MEASUREMENT OF CHANGE IN TOTAL BODY FAT

Laurence H. Kyle, … , John J. Canary, Bernice Pachuta

J Clin Invest. 1959;38(9):1475-1478. https://doi.org/10.1172/JCI103924.

MEASUREMENT OF CHANGE IN TOTAL BODY FAT *

By LAURENCE H. KYLE, EDWARD J. WERDEIN,† JOHN J. CANARY † AND BERNICE PACHUTA

(From the Department of Medicine, Georgetown University School of Medicine and the Georgetown University Hospital, Washington, D. C.)

(Submitted for publication February 10, 1959; accepted May 7, 1959)

Growing interest in the mechanisms and management of obesity has promoted investigation of methods for measuring total body fat, and has emphasized the need for accurate and practical methods of quantifying change in fat. Expressions based on either volume distribution or densitometric analysis lack validity when applied singly under conditions of abnormal hydration and provide doubtful accuracy in extreme obesity or severe emaciation (1). Substitution of parallel measurements of total body water and body density into the same fat prediction equation circumvents hydration abnormality, but requires the difficult measurement of body volume, which to date has been most satisfactorily accomplished by underwater weighing (2). More important, estimation of fat with methods that require densitometric analysis necessitates dependence upon the possibly invalid assumption of a known and constant density of the fat-free body.

Edelman, Brooks and Moore have explored the utility of concurrent measurement of nitrogen balance and volume distribution of deuterium oxide to assay change in fat (3). Behnke, Osserman and Welham commented upon the feasibility of checking the validity of such techniques by parallel densitometric analysis (4).

The present study concerns: *1)* evaluation of the use of measurement of nitrogen balance and total body water to estimate change in body fat; and *2)* comparison of the loss or gain in fat so determined with changes obtained by parallel densitometric analysis.

* This study was supported by the William Wade Hinshaw Fund and by a contract between Georgetown University and the Office of Naval Research. Reproduction in whole or in part is permitted for any purpose of the United States Government.

† Formerly a Research Fellow of the National Institutes of Health.

MATERIALS AND METHODS

Subjects of the study consisted of five men and three women. Three were obese, one was normally constituted and the others had several types of metabolic disease (Cushing's syndrome in two, myxedema in one and cirrhosis with malnutrition and ascites in the other). Studies were conducted under conditions of metabolic balance for periods ranging from 20 to 158 days, change in fat (Δ fat) being calculated from the beginning to the termination of each study. Δ Fat was calculated by two independent methods: *1)* Body density (D) and total body water (TBW) were measured, respectively, by underwater weighing and volume distribution of antipyrine or D_2O as described previously (5, 6). Antipyrine was used in Cases 4, 5, 6 and 8 (Table I). Both D_2O and antipyrine were used to measure body water in Cases 1, 2, 3 and 7. The volume distribution of D_2O was in general slightly greater than that of antipyrine. When both were utilized the average of all determinations was used to calculate TBW. These values were substituted into the fat prediction equation (7):

$$\% \text{ fat} = \left(\frac{2.118}{D} - 0.780\ W - 1.354\right) \times 100;$$

where D is body density and W is body water expressed as per cent of body weight. Calculation of total body fat (TBF) by this method at the beginning and end of each study permitted estimation of Δ fat. This method of study will be termed "densitometric."

2) The second method of calculation was that outlined by Edelman, Brooks and Moore (3), *i.e.*, subtraction from change in total body weight (ΔTBwt) of the sum of the changes in the major mobile body constituents, protein and water:

$$\Delta \text{ fat} = \Delta \text{ TBwt} - (\Delta \text{ TBW} + \Delta \text{ protein}).$$

Δ Protein was determined by nitrogen balance by means of the conversion factor of 6.25.[1] The rationale of this

[1] Although Edelman and his associates (3) express the tissue nitrogen factor as a higher value, 6.25 is used here in accordance with older concepts and because of its use in the equations for fat estimation derived from densitometric and volume distribution techniques. Furthermore, in the type of study reported here loss or gain of labile protein stores would be anticipated; and in such instances the lower nitrogen factor would appear reasonable.

DENSITOMETRIC		COMPARTMENTAL	
D_1 = 1.047	D_2 = 1.035	$TBWt_1$ = 60.7 kg. $TBWt_2$ = 69.3 kg.	Δ TBWt = + 8.6
TBW_1 = 36 L	TBW_2 = 36 L	TBW_1 = 36.0 L TBW_2 = 36.0 L	Δ TBW = 0.0
F_1 = 12.5 kg.	F_2 = 19.9 kg.	NITROGEN = + 79 (x 6.25)	Δ PROTEIN = + 0.5
ΔF = + 7.4 kg.		ΔF = 8.6 − 0.5	= + 8.1 kg.

