Modern Methods For Assessing Human Body Composition

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Evaluation of body composition is essential for an understanding of the growth and development, and various health disorders including malnutrition of human subjects. Human body consists of three chemically distinct compartments. They are: fat mass (FM), fat free mass (FFM) and total body water (TBW). The chemical composition of FFM is assumed to be constant with a density of 1.1 g/ml at 37°C (1), TBW of 72-74% of FFM (2) and FM, stored as trighycordio, has a density of 0.9 g/ml at 37°C (3). Based on these body compartments all body composition methods were developed. Research to establish indirect methods for assessing body composition started by Behnke in 1940 (4). Subsequentiy, a variety of methods has been introduced. Some early review (5-7) give the details of the theory and practice of these methods. In this review some of these early methods that are traditionally used for determining human body composition will be described briefly with their limitations and later, recently developed methods will be discussed in detail.

Old Methods (Traditional)

1. Body Mass Index (BMI) :

BMI is is the body weight (in Kg) divided by the power of height in m^2 (8). Calculations, based on values for ideal body weight, suggest that BMI for normal men should be in the range of 20 to 25 Kg/m^2 while for women it should be in rage of 19-24 Kg/m^2 (9). In the case of infants and children, BMI changes with age beginning at 13 Kg/m^2 reaching a peak of 18 Kg/m^2 at about 1 year and then a nadir of 15 Kg/m^2 at about 6 years of age to be followed by a rise to adult values, as given above, during adolescence (10). Individuals with higher BMI are considered overweight, even obese, and those with lower indices are classified as undernourished. Although BMI is still widely used to assess the extent of overweightness or leanness. it is not always an accurate index of body composition. For instance, a human subject may

weigh much more than the average weight-for-height standards, yet still be underfat in terms of body's total amount of fat. The extra weight could simply be due to additional muscle mass.

2. Skinfold Thickness

Use of this method is usually utilized for the estimation of human body fatness. The measurement of skinfold thickness is made by grasping the skin and adjacent subcutaneous tissue between the thumb and forefinger, pulling it away from the body just for enough to allow the jaws of a caliper to impinge on the skin. The jaws of the caliper are calibrated to exert a constant pressure of 10 g/mm^2. Measurements are made at several places of a human body, such as chest, axila, triceps, subscapula, abdomen, thigh and suprailiac. There are several mathematical equations available for the prediction of body fatness, i e. FM, from the skinfold thickness measurements (11). Since this method is based on the assumption that the thickness of the subcutaneous adipose tissue reflects a constant proportion of the total body fat and the sites selected for measurement represent the average thickness of the subuntaneous adipose tissue and since neither of these assumptions have been proven to be true, the validity of this method is highly questionable. Moreover, since the distribution of fat in the human body could be different from one individual to another, the use of skinfold equations to predict body composition is restricted to populations from whom these equations are derived. Furthermore, the precosion of measurment of skinfold thickness is dependant upon the skill of the anthropometrist and the site measured.

Arm Circumference

Because of the impracticality of using laboratory methods in field studies, upper arm circumference and triceps skinfold have been used to assess nutritional status in popolations (12.) The arm circumference (C) is made to the nearest millimeter on the left arm midway between the tip of the acromion and olecranon process with arm relaxed. The triceps skinfold (S) is measured to the nearest 0.1 mm using a calibrated caliper at the same level as the mid-arm circumference on the posterior aspect of the arm. Calculation of fat (F) and muscle (M) from these measurements utilizes the following equations.

