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Body composition of women

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BODY COMPOSITION OF WOMEN

by

Mary Elizabeth Sturkie Prather

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INTRODUCTION

Various indices have been developed for the evaluation of the nutriture of individuals and population groups. Recently, the estimation of body composition in terms of water, fat, protein, and mineral content has become of importance in this connection. It is believed that knowledge of body composition may contribute to the evaluation of many disorders of nutritional origin and to the estimation of certain dietary requirements -- notably those for energy and protein. Furthermore, knowledge of body composition may increase the reliability of estimations of other indices of nutritional status.

For example, for many years height-weight relationships have served as an important criterion for nutriture especially in the clinical evaluation of obesity. Reliance upon standard height-weight tables may involve serious errors as has been shown with subjects with a large lean body mass (total body weight minus weight of fat) who, according to standard weight charts, were overweight but did not have excessive fat deposition. Welham and Behnke (1) have clearly demonstrated the inadequacies of height-weight tables for such classification and selection.

Also, lean body mass, if estimated with reliability, may provide a more satisfactory reference for measurement of basal oxygen consumption and nutritional requirements than factors customarily used, such as total body weight or surface area. If basal metabolism is expressed in terms of surface area for obese persons, the basal metabolic rate may appear to be subnormal; if expressed in terms of the fat-free body mass, the basal metabolism may be higher than for persons of average weight. Miller and Blyth (2, 3) found lean body mass a better tool to use in prediction of basal oxygen consumption than either surface area or body weight.

Several techniques for estimating body fat and lean body mass have been used; density or specific gravity, total body water, extracellular water, and anthropometry including body weight, skinfold thickness, roentgenograms, and skeletal measurements. These methods have proved useful in classifying individuals as to degree of fatness.

The estimation of fat from density, or specific gravity, is based on the assumption that lean body mass may be considered relatively constant and that the primary variable which determines individual body density is fat (4). The density of lean body mass is reported to be 1.100 gm per cubic cm and the density of fat approximately 0.900 gm per cubic cm. Lean body mass has been considered also to be relatively constant with respect to percentages of body water (5). With this assumption measurement of total body water has been used as an estimate of lean body mass and the total body fat (6).

Skinfold measurements have been used as an indirect method and prediction equations for estimating fat from skinfold thickness have been prepared for men (7, 8) and one for women (9).

Research on body composition of humans has been concerned primarily with men, and few data are available from studies of the body composition of women. Therefore, it was planned to evaluate the body fat and lean body mass of women varying in size and age by several methods. Further, it was planned to examine the relationship existing between the estimation of total body fat based on determinations of density and/or total body water and subcutaneous adipose tissue, estimated from skinfold thickness.

REVIEW OF THE LITERATURE

The major gross constituents of the body are water, fat, mineral, and protein. Carbohydrates and other organic substances are present only in very small amounts. All body constituents are influenced by many factors, such as, nutritional habits, age, sex, genetics, and disease, and undergo alterations during the life span.

The measurement of the gross body constituents and their distribution in living subjects is limited by the fact that there are few adequate methods for their assessment. Total body water may be measured _in vivo_ with a number of solutes by the dilution technique. Fat can be estimated from total body water or from the mean density of the entire body. Protein and mineral usually are listed together as fat-free solids and calculated by subtracting the total body water and fat from the total body weight. All methods for deriving total body composition have in common the fundamental relation that the sum of the proportional constituents by weight, or volume, must equal unit weight or volume; that is, fat + water + protein + mineral = 1.

Direct Analysis of Human Cadavers

There are a few studies available for reference from direct analysis of cadavers, but most of these analyses were on cadavers which would not be considered normal because of the circumstances leading to death. The data available have been summarized by Keys and Brožek (10). Of 5 cadavers, only 2, a 42-year-old female and a 46-year-old male, were considered to be healthy individuals. The data suggest a large variation in the ash to protein ratio that may be present in the population at large.

The exact meaning of mineral or ash content is not always clear in reports of analysis of body composition. If mineral, which includes only inorganic crystalline material, is reported then probably it is confined wholly to bone. Total ash includes some material that should be regarded as constituents of proteins. Bone accounts for only about 85% of the body's total mineral store while 15% of the inorganic salts are present in the fluid spaces and as metals associated with protein. On the basis of mineral analysis the density of bone is estimated at 3 gm per cubic cm (11). For most purposes in estimating total body composition by direct analysis protein is considered to contain 16% nitrogen, and a gram of nitrogen obtained corresponds to 6.25 grams of protein. In densitometric analysis knowledge of protein density is essential in deriving formulas. Siri (12) suggested that 1.34 gm per cubic cm is the best available estimate of density of protein in the living cell and calculated the combined mineral protein density of the body as 1.66 gm per cubic cm.

Body Water

Water constitutes the largest per cent of the total body composition; it varies from approximately 38 to 72% of the total body weight. Water is distributed in two major fluid compartments--intracellular fluid and extracellular fluid. Intracellular fluid is found within the cells, and the proportion of water may vary among cells of very different tissues. It is computed as the difference between extracellular and total body water. There is presently no method available for measuring intracellular fluid.

Extracellular fluid varies from approximately 15 to 20% of the body weight, is found outside the cells, is widely distributed throughout the body, and serves many functions. It is distributed chiefly throughout the interstitial spaces of tissues and organs and in the blood and is contained in the lymphatic system, intestinal tract, cerebro-spinal fluid, and in small amounts in renal glomeruli and tubules and vesicles of glands. Fluid in the renal pelvis, ureters, and the bladder are not regarded as part of the total body water because the water has been separated by the kidneys from the body's functional water pool and no longer takes part in physiological processes associated with water metabolism.

Water diffuses rapidly from one space to another, but in health and under normal conditions no large net shift in water occurs. The rapid transfer of water between fluid spaces has been demonstrated with deuterium or tritium labeled water; when these isotopes were given intravenously, their concentration in serum decreased rapidly until equilibrium was reached in the whole body water (13, 14).

The turnover of water with the external environment is slower than the transfer rates between fluid space. Schloerb _et al_. (13) reported that deuterium labeled water was lost from the body with a half time of about 9 days or turnover of about 13 days. Any factor which altered the rate of water excretion changed the turnover time, although the total quantity of water remained the same. Pinson and Anderson (14) found that in 1 subject given large amounts of water the rate of turnover was about 2 1/2 days.

The amount of water relative to body mass in the normally hydrated body is dependent primarily upon the quantity of depot fat and diminishes with increasing obesity. The range is approximately from 38 to 72% of the body weight. In obese people water has been found to constitute as little as 38% of the body weight (12) while in extremely lean people total body water was about 72% of the body weight (15).

The proportion of total body water in humans has been found to decrease rapidly from birth to 1 year of age, from about 80 to 60% of the body weight (16, 17). Women and men differed in the rate of change of body water up to about 20 to 25 years of age, with an increase in water content for men and a decrease for women (12, 18). At about 20 years of age the total body water of men began to decrease slowly with age. These differences have been attributed to difference in type of fat with age and sex.

Total body water may be estimated from specific gravity or density of the whole body, from naturally occurring K^{40}, or may be measured directly by the use of test solutes. Many substances have been suggested as test solutes for estimation of total body water, but most of them have been found unsatisfactory except for water labeled with either deuterium or tritium and antipyrine or its derivatives. Nitrogen-15-labeled urea has been used in a few animal studies but rarely used in humans and has not been tested to any extent. Other compounds which have been used but found to be unsatisfactory have been unlabeled urea, potassium, thiourea, sulfanilamide, alcohol and glycerol.

For a test solute to be suitable for measurement of total body water it must have a minimum rate of metabolism or excretion as compared to the rate of distribution in the body water, penetrate rapidly and have equal distribution throughout the fluid space of the body, have no accumulation in non-fluid sites, such as uptake in fat, have no toxic effects in amounts required for accurate measurement in blood or urine, and be readily and accurately measurable.

Antipyrine (2, 3-dimethyl-1-phenylprozolone-5) was introduced into medicine in 1884 and was originally employed for antipyresis and later prescribed for analgesia; it has been used widely since 1949 in determining total body water. The pharmacology and toxicology of antipyrine have been reviewed in a monograph by Greenberg (19). The substance has been found to be relatively nontoxic in the amount required for body water determinations, quickly and uniformly distributed throughout the body tissues and fluids of normally hydrated humans and other mammals, and readily measured in the amount required (20-22). It is metabolized at varying rates in different individuals; but the disappearance rates are constant in each individual, thus allowing correction to be made by extrapolation of plasma levels to time of injection.

Soberman _et al_. (20) reported that after intravenous injection in humans, antipyrine was excreted slowly, and the degradation rate was 6% per hour, varying in different subjects from 1 to 12%. Uniform distribution could be obtained in the normally hydrated person in 1 to 2 hours.

Varying doses of antipyrine have been used, but generally a total of 1 gm antipyrine is given intravenously in a 20 ml sterile water solution over a period of 2 to 5 minutes. Blood samples are taken before injection and at suitable intervals, usually 2, 4, and 6 or 2, 3, and 5 hours, after injection to estimate the disappearance curve. Plasma or serum is separated by centrifugation and is stable for several days at refrigerator temperature. The body water is calculated as:

$$\text{liters of body water} = \frac{\text{amount of antipyrine injected (mg)}}{\text{conc. in plasma water at zero time (mg/liter)}}$$

Plasma concentration at zero time is the concentration which would have resulted at the time of injection if uniform distribution had been instantaneous and if none of the antipyrine had been metabolized or excreted. The zero time is calculated by plotting the plasma levels of antipyrine on the arithmetical scale and projecting the line drawn through the points back to the time of injection. The three points of the plasma levels should fall on a straight line. The concentration of the antipyrine in plasma is calculated by dividing the plasma level of antipyrine at zero time by the per cent water in the plasma.

One of the most widely used methods for assay of antipyrine in blood is that of Brodie and co-workers (21).

The method consists of deproteinization of plasma filtrate with zinc hydroxide, and the antipyrine concentration determined spectrophotometrically by extrapolation between standards prepared from serial dilutions.

N-acetyl-4-aminoantipyrine (NAAP) has also been used to estimate total body water. Brodie _et al_. (23) found NAAP to have an advantage over antipyrine because unlike antipyrine it is not bound to any appreciable extent to proteins; its metabolism is negligible; it is excreted slowly; and urine samples may be used, thus avoiding numerous blood samples. Comparison of NAAP and antipyrine in 12 subjects gave good agreement. Two methods have been used for measuring total body water in man with NAAP. One was similar to that of antipyrine (23). The second involved a single measurement of plasma concentration and the measurement of urinary excretion 3 hours following administration of NAAP (24). In this procedure, the total body water was calculated thus:

liters of body water =

[amount of drug injected (mg) - amount excreted (mg)]
divided by concentration in plasma water (mg/liter).

Another derivative of antipyrine, 4-aminoantipyrine, was used by Huckabee (25) to measure total body water. He found close agreement between antipyrine and 4-aminoantipyrine in

8 humans; the averages were 50.2 and 49.4% respectively, of body weight as body water. Talso et al. (26) compared antipyrine, NAAP and I^{131}-labeled 4-iodoantipyrine and found for 16 subjects an average of 49.7%, 50.6% and 50.6% body water by the three methods, respectively.

Deuterium is a stable isotope of hydrogen of atomic mass two; it combines with oxygen to form deuterium oxide (D_2O), which has a molecular weight of 20. When D_2O is mixed with water, the deuterium in D_2O readily exchanges with hydrogen in water to form HDO, which has a molecular weight of 19 (27). Hevesy and Hofer (28) and McDougall et al. (29) in 1934 reported the use of deuterium for measuring total body water in man and in rats, respectively; at that time the isotope was not readily available, was expensive, and reliable instruments were not available for analysis of deuterium. At the present time HDO is available at moderate cost and satisfactory instruments may be obtained.

Deuterium oxide has been given both by mouth and by intravenous infusion (30, 31); generally 100 cc have been administered. In healthy persons, equilibrium was reached in 1 to 2 hours (13, 18, 32). The concentration of deuterium has been determined both in the venous blood serum and the urine (30, 33). When deuterium labeled water was ingested, equilibrium was reached in less than twice the time that was required by intravenous injection (13).

Two methods have been most widely used for assay of deuterium: the mass spectrometer and the falling drop method.

The falling drop method depends on the slight increment in density contributed to water by deuterium (27, 32, 34, 35). Direct estimates of the sample HDO concentration are made by comparison with the rate of fall of drops from serial dilutions of the original stock solution. Water of unusual purity is essential. Serum is easier to purify than urine, since serum water can be purified in a 2 stage vacuum distillation train while urine must be purified by chemical purification as well as multiple distillation. Schloerb et al. (32) were able to obtain an accuracy of ± 0.5% standard deviation in determination of volume per cent HDO in serum samples by the falling drop method; this corresponded to ± 200 cc of total body water for a lean adult. They estimated an overall error of ± 400 cc; this did not include the error due to hydrogen exchange. In 1955 Faller et al. (36) described a falling drop method that was suitable for urine analysis.

The mass spectrometer is considered the most sensitive method for measuring deuterium concentration but the cost of the instrument and its maintenance are very high (21, 37). The instrument was developed primarily to measure stable isotopes. A procedure was given in detail by Soloman and

Soloway (37). The total error, except for hydrogen exchange, in the total body water determined was estimated to be about ± 1% of body water, or about ± 400 cc in a lean 70 kg man. This was the same degree of magnitude as Schloerb *et al.* (32) reported for the falling drop method.

Tritium also has been used for the measurement of body water. It is the radioactive isotope of hydrogen which has a mass of 3 and combines with oxygen and hydrogen to form HTO which has a molecular weight of 20. Tritium has a half-life of about 12 years and emits soft beta particles of 18 Kev maximum energy with an average of 5.7 Kev (38). Tritium is assayed by detection of beta particles emitted in the course of radioactive decay to helium, He^3. Pinson and Anderson (14) reported that the biological half time of tritium equals 9 to 14 days, but its half time in the body could be reduced to about 2 1/2 days by increased consumption of water (14). Because of its low energy of radiation, tritium is one of the most difficult of all radioactive isotopes used in tracer applications to measure. In general, it is necessary to place the tritium from a biological sample directly into the sensitive region of a radiation-detecting device in a form that voids self-absorption.

The possible routes of tritium oxide entry into the body were studied extensively by Pinson and Langham (39). Ingested tritium was completely absorbed from the gastrointestinal tract and appeared in the venous blood 2 to 9 minutes following ingestion, reached maximum concentration in 45 minutes and equilibrium in about 2 hours. Tritium may be given either orally or intravenously. Pinson and Langham (39) estimated the maximum permissible body burden of tritium in human adults to be 3.7 mc; but generally less is used for determination of total body water. Tritium doses reported in the literature varied from 0.2 to 3.2 mc.

Siri (12) reported that it is not necessary to estimate a disappearance curve since the turnover for tritium is in the order of 13 days; several fluid samples are taken within the first six hours and the tritium specific activity is analyzed. In patients with edema or ascites, equilibrium takes place less rapidly, and specimens should be taken during and between 8 and 24 hours after administration of tritium. The values must then be extrapolated to time of administration to compensate for the disappearance of tritium, which is about 7% per day.

Several methods and instruments have been used for estimating tritium. The Gieger-Muller counter was used in early studies by Pace et al. (40), but the counter tubes do not tolerate appreciable quantities of either water vapor or hydrogen. It is considered to be the least desirable instrument for measuring tritium in urine or blood samples. The proportional counter is found to be fairly successful when tritium is incorporated into an organic gas that does not interfere with the operation of the counter. Methods for assaying tritium using the proportional counter have been described by Robinson (41), Kennedy (42), and Christman (43). Several methods employing an ionization chamber have been described by Wilzbach and co-workers (44, 45), Eidinoff _et al_. (46), and Prentice _et al_. (47).

The liquid scintillation counter appears to be the best instrument for measuring tritium, but it is also the most expensive because of its complex electronic circuits and maintenance. The liquid scintillation counter allows a small proportion of water that can be added to the liquid scintillator without interfering with its function. Use of the liquid scintillator counter has been described recently by many investigators (48-54).

Results of some of the studies where comparisons have been made between 2 or more methods for determination of total body water are summarized in Table 1.

Pace _et al_. (40) found that results obtained by using tritium agreed well with those obtained by desiccation or by measurement of specific gravity when the 3 procedures were used for determination of the total body water of 2 rabbits. There was good agreement also between results obtained by the use of tritium and by the determination of specific gravity in the estimation of total body water of 1 male subject.

Table 1. Comparison of methods of analysis of total body water

Ref. no.	Subject	% of total body weight as total body water				
		Deuterium	Tritium	Antipyrine or NAAP	Desiccation	Specific gravity
33	33 men	61.2		58.5		
55	1 man	39.7[a] (38.8-40.6[a])		36.1[a] (33.8-39.6[a])		
	1 man	45.8[a] (44.4-47.2[a])		41.8[a] (38.6-43.9[a])		
40	rabbit A		54.9		55.5	51.9
	rabbit B		58.4		55.9	54.7
	man		64.7			65.2
22	monkey 1			62.8	66.4	
	monkey 2			71.0	69.8	
	monkey 3			69.4	71.6	
	monkey 4			67.2	69.9	
	monkey 5			72.1	69.4	
	dog 1			75.7	71.3	
	dog 2			63.9	68.1	
	dog 3			69.5	72.5	
	dog 4			73.9	72.5	
56	rabbit 1			74.6	75.8	
	rabbit 2			68.8	69.6	
	rabbit 3			75.8	72.9	
	rabbit 4			77.8	77.0	
57	9 rabbits	72.8 (67.6-77.4)			73.6 (71.4-75.8)	

[a]Reported as liters of body water not percent body weight.