FIG. 1. EXAMPLE OF FAT GAIN

method of measurement rests on the facts that turnover of the mineral phase of the body results in minimal change in weight (from 350 to 500 Gm. with loss or gain of 10 per cent of body stores of ash) and that body carbohydrate is inconsequential in amount and subject to limited variation. Consequently, change in body weight is governed almost entirely by loss or gain of fat, water and protein. This method of measuring Δ fat will be termed "compartmental."

The method of measuring nitrogen balance has been reported from this laboratory (6). Calculations of the assumed error of the methods were made as outlined by Siri (7).

RESULTS

Figure 1 demonstrates the method of calculation and changes in total body fat as determined by densitometric and compartmental techniques in a normally constituted man (Case 1, Table I) in whom weight gain of 8.6 Kg. was encouraged, over a study period of 105 days, by administration of cortisol. Densitometric analysis indicated a gain of 7.4 Kg. and compartmental measurement indicated a gain of 8.1 Kg. of total body fat. Figure 2 depicts similar calculation of Δ fat in an obese man (Case 2, Table I) who lost 27.0 Kg. of weight during 50 days of stringent caloric restriction. Densitometric measurement indicated a loss of 15.3 Kg. of fat, whereas by compartmental analysis the loss of fat was 11.8 Kg. The substantial difference in Δ fat calculated by the two methods was less than the possible error of the methods, 4.2 Kg., necessarily large in this very obese subject.

Table I summarizes the salient data in the eight studies. There were no significant differences in measurements of body fat obtained by the two methods ($p > 0.90$). Comparison of individual studies revealed that differences between results of the two methods were well within the assumed systematic error of fat estimation, with one exception which will be discussed below.

Table I also summarizes the differences between densitometric and compartmental estimation of Δ fat expressed as per cent of mean total body fat and as per cent of mean change in fat. Differences averaged 2.9 per cent of total fat and 10.7 per cent of the mean change in fat.

DISCUSSION

While measurement of body volume and subsequent calculation of body density has permitted crude but useful division of the body into fat-free

DENSITOMETRIC		COMPARTMENTAL	
D_1 = 0.988	D_2 = 0.997	$TBWt_1$ = 185.2 kg. $TBWt_2$ = 158.2 kg.	Δ TBWt = − 27.0
TBW_1 = 71.6 L	TBW_2 = 58.4 L	TBW_1 = 71.6 L TBW_2 = 58 4 L	Δ TBW = − 13.2
F_1 = 90.3 kg.	F_2 = 75.0 kg.	NITROGEN = −329 (x 6.25)	Δ PROTEIN = − 2.0
ΔF = − 15.3 kg.		ΔF = 27 − (13.2 + 2.0) ΔF = 27 − 15.2	= − 11.8 kg.

FIG. 2. EXAMPLE OF FAT LOSS

TABLE I

Comparison of Δ fat as determined by densitometric and compartmental methods

Case & sex	Clinical problem	Days of study	Δ in fat (Kg) I Densitometric (D+TBW)	Δ in fat (Kg) II Compartmental (TBW+ Nit Bal)	Difference I-II (Kg)	Calculated total possible error (Kg)	Difference I − II % of mean total body fat	Difference I − II % of mean change in fat
1 ♂	Normal	105	+7.4	+8.1	+0.7	(1.7)	4.3	9.0
2 ♂	Obesity	50	−15.3	−11.8	−3.5	(4.2)	4.2	26.0
3 ♀	Obesity	28	−3.9	−3.9	0.0	(2.7)	0.0	0.0
4 ♂	Obesity	20	−1.8	−1.7	−0.1	(4.1)	0.1	5.7
5 ♀	Cirrhosis Malnutrition	38	−6.8	−7.2	+0.4	(1.7)	3.1	5.7
6 ♂	Myxedema	41	−1.9	−2.2	+0.3	(2.3)	0.8	14.5
7 ♀	Cushing's Syndrome	27	+6.5	+6.8	+0.3	(1.3)	1.7	4.5
8 ♀	Cushing's Syndrome	158	−12.7	−15.6	+2.9	(1.8)	8.9	20.0
					p > 0.90		Av. = 2.9%	Av. = 10.7%

and lipid components, this basic technique has numerous disadvantages. Measurement of body volume by underwater weighing is difficult and time consuming in all subjects, impossible in the bedridden patient. Utilization of the helium concentration technique of Siri (8) may solve the problem of conducting densitometric measurement in patients who lack the stamina necessary for underwater weighing, but scarcity of facilities for this type of measurement prohibits general clinical application. While abnormal hydration may be partly circumvented by measurement of total body water, deviation of density of the fat-free body (lean body mass) from the assumed norm constitutes a major impediment to densitometric quantitation of total body fat. Fortunately, in the type of study reported here, abnormality of the fat-free body density introduces minimal error when successive densitometric measurements are conducted in the same person to calculate Δ fat. Despite these multiple limitations, densitometric evaluation of body fat, when conducted under the proper conditions and with suitable correction of abnormal hydration, is the most accurate method for measurement of gross body composition and serves as the best standard of reference for evaluating other techniques of fat estimation. As emphasized by Siri, however, increased accuracy of fat measurement is contingent upon development of methods independent of densitometry (8).

