weight. 2. The difference between abdominal and thoracic girth can be correlated with specific gravity.

In table 2 the values for residual air indicate that any error in the determinations will not appreciably alter the relative classification of the subjects with respect to specific gravity. It is apparent that the range of values for residual air is large so that any individual measurement of specific gravity must be accompanied by an actual determination of residual air. For groups of twenty or more men, however, when average values are compared, an arbitrary figure of 1,450 cc. for residual

TABLE 4.–*Specific Gravity in Relation to Weight, Age, Height and Measurements of Thoracic and Abdominal Circumference*

		Average Weight				Average Height		Average Circumference					
								Chest		Abdomen			
Specific Gravity	Number of Men	Pounds	Kg.	Range, Pounds	Average Age	Inches	Cm.	Inches	Cm.	Inches	Cm.	Average Difference Inches	Difference Range
1.020-1.029	2	233	105.9	221-245	34	68.9	175.0	41.5	105.4	41.6	105.7	–0.1	–0.75-0.50
1.030-1.039	2	187	85.0	174-200	48	71.0	180.3	36.7	93.2	35.9	91.2	0.9	0.75-1.00
1.040-1.049	4	166	75.4	145-184	31	66.9	169.9	38.0	96.5	33.7	85.6	4.2	3.00-5.25
1.050-1.059	20	171	77.7	126-208	33	69.3	176.0	37.2	94.5	33.0	83.8	4.2	1.00-7.25
1.060-1.069	23	158	71.8	131-202	24	68.1	173.0	35.6	90.4	30.3	77.0	5.2	3.25-7.00
1.070-1.079	27	153	69.5	131-199	26	69.4	176.3	35.7	90.7	30.0	76.2	5.6	2.50-8.50
1.080-1.089	14	148	67.3	130-164	24	69.4	176.3	35.7	90.7	29.7	75.4	6.1	275.-7.75
1.090-1.099	7	140	63.5	125-163	23	69.9	177.5	35.5	90.2	28.6	72.6	6.9	5.25-8.25

TABLE 5.–*High, Intermediate and Low Specific Gravity Group Values in Relation to Weight and Circumferential Measurements*

			Average Weight		Average Circumference					Average Height	
					Chest		Abdomen				
Number of Men	Average Specific Gravity	Range	Pounds	Kg.	Inches	Cm.	Inches	Cm.	Difference, Inches	Inches	Cm.
38	1.081	1.075-1.097	148.7	67.6	35.3	89.7	29.6	75.2	5.7	69.7	177.0
33	1.066	1.060-1.074	156.6	71.2	35.8	90.9	30.4	77.2	5.4	68.3	173.5
28	1.056	1.021-1.059	176.0	80.0	37.6	95.5	33.9	86.1	3.7	69.0	175.3

pulmonary volume will not introduce an error greater than ±0.003 in the computation of specific gravity.

In table 5 the ninety-nine subjects are divided into three groups on the basis of high low and middle range values for specific gravity. In the low group are listed all values below 1.060, and in the high group are values above 1.074.

Table 3 indicates how the loss of 19.5 pounds of adipose tissue in one subject results in a change in specific gravity. The values for the weight in water have been corrected for a residual air volume of 1,200 cc. One notes that a decrease in abdominal girth is followed by an increase in specific gravity.

COMMENT

Difference in Thoracic and Abdominal Girth as an Index of Corpulence.– Although variation in individual values except for the most obese subjects is considerable, the group values in relation to specific gravity show a definite trend according to table 4. The lean subjects on inspection possess the greater circumferential difference between chest and abdomen in comparison with the corresponding difference in fat men.

Body Weight and Specific Gravity.– The relationship between body weight and specific gravity (table 4) is not absolute but relative in the sense that for any selected group of homogeneous persons the heaviest men tend to have specific gravity values in the low range of the scale. The rather uniform decrease in average weight in relation to specific gravity is to be regarded as coincidental. Lean men, for example, weighing 200 pounds will have high specific gravity values in contrast with the measurements on fat men of the same weight.

The average weight, for example, of thirty-eight men in the high specific gravity group (table 5) was 148.7 pounds. In a separate series of determinations on exceptional athletes, presented in the second paper, a similar high value for specific gravity was associated with an average weight of 200 pounds. These facts suggest a fundamental relationship between adiposity and specific gravity.