Table 1. (Continued)

Ref. no.	Subject	% of total body weight as total body water				
		Deuterium	Tritium	Antipyrine or NAAP	Desiccation	Specific gravity
58	30 cattle			54.3 (43.9-63.0)		54.5 (44.9-62.5)
59	6 cattle			52.5 (45.4-61.0)		51.9 (46.2-59.2)
	24 cattle			54.4 (43.9-63.0)		54.1 (43.1-63.3)
60	24 hogs			46.8 (36.7-64.5)		44.1 (33.8-59.6)
20	woman	50.3		49.5		
	woman	42.0		39.3		
	man	53.9		51.5		
	man	48.1		50.4		
	man	56.9		57.0		
	man	55.2		55.0		
	man	60.6		55.0		
	man	59.5		57.9		
	avg. men	55.7		54.5		
15	81 men			61.1 (43.0-72.9)		61.0 (44.0-72.0)
61	9 men			53.9 (43.3-60.5)		54.3 (44.0-72.0)

Table 1. (Continued)

Ref. no.	Subject	% of total body weight as total body water				
		Deuterium	Tritium	Antipyrine or NAAP	Desiccation	Specific gravity
62	10 humans		56.2 (49.3-67.1)	54.6 (46.8-68.9)		
	5 males		58.9 (53.3-63.0)	56.1 (52.4-61.4)		
63	9 humans (heart dis.)	47.6 (35.9-62.8)		46.8 (33.5-64.0)		
64	29 humans w/edema	64.2[a] (40.6-83.2[a])		54.6[a] (36.0-66.0[a])		

Prentice *et al.* (62) used both tritium and antipyrine for measurements of body water in humans; the values obtained by the 2 procedures were similar although the per cent of body water estimated with tritium was slightly higher than that estimated with antipyrine. Deuterium, like tritium, also has been found to give slightly higher results than antipyrine in the determination of body water (20, 33, 55). In general, results obtained with the use of antipyrine have agreed fairly well with those obtained by desiccation or by specific gravity (58-61). However, Moore (57) found that, in studies of the body water of rabbits, results obtained using deuterium agreed satisfactorily with values obtained after desiccation.

Both tritium and deuterium form ideal solutions with water, diffuse throughout the body at a rate similar to water, and show no isotope effect on excretion and metabolism; the distribution of the 2 isotopes in the body is similar to that of water. After equilibrium, the concentration of deuterium in the urine, gastric juice, cerebrospinal fluid, and sweat was identical to the concentration in the serum (28, 32). Tritium also has been found to concentrate equally in the serum, urine, sweat, and expired water vapor by Pinson and Anderson (65). The turnover time for deuterium (32) and tritium (12, 66) is the same as for the total body water estimated from water balance, about 13 days.

Since results obtained by the measurement of total body water with deuterium and with tritium have exceeded slightly those obtained using antipyrine, the possibility exists that there is an over-estimation of body water by the use of deuterium or tritium. This may result from the exchange of hydrogen in water with the labile hydrogen atoms in cellular materials (67). Hevesy and Jacobsen (68) estimated labile hydrogen to be equivalent to about 0.5 to 2.0% of body weight. Schloerb _et al_. (13) reported that deuterium gave values for total body water of about 2% of the body weight greater than actual values; Prentice _et al_. (47) estimated an error of about 1 to 2% of body weight from studies on rabbit tissue. Concurrent measurements with antipyrine and deuterium (20, 33, 55) and with antipyrine and tritium (62) gave higher values for deuterium and tritium than for antipyrine by about 2%.

Although antipyrine appears to be slightly soluble in fat and fat solvents (19), the customary procedure of extrapolating the plasma disappearance curve should compensate for the absorption of antipyrine in fat as well as for its degradation and excretion. In a comparison of antipyrine spaces with those of deuterium over a period of 2 months in 2 human subjects, Ljunggren (55) found that the variability of the deuterium spaces was less than those of antipyrine. The coefficients of variation were 1.8 and 2.0% for the deuterium spaces and 4.5 and 5.4% for the antipyrine spaces for the 2 subjects, respectively. Antipyrine has been shown to be suitable for measuring total body water in normally hydrated bodies, but it is not considered reliable for measurements of total body water in patients with edema or ascites since its rate of diffusion is relatively slow. In these conditions, measurements of total body water with deuterium and tritium are considered more reliable than measurements with antipyrine.

Deuterium and tritium require special apparatus for measuring where antipyrine does not, but both can be measured with greater accuracy than antipyrine except that labeled water over-estimates total body water as mentioned above. Advantages in the use of deuterium and tritium are that the substances can be given orally and assayed in the urine, thus there is not the inconvenience of venous punctures.

At the present time, in vivo measurements of extracellular fluid can be made only by solute dilution techniques. The solute which is used must be a substance that diffuses rapidly across capillary membranes but is excreted slowly, strictly barred from diffusion through cellular walls, and is not metabolized to any large extent.

Attempts have been made to measure extracellular fluid with various compounds but only a few have the necessary

Table 2. Comparison of methods of analysis and solutes used in
fluid

Ref. no.	Subject	Per cent of body weight a				
		Inulin	Thiocyan.	Thiosulf.	Bromide	
69	man 1		21.7			
	man 2		40.1			
	man 3		34.1			
70	4 men	15.2-25.3				1
71	4 men	9.5-16.0	19.2-24.0			
	10 dogs	20.3-23.2	25.8-35.5		28.1-32.7	
72	4 men	15.2			26.9	
		13.3-17.3			20.4-32.4	
73	man 1	10.5[a]				
	man 2	10.9[a]				
	man 3	11.1[a]				
74	24 humans	6.4-12.7[a]		8.1-14.6[a]		
75	14 women			8.6-15.1[a]		9
76	man 1	14.3			24.0	
	man 1	14.9	22.2			
	man 2	16.8	24.1			
	man 3	14.2	21.6		20.6	
	man 4	15.8	21.6		21.3	
		16.0	24.5			
	man 5	16.5	26.8			
	man 6	18.0	25.3			
	man 7	16.1	27.5		25.7	
	29 men	16.2				
77	14 humans		18.8[a]			
78	5 humans				16.7[a]	
	10 humans				15.8[a]	

[a]Reported as liters of extracellular fluid, not percent body

analysis and solutes used in the determination of extracellular

	Per cent of body weight as extracellular fluid					
cyan.	Thiosulf.	Bromide	Sucrose	S^{35}	Na^{24}	Cl^{38}
.7			21.5			
.1			36.1			
.1			30.0			
			15.2-23.8			
-24.0						
-35.5		28.1-32.7		26.7-33.0		
		26.9				
		20.4-32.4				
				10.8[a]		
				10.8[a]		
				10.3[a]		
	8.1-14.6[a]					
	8.6-15.1[a]		9.2-13.8[a]			
		24.0			26.4	
.2						
.1						
6		20.6			27.0	
6		21.3				
5					26.4	
8						
3						
5		25.7				
8[a]					18.8[a]	
		16.7[a]	11.6[a]		16.7[a]	15.6[a]
		15.8[a]				15.4[a]

-

llular fluid, not percent body weight.

Table 2. (Continued)

Ref. no.	Subject	Per cent of body weight as e:				
		Inulin	Thiocyan.	Thiosulf.	Bromide	Suc:
79	9 dogs	9.8-14.5[a]				
80	19 dogs	20.4 18.0-24.3		24.6 21.1-30.8		
81	1 dog 2 dogs 4 dogs	18.5				
82	dog 1	19.0 19.8 18.7 18.7	35.5 34.3 ---- 34.5			
	dog 2	19.5 17.6 18.4 17.5	32.0 ---- 29.9 34.4			
	dog 3	20.3 20.1 20.1	32.5 30.7 28.5			
	dog 4	19.1 19.8	25.8 ----			
	dog 5	19.9 17.6 19.0 18.2 20.4 20.8 21.4	31.6 ---- 31.2 35.6 39.8 37.5 40.0			
	dog 6	21.8 18.9 19.6	33.7 30.2 33.9			
	dog 7	19.3	38.0			
	dog 8	19.8	35.0			

Per cent of body weight as extracellular fluid						
ocyan.	Thiosulf.	Bromide	Sucrose	S^{35}	Na^{24}	Cl^{38}
					8.8-13.9[a]	
	24.6					
	21.1-30.8					
						27.7
					21.1	19.5
					24.3	23.3
.5						
.3					31.4	
--					27.0	
.5					27.5	
.0					31.0	
--					32.4	
.9					----	
.4					----	
.5					26.7	
.7					----	
.5					----	
.8					33.0	
--					----	
.6					30.5	
--					----	
.2					30.5	
.6					----	
.8					----	
.5					----	
.0					----	
.7					33.7	
.2					----	
.9					31.6	
0					----	
0					----	

characteristics. Table 2 presents a summary of data obtained for studies in which different solutes have been compared. Sodium-24 (77), chloride-38 (83, 84) and bromide (85, 86) have been used unsuccessfully since these substances penetrate the tissue cells. Sulfanilamides were found to be unsuitable as solutes (87). Thiosulfate has been used (88, 89) but has been found to be rapidly excreted (90, 91).

Inulin probably gives the most reasonable results for the estimation of extracellular water although constant infusion of the compound is required. Inulin does not penetrate red blood cells, cells of the normal renal tubules or cells of tissues. It does not affect fluid balance between compartments, is lipid insoluble, is not metabolized appreciably, and can be quantitatively recovered in the urine (71, 92, 93). Inulin has a large molecular weight of 5101 (94), and its entry and distribution into the whole extracellular space is slow while it is rapidly excreted; therefore equilibration of inulin cannot be achieved with administration of a single dose except in renal insufficiency and in nephrectomized animals. The method used, therefore, must be one of continual infusion into a vein until the serum level remains constant. A steady state is reached in two hours in dogs and in about 6 hours in man (71). This method, as well as all the others mentioned, is not suitable in the presence of edema or ascites.

The use of sulfur-35 provides a method that is simple and rapid; it has been found to agree closely with inulin (72, 79, 95). A single dose of 100 mc of carrier-free S^{35} is injected intravenously as H_2SO_4 and the blood level of S^{35} then followed for 5 to 6 hours.

Sucrose has generally been found to give too high results (69, 96), but Deane *et al.* (70) found good agreement between inulin and sucrose in measurements on men. Mannitol was found to give slightly high results by Elkinton (97) who reported mannitol space in 8 normal humans to be between 17.1 to 25.5% of body weight; he was able to get full recovery of mannitol. Mannitol and sucrose both penetrate through capillary walls to a slight extent, are excreted rapidly, and are metabolized to some extent.

Thiocyanate has been used widely. Bass and co-workers (98) made a study of the kinetic of diffusion *per se* in 25 healthy young men and found that the optimal time of diffusion of thiocyanate after intravenous injection was obtained in 2 hours. Thiocyanate does enter the red blood cells, gastric mucosa, and other tissues (69, 99), but Keys and Brožek (10) found that by using a factor of .7 to convert the thiocyanate space to extracellular space that the values for the extracellular space calculated from thiocyanate and inulin gave good agreement.

Body Fat

Body fat varies more than any of the other major constituents in the body. The relative amount of body fat may be an important factor in health and longevity. The estimation of body fat promises to be a useful tool in studying obesity and inanition.

There are several kinds of fat in the body. In general, the term body fat includes the total ether-soluble extract of tissues, that is, the phospholipids, glycolipids, sterols, and neutral fats or glycerides. Neutral fat makes up most of the so-called storage fat, obesity tissue, or non-essential lipids. The lipids except neutral fat form an essential constituent of cell walls and protoplasm and are present in all tissue; these lipids remain nearly constant in cells and are not affected to any extent by changes in body weight. Behnke and co-workers (100) estimated the essential lipids as 2% of the lean body, but the total quantity of essential lipids has not been well established.

Fat content varies widely; there are differences due to nutrition, sex, age, and diseases. Siri (12) found that storage fat varied over a wide range, from nearly zero in severe undernourishment to as high as 50% of body weight in clinically normal persons. Behnke _et al_. (100) reported a range from 1.5 to 38.5% of body weight as fat in a group of

Table 3. Per cent of body weight as fat in humans and animals

Ref. no.	Subject	Per cent body fat			
		Dessication (ether extract)	From sp. gr.	From antipyrine	Separable fat
101	20 m. rats	14.6			
102	68 rats	24.2-36.1			
	458 rats	6.7-44.3			
103	51 m. rats	18.1			
		16.2-20.5			
	51 f. rats	20.1			
		19.2-23.3			
104	rats	9.0			
	guinea pigs	10.0			
	rabbits	7.8			
	cat	7.9			
105	3 rabbits	2.5			
		2.5-3.0			
	2 dogs	6.5			
		14.6-25.6			
	2 monkeys	6.5			
		2.0-11.0			
106	7 rats	15.3			

Table 3. (Continued)

Ref. no.	Subject	Percent body fat: Dessication (ether extract)	From sp. gr.	From antipyrine	Separable fat
5	50 guinea pigs	12.3 1.5-35.8			
40	rabbit 1 rabbit 2		29.1 25.3		
58	30 cattle		24.9 13.9-38.2	25.2 13.2-39.5	
59	30 cattle	25.7 14.4-39.3	26.3 13.9-40.1	26.7 13.5-41.1	25.2 13.6-39.5
60	24 hogs		40.8 19.9-54.5	36.7 12.0-49.9	38.4 17.8-53.1
61	9 humans		25.3 17.0-39.0	25.6 16.3-41.5	
15	81 men		15.0 0.0-38.4	15.0 0.0-40.1	

young naval personnel.

Estimation of body fat

Fat may be estimated indirectly by a number of methods, for example, by determination of specific gravity or density, total body water, potassium-40, or fat soluble gases, by skinfold measurements, or by a combination of procedures. The direct measurement of fat is a laborious procedure which has been rarely carried out in man or other animals of comparable size; the data on small laboratory animals are also few. Data available on human cadavers have been summarized by Keys and Brožek (10). Data which have been reported on the fat content of laboratory animals are summarized in Table 3.

The desorption or absorption of gases, for example, nitrogen and cyclopropane, has been used with some success to determine the amount of fat present in animals. Nitrogen exchange has been investigated the most thoroughly. Nitrogen is 5 times more soluble in fat than in tissue fluids and is washed out of the fat depot at a slower rate than from the rest of the body when oxygen is inspired (107). Fat is estimated indirectly from nitrogen by observing the nitrogen elimination curve for a sufficiently long time until its rate of washout corresponds to its removal from fat alone.

Lesser *et al.* (108) investigated the use of cyclopropane in rats. The gas is 26 times more soluble in fat than in tissue fluids; therefore the differential rates of absorption are easily measured. The authors reported good agreement between fat estimated from cyclopropane and fat determined by ether extraction in 10 rats; the mean fat content from both analyses was 13.2% fat. Cyclopropane has not been tried in man, since for man the gas concentration cannot be greater than 5% in air to be safe.

Determination of body density

Densitometry has been used as an indirect method for estimation of body fat. Since water, fat, protein, and minerals have different densities, this method appears practicable, if there is a predictable relationship among the constituents. The density of the body is defined as the total weight in air divided by the total volume. Body volume may be determined by underwater weighing or by a helium dilution method. The possibility of measuring fat by densitometry was recognized as early as 1901 by Stern (109) and in 1915 by Spivak (110), but they lacked means of obtaining accurate density measurements and had no means of direct estimation of fat.

In 1941, Behnke (4) suggested that total body fat could be estimated from the specific gravity of the body. Data obtained by specific gravity measurements and direct measurement of fat in small mammals by Pace and Rathbun (5) supported this concept which has been validated in guinea pigs (6, 111) and albino rats (102).

The method first developed for measuring body density, that is, underwater weighing, was an adaptation of Archimedes' famous experiment in hydrostatic weighing. The modern application of this method to determine density was by Behnke _et al._ (112) who also showed that there was a qualitative relationship between density and body fat. Later the method was refined further by Brožek _et al._ (113) by providing for the measurement of residual air at the moment that the underwater weight was obtained. The principle is the same as that of Archimedes' original experiment. The weight of the body in air minus its weight in water when totally submerged is considered to be equal to the volume of water displaced. The relationship between these quantities is expressed as:

total density of the body = $d_w W_a$ divided by $(W_a - W_w)$,

where W_w equals the body weight in water, d_w equals density of water at which W_w was obtained, and W_a equals body weight in air. This value for total body density is affected by the air left in the respiratory passages and lungs and gas in the gastrointestinal tract. Since these gas spaces constitute a volume, V, at the moment the submerged body weight is taken, the true tissue density would be expressed by:

$$d = (d_w W_a) / (W_a - W_w - Vd_w).$$

Absolute residual air increases with age in clinically healthy men and women; means reported by Keys and Brožek (10) were for young men 1600 ml, middle age men 2200 ml, young women 1250 ml, and middle age women 1300 ml. In determination of fat from specific gravity data, residual air should be measured for each subject.

There is no method for measuring the intestinal gas volume, but several methods have been used for measuring the air in the respiratory system. In one procedure, the volume was measured before or after underwater weighing by forced maximal expiration. The residual air was about 1500 ml which with practice was reproducible with a standard deviation of about ± 100 ml (12).

Cournand _et al_. (114) described a method for obtaining the absolute value of residual air by volumetric analysis of nitrogen following wash-out with oxygen in an open-circuit system. Following maximal expiration, or immediately following weighing if an underwater measurement is made, the subject inhaled oxygen and the expired air was collected in a Tissot gasometer or Douglas bag. The residual air volume was calculated from the total volume and the nitrogen concentration of the expired gas collected for a 7-minute interval. Brožek *et al.* (113) modified the method of Cournand *et al.* (114) so that residual air could be measured at the same time as the underwater weighing.

Helium has been used also to estimate residual air (115, 116). This method involves the inhalation of a helium-oxygen mixture which is washed out of the lungs by inhalation of air or oxygen and its volume measured.

Gas in the gastrointestinal tract is usually disregarded in correcting body density for residual gas. Siri (12) estimated that for an uncertainty of 100 ml in the volume of a 70 kg subject whose density is 1.050 gm per cubic cm and residual air of 1500 ml, the error in density would be .15% and would be acceptable for most purposes. This volume of gas might exceed several hundred ml although the subject would probably be in apparent distress and thus disqualified.

Specifications for the tank, scales, and necessary equipment for underwater weighing have been reported by Miller (117). The subject is on a seat which is suspended from a scale hook; the subject with breath held in maximal expiration is submerged until only the scale hook remains above the water level. The scale is unhooked and the submerged weight recorded; the scale is locked again and the subject brought to the surface. The procedure requires 10 to 15 seconds.