$F = SC/2 + \pi S^2/4$ and $M = (C - \pi S)^2/4\pi$

4. Densitometry

The measurement of body density from the body volume is based on the Archimedes' principle which states that the volume of an object submerged in water equals the volume of water the object displaced. If one measures weight in air and weight in water, the difference corrected for the density of the water corresponding to the temperature of water at the time of underwater weighing, is the apperent body volume. It is also mandatory to determine the residual lung volume (RV) by nitrogen washout and gastrointestinal gas volume which is about 0.1 liter. The general equation to determine body density (D^b) is :

$D_b = \frac{Wa}{\{(Wa-Ww)/Dw\}-RV-0.1}$ where Wa=weight in air Ww=weight in water and Dw=density of water at a temperature at which the measurement is made. The underwater weighing system, originally described by Goldman and Buskirk (13) and later modified by Akers and Buskirk (14) has gained widespread use. A common equation for the calculation of per cent body fat (%F) from body D_b is given by Brozek et al (15) as ;

$\%F = (4.570/D^b) - 4.42$. Another equation developed by Siri (16) is :

$\%F = (4.95/D^b) - 4.50$ which yields higher values for subjects with more than 30% fat compared to the values given by the equation of Brozek et all (15). Because of the variability in bone density and hydration states of the FFM an error of 3-4% for predicting body fatness is expected from the results of densitometry. The result is also dependant on the cooperation of the participants. This is a laboratory method which, however, cannot be used for small babies and hospitalised patients.

5. Isotopic Dilution

The findings that water occupies a relative fixed fraction (72-74%) of FFM (12) have stimulated the estimation of TBW as an index of human body composition. Isotopes of hydrogen (^1H) such as duaterium (^2H) and tritium (^3H), are exchanged by the body in a same manner as water (17). Therefore, the dilution principle can be used to quantitate TBW by following the relationship : $C_1V^1 = C_2V_2$, where C_1V^1 is the amount of isotopic water, i.e. $^2H_20$ or $^3H_20$, given as tracer, C_2 is the final concentration of the tracer and V_2 is the volume of TBW. The use of radioactive ^3H has been restricted in research involving children and female of child bearing age and/or in case of repeated measurements with short period of time. Because of the availability of new techniques, such as gas chromatography (18), GCMS (19), IR (20), add NMR increased use of $^2H_20$ has occured in recent years.

The typical procedure for using isotopic water includes either ingestion or intravenous injection of a specified quantity of tracer, an equilibration period of about 2-4 hours and sampling. The quantity of tracer given depends upon the type of tracer administered, analytical system used, and the objective of the research. A dose of 10g of ^2H_2O (99.7% purity) for an adult human subject is sufficient to provide good analytical precision and accuracy by using I R (20) and NMR (21) methods. In sample collections, although plasma or serum tracer concentrations have been used, under adequate conditions saliva and urine samples can be used. Recently, the use of oxygen-18, i.e. $H^{218}O$, as a tracer has been proposed to measure TBW (22), but the implementation of this technique is difficult outside of a specialized research laboratory.

6. Urinary Creatinine Excretion

Folin (23) first proposed the use of urinary creatinine for estimating body composition and Hoberman et al (24) later demonstrated the direct proportionality of the body creatine to urinary creatinine output. Creatinine is formed by the non-enzymatic hydrolysis of free creatine liberated during the dephosphorylations of creatine phosphate which is located mostly (98%) in skeletal muscle (25). The urinary creatinine excretion is related to FFM and muscle mass (26). The greatest drawback of this method is the large intra-individual variability in daily urinary excretion of creatinine from the renal processing (27). In addition to this, diet can also effect the daily creatinine excretion (28).

Modern Methods (New)

Various problems are associated with all the traditional methods as described above. Some are invalid, some cannot be used for field studies and most of them are time consuming and cumbersome. Therefore, the development of methods that are non-invasive, rapid and accurate has been the subject of extensive investigations primarily in the USA to-day. Some of these modern methods have been described below with their brief theory and practices in the determination of various body compartments.

1. Bioelectrical Impedance Analysis (BIA)

Since FFM is the main reservoir of all body electrolytes, and since body electrolytes behave like electrical conductor, it is therefore, commonly believed that the measurements of

bioelectrical impendence, of lean tissues should provide an assessment of this body compartment. The fact that the ionized electrolytes are virtually confined to the total volume of water in the body, it is also possible to derive TBW from BIA measurements. Hoffer et al (29) were the first to use this impedance method to estimate TBW by assuming the complex geometry of humam body as a simple cylindrical conductor of length L and area A and modifying the equation.