Specific Gravity and Obesity.– Corporeal density serves as an index of the amount of excess adipose tissue. In table 5 the average weight in water of the low specific gravity group was 9.4 pounds, corresponding to a specific gravity value of 1.056. The corresponding values for the high specific gravity group were 11.1 and 1.081. The difference in weight in air between the two groups is 27.3 pounds.

On the assumption that a loss of 27.3 pounds of body weight in air is associated with a gain of weight in water of 1.7 pounds (11.1 - 9.4), the specific gravity of the low group following this loss of weight will be raised from an initial value of 1.056 to 1.081.

Thus, for every pound of weight lost the weight of the body in water is increased 0.062 pound (1.7 + 27.3). The specific gravity of the reduced tissues is therefore 0.94 (1 + 1.062), or a value in accord with the specific gravity of adipose tissue.

The average difference in thoracic and abdominal measurements of 5.8 and 3.7 inches for the high and low groups respectively suggests that excess adipose tissue accounts essentially for the difference in values for specific gravity of the two groups.

Individual Loss in Weight (table 3).– A man placed on a restricted diet and engaging in systematic exercise lost 19.5 pounds over a period of seven months. The net weight in water increased from 10.8 pounds to 12.1 pounds, although the corresponding weight in air decreased from 202.5 pounds to 183.0 pounds. Thus, for every pound of weight lost in air the weight in water increased 0.067 pound (1.3 + 19.5). The specific gravity of the reduced tissue is therefor 0.937 (1.000 + 1.067), or a value again in accord with the specific gravity of neutral fat.

The reduction in abdominal girth further suggests that the eliminated tissue was chiefly fat.

Specific Gravity and Composition of the Body.– Of all the constituents of the tissues of the body, fat and

TABLE 6.–*Body Composition, Showing the Effect of Variations in the Percentage of Bone and of Fat on Specific Gravity*

		Percentage of Bone (10)			Percentage of Bone (14)			Variation in Fat Content		
	Specific Gravity	Percentage	Weight, Pounds	Volume	Percentage	Weight, Pounds	Volume	Percentage	Weight, Pounds	Volume
Bone salts*...............	3.0	5	10	3.3	7	14	4.66	5	7.0	2.3
Essential lipoids........	0.94	10	20	21.2	10	20	21.20	10	14.0	14.9
Tissue........................	1.06	85	170	160.4	83	166	156.60	85	119.0	112.2
Totals...			200	184.9		200	182.46	Lean Man	140.0†	129.4
									60.0†	63.8
								Fat Man	200.0§	193.2
Specific gravity of the body as a whole.........		1.082				1.095		† 1.082; § 1.035		

*$Ca_2(PO_4)_3$ and $Ca\ (CO_3)_2$, approximately one half the weight of marrow free bone. ‡Excess adipose tissue.

bone appear to be the chief determinants of the ultimate values for specific gravity. In the comparison of the three groups (table 5) the difference between the average of the high and low values could best be attributed to a variation in adipose tissue. On the other hand, it is expected that the relative amount of bone may alter individual values within a limited range.

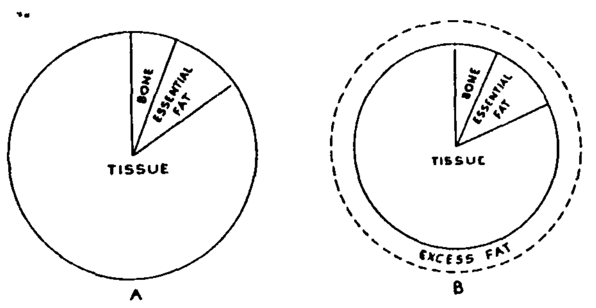
In table 6 hypothetic examples are presented to clarify the relationship between specific gravity and the composition of the body especially with respect to variation in the percentage of bone and fat.

For the purpose of our analysis the body may be viewed as comprising calcium salts representing 50 per cent of the weight of bone, essential or irreducible lipoid substance, excess adipose tissue, and all other tissues of the body embracing chiefly muscle, organs, brain, skin and blood.