Several attempts have been made to measure body density or volume by methods that could replace the underwater weighing technique; the only procedure described in the literature with estimations of reliability and reproducibility is the helium dilution method developed for human subjects by Siri (118). Walser and Stein (119) have also used helium displacement for obtaining density in intact animals. Body volume was determined from the dilution of helium in a chamber by a quantity of air that varies inversely with the volume of the subject. The apparatus developed by Siri consists of two chanbers connected to form a closed system. Since helium comes to equilibrium in the air spaces (lungs and respiratory tract) in less time than was required to mix the gases in the chambers, no correction was required for these factors. Helium is absorbed in tissues and fluids but Siri (12) estimated that the error was cancelled by the fact the gas in the gastrointestinal tract was about 100 ml, as mentioned previously, and was nearly equivalent to the amount absorbed in the body fluids and tissues.

The densitometric method depends upon the accuracy in obtaining density and upon the correctness of densities of the fat, water, protein, and mineral in the body measured. The method for obtaining density must be very accurate because the range of density extends only from about 1.1 gm per cubic cm to less than 1 gm per cubic cm which is a range of about 10% while fat varies from nearly zero to about 50% of total body weight. Since the difference in the density of fat and water is very small, the large variation in their proportion produces only small changes in total body density.

Prediction of body fat from density

The density of fat, water, protein, and mineral in animals and in humans has been studied; the best values for the densities of these tissues in adult humans appear to be the following:

density of fat = .9000 gm per cubic cm at 37°C (120)
density of water = .993 gm per cubic cm at 37°C (121)
density of protein = 1.340 gm per cubic cm at 37°C (122)
density of mineral = 3.000 gm per cubic cm at 37°C (11)

The density of fat varies among animals of different species (120) and among the same species with alterations in the diet and environment. Density varies with temperature, therefore it is important to know the density of the fat at the temperature of the densitometric measurement. Fidanza *et al.* (120) found for adult humans the mean value for the density of fat to be .9000 gm per cubic cm at 37°C, with a range from .8992 to .9009 gm per cubic cm. At 36°C the mean density of fat was .9007 gm per cubic cm. The value .9179 gm per cubic cm which was used by Rathbun and Pace (6) was correct for 15°C but not for the temperature at which the bodies were measured.

One method for the prediction of fat from body density is based on the relationship: $f = \frac{a}{d} + b$ where a and b are constants and d is whole body density. An equation obtained by Pace and Rathbun (5) from studies on guinea pigs, whose specific gravities were determined by underwater weighing and fat determined by extraction with petrol ether, was as follows:

$$\% \text{ fat} = 100 \left(\frac{5.135}{\text{sp. gr.}} - 4.694\right).$$

The equation proposed by these same workers (6) for humans was:

$$\% \text{ fat} = 100 \left(\frac{5.548}{\text{sp. gr.}} - 5.044\right).$$

These constants were derived for a lean-body mass with a specific gravity of 1.100 gm per cubic cm and a human fat density of 0.918 gm per cubic cm. Since this equation is based on density of fat at 15°C instead of 37°C which is usually used for underwater weighing, Keys and Brožek (10) suggested as constants: a = 5.120 and b = -4.684. Although the modified equation gives a better estimate of body fat, the assumption is still inherent that the proportions of the body constituents are either constant or exactly predictable.

That is, the prediction is based on the assumption of a basic lean body of fixed density to which is added fat of a constant composition and density.

Keys and Brožek (10) modified this equation further to permit estimates of difference in fat content. The constants were adjusted to represent the difference in fat between the subject and that of a standard man. The constituents were derived on the assumption that obesity tissue consists of 62% fat, 14% extracellular fluid, and 24% cellular matter with a density of 0.9395 gm per cubic cm. The difference in fat is then given by the equation:

$$\Delta \text{ fat} = \frac{5.427}{d} - 5.106.$$

These factors are still dependent upon the assumption that the composition of fat remains constant over the obesity range.

The following equation for estimating fat:

$$\text{fat} = \frac{4.950}{d} - 4.500.$$

was derived by Siri (123) who assumed that if the fat-free body was the correct reference then the density of the fat-free body would be 1.100 gm per cubic cm and the density of fat would be 0.900 gm per cubic cm. Siri calculated the standard deviation in fat estimation by this equation as ± 4.0% body weight.

The estimation of fat from density alone requires the assumption that all adult humans are identical in body composition except for differences in the amount of fat; since there is normal variability in body constituents, the accuracy of this assumption is limited. Even with the recognition of the limitations of the method, the use of densitometry in determining body fat was considered by Siri (12) to be the most reliable *in vivo* method when applied singly to the normally hydrated adult human; if there are gross differences from the normal in any of the constituents except fat, the equation may no longer be valid and thus may not be used with reliability for patients with edema or other transudations.

Prediction of body fat from total body water

The amount of fat has been expressed as the difference between the fat-free body mass and the total body mass. Studies by Murray (124) showed that the fat-free body had a substantially fixed composition. Behnke *et al*. (100) reported that the relationship between the amount of water and the amount of protein in the fat-free body was fairly constant. On this basis, it is assumed that it is possible to measure total body water and to estimate fat-free weight on the basis of the relationship of water to protein; from these data, total body fat can be derived. Minerals represent only a small fraction of the body (125, 126), and small variations in the mineral composition would have a negligible effect on the results.

The total water content of the leanest body and the fat-free body is estimated to be near 72% of the fat-free body weight. Theoretically, the lean body component of a person would be equivalent to the total body water divided by .72, and the percent of fat would be equivalent to 100 - 139w, where w is the per cent of body water. Since the body cannot be regarded as a lean mass on which pure fat or obesity tissue of fixed composition is added, the use of these factors is not wholly valid.

Keys and Brožek (10) reported that obesity tissue contained 62% fat, 31% water, and 7% protein; this relationship could be expressed as:

$$w = .72\ (1 - f/.62) + (.31/.62).$$

From these values, Siri (12) derived the equation:

$$f = 1.00 - 1.51w.$$

Rathbun and Pace (6) analyzed 50 eviscerated guinea pigs and found that water accounted for a mean of 72.4% of the fat-free mass with a standard deviation of ± 2.11%. There was a range from 68.2 to 76.6% body water of the fat-free weight for 90% of the guinea pigs. A wider range in percentage water would probably have been found if the viscera had been included in the determinations. Rathbun and Pace (6) summarized the data for guinea pigs along with other data on rats, monkeys, cats, dogs and rabbits and found that the mean per cent water in the fat-free body ranged from 69.9% for dogs to 76.3% of the body weight for rabbits.

The data on man are scanty; but from the desiccation of 2 normal subjects reported by Widdowson _et al_. (127) and Forbes _et al_. (125), it appeared that the human adult fat-free body contained between 68 and 75% water. McCance and Widdowson (128) concluded that the fat-free adult human body has an average of 71% water while Pace and Rathbun (5) suggested a mean of 73.2% water. Osserman _et al_. (15) studied 81 normal men from 18 to 46 years of age and found that the per cent water content, estimated by antipyrine, ranged from 66.3 to 79.0% with an average of 71.8% of the total fat-free body weight. This value was obtained by calculating the per cent fat from specific gravity and then the per cent water in lean body mass from the antipyrine results. They used the following equation to estimate fat content from per cent water:

$$\%\ \text{fat} = 100\left(\frac{71.8 - \%\ \text{body weight}}{71.8}\right).$$

Percentages of body weight as fat calculated from specific gravity and from body water determinations using antipyrine and a mean of 71.8% water in lean body mass agreed closely in most subjects. For 10 subjects, however, differences in estimation by the 2 methods were greater than 5%.

Prediction of body fat from density and total body water

Bases for the prediction of fat from determinations of body density and of total body water have been derived by Keys and Brožek (10) and Siri (12, 123). The relationship can be expressed by the general equation:

$$f = \frac{d_f}{d_s + d_f} [\frac{d_s}{d} - w (\frac{d_s - d_w}{d_w}) - 1],$$

where s represents non-fat solid. This equation was developed from the basic premises that the sum of the proportion of the principle body constituents equal unity, that is, 1 = w (water) + f (fat) + p (protein) + m (mineral) and that the sum of the fractions of constituents and their respective densities equal the density from the whole body;

$$\frac{1}{d} = \frac{w}{d_w} + \frac{f}{d_f} + \frac{p}{d_p} + \frac{m}{d_m}.$$

Thus, it may be hypothesized that the quantities of any 2 substances may be derived from the body density and direct measurement of the other 2 constituents. Since only 1 constituent (total body water) other than fat, can be measured, protein and mineral were combined as a single compartment and termed non-fat solid ($s = p + m$). Siri (123) substituted values for densities in the above equation and derived the following expression:

$$f = (2.118/d) - .780w - 1.354.$$

The values used by Siri for the density of fat and water at body temperature were .900 gm per cubic cm and .993 gm per cubic cm, respectively. The density of solids used was 1.565 gm per cubic cm. Siri estimated the total overall error due to density and water measurements and error due to the density value of non-fat solid and found a standard deviation in fat equal to ± 2.0% of the body weight. This combined method, therefore, gives less error than estimates from density, or water separately, and can be used for patients with edema and ascites.

Prediction of body fat from density and extracellular fluid

Keys and Brožek (10) derived an equation for estimating fat in terms of body density and extracellular fluid and expressing the fat as the difference in fat between the reference man and a subject. The equation was:

$$\Delta f = (5.359/d) - .256T - 4.982,$$

where T equals the extracellular water fraction of the body measured by thiocyanate. This equation is based on the fat-free body as the reference standard and a value of 18% of the weight of the fat-free body as extracellular water. According to Siri (123) this equation takes into account possible abnormal hydration, but the reliability is limited due to the large uncertainty in measuring extracellular fluid and the normal variability in total body water and the mineral-protein ratio. These limitations may lead to an uncertainty greater than that in the prediction of body fat from density alone.

Prediction of body fat from potassium-40

Another method used recently to estimate lean body mass and total body fat involves the determination of total body potassium by whole-body scintillation counting of potassium-40. Normal potassium found in the body is associated with an isotope, potassium-40, which is radioactive. The potassium is determined by measurement of the gamma-ray emission of potassium-40 in a human scintillation counter. The instrument for measurement of total body potassium-40 is very expensive and, therefore, is limited in widespread and practical application of the procedure for estimating total body fat. A review of the literature covering this method has been presented by Anderson and Langham (129). In 1953, Reines *et al*. (130) reported the measurement of potassium by whole-body scintillation counting of potassium-40. Since 1953, the Biomedical Research Group of the Los Alamos Scientific Laboratory has been studying the use of whole-body scintillation counting of potassium-40 in the measurement of the gross body composition including fat. In 1956 data collected with regard to the relationship among total body potassium, lean body mass as estimated from tritium data, and fat in humans were reported by Woodward et al. (131).

In 1959, Anderson and Langham (132) extended their earlier report on humans and presented data for the potassium-40 measurement on 1590 males and females ranging in age from less than 1 year to 79 years. Later, Allen et al. (133) reported comparisons of lean body weights calculated from measurement of potassium-40, total body water, and body density. The agreement among the various methods was good with a standard deviation of ± 5%.

Determinations of lean body mass and/or body fat from measurements of potassium-40 are based on the concept that total body mass has a constant potassium content. In 1956, Woodward et al. (131) reported that the potassium (meq) per lean body weight was 63 meq per kg. In a later report by Anderson (134), allowance was made for the fact that fatty tissue contains about 20% water; on this basis, potassium per lean body weight was estimated to equal 73 meq per kg.

Forbes *et al*. (135) have used 68.1 meq potassium per kg lean body mass to calculate values for lean body mass.

Prediction of body fat from anthropometric measurements

Lean body mass and body fat have been predicted from various anthropometric measurements, such as height, biacromial width, biiliac width, chest width, and the circumference of certain areas as the ankle, knee, leg, and arm; skinfold measurements and roentgenograms have also been used.

Behnke *et al*. (136) presented data for the estimation of fat in men from anthropometric measurements of the body trunk which included circumferences of the chest, abdomen, buttocks, and thighs and the extremities which included the circumferences of the biceps, forearm, wrist, knee, calf, and ankle, as well as the bideltoid diameter; fat was estimated also from density determinations. In a related article, Behnke (137) described the estimation of lean body mass in male subjects from various combinations of "skeletal" dimensions and x-rays of extremities and trunk areas and derived equations for estimating lean body mass. Comparisons were made between value for lean body mass predicted by these equations and those estimated from body density and total body water determinations; correlation coefficients ranged from .80 to .90.

Since the subcutaneous fat depot contains a large fraction of adipose tissue (10), it has seemed feasible that measurements of the thickness of skinfolds at selected sites may be used for an estimate of the degree of adiposity. Such a method for prediction of total body fat would be relatively inexpensive and more easily applied than other procedures, i.e., the estimation of body fat from total body water and density. Factors which have been studied in the investigation of the reliability of information gained from skinfold measurements have included the variation in the amount of subcutaneous fat at different body sites, the differences in distribution of subcutaneous fat between men and women, and the reproducibility of measurements.

Edwards (138) obtained measurements of skinfolds for as many as 93 different body sites; this report has provided helpful information for the selection of particular sites for skinfold measurements. In addition, Edwards (139) determined the skinfold thicknesses in females and males ranging in age from 5 to approximately 50 years. He found that the distribution of fat in different parts of the body was similar for both sexes before puberty but that, after puberty, women had about 1.2 times as much subcutaneous fat on their legs as men and a total of about 1.7 times as much subcutaneous fat as men when all skinfold measurements were evaluated. Garn and Saalberg (140) also reported that women had a higher per cent of fat on the legs than men and that there was an increase in the fat on the legs of women with an increase in age. Allen _et al_. (141) found that the thickness of the sites differed between men and women; his study included 58 men and 29 women in Formosa. Since there are differences in the distribution of subcutaneous fat throughout the body in adult men and women and since the distribution of subcutaneous fat may also be a function of age, equations for prediction of fat from skinfold measurements may be needed for different age groups of each sex.

Absolute values for skinfold thicknesses will vary with the type of caliper which is used and the amount and length of time that pressure is applied. Keys and Brožek (10) reported that Sandler (142) found a large change in apparent skinfold thickness with an increase in the caliper pressure from 2 to 10 gm per square mm and that the length of time the pressure was held also affected the skinfold reading. Brožek _et al_. (143) reported a systematic investigation on a variety of calipers, using different pressures, and found a marked, non-linear decrement in apparent skinfold thickness as the pressure was increased to about 5 gm per square mm; with pressures exceeding 10 gm per square mm, increments in pressure resulted in increments in skinfold thickness. At low pressures the variability of the duplicate measurements was greater than at higher pressures. The length of time the pressure was applied and the time between repeated measurements also affected the reproducibility of the measurement. Garn and Gorman (144) reported a reduction in skinfold measurements due to tissue compression of the caliper and calculated the value of the skinfold to be 70% of the calculated true values obtained from roentgenogramic techniques. Edwards et al. (145) also gave a detailed report on differences obtained from different calipers and using different pressures; he recommended a pressure of 9 to 19 gm per square mm for best accuracy and reproducibility.

In order to study the relative distribution of subcutaneous and internal fat throughout the body, roentgenograms have been helpful. In animals, X-ray data and fat extraction have shown that a large increase in fat in the subcutaneous areas occurs with a large increase in body fat. Mickelsen et al. (146) used X-ray data to compare rats which became obese on a high-fat diet and found a large increase in the amount of fat in the subcutaneous area as well as in the abdominal cavity. Pitts (147) reported data for 26 adult males and 21 adult female guinea pigs in which he extracted fat from the carcasses which had been separated into 11 sections and found that the subcutaneous fat was directly proportional to their total body fat. Garn (148), using X-ray data, found little difference in the absolute fat in 81 men and 107 women, but when calculated on a weight basis the per cent fat was 23.7% for females and 16.8% for males.

Several equations have been developed for predicting body fat or body density from skinfold thicknesses determined on various sites of the body. Measurements of body fat by densitometry or by determination of total body water have been used to relate skinfold thickness to total body fat.

Brožek and Keys (7) have reported prediction equations calculated from data obtained for 116 young and 214 older men with mean ages of 21.9 years and 49.2 years, respectively. The equations were based on specific gravity measurements and thicknesses of 5 different skinfolds plus relative body weights. Pascale et al. (8) reported data obtained for skinfolds and body specific gravity of 88 soldiers from 17 to 25 years of age and found a high correlation between these 2 measurements. From these data a prediction equation for estimating body fat from skinfold thicknesses was developed. Allen et al. (141) reported a prediction equation for estimating adiposity from total body weight and the sum of the thickness of subcutaneous folds at 10 sites, and another equation which included the above measurements plus surface area. No differentiation was made for sex. Brožek and Mori (149) presented equations for predicting body density from roentgenograms and skinfolds, for predicting skinfolds from roentgenograms, and for predicting roentgenograms from skinfolds. The coefficient of correlation for predicting density from skinfold was -.68.

Many values are available for body density and skinfold measurements of men, but few data have been reported for women. Chen (150) studied the specific gravity of 65 healthy Minnesota women; Škerlj _et al_. (151) reported data for skinfolds for 84 women from 18 to 67 years of age. Allen _et al_. (152) reported density values for 26 young Chinese University women with a mean age of 22.6 years and ranging from 19 to 29 years except for 1 subject who was 39 years old; an equation based on data for body density of 29 Chinese women was presented for predicting adiposity from height and weight. Young _et al_. (153) reported specific gravity and skinfold data for 94 women. Edwards (138) and Garn (148) also have reported skinfold measurements for women.

Before the present study was begun no equations had been developed for the estimation of fat from skinfolds; since completion of this study, Young _et al_. (9) have presented an equation for the estimation of density from 1 skinfold plus percentage "standard" weight for young women. Young's data were obtained using 94 women from 17 to 30 years old with a mean age of 20.36 years.