The data reported here indicate that concurrent measurement of nitrogen balance and TBW serves as a fairly simple and, in terms of the densitometric reference, quite accurate technique for evaluation of change in body fat. Use of TBW measurements to correct densitometric analysis and to calculate change in fat by compartmental methods would obviously tend to dampen differences between the two methods; but the complete independence of the techniques is equally apparent. Two of the studies demonstrated considerable differences between the two methods in their measurements of total fat change and these studies deserve further comment.

In Case 2 the patient was an extremely obese man whose body density was 0.988 at the beginning and 0.997 at the end of 50 days of a restricted caloric intake. Δ Fat calculated densitometrically was −15.3 Kg., whereas by compartmental analysis loss of fat was 11.7 Kg. Considering, however, that adipose tissue contains approximately one-fifth of its volume as water, as well as a small amount of nitrogenous tissue, it would appear that compartmental analysis would, with significant fat loss in extremely obese subjects, indicate a lesser degree of loss than that demonstrated by densitometric techniques. In Case 2 rough calculation indicates a possible overestimate of fat loss by densitometry, approaching 2.0 Kg., with consequently a true difference between the two techniques of fat estimation, approximating 1.5 rather than 3.5 Kg. Calculation of the density of the lost tissue

$$\left(\frac{\Delta \text{ body weight}}{\Delta \text{ body volume}}\right)$$

which was 0.941 in this subject, provides some validation of these assumptions.

In the other instance in which there existed discrepancy between the two methods (Case 8), factors were present that could distort fat estimate obtained by densitometric techniques. This patient had Cushing's syndrome and measurements were made before, and for several months following, subtotal adrenalectomy. Gradual correction of abnormal hydration and change in the density of the fat-free body of this protein and mineral depleted patient would be expected to induce error in the densitometric estimation of Δ fat. Furthermore, the length of this study (158 days) might result in a considerable cumulative error in nitrogen balance.

Although a real need exists for more precise methods of fat measurement than are provided by either densitometric or compartmental analysis, the data presented here indicate the utility of both techniques. Whereas densitometric analysis requires a relatively healthy, intensely cooperative patient and specialized facilities, measurement of fat change by determinations of nitrogen balance and total body water is comparatively simple and applicable in any metabolic unit. This admittedly gross technique provides the opportunity to assess many aspects of fat metabolism that have been poorly explored and permits the accumulation of needed data on the loss or gain of this important body constituent.

SUMMARY

Comparison was made of two independent methods of estimating body fat changes in eight patients studied under conditions of metabolic balance over periods from 20 to 158 days. Serial measurements of body fat were obtained by substituting values for body density (underwater weighing) and total body water into a single fat prediction equation. Change in total body fat, which ranged from a gain of 7.4 Kg. to a loss of 15.3 Kg., as determined densitometrically, was compared with variations in fat as determined by subtracting the sum of measured changes in protein and water from change in body weight. In the eight studies there was no significant difference in calculated Δ fat as determined by the two methods ($p > 0.90$). Comparison of individual studies revealed differences that fell within the potential error of the methods. The close correlation between the two methods strengthens the validity of both and indicates that estimation of change in total body fat can be approached by readily available volume distribution and balance techniques.

REFERENCES

1. Keys, A., and Brozek, J. Body fat in adult man. Physiol. Rev. 1953, **33**, 245.
2. Kyle, L. H. Estimation of body fat. J. clin. Endocr. 1954, **14**, 969.
3. Edelman, I. S., Brooks, L., and Moore, F. D. Endogenous fat metabolism studied by heavy water dilution and nitrogen balance (abstract). J. clin. Invest. 1952, **31**, 626.
4. Behnke, A. R., Osserman, E. F., and Welham, W. C. Lean body mass. Its clinical significance and estimation from excess fat and total body water determinations. A. M. A. Arch. Intern. Med. 1953, **91**, 585.
5. Kyle, L. H., Welham, W. C., Doolan, P. D., and Schaaf, M. Study of the extrathyroidal effects of thyroid-stimulating hormone. J. clin. Endocr. 1954, **14**, 1029.
6. Kyle, L. H., Meyer, R. J., Schaaf, M., and Werdein, E. J. The effects of Compound A (11-dehydrocorticosterone) and Compound F (17-hydroxycorticosterone) on total body fat. J. clin. Invest. 1956, **35**, 1045.
7. Siri, W. E. Body composition from fluid spaces and density: Analysis of methods. Donner Laboratory of Biophysics and Medical Physics, University of California, Berkeley, Cal., March 19, 1956, UCRL 3349.
8. Siri, W. E. The gross composition of the body. Advanc. biol. med. Phys. 1956, **4**, 239.