The specific gravity of the mineral substance of bone is of the order of 3.0, adipose tissue 0.94, and all other tissue 1.060. This last figure is an approximation based on the specific gravity of blood and various other tissues according to Vierordt (4) and Nadeshdin (5).

With reference to the specific gravity of blood, eighty-one determinations made according to the method of Barbour and Hamilton on eighteen of the ninety-nine subjects reported on in this paper gave an average in agreement with the data of Stern (1) of 1.060, standard deviation 0.002.

The percentage of skeletal weight in relation to the body as a whole exclusive of excess adipose tissue may not be expected to vary more than 4 units. Corresponding to this variation of 4 units in the percent-



A represents the volume percentages of the three major specific gravity determinants of the body for a 200 pound, 90.9 Kg., lean man. The calculations were based on the following data: bone 10 per cent of body weight, specific gravity 1.60; essential fat 10 per cent, specific gravity 0.94; tissue 80 per cent, specific gravity 1.06. The volume percentages are therefore bone 6.8 per cent, essential fat 11.5 per cent, tissue volume 81.7 per cent. The specific gravity of this man would be 1.082. The solid inner circle in B represents the volume percentages for a 140 pound, 63.6 Kg., lean man. The volume percentages and specific gravity are the same as for the 200 pound (90.9 Kg.) lean man. The dotted outer circle represents the addition of 60 pounds of excess fat to the 140 pound lean man. The bone volume percentage is lowered to 4.5 per cent, the fat volume percentage is increased to 40.8 per cent and the tissue volume is reduced to 54.7 per cent in this man. Thus the specific gravity of the body is reduced to 1.035.

4. Vierordt, H.: Anatomische, physiologische und physikalische Daten und Tabellen, 3d rev. ed., Jena, Gustav Fischer, 1906.

5. Nadeshdin, W. A.: Zur Untersuchung der Minderwertigkeit der Organe an Leichen, Deutsche Ztsch. f. d. ges. gerichtl. Med. 18: 426-431, 1932.

age of body weight attributed to bone is a fluctuation of specific gravity of 13 units (table 6).

In contrast with bone, the amount of excess fat is subject to wide variations and a value of 30 per cent of the total body weight is not unreasonable for obese persons. If a lean man weighing 140 pounds, for example, accumulates 60 pounds of adipose tissue, the corporeal specific gravity will be lowered from 1.082 to 1.035, representing a difference of 46 units.

Since the density of the mass of tissue exclusive of bone and fat is probably constant for healthy men, the amount of fat appears to be the main factor affecting the specific gravity of a person.

Our concepts with regard to the composition of the body can be summarized by the accompanying diagrams. A, for example, the volume of a lean body mass weighing 200 pounds (90.9 Kg.), specific gravity 1.082. is divided into its components 1, 2 and 3.

In B the inner circle encompasses a mass similar to weight by 60 pounds (27.3 Kg.). The outer circle circumscribes an accumulation of 60 pounds (27.3 Kg.) of adipose tissue. The specific gravity of this 200 pound mass can be computed as 1.035, in contrast with the value of 1.082 for the mass represented by the inner circle.

The fundamental problem of the amount of variation of constituents 1 and 2 within the lean body mass remains to be determined. For the present the assumption is made that the percentage variation of these constituents based on body weight is small for lean men.

Excess fat therefore is viewed as the prime factor governing the level of specific gravity.

Precise measurements, however, of this excess fat will necessarily await a knowledge of the relative percentage variation of the weight of the skeleton in lean persons.

Of the anthropometric measurements, the chest diameters and height are expected to modify the values for specific gravity in persons possessing the same degree of obesity.

CONCLUSIONS

1. The fundamental biologic characteristic of corporeal density can be accurately measured usually within 0.004 unit by the method of hydrostatic weighing, provided a correction is made for the air in the lungs.
2. Values of specific gravity for healthy men ranging in age between 20 and 40 fall between 1.021 and 1.097.
3. Low values for specific gravity indicate obesity and, conversely, high values denote leanness.
4. Individual loss in weight through exercise and a restricted diet is associated with an increase in specific gravity.
5. Difference in the circumferential measurements of chest and abdomen serve as a criterion of obesity and can be correlated with specific gravity.
6. Variation in the percentage of bone in relation to body weight, excluding excess fat, is not expected to produce deviation of more than 0.013 units in comparable values.