Investigations reported to date indicate that skinfold measurements may serve as a useful tool in studies of nutritional status. Brožek and Mori (149) have warned that care must be taken not to apply predicting equations from skinfold measurements to individuals differing in sex or age from the sample used in obtaining these equations. Variations in technique among investigators conceivably may limit the comparisons which may be made among groups studied by different workers. Uniformity in the type and use of calipers and clearly defined sites of measurements may, however, reduce such variations among laboratories. According to the Committee on Nutritional Anthropometry of the Food and Nutrition Board of the National Research Council the body sites which should be included in studies of skinfold thickness include the upper arm skinfold and the subscapular skinfold (154).

METHOD OF PROCEDURE

Experimental Plan

Forty-eight apparently healthy women from 25 to 55 years of age were studied. The following tests were made on 25 women: total body water, extracellular water, density, and anthropometric measurements including skinfold thickness. Density and anthropometric measurements were made on 23 additional women. All tests were made on a subject on the same day with the exception that a few of the subjects had to have the density measurements repeated because of difficulty in the operation of the body-volume determinator on the test day. Measurements of total and extracellular body water were repeated on 3 subjects.

The following schedule was used for the women who had all tests. The subjects were instructed to spend a quiet relaxing evening with no strenuous exercise, to get 8 hours rest, and to have nothing to eat or drink except water after 7:00 p.m. on the night preceding the test. Water could be consumed until 10:00 p.m. The subject was called for at 7:00 a.m., transported to the metabolism room in the Home Economics Building, weighed after emptying her bladder, taken to the University Hospital and given 50 ml water to drink. The subject rested in bed except for a brief period when the skinfold measurements were taken. At 8:00 a.m. a physician took the first blood sample of approximately 15 ml from the antecubital vein with minimum stasis and administered intravenously a measured quantity of antipyrine and sodium thiocyanate over a two-minute period; the exact time was recorded. After the injection the subject was given 100 ml orange juice and a sweet roll. One hour later, skinfold measurements were made. Approximately 2 hours after the injection, another 15 ml blood sample was taken from the opposite arm, the exact time recorded, and 100 ml of water was given orally. After the second blood sample was obtained the subject returned to the metabolism room in the Home Economics Building for the remainder of the tests. At approximately 3 hours after injection, a third blood sample of 10 ml was taken, the exact time recorded, and the subject was given 100 ml water and a sweet roll.

The body volume determinations were then made. Four hours after injection, another 100 ml of water was given. Approximately 5 hours after injection, a fourth blood sample of 10 ml was taken and the exact time recorded.

The subjects who did not have the total and extracellular body water tests made had the body volume determination and anthropometric measurements, including skinfold measurements, made at the same appointment. These subjects were not in the post-absorptive state but were requested to empty their bladder before their weight was obtained.

Subjects

Forty-eight apparently healthy women ranging in age from 25 to 55 years were used as subjects. The subjects were not randomly selected but were members of the University faculty, graduate students, and other women in the community of Ames, Iowa, who volunteered to participate in the study. Subjects were screened for allergies and individuals who had a history of allergies were not used for the total body water and extracellular water determinations. Density, total body water, extracellular water and anthropometric measurements were made on 25 subjects (no's. 1-25). Density and anthropometric measurements were made on 23 additional subjects (no's. 26-48).

Anthropometric Techniques

Nude weight was determined using a Howe scale and weight recorded to .001 kg. Height was obtained on a platform with a rigid vertical upright to which a measuring stick calibrated in tenths of cm was attached. The subject stood erect, barefooted, with heels, buttocks and shoulders touching the upright and with the head held comfortably erect so that the line of sight was horizontal. The height was determined by lowering a rectangular wooden object, remaining in contact with the vertical measuring scale until it made firm contact with the subject's head.

A caliper was used for the biacromial and biiliac diameters. These sites were measured with the subject in standing position, feet together, shoulders straight but relaxed, and arms hanging freely at the sides. The width of the pelvic girdle was obtained as the greatest distance between the lateral margins of the iliac crest. Pressure was exerted on the contact surface of the anthropometer in order to minimize the amount of soft tissue. The width of the shoulder girdle was determined as the distance between the most lateral margins of the acromion process of the scapula.

A flexible steel tape, calibrated in mm was used for obtaining the circumference of the calf and upper arm. The calf measurement was made with the subject sitting, feet flat on the floor, and legs perpendicular to the floor. The circumference was obtained on the largest portion of the calf. The upper arm circumference was measured with the arm hanging freely at the side, at a right angle to the long axis of the arm, and at the same level as the arm skinfold measurement, namely, at the level midway between the tip of the acromial process of the scapula and the tip of the elbow.

The tape for both measurements was applied lightly to the skin, without deforming the contour of the skin.

Skinfold measurements were made with a skinfold caliper obtained from the Laboratory of Physiological Hygiene, University of Minnesota. The caliper was calibrated to exert a pressure of 10 gm per square mm of jaw surface. The area of the jaw surface was 20 square mm. At all sites the skin was lifted by firmly grasping the fold between the thumb and the forefinger of the left hand, about 1 cm from the site at which the skinfold was to be measured. The thickness of the skinfold included double thickness of the skin plus tela subcutanea. The caliper was applied with the right hand and the pressure exceeded at first and then returned to the standard mark.

Instructions for measurements suggested by the Committee on Nutritional Anthropometry of the Food and Nutrition Board, National Research Council (154), were used. Measurements were made at each site and then repeated. Six sites, primarily on the right side of the body, were used. They included the chin, the subscapula, the knee, the waist, the upper arm, and the lateral aspect of the thorax. These sites were measured in the following manner:

Chin: With the head held comfortably erect so that the line of sight was horizontal, the skin under the mandible was picked up so that the fold was at a

45° angle with the median plane of the body.

Subscapula: The skinfold below the tip of the scapula was lifted so that it ran from the spine diagonally down to a point below the scapula, at an angle of about 45° with the spine.

Knee: The skinfold over the patella was lifted so that it was parallel to the sagital plane. The subject was in a sitting position with leg extended forward and straight, but relaxed.

Upper arm: The back of the upper arm over the triceps was measured at the midpoint between the top of acrominal process of the scapula and the tip of the elbow. The point was located with the arm flexed at 90° and held forward. The skinfold was obtained with the arm hanging freely at the side. The skinfold was lifted parallel to the long axis of the arm to obtain the measurement.

Waist: The side was located along the mid-axillary line halfway between the lower ribs and the iliac crest; the skinfold was lifted parallel with the mid-axillary line of the body.

Thorax: The site was located at the lateral aspect of the thorax just beneath the rib midway between the axillary plane and the median plane. The fold was lifted at an angle about 45° to the median plane.

Density Measurement

Body volume was determined by the helium dilution method using a Body Volume Determinator as described by Siri (118). The instrument used was designed by Dr. William E. Siri, University of California, Berkeley, and constructed by the National Instrument Company, Washington, D. C. This apparatus utilizes the gas-dilution technique, namely, the dilution of a measured quantity of helium by a quantity of air that depends upon the volume displaced by the subject.

The procedure is fairly rapid requiring about 15 minutes per run for each subject and does not require trained subjects. Three determinations were made on each subject and 2 determinations were made on carboys of known volume which bracketted the volume of each subject.

The observations which were made for each run included: the temperature of the chamber air and the helium before injection of helium; the relative humidity in the chamber, before and after injection of helium; the resistance of the thermal-conductivity cell, before and after injection; and the temperature of the chamber after injection of helium. The equation used to determine the volume of the subject was:

$$V_x = \frac{AB\ (R_x - R_2) - CD\ (R_x - R_1)}{d_x\ [D\ (R_x - R_1) - B\ (R_x - R_2)]},$$

where: $A = (V_c - V_1)d_1 - V_c d_x$; $B = (V_c - V_2)d_2 + v$; $C = (V_c - V_2)(d_2) - V_c d_x$; and $D = (V_c - V_1)d_1 + v$. In the above figures the subscripts 1 and 2 pertain to data obtained on 2 sets of carboys of known volume, and the subscript x refers to the subject's data; V = volume; V_c = chamber volume; R = thermal-conductivity response in millivolts; v = helium gas volume; and d = temperature and water vapor corrections. The forms used to record and calculate the volume of each subject are given in the Appendix, Forms 1 and 2.

A short house coat was provided for the subject to wear during the determination. The coat was also used in the runs with the carboys of known volumes. The volumes of the glass carboys used for bracketting the volume of each subject were determined by underwater weighing.

The average of the mean deviations of the body volume determinations for the 48 subjects was .166 liters.

Equations 1 and 2, presented by Siri (123) and Rathbun and Pace (6), respectively, were used to estimate body fat from density.

$$\%\text{ body fat} = \frac{490.0}{\text{density}} - 450.0 \qquad \text{(Eq. 1)}$$

$$\%\text{ body fat} = \frac{554.8}{\text{sp. gr.}} - 504.4 \qquad \text{(Eq. 2)}$$

Body Water Measurement

Total body water was determined by the antipyrine technique of Soberman (22) and extracellular water by sodium thiocyanate technique of Bass *et al*. (98). Known quantities of antipyrine and sodium thiocyanate were administered intravenously and simultaneously. All subjects were in the fasting state initially; at specified intervals of time, water, orange juice, and a sweet roll were given as stated above. Osserman *et al*. (15) reported that there was no apparent significant difference between results of subjects tested in the fasting state and those who were allowed their usual food and fluid intake. The subject remained in bed except during the skinfold measurements, which were made 1 hour after injection.

A blood sample was taken before the injection and again at 2, 3, and 5 hours after injection for the antipyrine determinations. Sodium thiocyanate determinations were made on the control blood sample and the 2-hour sample.

Immediately after withdrawal, the blood sample was transferred to a container having a dried film of sodium heparinate sufficient to provide approximately 150 units per ml of blood, mixed, and centrifuged.

The plasma concentrations of antipyrine were determined according to the procedure of Brodie *et al*. (21); the optical densities of the solutions were measured in a Beckman D. U. Spectrophotometer at a wave-length of 350 mμ. The plasma concentration of antipyrine was determined by use of a standard curve obtained from serial dilutions of a known quantity of antipyrine. To obtain the plasma concentration at zero time, the data were plotted on a semi-logarithmic paper with the concentration of antipyrine in the plasma on the logarithmic scale against time on the non-logarithmic scale and extrapolated to zero time. This value was then corrected for plasma solids to obtain the plasma water level. The following equations were used to calculate the concentration of antipyrine in the plasma water, the antipyrine space, and the per cent body water.

$$\text{Concentration of antipyrine in plasma water (mg/ml)} = \text{plasma concentration (mg/ml)} \div \frac{100 - \text{plasma protein (gm/100 ml)}}{100};$$

$$\text{Antipyrine space (liters)} = \frac{\text{mg antipyrine injected}}{\text{conc. antipyrine in plasma water (mg/ml)}} \div 1000;$$

$$\text{\% body water} = \frac{\text{antipyrine space (liters)}}{\text{body weight (kgs)}} \times 100.$$

Plasma concentration of sodium thiocyanate was determined according to the procedure of Bowler (155) and the optical densities of the solutions read in a Beckman D. U. Spectrophotometer at a wave-length of 480 mμ. The plasma concentration of sodium thiocyanate was determined by the use of a standard curve obtained from serial dilutions of a known quantity of sodium thiocyanate. The values were corrected for plasma solids to obtain the plasma water level. The following equations were used to calculate the concentration of sodium thiocyanate in plasma water, the thiocyanate space, and the per cent extracellular water:

$$\text{Concentration of NaSCN in plasma water (mg/ml)} = \text{plasma concentration (mg/ml)} \div \frac{100 - \text{plasma protein (gm/100 ml)}}{100};$$

$$\text{Thiocyanate space (liters)} = \frac{\text{mg NaSCN injected}}{\text{conc. NaSCN in plasma water (mg/ml)}} \div 1000;$$

$$\text{\% body extracellular water} = \frac{\text{thiocyanate space (liters)}}{\text{body weight (kg)}} \times 100.$$

Plasma proteins were determined according to the procedure as outlined in Practical Physiological Chemistry (156, pp. 553-556) by the use of standard copper sulfate solutions of known and varying specific gravity.

Individual sterile ampoules containing 50 mg antipyrine per ml and 17.5 mg sodium thiocyanate per ml were obtained from Atlas Pharmaceutical Laboratories, Inc., Detroit, Michigan. Each ampoule contained 25 ml of solution; approximately 20 ml of solution was injected. Syringes were calibrated to obtain the exact amount of solution delivered at 25°C.

Before determinations were made on the subjects, several tests were made on a random sample of the ampoules. The concentration of antipyrine and sodium thiocyanate in the ampoules was determined by standard analytical procedures using N. F. crystals of antipyrine and sodium thiocyanate as standards. The solution in the ampoules was tested for pyrogens according to the procedure as outlined in The National Formulary (157, pp. 707-708) and The Pharmacopeia of the United States of America (158, pp. 883-885). Atlas Pharmaceutical Laboratories, Inc., ran the standard Food and Drug Administration sterility test.

Injection of the test solution was administered by Iowa State University Hospital physicians; the physicians also took the first 2 blood samples. The last 2 blood samples were taken by a medical technician approved by the University Health Service.

Two equations, presented by Siri (123), were used to estimate per cent body fat from body water. They were as follows:

$$\% \text{ body fat} = 100 - 139 (\% \text{ water}) \qquad \text{(Eq. 3)}$$

$$\% \text{ body fat} = 109 - 151 (\% \text{ water}) \qquad \text{(Eq. 4)}$$

An equation, containing per cent total body water and per cent thiocyanate space, suggested by Keys and Brožek (10), was also used to estimate per cent body fat. It was as follows:

$$\% \text{ body fat} = 100 - 156.3 (\% \text{ water}) + 34.9 (\% \text{ thiocyanate space}) \qquad \text{(Eq. 5)}$$

Equation 6, presented by Siri (123), was also used to estimate per cent body fat; the equation contained both density and total body water.

$$\% \text{ body fat} = \frac{211.8}{\text{density}} - 78 (\% \text{ water}) - 135.4 \qquad \text{(Eq. 6)}$$

Statistical Analysis

Means, standard deviations, correlation coefficients, multiple and simple linear regression equations, and other statistical measures were obtained through the use of the IBM 1620 electronic computer.

A stepwise multiple regression program was used to obtain the best fitting regression equations for predicting density from among 8 selected variables. A minimum F-value of 1.000 for the additional sum of squares accounted for by the inclusion of a variable in the equation was used as a criterion for selection. Intermediate and final equations were determined through the aid of this test. The general procedure was as follows:

1. The highest simple correlation coefficient squared (r^2) among the 8 variables (X_1, X_2, ... X_8) is determined.
2. (a) If the sum of squares accounted for by this variable in the test of significance for regression yields $F < 1.000$, the computer records the final results and halts.
   (b) If $F > 1.000$, the computer proceeds to the next step.
3. The highest multiple correlation coefficient (R^2) among the other X's with the first X already in the equation is determined.
4. (a) If the additional sum of squares accounted for by the new variable yields $F < 1.000$, the computer records the final results and halts.
   (b) If $F > 1.000$, the computer records the results of the intermediate multiple regression equation and proceeds to the next step.
5. A test is made on the sum of squares accounted for by the old variable with the new variable already in the equation.
   (a) If $F < 1.000$ for the old variable, this measure is eliminated from the equation, intermediate output is

recorded, and the computer proceeds to the next step.

(b) If F > 1.000, the computer proceeds to the next step.

6. The computer searches out the most potent third variable with the first 2 variables already in the equation (4b, 5b) or with 1 variable in the equation where 1 variable was deleted in an intermediate step (5a).

7. (a) If F < 1.000 for the new variable, the computer records the final results and halts.

   (b) If F > 1.000 for the new variable, the result is recorded and the computer proceeds to the next step.

8. (a) If F < 1.000 for either of the old variables, that measure is eliminated from the equation, intermediate output is recorded, and the computer proceeds to the next step.

   (b) If F > 1.000 for either of the old variables, the computer proceeds to the next step.

9. The computer next proceeds to examine all other variables in a like manner until it reaches a final result and halts, or has examined and incorporated all possible variables in the equation, records the final results, and halts.

RESULTS AND DISCUSSION

The following sections present the height, weight, density, body water, and anthropometric measurements of the subjects. These data have been used for the prediction of body fat of women by various equations reported in the literature. Variations in body fat among individuals and the changes in fat content with age will be discussed.

Height - Weight

The age, height, and body weight of the 48 subjects are given in Table 4. Ages of the subjects ranged from 25 to 55 years. The mean height was 165.2 cm with a range of 154.8 to 180.9 cm. Nude body weights ranged from 48.020 to 93.822 kg with a mean of 61.237 kg.

Height and weight relationships have been used as one criterion of nutriture. Over the years, various tables on height and weight of humans have been published (159-161). Various sources and methods of selection of data have been used in the compilation of height-weight tables and data have been used for different conditions of dress. Although these tables have been used for standards of body weight in relation to height and age, considerable latitude is necessary in the application of the tables to individuals.

Table 4. Physical description of 48 subjects

Subject no.	Height cm	Weight kg	Age yr	Relative weight[a] %	Relative weight[b] %
1	164.1	48.371	31	78.6	85.3
2	161.8	70.569	49	109.0	117.6
3	163.2	56.594	31	93.2	102.1
4	163.2	64.245	29	110.2	111.0
5	163.4	60.100	45	94.0	109.2
6	167.5	65.485	43	96.2	111.7
7	165.9	60.495	29	101.5	106.5
8	174.9	63.902	31	91.6	100.4
9	163.8	71.718	33	117.3	118.0
10	177.1	59.915	36	83.4	91.5
11	174.8	56.454	29	84.4	88.7
12	165.2	54.685	31	88.2	96.2
13	164.1	66.593	34	106.7	117.2
14	171.6	63.823	51	86.2	96.4
15	180.9	70.935	28	99.0	105.7
16	169.0	58.872	32	92.1	99.6
17	171.6	51.335	26	79.9	83.2
18	167.4	57.632	41	85.2	98.5
19	162.4	93.822	43	143.8	146.4
20	171.2	57.060	48	82.3	95.3
21	161.0	58.110	43	93.1	108.6
22	164.5	51.670	41	78.7	91.1
23	160.3	67.798	55	104.4	126.7
24	162.2	61.690	41	95.9	111.5
25	162.0	59.140	54	89.1	106.9

[a]Based on averages reported by The Society of Actuaries (160).