$Z = rohL/A$ [1]

where Z is the impedance and is equal to

$\sqrt{R^2 + X^2}$ (R=resistance and X=reactance). and roh is the resistivity, to

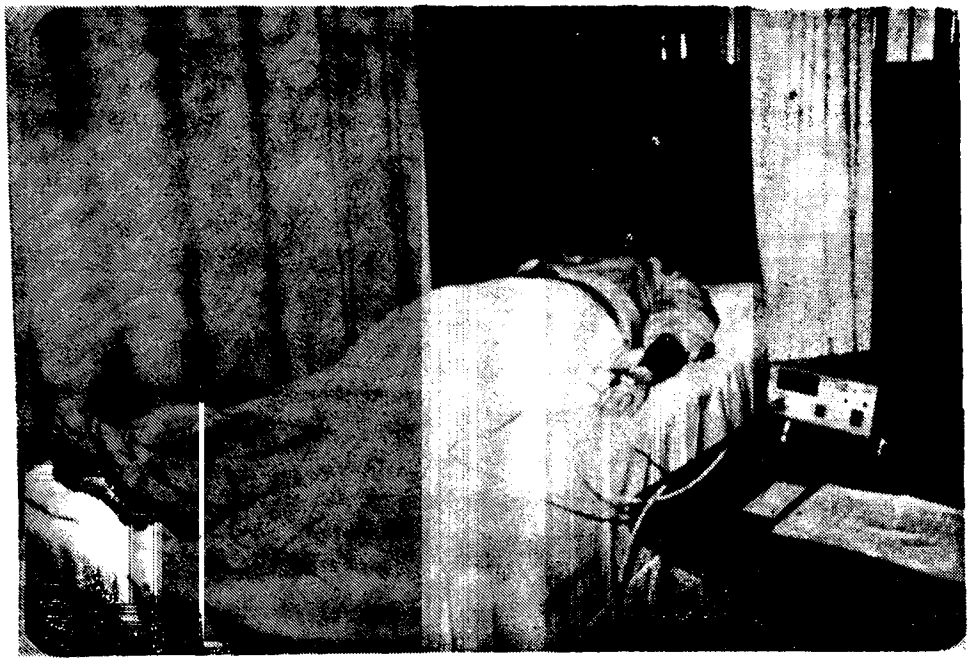
$Z = rohL^2/V$ [2]

where V is the volume.

Determinations of resistance and reactance are made by using a tetrapolar impedance plethysmograph. Such an instrument, model 101, manufactured by RJL Inc. Detroit, Mich, USA, is shown in Figure 1. The subject, as shown in this figure, lies supine on a cot wearing cloths but without shoes and socks. Aluminum foil spot electrodes are positioned in the middle of the dorsal surfaces of hands and feet proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints respectively, and also medially between the distal prominances of the radius and the ulna and between the medial and lateral malleoli at the ankle. A thin layer of electrolyte gel is applied to each electrode before application to the skin. An excitation current of 800 μA at 50 KHz is introduced into the subject at the distal electrodes of the hand and foot, and the voltage drop is detected by the proximal electrodes (see Fig. 1). According to Ohm's law Z to an alterating current of a circuite is measured in terms of voltage (E) and current (I) as $Z = E/I$. By using phase sensitive electronics one can quantitate the geometrical compenents of Z:R is the sum of in-phase vectors and X is the sum of out-of-phase vectors. Determinations of R and X are made by placing the electrodes on the ipsilateral and contralateral side of the body. The impedence value for a subject is used to calculate conductance (height^2/impedance) and to predict FFM and TBW, The precision of the method is less than 2% (30),

The BIA method has been used to assess body composition in healthy adults. Lukaski et al (30,31) have used standard methods to establish models to estimate TBW, FFM and potassium in healthy human subjects. Kushner and schoeller (32) have demonstrated the validity of the BIA method to Predict TBW in patients with either inflammatory bowel disease and receiving total parenteral nutrition and diabetes. However, this method was found to overestimate fatness in lean males and underestimate it in overweight subject compared to hydrostatic densitometry (33).