[b]Based on averages reported by Hathaway and Foard (161).

Table 4. (Continued)

Subject no.	Height cm	Weight kg	Age yr	Relative weight[a] %	Relative weight[b] %
26	158.5	50.790	25	93.6	104.7
27	154.6	53.522	25	100.8	105.4
28	168.3	55.287	25	90.6	94.5
29	158.8	58.840	25	107.8	111.8
30	165.0	54.743	26	92.4	96.6
31	172.0	63.398	26	97.8	111.0
32	160.0	68.745	26	121.4	128.5
33	154.8	53.463	27	100.7	105.3
34	167.3	48.020	28	79.2	88.2
35	173.0	57.190	28	88.6	92.7
36	157.8	66.775	32	115.3	128.0
37	154.0	47.884	34	85.7	94.3
38	157.4	65.282	36	112.8	125.1
39	155.8	50.657	38	90.5	99.7
40	164.9	59.823	41	90.7	105.5
41	166.5	56.325	41	83.4	96.3
42	158.9	81.886	42	129.8	141.1
43	156.9	51.260	44	84.3	98.3
44	172.6	65.338	44	90.9	98.6
45	167.1	54.610	48	80.9	93.3
46	172.7	69.808	49	96.9	113.2
47	166.4	86.908	51	122.9	139.8
48	171.2	67.790	52	94.1	105.2
$\bar{x}$	165.2 ± 6.3[c]	61.237 ± 9.511	36.8 ± 9.2	96.6 ±14.2	106.3 ± 14.4

[c]Standard deviation = $\sqrt{\dfrac{\Sigma(X - \bar{x})^2}{n - 1}}$.

Some tables make no allowance for body build although this factor is important in determining the relative degree of obesity; Keys and Brožek (10) pointed out the significance of variations in body build, using the data of Munro (159). In a recent publication from the Agricultural Research Service, United States Department of Agriculture, Hathaway and Foard (161) have compiled published data on heights and weights of adults.

The "desirable" body weight of each subject in this study was taken from the table of average weights for height and age report in the _1959 Build and Blood Pressure Study_ by the Society of Actuaries (160) and from the table of suggested weights for heights (161). Since the data in the _1959 Build and Blood Pressure Study_ were reported for persons wearing shoes and other clothing, a correction of the height of shoe heels and weight of clothing was made for the observed heights and weights of the subjects. An average heel height of two inches was added for each height and five pounds were added to each body weight for clothing as was suggested by Hathaway and Foard (161). The suggested weights for heights given by Hathaway and Foard were for persons without shoes or other clothing; therefore, no correction was needed for the body weights as obtained for these subjects.

The relationship of the observed body weight to the "desirable" body weight was calculated for each subject for both standards. The relationship is given in Table 4 as the relative weight or per cent of the average weight.

When the relative weights were calculated as per cent of the average weight from the _1959 Build and Blood Pressure Study_, the mean relative weight was 96.6 ± 14.2% with a range of 78.6 to 143.8%. If the range for desirable weight for the height is considered to be ± 10% of the desirable weight, then 24 (50%) of the subjects were of average weight, 16 (33.3%) were below average and 8 (16.7%) were above average.

On the basis of the weights for heights suggested by Hathaway and Foard (161), the mean relative weight was 106.3 ± 14.4% with a range of 83.2 to 146.4%. There were 28 (58.3%) of the subjects within the range of 90 to 110%, that is, of desirable body weight. Four (8.3%) of the subjects were underweight and 16 (33.3%) were overweight.

Averages reported in the _1959 Build and Blood Pressure Study_ (160) were given for several age groups without reference to body build. Averages in the report by Hathaway and Foard (161) were selected for adults who were 20 to 24 years of age, and it was assumed that throughout adulthood the body weight probably should not vary more than 5 lb for short persons and 10 lb for tall persons.

Comparison of the results from the 2 tables for weight and height showed wide differences in the per cent of desirable weight for some individuals. Standard weights taken from the table of Hathaway and Foard (161) gave higher relative weights for all subjects than the standard weights taken from the actuarial study. However, the group of 16 subjects judged to be overweight according to the values of Hathaway and Foard included the 8 subjects classed as overweight by values from the actuarial study. The 4 subjects who were grouped as underweight according to the range from desirable body weight based on the tables of Hathaway and Foard were included in the group of 16 subjects who were classed as underweight according to the figures of the actuarial study.

Body Density

Body densities of the 48 women subjects are given in Table 5. The mean body density for the group was 1.0215 ± .0162 gm per cubic cm. Values ranged from .9853 to 1.0494 gm per cubic cm. The median was 1.0252 gm per cubic cm. The body density of each subject was converted to specific gravity in order to facilitate comparison of these values with data reported as specific gravity in the literature. Calculated values for specific gravity ranged from .9918 to 1.0563 gm per cubic cm; the mean was 1.0282 ± .0163 gm per cubic cm; the median was 1.0320 gm per cubic cm.

Twenty-four subjects, 25 to 55 years of age, whose body weights were within ± 10% of desirable body weight (Society of Actuaries, 1959; 160) had a mean density of 1.0209 gm per cubic cm; the range was from .9978 to 1.0494 gm per cubic cm. Nine subjects, 25 to 29 years of age, whose body weights were also within ± 10% of desirable weight, had a mean density of 1.0266 ± .0084 gm per cubic cm with a range of 1.0104 to 1.0350 gm per cubic cm. The median for this group was 1.0290 gm per cubic cm.

Table 5. The body density and corresponding specific gravity of 48 adult women

Subject no.	Age yr	Density gm/cm^3	Specific gravity gm/cm^3
1	31	1.0432	1.0501
2	49	1.0413	1.0482
3	31	1.0494	1.0563
4	29	1.0427	1.0496
5	45	1.0152	1.0219
6	43	1.0056	1.0122
7	29	1.0252	1.0320
8	31	1.0179	1.0246
9	33	1.0338	1.0406
10	36	1.0328	1.0396
11	29	1.0434	1.0503
12	31	1.0252	1.0320
13	34	.9978	1.0044
14	51	1.0065	1.0131
15	28	1.0292	1.0360

Table 5. (Continued)

Subject no.	Age yr	Density gm/cm^3	Specific gravity gm/cm^3
16	32	1.0244	1.0312
17	26	1.0334	1.0402
18	41	1.0086	1.0153
19	43	.9916	.9981
20	48	1.0426	1.0495
21	43	1.0044	1.0110
22	41	1.0370	1.0438
23	55	1.0047	1.0113
24	41	1.0199	1.0266
25	54	1.0042	1.0108
26	25	1.0334	1.0402
27	25	1.0350	1.0418
28	25	1.0280	1.0348
29	25	1.0157	1.0224
30	26	1.0290	1.0358
31	26	1.0104	1.0171
32	26	1.0198	1.0265
33	27	1.0338	1.0406
34	28	1.0422	1.0491
35	28	1.0338	1.0406
36	32	.9988	1.0054
37	34	1.0415	1.0484
38	36	1.0080	1.0147
39	38	1.0297	1.0365
40	41	1.0098	1.0165
41	41	1.0270	1.0338
42	42	1.0085	1.0152
43	44	1.0294	1.0362
44	44	1.0272	1.0340
45	48	.9907	.9972
46	49	1.0028	1.0094
47	51	.9853	.9918
48	52	1.0124	1.0191
$\bar{x}$	36.8	1.0215	1.0282
	± 9.2	± .0162	± .0163

Young *et al*. (153) have reported body densities of 94 American women; the values were somewhat higher than the body densities of these subjects. The mean density for the 94 women was 1.0342 ± .0094 gm per cubic cm; the range was from 1.0150 to 1.0595 gm per cubic cm; the median was 1.0342 gm per cubic cm. The ages of the women ranged from 17.2 to 27.2 years; the mean was 20.36 years. The mean body weight of the group was 58.96 ± 6.445 kg. Values for 26 Chinese University women at the Medical College of the National Taiwan University reported by Allen *et al*. (152) averaged 1.0397 gm per cubic cm. The Chinese women were from 19 to 39 years of age; the mean age was 22.6 years and only one of the subjects was over 29 years old. The mean body weight was 49.3 kg. The mean specific gravity of 25 Minnesota women studied by Chen (150) was 1.0458 ± .0099 gm per cubic cm. This group ranged in age from 18 to 30 years (mean, 24.4 years) and had a mean body weight of 55.44 ± 6.42 kg.

Only the 9 subjects of this study who were 25 to 29 years of age and who were of average body weight were in an age range similar to that of the women studied by Young *et al*. (153), Allen *et al*. (152) and Chen (150). The mean density for these subjects, 1.0266 and the calculated specific gravity, 1.0334, were somewhat lower than the reported values although higher than the means for the entire group of 48 women.

Body Water

Table 6 presents the antipyrine space and the sodium thiocyanate space for each of 25 subjects for whom determinations of body water were made. The subjects ranged in age from 26 to 55 years. The mean body weight was 62.040 ± 9.004 kg. These subjects were among the entire group of 48 women; the age range and mean body weight of the sub-sample were similar to those of the total group. Both antipyrine space and sodium thiocyanate space are expressed as liters and as per cent of body weight in Table 6. Since antipyrine space as per cent of body weight is used as an index of total body water, these terms will be used interchangeably.

The mean antipyrine space was 30.317 ± 3.493 liters; values for individual subjects ranged from 24.551 to 39.217 liters. The mean total body water was 49.204 ± 4.343% of the body weight. The mean lean mass or fat-free weight calculated on the basis of antipyrine space and assuming that lean body mass contains 72% water, was 68.2% of the body weight. Values for total body water ranged from 41.8 to 56.4%.

Data for the total body water of 94 normal healthy women with a mean age of 20.4 years and ranging from 17.0 to 27.2 years of age, were reported by Young *et al*. (153). The test solute used was N-acetyl-4-amino antipyrine (NAAP). The NAAP space was 30.33 ± 4.363 liters, which was equivalent

Table 6. The antipyrine space and sodium thiocyanate space of 25 subjects

Subject no.	Weight kg	Antipyrine space liters	Antipyrine space % body wt	Na-thiocyanate space liters	Na-thiocyanate space % body wt
1	48.371	24.551	50.8	14.800	30.6
2	70.569	38.889	55.1	18.429	26.1
3	56.594	29.895	52.8	15.216	26.9
4	64.245	27.518	42.8	17.533	27.3
5	60.100	30.582	50.9	16.853	28.0
6	65.485	28.867	44.1	15.004	22.9
7	60.495	27.985	46.3	16.421	27.1
8	63.902	31.435	49.2	18.327	28.7
9	71.718	31.463	43.9	16.017	22.3
10	59.915	32.817	54.8	18.330	30.6
11	56.454	31.379	55.6	16.318	28.9
12[a]	54.685	29.096	53.2	15.978	29.2
13	66.593	29.257	43.9	15.491	23.3
14	63.823	29.139	45.7	14.743	23.1
15	70.935	34.452	48.6	18.003	25.4
16	58.872	29.201	49.6	15.545	26.4
17	51.335	25.993	50.6	13.506	26.3
18	57.632	28.625	49.7	15.064	26.1
19	93.822	39.217	41.8	20.774	22.1
20	57.060	32.177	56.4	18.528	32.5
21	58.110	26.118	44.9	11.711	20.2
22	51.670	28.423	55.0	16.049	31.1
23	67.798	32.821	48.4	17.153	25.3
24	61.690	30.248	49.0	16.317	26.5
25	59.140	27.767	47.0	15.143	25.6
$\bar{x}$	62.040	30.317	49.2	16.290	26.5
	± 9.004	± 3.493	± 4.3	± 1.870	± 3.1

[a]Urticaria occurred immediately after injection and epinephrine was administered.

to 51.66% body weight. The mean fat-free weight calculated on the basis of NAAP space was 71.76 ± 9.099% of the body weight. As stated previously, the body densities of the subjects studied by Young *et al*. (153) were higher than the body densities of the subjects of this study. Thus it would be expected that the mean fat-free weight would be correspondingly higher also.

Using deuterium oxide as the test solute, McMurrey *et al*. (162) determined the body water of 10 normal females. Ages ranged from 23 to 51 years (mean 33.7 years); per cent body water ranged from 55.9 to 40.7% with a mean of 48.6 ± 4.7%. These women corresponded in age range to the subjects reported here; the mean total body water of the 2 groups was essentially the same. Johnston and Bernstein (163) studied 17 healthy women, 21 to 59 years of age, with relative weight ranging from 60.0 to 284.0%. Measurements for total body water using antipyrine ranged from 31.4 to 60.8% of body weight. This range was considerably greater than the range in body water for the 48 subjects of this study. However, the range in relative body weight was also much greater than for these subjects.

The mean sodium thiocyanate space of the subjects in this study was 16.290 ± 1.870 liters with a range from 13.506 to 20.774 liters. When the values were expressed as per cent of body weight, the range was from 20.2 to 32.5% with a mean of 26.500 ± 3.078. Since thiocyanate is reported to overestimate the extracellular fluid, the factor .7, which was recommended by Keys and Brožek (10), was used to convert the thiocyanate space to extracellular space; the mean extracellular fluid was then 18.3% of body weight with a range from 13.7 to 22.7% of body weight. This value is slightly lower than the values of 22 to 25% of body weight reported for men (10, 69, 76, 77, 82, 96, 164) but slightly higher than the mean value of 14.9% of body weight with a range from 9.8 to 21.4% reported by Johnston and Bernstein (163) for 17 women. Inulin was used as the test solute by Johnston and Bernstein.

Repeated determinations for total body water and extracellular water

Repeat measurements of total body water and extracellular water were made for 3 subjects to gain information about individual variation in total body water and the distribution of body water. No attempt was made to have the second measurement within a few days after the first since this would have been difficult for the subjects to schedule and it was considered desirable to avoid any residual effects of the first measurement. The time period between measurements was from 3 to 4 1/2 months. The data are presented in Table 7.

Subject 1 had 24.715 and 24.551 liters of total body

Table 7. The antipyrine and sodium thiocyanate spaces of 3 subjects over a period of time

Subject no.	Date	Weight kg	Antipyrine space Liters	Antipyrine space %	NaSCN space Liters	NaSCN space %	Fat[a] %
1	4- 2-60	51.490	24.715	48.0	14.807	28.7	33.3
	7-23-60	48.371	24.551	50.8	14.800	30.6	29.4
2	4- 7-60	70.569	38.889	55.1	18.429	26.1	23.4
	8-18-60	73.770	38.905	52.7	19.032	25.8	26.8
5	5-20-60	59.668	30.729	51.5	16.657	27.9	28.4
	8-19-60	60.695	30.582	50.9	16.853	28.3	29.2

[a]Per cent fat calculated from Equation 3.

water (antipyrine space) and 14.807 and 14.800 liters of sodium thiocyanate space on the 2 different test days; there was a loss of weight of 3.119 kg between determinations. Subject 2 had 38.889 and 38.905 liters of total body water and 18.429 and 19.032 liters of thiocyanate space respectively on the 2 test days. Values for subject 5 on the 2 days were 30.729 and 30.582 liters of total body water and 16.657 and 16.853 liters of thiocyanate space, respectively. There was no appreciable change in total body water between tests for any of the subjects; the only change in extracellular space was an increase of .603 liters for subject 2 and an increase of .196 liters for subject 5. Keys and Brožek (10) have reported that subjects gaining weight from a previously normal, well-fed state showed an increase in extracellular space. Subject 2 gained approximately 3 kg between the 2 determinations; however, subject 5 gained only 1 kg. Keys et al. (165) reported that there was practically no change in absolute thiocyanate space during an average weight loss of 12.6 kg for subjects on a severe calorie deficit. Subject 1 lost 3.119 kg and showed no significant loss of thiocyanate space.

Since the lean mass of the body contains approximately 72% water, it would be expected that values for total body water would be relatively constant unless a shift in the plane of nutrition occurred, resulting also in a change in in lean body mass. The data in Table 7, although based only on duplicate observations on 3 individuals, support this hypothesis.

Body Fat

Values for body density and/or body water were used for estimating the amount of body fat of the subjects. The expression "body fat" has been used to refer to total body fat and includes the essential body lipids unless otherwise indicated.

Estimation of body fat from density

Several equations have been reported in the literature for estimating body fat from density. If one considers only the density of the whole body (d), density of the fat-free body (d_o), and density of fat (d_f), the following equation applies:

$$\frac{1}{d} = \frac{f}{d_f} + \frac{1-f}{d_o}$$

Using the constants 1.100 and 0.900 for density of the fat-free body and pure fat, respectively, Siri (123) obtained the following equation for estimating percentage of body fat from body density:

$$\% \text{ body fat} = \frac{495.0}{\text{density}} - 450.0 \qquad \text{(Eq. 1)}$$

Siri (123) estimated a standard deviation of ± 4.0% body weight in the calculation of body fat, assuming that body density was measured with a reliability of ± .005 gm per cubic cm. If no allowance was made for error in measuring density, the uncertainty in fat estimation theoretically would be only ± 3.8% body weight.

From studies on guinea pigs, Rathbun and Pace (6) derived an equation (Equation 2) for estimating the per cent fat from the specific gravity of humans. Constants used in this equation were 0.918 gm per cubic cm for the density of fat and 1.000 gm per cubic cm for the density of the fat-free body.

$$\% \text{ body fat} = \frac{554.8}{\text{sp. gr.}} - 504.4 \qquad \text{(Eq. 2)}$$

The per cent body fat of the women was estimated from Equations 1 and 2. Results for the individual subjects are presented in Table 8. The per cent fat estimated by Equation 1 ranged from 21.7 to 52.4% of body weight with a mean of 34.70 ± 7.74%. The mean per cent fat estimated by Equation 2 was 35.29 ± 8.63% of body weight with a range of 20.8 to 55.0%. Thus, there was good agreement between the values for body fat predicted from Equation 1 and those predicted from Equation 2.

Table 8. Estimated per cent fat from density and specific gravity equations for 48 subjects

Subject no.	Fat from Equation 1 %	Fat from Equation 2 %
1	24.5	23.9
2	25.4	24.9
3	21.7	20.8
4	24.7	24.2
5	37.6	38.2
6	42.2	43.7
7	32.8	33.2
8	36.3	37.1
9	28.8	28.8
10	29.3	29.3
11	24.4	23.8
12	32.8	33.2
13	46.1	48.0
14	41.8	43.2
15	31.0	31.1
16	33.2	33.6
17	29.0	29.0
18	40.8	42.0
19	49.2	51.5
20	24.8	24.2
21	42.8	44.4
22	27.3	27.1
23	42.7	44.2
24	35.3	36.0
25	42.9	44.5
26	29.0	29.0
27	28.3	28.1
28	31.5	31.7
29	37.4	38.2
30	31.1	31.2

Table 8. (Continued)

Subject no.	Fat from Equation 1 %	Fat from Equation 2 %
31	39.9	41.1
32	35.4	36.1
33	28.8	28.8
34	25.0	24.4
35	28.8	28.8
36	45.6	47.4
37	25.3	24.8
38	41.1	42.4
39	30.7	30.9
40	40.2	41.4
41	32.0	32.3
42	40.8	42.1
43	30.9	31.0
44	31.9	32.2
45	49.6	52.0
46	43.6	45.2
47	52.4	55.0
48	38.9	40.0
$\bar{x}$	34.70 ± 7.74	35.29 ± 8.63

The percentage fat ranged from 28.3 to 39.9% for the 9 women who were 25 to 29 years of age and whose body weights were within ± 10% of desirable body weight. The mean for this group was 32.20 ± 3.75% and the median was 31.1%. The use of Equation 2 gave a mean of 32.49 ± 4.42% with a range of 28.1 to 41.1% fat; the median was 31.2% fat. These figures are higher than the mean of 28.69 ± 4.856% (ranging from 15.81 to 38.62%) reported by Young *et al.* (153), and 26.11 ± 5.07% fat reported by Chen (150). From the mean density data reported by Allen *et al.* (152) and Equation 2, the mean percentage of body fat for the Chinese University women was calculated to be 29.2%, with a range of 20.5 to 43.6%.

Estimation of body fat from body water

Table 9 gives the percentage of body fat calculated from data for total body water by two equations, Equations 3 and 4 (123), and by an equation which involves both total body water and extracellular water, Equation 5 (10).

$$\% \text{ body fat} = 100 - 139 \ (\% \text{ water}) \qquad \text{(Eq. 3)}$$

$$\% \text{ body fat} = 109 - 151 \ (\% \text{ water}) \qquad \text{(Eq. 4)}$$

$$\% \text{ body fat} = 100 - 156.3 \ (\% \text{ water}) + 34.9 \ (\% \text{ thiocyanate space}) \qquad \text{(Eq. 5)}$$

The per cent of body weight as fat estimated from Equations 3, 4 and 5 ranged from 21.6 to 41.9%; 23.8 to 45.9%; and 23.0 to 42.6%, respectively. The means were 31.60 ± 6.027%; 34.70 ± 6.554%; and 32.34 ± 5.970%, respectively.

Table 9. Estimated per cent fat from 6 different equations for 25 subjects

Subject no.	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6	$\bar{x}$
1	24.5	23.9	29.4	32.3	31.3	28.0	28.2 ± 3.47
2	25.4	24.9	23.4	25.8	23.0	25.0	24.6 ± 1.12
3	21.7	20.8	26.6	29.3	26.9	25.2	25.1 ± 3.26
4	24.7	24.2	40.5	44.4	42.6	34.3	35.1 ± 8.94
5	37.6	38.2	29.2	32.1	30.2	33.5	33.5 ± 3.74
6	42.2	43.7	38.7	42.4	39.0	40.8	41.1 ± 2.00
7	32.8	33.2	35.6	39.1	37.0	35.1	35.5 ± 2.36
8	36.3	37.1	31.6	34.7	33.1	34.3	34.5 ± 2.02
9	28.8	28.8	39.0	42.7	39.2	35.3	35.6 ± 5.79
10	29.3	29.3	23.8	26.3	25.1	27.0	26.8 ± 2.22
11	24.4	23.8	22.7	25.0	23.2	24.2	23.9 ± .84
12	32.8	33.2	26.1	28.7	27.0	29.7	29.6 ± 2.93
13	46.1	48.0	39.0	42.7	39.5	42.7	43.0 ± 3.55
14	41.8	43.2	36.5	40.0	36.7	39.4	39.6 ± 2.68
15	31.0	31.1	32.4	35.6	32.9	32.5	32.6 ± 1.67

Table 9. (Continued)

Subject no.	Eq. 1	Eq. 2	Eq. 3	Eq. 4	Eq. 5	Eq. 6	$\bar{x}$
16	33.2	33.6	31.1	34.1	31.7	32.7	32.7 ± 1.15
17	29.0	29.0	29.7	32.6	30.1	30.1	30.1 ± 1.33
18	40.8	42.0	30.9	34.0	31.4	35.8	35.8 ± 4.69
19	49.2	51.5	41.9	45.9	42.4	45.6	46.1 ± 3.75
20	24.8	24.2	21.6	23.8	23.2	23.7	23.6 ± 1.10
21	42.8	44.4	37.4	41.2	36.9	40.5	40.5 ± 2.95
22	27.3	27.1	23.6	26.0	24.8	25.9	25.8 ± 1.40
23	42.7	44.2	32.7	35.9	33.2	37.6	37.7 ± 4.81
24	35.3	36.0	31.9	35.0	32.6	34.1	34.2 ± 1.61
25	42.9	44.5	34.7	38.0	35.4	38.8	39.0 ± 3.95
$\bar{x}$	33.90 ± 7.943	34.40 ± 8.854	31.60 ± 6.027	34.70 ± 6.554	32.34 ± 5.970	33.27 ± 6.144	

These equations differ slightly in the basic assumptions made in the derivations. Equation 3 is based on the assumption that lean body mass has a constant proportion of 72% water in lean body mass. Siri (123), assuming that the accuracy of total body water measurement was ± 2% body weight, estimated the uncertainty in fat estimation to be not less than ± 4% body weight. Equation 4 is based on the assumption that lean body mass equals 72% water, 21% protein and 7% minerals, and that fat is added as obesity tissue which contains 62% pure fat, 31% water, and 7% protein. The total body water is then the sum of the water associated with lean body mass and with fat. Basic to Equation 5 is the assumption that a normally hydrated body has 16% extracellular water, and that the extracellular space is estimated from thiocyanate space with thiocyanate space equal to the extracellular fluid divided by .7. Keys and Brožek (10) considered that the inulin space was more nearly correct for true extracellular space than thiocyanate space. From comparisons of measurements made with thiocyanate and with inulin, they found that the inulin space was very close to 70% of the thiocyanate space; therefore, the extracellular fluid space could be taken as .7 times the thiocyanate space for better estimation. In this equation Keys and Brožek used a value of 70% for water in lean body mass. If the subjects are normally hydrated (i.e., extracellular

Table 10. Correlation coefficients between mean values of body fat estimated from 6 different equations[a]

Equation	2	3	4	5	6
1	.9999	.6322	.6323	.6012*	.9033
2		.6348	.6350	.6038*	.9048
3			.9990	.9943	.9033
4				.9941	.9034
5					.8828

[a]The probability (P) by the use of *z* transformations was < .001 for all the correlation coefficients except the ones marked with an asterisk for which P was < .005.

fluid equals 16% total body weight) Equations 4 and 5 should give similar results except for the fact that values of 70% and 72% for water in the lean body mass were used for Equations 5 and 4, respectively. In all subjects, Equation 5 gave slightly lower values for per cent fat than Equation 4; however, the results showed close agreement. The correlation coefficient between Equations 3 and 4 was .9990; between Equations 3 and 5, .9943; and between Equations 4 and 5, .9941; all 3 comparisons had a probability of < .001. The correlation coefficients for values estimated by the equations are presented in Table 10.

Johnston and Bernstein (163) used antipyrine to estimate the per cent fat in 17 healthy women from 21 to 59 years of age. The percent fat ranged from 16.9 to 57.2% of body weight. The relative weight of their subjects ranged from 60 to 284%. McMurrey _et al_. (162) calculated body fat from total body water data, obtained from deuterium oxide, in 10 females from 23 to 51 years of age (mean age 33.7 years). The per cent fat ranged from 23.6 to 44.4% of body weight.

Estimation of body fat from density and of total body water

The measurement of both density and total body water gives a method for estimating body composition which does not require explicit description of the composition of adipose tissue and allows for an estimate of fat to be made from density in which the double component system comprises fat and the lean body mass minus the separately analyzed body water (10, 12). The data obtained by use of a combined equation (Equation 6) were given also in Table 9. The equation was:

$$\%\ \text{body fat} = \frac{211.8}{\text{density}} - 78\ (\%\ \text{water}) - 135.4 \qquad \text{(Eq. 6)}$$

The per cent fat estimated by this equation ranged from 23.7 to 45.6% of body weight with a mean of 33.27 ± 6.144%.

The above equation was derived by Siri (123) by combining the density equation (Equation 1) and the total body water equation (Equation 3). He also assumed that the density of the fat-free body was equal to 1.100 gm per cubic cm, the density of fat was equal to .900 gm per cubic cm, and added the density of the protein-mineral solids equal to 1.565 gm per cubic cm. The reliability of this equation was estimated by Siri to be ± 2% of body weight.

Comparison of results of various methods for estimating body fat

The mean and standard deviation of 6 values estimated for the body fat of each subject were included in Table 9. Coefficients of correlation between estimates of body fat were given for Equations 1-6 in Table 10. Estimations of fat by the different equations for individual subjects agreed within ± 4.00% (standard deviation) for all subjects except numbers 4, 9, 18, and 23 who had standard deviations for estimation of fat of 8.93, 5.79, 4.69, and 4.81%, respectively. The equations using density or specific gravity alone (Equation 1 or 2) agreed very closely as one might expect (correlation coefficient, .9999). Equation 5, which included total body water and extracellular water, showed little difference in the estimation of fat from either Equation 3 or Equation 4 which were calculated from total body water alone (correlation coefficients of .9943 and .9941, respectively).

The estimation of fat by Equation 6, which included density and total body water, gave the best agreement for nearly all subjects with the mean estimate. The values agreed within ± .7% for all subjects. As mentioned previously, Siri (123) calculated that the best estimate (± 2% body weight) for body fat would be obtained by prediction from both density and total body water. Allen *et al.* (166) reported data for the total body water, density, and bone minerals for 30 healthy subjects, male and female. These investigators considered that it was desirable to measure bone minerals using roentgenograms for the best prediction of body fat. They compared their data with those of Siri (12) and found remarkably good agreement for healthy persons of either sex with quantities of fat ranging from 8 to 48 kilograms. Data reported by Siri were calculated according to Equation 6 (Siri, 123).

It is evident that the best prediction of body fat would be obtained from data for both total body water and density, (Equation 6). However, since it may be desirable to make only one measurement, comparisons of Equation 6 with equations utilizing density only (Equations 1 and 2) and total body water only (Equations 3 and 4) were made. All 4 of the correlation coefficients were highly significant; values ranged from .9033 to .9048. Values for body fat predicted from body density correlated positively with those predicted from body water; however, the correlation coefficients were lower for comparisons between values obtained from body density and from body water than comparisons between values obtained from equations involving body density only or between values obtained from equations involving body water only.

Anthropometric Measurements

Measurements were made of the skinfold thickness, the circumference of the arm and calf, and the biacromial and biiliac diameter. Data for individual subjects are presented in Table 11. The groups of 48 subjects were subdivided into 3 age groups: age 25 to 29 years, age 31 to 39 years, and age 41 to 55 years. Statistical measures for the 3 groups are given in Table 12. Since there were only 2 subjects above 49 years of age, the oldest group is listed as 41 to 55 years of age in order to include these 2 subjects.

Skinfold measurements were made at 6 body sites. The skinfold of the thorax and arm had the highest mean values, 16.97 ± 7.74 mm and 16.82 ± 6.06 mm, respectively. Other sites measured included the subscapula (14.68 ± 7.65 mm), the knee (12.83 ± 5.78 mm), the waist (11.61 ± 7.91 mm), and the chin 5.64 ± 1.82 mm).

The mean of the arithmetic total of the 6 skinfold measurements increased with an increase in mean age, yet the mean relative weight was approximately the same for all age groups. The mean increment with age decade was essentially

Table 11. Anthropometric measurements including skeletal, circumference, and skinfold thickness of 48 subjects

Subject	Biacromial width	Biiliac width	Circumference		Skinfold					
			Arm	Calf	Chin	Arm	Knee	Sub-scapula	Thorax	Waist
no.	cm	cm	cm	cm	mm	mm	mm	mm	mm	mm
1	35.3	26.3	23.9	33.5	7.0	8.75	7.25	8.25	9.0	7.25
2	38.5	32.6	31.5	39.7	7.75	20.5	13.75	14.25	19.75	7.75
3	36.9	27.3	26.0	37.5	5.5	14.25	18.25	9.0	9.25	5.25
4	38.4	31.7	29.0	39.5	7.75	24.0	13.5	18.5	19.25	12.0
5	37.0	29.6	28.0	34.8	5.0	15.75	9.75	13.5	12.75	9.5
6	36.4	30.9	28.5	36.2	5.0	18.75	16.75	14.25	15.5	13.0
7	37.9	29.6	27.9	37.2	4.5	20.5	13.25	12.25	19.75	13.0
8	37.7	28.8	26.5	36.1	4.75	9.5	8.5	10.5	14.5	11.5
9	39.9	30.5	30.4	41.6	8.0	25.5	10.75	11.25	18.0	13.75
10	39.8	29.8	24.5	35.6	3.0	11.75	6.0	10.75	16.25	10.0
11	38.8	30.8	23.9	34.4	4.0	8.0	9.0	8.25	8.75	5.0
12	36.9	30.4	24.4	33.3	5.0	12.75	5.25	10.75	7.25	5.75
13	35.7	32.6	30.2	38.1	7.5	25.5	26.75	19.75	29.5	20.5
14	40.5	31.2	29.5	33.8	6.0	18.75	6.75	18.75	20.25	11.0
15	39.7	30.8	29.2	36.3	6.25	17.75	12.75	14.25	17.75	10.0
16	36.8	30.8	26.2	37.0	4.75	14.75	9.5	11.75	9.75	7.25
17	38.3	28.9	23.2	32.5	3.25	13.0	14.0	13.25	11.75	9.25
18	34.1	28.8	27.3	36.0	5.75	14.0	11.0	12.75	14.0	8.0
19	39.4	36.1	35.2	44.6	11.75	30.0	34.5	36.75	40.5	38.0
20	37.4	31.3	25.2	35.8	3.5	9.5	9.75	9.5	9.0	4.0
21	36.3	30.8	26.6	36.5	6.0	18.75	15.75	15.25	14.25	14.25
22	34.5	28.8	25.0	36.2	4.0	9.75	7.0	7.0	10.25	6.25
23	36.2	32.2	32.5	34.5	6.0	21.0	8.5	16.0	17.75	14.0
24	36.0	32.5	27.3	35.5	6.0	18.0	14.75	15.25	19.5	12.25
25	37.5	29.1	29.8	36.8	6.25	20.0	13.0	11.0	22.0	7.25

Table 11. (Continued)

Subject	Biacromial width	Biiliac width	Circumference		Skinfold					
			Arm	Calf	Chin	Arm	Knee	Sub-scapula	Thorax	Waist
no.	cm	cm	cm	cm	mm	mm	mm	mm	mm	mm
26	32.0	27.1	23.5	34.3	3.0	9.5	8.0	12.0	12.25	9.0
27	36.1	26.6	26.6	34.5	3.75	13.5	14.75	12.0	16.75	8.25
28	35.0	28.5	25.6	37.5	5.0	12.75	9.0	9.0	13.25	8.25
29	35.8	29.4	26.5	35.1	5.25	14.25	12.0	16.5	21.75	13.75
30	38.7	27.7	24.0	34.2	5.0	8.5	11.75	9.75	10.75	7.75
31	33.3	29.1	28.8	38.1	5.75	21.0	11.75	24.0	24.75	11.0
32	34.3	30.6	29.0	45.0	6.0	20.0	17.0	15.5	21.5	7.5
33	35.2	25.9	26.2	35.3	3.75	14.75	16.75	13.5	12.0	6.25
34	33.2	25.9	22.0	34.0	3.50	7.50	8.0	7.75	9.25	6.0
35	36.0	30.7	23.5	34.3	4.75	8.25	9.25	8.75	9.25	7.75
36	36.7	30.4	32.2	38.0	6.0	26.0	15.5	25.5	28.5	18.0
37	34.0	26.1	25.1	34.9	3.0	12.0	10.25	10.5	10.5	8.25
38	36.3	30.5	31.2	41.9	8.0	21.0	28.25	18.25	17.5	10.25
39	33.8	27.8	26.5	34.7	6.25	22.0	9.0	12.0	22.0	8.25
40	36.2	29.6	26.9	37.5	5.25	14.75	11.5	15.25	14.0	9.0
41	35.4	29.4	26.4	36.2	5.0	15.75	7.0	8.0	12.75	7.0
42	39.4	32.6	37.4	41.6	6.75	29.75	19.0	36.75	30.0	27.25
43	36.8	27.5	26.6	37.5	4.25	15.5	9.0	8.0	12.0	5.0
44	38.8	31.7	26.5	37.5	6.5	14.25	16.25	15.0	10.25	11.75
45	36.7	29.2	26.2	33.2	6.0	17.75	7.75	14.0	23.25	17.25
46	36.0	30.6	29.1	37.2	6.0	19.25	13.0	13.5	21.5	17.25
47	37.8	33.4	36.2	39.2	11.25	31.5	18.5	45.0	42.5	47.0
48	39.5	32.2	28.5	40.0	6.25	17.25	16.75	11.25	12.0	10.0
$\bar{x}$	36.7	29.9	27.6	36.8	5.64	16.82	12.83	14.68	16.97	11.61
	± 2.0	± 2.1	± 3.3	± 2.8	±1.82	± 6.06	± 5.78	± 7.65	± 7.74	± 7.91

Table 12. Mean and range of skinfold measurements and density of 48 women in 3 age groups

Measurement	Mean	Range
Age 25 - 29 years; n = 15		
Chin (mm)	4.77 ± 1.30	3.00 - 7.75
Arm (mm)	14.22 ± 5.38	7.50 - 24.00
Knee (mm)	12.05 ± 2.94	8.00 - 17.00
Subscapula (mm)	13.02 ± 4.38	7.75 - 24.00
Thorax (mm)	15.25 ± 5.26	8.75 - 24.75
Waist (mm)	8.98 ± 2.56	5.00 - 13.75
Total skinfold (mm)	68.28 ± 18.62	42.00 - 98.25
Relative weight (%)	96.5 ± 11.5	79.9 -121.4
Density (gm/cm^3)	1.0303± .0096	1.0104- 1.0434
Age 31 - 39 years; n = 12		
Chin (mm)	5.73 ± 1.73	3.00 - 8.00
Arm (mm)	16.98 ± 6.56	8.75 - 26.00
Knee (mm)	12.94 ± 7.74	5.25 - 28.25
Subscapula (mm)	13.19 ± 5.19	8.25 - 25.50
Thorax (mm)	16.00 ± 7.53	7.25 - 29.50
Waist (mm)	10.50 ± 4.76	5.25 - 20.50
Total skinfold (mm)	75.33 ± 28.47	46.75 -129.50
Relative weight (%)	96.3 ± 13.2	78.6 -117.3
Density (gm/cm^3)	1.0252± .0169	.9978- 1.0494
Age 41 - 55 years; n = 21		
Chin (mm)	6.20 ± 2.01	3.50 - 11.75
Arm (mm)	18.60 ± 5.82	9.50 - 31.50
Knee (mm)	13.33 ± 6.24	6.75 - 34.50
Subscapula (mm)	16.71 ± 10.08	7.00 - 45.00
Thorax (mm)	18.75 ± 9.18	9.00 - 42.50
Waist (mm)	14.13 ± 10.84	4.00 - 47.00
Total skinfold (mm)	87.58 ± 41.39	42.25 -195.75
Relative weight (%)	96.8 ± 16.9	78.7 -143.8
Density (gm/cm^3)	1.0131± .0161	.9853- 1.0426

the same for the skinfold thickness on the chin, arm, and knee. However, the increment in skinfold thickness for women 41-55 years of age, as compared with women 31-39 years of age, was greater for the measurements at the subscapula, thorax, and waist than the mean increment for the measurements for women 31-39 years of age compared with women 25-29 years of age.

Means and standard deviations for the 48 subjects and 15 younger subjects ranging from 25 to 29 years of age for 6 skinfold measurements are given with corresponding measurements for subjects from the Cornell study (9) and for young women from the Minnesota study (150) in Table 13. Means of all the skinfold measurements for the young women (age 25 to 29 years) in this study were slightly smaller than the means for all the women (age 25 to 55 years) in this study. Comparison of the young women from Iowa State with the young women of the Cornell study showed smaller skinfolds at the chin, waist, and arm, and larger skinfolds at the subscapula, thorax, and knee for the Iowa State women. The Iowa State women had a slightly lower mean density (1.0303 gm per cubic cm) than the Cornell women (1.0342 gm per cubic cm) and slightly more fat estimated by the Rathbun and Pace equation (6), Equation 2. (Iowa State young women 30.58 per cent fat, Cornell women 28.69 per cent fat).

The biacromial and biiliac diameters, and the

Table 13. Comparison of skinfold thickness of Iowa State, Cornell, and Minnesota women

Site	Iowa State[a]	Iowa State[b]	Cornell[c]	Minnesota[d]
Chin	4.77 ± 1.30	5.64 ± 1.82	7.06 ± 2.25	8.7 ± 2.14
Subscapula	13.02 ± 4.38	14.68 ± 7.65	12.07 ± 4.10	16.0 ± 4.68
Thorax	15.25 ± 5.25	16.97 ± 7.74	10.46 ± 4.12	13.8 ± 4.14
Waist	8.98 ± 2.56	11.61 ± 7.91	14.65 ± 6.89	16.4 ± 3.95
Arm	14.22 ± 5.38	16.82 ± 6.06	25.43 ± 6.83	22.3 ± 4.91
Knee	12.05 ± 2.94	12.83 ± 5.78	11.37 ± 3.80	15.5 ± 3.53
Total	68.28 ± 18.62	78.55 ± 33.02	81.04	92.7

[a]Fifteen women mean age 26.8 years, caliper pressure 10 gm per square mm.

[b]Forty-eight women mean age 36.8 years, caliper pressure 10 gm per square mm.

[c]Ninety-four women mean age 20.4 years, caliper pressure 10 gm per square mm.

[d]Twenty-five women mean age 24.4 years, caliper pressure 10 gm per square mm.

Table 14. Comparison of skeletal and circumference measurements of young women

Site of measurement	Iowa State women	Cornell women
Biacromial width, cm	36.18 ± 2.36	37.24 ± 1.73
Biiliac width, cm	28.89 ± 1.89	28.50 ± 1.41
Upper arm circumference, cm	26.59 ± 3.68	25.55 ± 5.81
Calf circumference, cm	36.13 ± 3.08	35.55 ± 1.99

circumference of the arm and calf for the 48 subjects are given in Table 11. The means of these measurements for the young age group at Iowa State were slightly smaller than for the 48 subjects at Iowa State. The biacromial width ranged from 32.0 to 40.5 cm with a mean of 36.7 ± 2.0 cm. The biiliac width ranged from 25.9 to 33.4 cm with a mean of 29.9 ± 2.1 cm. The mean circumference of the arm was 27.6 ± 3.3 cm with a range from 22.0 to 37.4 cm. The calf circumference ranged from 32.5 to 45.0 cm with a mean of 36.8 ± 2.81 cm. Comparisons of these measurements for the young age group of Iowa State women with the Cornell women are presented in Table 14. The mean of the biacromial width of the young age group at Iowa State was slightly smaller than the Cornell women while the other measurements were slightly larger.

Correlations among Selected Variables

Correlations between the skinfold measurements at 6 sites and between each site and total skinfolds, density, and relative weight for the 48 women subjects are given in Table 15. The correlation coefficients were highly significant for all comparisons ($P < .01$ to $P < .001$). Among the 6 individual skinfold measurements the subscapula and the waist gave the highest correlation coefficient (.9034) and the knee and waist gave the lowest correlation coefficient (.5613). Correlation coefficients between relative weight and the individual skinfold measurements were very similar with a range from .6972 to .7992. A total of the 6 skinfold measurements gave a higher correlation coefficient (.8364) than any singular skinfold measurement. Correlation coefficients between density and the individual skinfold measurements, the total of the skinfold measurements, and relative weight are given in the last column of Table 15. The thorax gave the highest correlation coefficient (-.7046) of all the skinfold measurements with density; the total of the 6 skinfold measurements gave the second highest correlation coefficient (-.6985). The 2 lowest coefficients of correlations for density were with the knee and with relative weight, -.4244 and -.4289, respectively.

Correlations between the various individual skinfold measurements, the total skinfold measurements, relative

relative weight, and density are given for each age group in Tables 16, 17, and 18 for the women aged 25 to 29, 31 to 39, and 41 to 55 years, respectively. The correlation coefficients between the individual skinfold sites differed among the age groups. In the age group from 41 to 55 years of age the correlation coefficients were highly significant ($P < .001$) between all individual skinfold sites except between the knee and the thorax which was still significantly different from zero ($P < .01$). In the age group from 25 to 29 years of age the correlation coefficients between individual skinfold sites were highly significant only between the subscapula and the arm, between the subscapula and the thorax, and between the arm and the thorax ($P < .001$). In the age group from 31 to 39 years of age only one correlation coefficient, between the waist and the thorax, was highly significant ($P < .001$).

The relationship of the skinfold thickness at each site to the total skinfold thickness and to the relative weight was highly significant ($P < .001$) for the women in the older age group. In the age group from 31 to 39 years, all the correlations were significant, but the level of significance varied from $P < .05$ to $P < .001$. For the total skinfold thickness the highest correlation coefficient was obtained for the thorax (.9146) while the lowest correlation was obtained for the chin (.6044). In the age group from 25 to 29 years of age the correlation coefficients between relative

Table 15. Correlation coefficients between skinfold measurements, relative weight and density for 48 subjects, age 25 to 55 years

Measurement	Arm	Knee	Sub-scapula	Thorax	Waist	Total skinfold	Relative weight	Density
Chin	.7752	.6238	.7105	.7375	.7390	.8219	.7106	-.5372
Arm		.6071	.7945	.8619	.7400	.8967	.7992	-.6294
Knee			.6016	.5749	.5613	.7293	.7231	-.4244[a]
Subscapula				.8722	.9034	.9426	.7715	-.6475
Thorax					.8691	.9445	.7584	-.7046
Waist						.9277	.6972	-.6831
Total skinfold							.8364	-.6985
Relative weight								-.4289[a]

[a]Statistical probability was < .01; statistical probability was < .001 for all other correlation coefficients.

Table 16. Correlation coefficients between skinfold measurements, relative weight and density for 15 subjects, age 25 to 29 years[a]

Measurement	Arm	Knee	Subscapula	Thorax	Waist	Total skinfold	Relative weight	Density
Chin	.7001**	.2657	.5591*	.6081*	.4588	.6804**	.6277*	-.2716
Arm		.6185*	.7951***	.8528***	.6352*	.9507***	.7287**	-.4185
Knee			.4535	.4767	.1673	.6196*	.6529**	-.2588
Subscapula				.8501***	.6126*	.9000***	.5761*	-.6075*
Thorax					.7359**	.9477***	.7626***	-.7340**
Waist						.7314**	.4454	-.5223*
Total skinfold							.7696***	-.6037*
Relative weight								-.4606

[a]Statistical probability is indicated by asterisks as follows: *** probability < .001, ** probability < .01, and * probability < .05.

Table 17. Correlation coefficients between skinfold measurements, relative weight and density for 12 subjects, age 31 to 39 years[a]

Measurement	Arm	Knee	Subscapula	Thorax	Waist	Total skinfold	Relative weight	Density
Chin	.6453*	.5717	.3646	.4147	.3936	.6044*	.6476*	-.3524
Arm		.5714	.7388**	.8189**	.7065*	.8937***	.8685***	-.5946*
Knee			.6212*	.5085	.4909	.7677**	.6411*	-.5446
Subscapula				.8160**	.7801**	.8901***	.7301**	-.8798***
Thorax					.8929***	.9146***	.6519*	-.7469**
Waist						.8654***	.6860*	-.7709**
Total skinfold							.8339***	-.7932**
Relative weight								-.6294*

[a]Statistical probability is indicated by asterisks as follows: *** probability < .001, ** probability < .01, and * probability < .05.

Table 18. Correlation coefficients between skinfold measurements, relative weight and density for 21 subjects, age 41 to 55 years[a]

Measurement	Arm	Knee	Sub-scapula	Thorax	Waist	Total skinfold	Relative weight	Density
Chin	.8481***	.7729***	.8391***	.8893***	.8720***	.9192***	.8340***	-.5793**
Arm		.6807***	.8984***	.9255***	.8778***	.9435***	.8972***	-.6590**
Knee			.6811***	.6492**	.6917***	.7771***	.8347***	-.4003
Sub-scapula				.9012***	.9470***	.9639***	.8719***	-.5964**
Thorax					.9232***	.9578***	.8221***	-.6838***
Waist						.9708***	.8213***	-.6953***
Total skinfold							.9054***	-.6669***
Relative weight								-.4323

[a]Statistical probability is indicated by asterisks as follows: *** probability < .001 and ** probability < .01.

weight and the total skinfold measurements (.4454) was not significant while all other correlations were significant from $P < .05$ to $P < .001$.

Correlations with density varied among the 3 age groups. For the age group from 41 to 55 years of age the only correlation coefficients with density which were not significant were the knee and relative weight. For the age group from 31 to 39 years of age, the correlation coefficients between density and the chin or the knee were not significant. In the age group from 25 to 29 years of age the correlation coefficients between density and the chin, the arm, the knee, and relative weight were not significant; the highest significant correlation coefficient for density was with the thorax ($P < .01$).

In general the absolute values for the correlation coefficients which were calculated were higher from the women aged 41 to 55 years than for women in the other age groups.

Prediction of density from skinfold measurements

A stepwise procedure was used to determine the multiple regression equations for prediction of density from skinfold measurements. The technique is explained in the Method of Procedure, Statistical Analysis. For the 48 subjects, 4 regression equations were found to be significant for predicting density from skinfolds, or skinfolds and relative wieght. These 4 equations (Equations 7-10) are presented in Table 19. The thorax was the best single predictor of density. The regression equation and standard error of the regression coefficient (s_b), in parenthesis, obtained for predicting density from the thorax skinfold were as follows:

$$\hat{Y} = 1.0466 - \underset{(.0002194)}{.0014773}X_5 \qquad \text{(Eq. 7)}$$

where X_5 is the thickness of the skinfold in mm and $\hat{Y}$ is the predicted density in gm per cubic cm. The simple correlation coefficient was -.7046 which is highly significant ($P < .001$). The standard deviation from regression ($s_{y \cdot x}$) was ± .0116 gm per cubic cm. The individual differences between the determined and predicted densities ranged from .0004 to .0239 gm per cubic cm.

Intermediate equations which include the measurement of the thorax and relative weight (Equation 8) and the thorax, total skinfolds, and relative weight (Equation 9) were also highly significant ($P < .001$). For these two equations the multiple correlation coefficients were .7228 and .7601, respectively, and the standard deviations from regression ($s_{y \cdot x}$) were ± .0115 and ± .0109 gm per cubic cm, respectively.

The best fitting multiple regression equation for the 48

Table 19. Regression equations for predicting density from skinfold measurements or skinfold measurements and relative weight

Eq. no.	Equation[a]	F ratio: Each variable		F ratio: All variables	Cor. coef.	Std. dev.
		Age 25 - 55 years; n = 48				
7	$\hat{Y} = 1.0466 - .0014773X_5$		45.3354***	45.3354***	.7046	.0116
8	$\hat{Y} = 1.0259 - .0018718X_5 + .0002834X_8$	(X_5)	31.8956***			
		(X_8)	2.4627	24.6198***	.7228	.0115
9	$\hat{Y} = 1.0098 - .0005479X_5 - .0004243X_7$	(X_5)	.7429			
		(X_7)	5.7520*			
	$+ .0005627X_8$	(X_8)	7.3537*	20.0638***	.7601	.0109
10	$\hat{Y} = 1.0078 - .0005568X_7 + .0005942X_8$	(X_7)	40.5042***			
		(X_8)	8.5113**	29.8949***	.7554	.0109
		Age 25 - 29 years; n = 15				
11	$\hat{Y} = 1.0507 - .0013378X_5$		15.1950**	15.1950**	.7341	.0067
12	$\hat{Y} = 1.0495 + .0013531X_2 - .0025201X_5$	(X_2)	6.2470*			
		(X_5)	20.6419***	13.7875***	.8348	.0057

[a]Key: X_2 = arm; X_3 = knee; X_4 = subscapula; X_5 = thorax; X_6 = waist; X_7 = skinfold totals; X_8 = relative weight (skinfolds in mm; relative weight as per cent of average weight; density in gm per cubic cm).

Table 19. (Continued)

Eq. no.	Equation[a]	F ratio: Each variable	F ratio: All variables	Cor. coef.	Std. dev.
	Age 31 - 39 years; n = 12				
13	$\hat{Y} = 1.0629 - .0028594X_4$	34.2592***	34.2592***	.8798	.0084
	Age 41 - 55 years; n = 21				
14	$\hat{Y} = 1.0276 - .0010303X_6$	17.7879***	17.7879***	.6953	.0118
15	$\hat{Y} = .9958 - .0015497X_6 + .0004055X_8$	(X_6) 14.0135** (X_8) 2.3337	10.6851**	.7367	.0115
16	$\hat{Y} = .9888 - .0025526X_2 - .0009566X_6$ $+ .0008812X_8$	(X_2) 5.6789* (X_6) 4.6218* (X_8) 8.1083*	10.8680***	.8107	.0102
17	$\hat{Y} = .9720 - .0030954X_2 - .0009570X_3$ $- .0008201X_6 + .0012716X_8$	(X_2) 7.7127* (X_3) 1.9172 (X_6) 3.4047 (X_8) 9.4914**	9.0701***	.8331	.0099

subjects was the total of skinfold measurements (X_7) and relative weight (X_8). The equation and the standard errors of the regression coefficients were as follows:

$$\hat{Y} = 1.0078 - \underset{(.0000875)}{.0005568X_7} + \underset{(.0002037)}{.0005942X_8} \qquad \text{(Eq. 10)}$$

This relationship was highly significantly different from zero ($P < .001$). The multiple correlation coefficient was .7554. The standard deviation from regression was ± .0109 gm per cubic cm. A test of significance of the individual regression coefficients for the total skinfolds and relative weight gave probabilities of < .001 and < .01, respectively. The individual differences between the determined and predicted densities ranged from .0001 to .0223 gm per cubic cm.

For the first age group, 25 to 29 years of age, the thorax was the best single predictor, but a combination of the arm and the thorax was better. The best fitting regression equation for this age group was Equation 12 (Table 19). The regression equation and the standard errors of the regression coefficients were:

$$\hat{Y} = 1.0495 + \underset{(.0005414)}{.0013531X_2} - \underset{(.0005547)}{.0025201X_5} \qquad \text{(Eq. 12)}$$

where X_2 and X_5 are the thickness of the skinfold of the arm and thorax, respectively. This equation had a multiple correlation coefficient of .8348, which was highly significant ($P < .001$). The standard deviation from regression was $\pm$ .0057 gm per cubic cm. The individual differences between determined and predicted densities ranged from .0004 to .0094 gm per cubic cm.

The best single skinfold site as a predictor of density for the age group from 31 to 39 years was the subscapula measurement (X_4). No other site, single or combined, gave an _F_-ratio > 1.000 after this variable was in the equation. The equation and standard error of the regression coefficient were:

$$\hat{Y} = 1.0629 - \underset{(.0004885)}{.0028594}X_4 \qquad \text{(Eq. 13)}$$

Equation 13 had a simple correlation coefficient value of -.8798, which is highly significant ($P < .001$). The standard deviation from regression was < .0084 gm per cubic cm. The differences between the determined and predicted densities ranged from .0006 to .0150 gm per cubic cm.

In the oldest age group, 41 to 55 years, it appeared that a combination of several skinfolds was a better predictor of density than a single skinfold. Table 19 shows that 4 regression equations which were significant for predicting density in this age group. The best single skinfold measurement for predicting density was the skinfold of the waist, but multiple variables gave a better fitting regression equation. The best fitting multiple regression equation and the standard errors of the regression coefficients were as follows:

$$\hat{Y} = .9720 - \underset{(.0011146)}{.0030954X_2} - \underset{(.0006911)}{.0009570X_3} - \underset{(.0004445)}{.0008201X_6} + \underset{(.0004127)}{.0012716X_8} \qquad \text{(Eq. 17)}$$

This equation includes measurements of the arm (X_2), knee (X_3), and waist (X_6), and relative weight (X_8) and had a multiple correlation coefficient of .8331, which is highly significant ($P < .001$). However, only the arm (X_2) and relative weight (X_8) had coefficients that were significantly different from zero ($P < .05$ and $P < .01$, respectively). The standard deviation from regression was ± .0099 gm per cubic cm. The differences between the determined and predicted densities ranged from .0008 to .0154 gm per cubic cm.

The accuracy in predicting density was improved if the subjects were subdivided into age groups as shown by the standard deviation from regression. The site of measurement and the best fitting regression equation varied with the age group; the arm and thorax combined gave the highest multiple correlation coefficient for the age group from 25 to 29 years; the subscapula gave the highest simple correlation coefficient for the age group from 31 to 39 years; and the arm, knee, waist, and relative weight have the highest multiple correlation coefficient for the age group from 41 to 55 years. The accuracy of prediction equations for the young age group was better than for the older age groups. From the sites measured in this study, the best fitting regression equations for predicting density in the 3 age groups are Equations 12, 13 and 17. However, some of the other equations would likely give results that were not significantly different from the best fitting equations.

In another trial, prediction equations for density were also obtained for the variables used above and for additional variables that were formed by various combinations of the skinfold measurements. Additional intermediate equations were obtained, but the final results were the same as given in Table 19.

Siri (123) calculated the standard deviation for the estimation of fat from density as ± 4.0% of body weight; the standard error in the measurement of the subject's density was taken as ± .0025 gm per cubic cm. No improvement was obtained in the uncertainty in fat estimation in attempting to measure body density more accurately than ± .005 gm per cubic cm. The density prediction equations of best fit in this study gave standard deviations from regression as ± .0057, ± .0084, and ± .0099 for the 3 age groups 25-29 years, 31-39 years, and 41-55 years, respectively. The standard errors (s_y) of density for an individual person, figured at the means of the predicting variables, are ± .0058, ± .0087, and ± .0102 for the 3 age groups in the order mentioned. If one were to predict the density of an individual whose measurements differed from these means, the standard error of the predicted density would increase. However, it would appear that the standard errors for predicting density for women from well chosen skinfold sites, especially in the 25-29 year age groups, are close to the standard error set forth by Siri (123). Therefore, it appears that where time and money are limited the use of skinfold measurements would be of value in obtaining the body density which could be used for the estimation of the percentage of body fat.

Changes in Body Composition with Aging

Studies of body composition have enabled investigators to evaluate the changes in the relative proportion of body weight as fat which occur with age. Brožek *et al*. (167) used a linear prediction equation based on the least square fit of the values obtained by underwater weighing and calculated the percentages of total body fat for women from 25 to 55 years of age as 26.5, 30.5, 34.5, and 38.5% fat at ages 25, 35, 45, and 55 years, respectively. These women were on the average about 95 to 97% relative standard weight.

In 1958 Mickelsen (168) reported a summary of the literature on changes in body composition with age. Data from height-weight tables, subcutaneous fat determinations, and body water, indicated an increase in body fat with an increase in age. In 1961 Brožek (169) discussed the changes that occur in body composition with age, sex, exercise, and nutritional state and pointed out that marked changes take place with time. Brožek (170) reported decreases in density in women from 20 to 60 years of age of 1.040 to 1.016 gm per cubic cm; 23 women aged 18 to 30 years (mean 24.2 years) had a mean density of 1.040 gm per cubic cm; 19 women aged 31 to 45 (mean 39.1 years) had a mean density of 1.027 gm per cubic cm; 20 women aged 46 to 67 (mean 56.0 years) had a mean density of 1.016 gm per cubic cm. These groups had 23, 28 and 32% fat, respectively.

Parker *et al.* (171) reported a decrease in intracellular body water from 25.9 to 22.4% with an increase in age in females. This decrease accounted for most of the decrease in relative value for total body water. McMurrey *et al.* (162) reported values for 10 females, ranging in age from 23 to 51 years; there was a decrease in total body water from 55.9 to 40.7% and an increase in fat from 23.6 to 44.4% with an increase in age.

As stated previously, the percent of body weight as body fat of the subjects in this study was higher for women in the middle years of adulthood than for the young women. Values for the 48 women were used to calculate a prediction equation with per cent of body fat as a function of age in years. The sample regression equation which was obtained was:

$$\% \text{ body fat} = 19.3978 + .4156 \text{ (age)} \qquad \text{(Eq. 18)}$$

By use of this equation, percentages of total body fat predicted for women at ages of 25, 35, 45, and 55 years, were 29.8, 33.8, 38.1, and 42.3%, respectively. These values are approximately 3% higher than the mean percentages of total body fat reported for women of corresponding ages by Brožek *et al*. (167). The 48 women, however, represented a wider range of body weight in relation to desirable body weight than the subjects studied by Brožek and co-workers.

Of the subjects in this study, 24 were of desirable body weight or within the range of 90 to 110% of the average body weight according to the *1959 Build and Blood Pressure Study* (160). Values for density, per cent of body weight as fat, and skinfold measurements of these subjects are given in Table 20; the subjects were distributed among 4 age groups: 25 to 29, 31 to 39, 41 to 49, and 51 to 55 years, respectively. The mean per cent of body fat for these 4 age groups was 32.2, 33.6, 37.4, and 40.8%, respectively. The per cent of body fat calculated from the linear regression equation

(Equation 18) at the mean age for each of the above 4 groups was 30.3, 33.2, 37.8, and 41.6%, respectively. The mean per cent body fat for the women who were within ± 10% of desirable weight and in the age group from 25 to 29 years was higher than the per cent fat predicted from the linear regression equation while the mean per cent body fat for the women aged 51 to 55 years was lower than the per cent fat predicted from the linear regression equation.

Although the mean values for per cent of body fat increased with corresponding increments in age, there was considerable variation in the total body fat of individuals within each age group. The widest range of values was for the 5 women of average body weight who were in the age range of 31 to 39 years. For this group, the body fat ranged from 21.7 to 46.1%; however, three of the subjects varied only from 30.7 to 36.3% in body fat. Of the 9 women who were between 25 and 29 years of age, 2 had values for body fat greater than 33%; the range was from 28.8 to 39.9%. There were only 2 of 8 women, aged 41 to 49 years, who had values for total body fat less than 33%. The range for this group was 25.4 to 43.6% and 4 of the subjects had values higher than 40%.

These data support the general observation that the relative proportion of total body fat increases with age. The extent of variation among individual subjects suggests, however, that the increase in body fat is not an obligatory function of aging. Longitudinal studies of individuals over a period of time would be of value in determining the relative degree of constancy of the ratio of body fat that may be maintained with weight control.

Table 20. Density, per cent fat, and skinfold measurements of subjects in 4 age groups and within 90 to 110% relative weight

Subject no.	Relative weight[a] %	Density gm/cm^3	Fat[b] %	Skinfold measurements Chin mm	Arm mm	Knee mm	Subscapula mm	Thorax mm	Waist mm
Age 25 - 29 years; $\bar{x}$ = 26.2 ± 1.5 years; n = 9									
26	93.6	1.0334	29.0	3.00	9.50	8.00	12.00	12.25	9.00
27	100.8	1.0350	28.3	3.75	13.50	14.75	12.00	16.75	8.25
28	90.6	1.0280	31.5	5.00	12.75	9.00	9.00	13.25	8.25
29	107.8	1.0157	37.4	5.25	14.25	12.00	16.50	21.75	13.75
30	92.4	1.0290	31.1	5.00	8.50	11.75	9.75	10.75	7.75
31	97.8	1.0104	39.9	5.75	21.00	11.75	24.00	24.75	11.00
33	100.7	1.0338	28.8	3.75	14.75	16.75	13.50	12.00	6.25
15	99.0	1.0292	31.0	6.25	17.75	12.75	14.25	17.75	10.00
7	101.5	1.0252	32.8	4.50	20.50	13.25	12.25	19.75	13.00
$\bar{x}$	98.2 ± 5.4	1.0266 ± .0084	32.2 ± 3.8	4.69 ± .98	14.72 ± 4.38	12.22 ± 2.67	13.69 ± 4.47	16.56 ± 4.87	9.69 ± 2.49

[a]Per cent relative weight based on averages reported in <u>1959 Build and Blood Pressure Study</u> (160).

[b]Per cent fat calculated from Equation 1.

Table 20. (Continued)

Subject no.	Relative weight[a] %	Density gm/cm^3	Fat[b] %	Skinfold measurements Chin mm	Arm mm	Knee mm	Subscapula mm	Thorax mm	Waist mm
Age 31 - 39 years; $\bar{x}$ = 33.2 ± 3.0 years; n = 5									
3	93.2	1.0494	21.7	5.50	14.25	18.25	9.00	9.25	5.25
8	91.6	1.0179	36.3	4.75	9.50	8.50	10.50	14.50	11.50
16	92.1	1.0244	33.2	4.75	14.75	9.50	11.75	9.75	7.25
13	106.7	.9978	46.1	7.50	25.50	26.75	19.75	29.50	20.50
39	90.5	1.0297	30.7	6.25	22.00	9.00	12.00	22.00	8.25
$\bar{x}$	94.8 ± 4.0	1.0238 ± .0187	33.6 ± 8.9	5.75 ±1.22	17.20 ± 6.44	14.40 ± 7.99	12.60 ± 4.17	17.00 ± 8.62	10.55 ± 6.00
Age 41 - 49 years; $\bar{x}$ = 44.4 ± 3.2 years; n = 8									
24	95.9	1.0199	35.3	6.00	18.00	14.75	15.25	19.50	12.25
40	90.7	1.0098	40.2	5.25	14.75	11.50	15.25	14.00	9.00
6	96.2	1.0056	42.2	5.00	18.75	16.75	14.25	15.50	13.00
21	93.1	1.0044	42.8	6.00	18.75	15.75	15.25	14.25	14.25
44	90.9	1.0272	31.9	6.50	14.25	16.25	15.00	10.25	11.75
5	94.0	1.0152	37.6	5.00	15.75	9.75	13.50	12.75	9.50
2	109.0	1.0413	25.4	7.75	20.50	13.75	14.25	19.75	7.75
46	96.9	1.0028	43.6	6.00	19.25	13.00	13.50	21.50	17.25
$\bar{x}$	95.8 ± 5.8	1.0158 ± .0133	37.4 ± 6.3	5.94 ± .91	17.50 ± 2.29	13.94 ± 2.44	14.53 ± .76	15.94 ± 3.92	11.84 ± 3.09

Table 20. (Continued)

Subject no.	Relative weight[a] %	Density gm/cm^3	Fat[b] %	Skinfold measurements: Chin mm	Arm mm	Knee mm	Subscapula mm	Thorax mm	Waist mm
Age 51 - 55 years; $\bar{x}$ = 53.5 ± 2.1 years; n = 2									
48	94.1	1.0124	38.9	6.25	17.25	16.75	11.25	12.00	10.00
23	104.4	1.0047	42.7	6.00	21.00	8.50	16.00	17.75	14.00
$\bar{x}$	99.2 ± 7.3	1.0086 ± .0056	40.8 ± 2.7	6.12 ± .18	19.12 ± 2.65	12.62 ± 5.83	13.62 ± 3.36	14.88 ± 4.06	12.00 ± 2.83

SUMMARY

The body composition of 48 apparently healthy women varying in age and size was investigated. Values were obtained for body weight, height, density, body water, and anthropometric measurements. Body fat was estimated by several techniques and the changes in body fat with an increase in age were examined.

The mean body weight of the subjects was 61.237 ± 9.511 kg with a range from 48.020 to 93.822 kg. The mean height was 165.2 cm with a range from 154.8 to 180.9 cm. Relative weight of each subject was calculated from the averages presented in the _1959 Build and Blood Pressure Study_ by the Society of Actuaries (160); the range in relative weight was from 78.2 to 143.8% with a mean of 96.6 ± 14.2%.

Density was measured by the helium dilution technique. The body densities of the 48 subjects ranged from .9853 to 1.0494 gm per cubic cm. The mean body density of the subjects was 1.0215 ± .0162 gm per cubic cm.

Body water values were obtained from a sub-group of 25 subjects. Antipyrine was used as a test solute to estimate the total body water. The mean total body water was 30.317 ± 3.493 liters, ranging from 24.551 to 39.117 liters. The mean total body water was 49.2% of body weight, ranging from 41.8 to 55.6% of body weight. Sodium thiocyanate was used

as a test solute to estimate the extracellular water. The mean extracellular water was 16.290 ± 1.870 liters with a range from 13.506 to 20.774 liters. The mean extracellular water was 26.5 ± 3.1% of body weight with a range from 20.2 to 32.5% of body weight. Total body water and extracellular water were determined again after a period of 3 to 4 1/2 months on 3 subjects. The results were similar to the original determinations.

Per cent body fat was calculated from 6 different equations involving density, total body water, and extracellular water. The means of the per cent body fat calculated from the 6 equations ranged from 31.60 to 34.70% of body weight. The individual per cent fat calculated from the 6 equations agreed within ± 4% of body weight except for 4 subjects. The correlation coefficients between the 6 equations were all significant ($P < .01$).

Anthropometric data, including skinfold thickness, were obtained for the 48 subjects. The biacromial width ranged from 32.0 to 40.5 cm with a mean width of 36.7 ± 2.0 cm. The biiliac width ranged from 25.9 to 33.4 cm with a mean of 30.0 ± 2.1 cm. The mean circumference of the arm was 27.6 ± 3.3 cm with a range from 22.0 to 37.4 cm. The calf circumference ranged from 32.5 to 45.0 cm with a mean of 36.8 ± 2.8 cm.

Skinfold measurements were made at 6 sites. Correlation coefficients between these 6 sites, a total of these 6 sites, relative weight, and density were presented. The group of 48 women were sub-divided into 3 age groups and regression equations for predicting density from skinfold measurements were presented.

The changes in body fat with an increase in age were examined and a linear prediction equation presented. The percentages of total body fat calculated from the prediction equation were 29.8, 33.9, 38.1, and 42.3% of body weight at ages 25, 35, 45, and 55 years, respectively.

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APPENDIX: DATA SHEETS FOR BODY VOLUME DETERMINATIONS

Form 1: Bottle Data

Bottle no.: Date:
Robe: Time:
Volume of bottles (V_b): Bar. Press. (P_b):

Initial MV: Final MV:

Corr. Fac.: Corr. Fac.:

Recorder: Recorder:

Corr. Fac.: Corr. Fac.:

TEMPERATURES			
He Tank	Chamber		
	Dry	Wet	Wet

$R_x = MV_f - MV_i =$ P_w: ________

$T_{dw} = T_{dry} - T_{wet} =$

$T = T_{He} + T_{dry} =$

$K = (P_b)(T_{dw})(.00066)[1 + (T_{dw}\ .00115)] =$

$(\quad)(\quad)(.00066)[1 + (\quad)(.00115)] =$

$P_v = P_w$
$-K$
P_v:

$P_{bv} = P_b$
$-p_v$
P_{bv}:

$P = P_{bv}/P_b =$

$d_x = (P)(T) =$

$V' = (V_c - V_b)d_x = (401.400 - \quad)(\quad) =$

$$C_x = \frac{v}{V' + v} = \frac{13.94}{(\quad) + 13.94} = \frac{13.94}{(\quad)} =$$

Form 2: Subject Data

Subject: Weight:
Date: Volume:
Time: Density:

Bar. Pressure (P_b):

Initial MV: Final MV:

Corr. Fac.: Corr. Fac.:

Recorder: Recorder:

Corr. Fac.:___ Corr. Fac.:____

Temperatures			
He Tank	Chamber		
	Dry	Wet	Wet
273.18	273.18	273.18	

p_w:

Data on Bottles:

R_1: G: $(V_c - V_1)\ d_1$ = (V' on bottle data sheet) =

R_2: H: $(V_c - V_2)\ d_2$ = (V' on bottle data sheet) =

$R_x = MV_f$ $-MV_i$ R_x:

$S_1 = R_x$ $-R_1$ S_1:

$S_2 = R_x$ $-R_2$ S_2:

$T_{dw} = T_{dry} - T_{wet} =$

$T = T_{He}/T_{dry} =$

$K = (P_b)\ (T_{dw})\ (.00066)\ [1 + (T_{dw})\ (.00115)] =$

$(\quad)\ (\quad)\ (.00066)\ [1 + (\quad)\ (.00115)] =$

$p_v = p_w$ $-K$ p_v:

$P_{bv} = P_b$ $-p_v$ P_{bv}:

$P = P_{bv}/P_b =$

$d_x = (P)\ (T) =$

$I = (V_c)\ (d_x) = (401.400)\ (\qquad) =$

A = G	C = H	B = H	D = G
-I	-I	+v 13.94	+ v 13.94
A:	C:	B:	D:

$S_1 \times D =$ $\qquad \times C =$

$S_2 \times B =$ $\qquad \times A =$

F = S_1D	E = S_2BA
$-S_2B$	$-S_1DC$
F:	E:

$V' = E/F =$

$V_x = V'/d_x =$

$$C_x = \frac{v}{(V_c - V_x)d_x + v}$$

$$= \frac{13.94}{(401.400 - \qquad)(\qquad) + 13.94}$$

$$= \frac{13.94}{(\qquad)}$$

$C_x =$