Recently Khaled et al (34) corrected the BIA method to estimate body fatness by taking into consideration of total body weight provided the body electrilyte is not altered. The advantages of this method are portability, safety (non-invassive), convenience, cost and acceptable levels of reliability and accuracy in the assessment of human body composition.

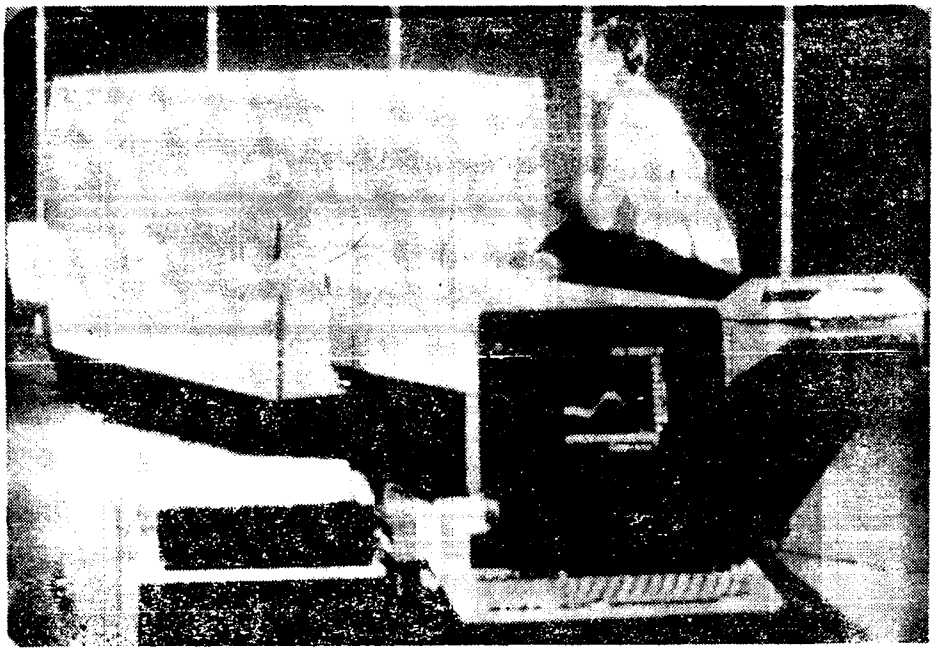


1. A typical display of the use of a BIA machine, RJL system BIA-101 on a human subject. Please note that two electrodes are attached on right hand and other two on the right foot forming a tetraporler electrode system.

2. Total Body Electrical Conductivity (TOBEC)

The basic principles of the TOBEC is similar to the BIA method. In this method, however, the excitation current is induced in the tissue by a time varying magnetic field which is generated by passing a radio frequency (rf) current at 2 to 5 MH_z through the coil surround-

ing the tissue. The TOBEC method actually originates from electronic meat measuring equipment (EMME) manufactured by the Dickey-John Co , Auburn, ILL, USA, for the estimation of lean content of ground meat packed in a rectangular shaped box. A second generation TOBEC machine has a circular shaped coil configuration as shown Figure 2. The subject lies supine on a stretcher on rollers and is passed through the tunnel which has magnetic field of about 80 cm in diameter and 190 cm long. Movement through this tunnel yields a phase curve representing the interaction of the magnetic field with the geometric shape and electrolyte, i.e. FFM or TBW content of the human subject. The Fourier analysis of this phase curve is employed for body composition analysis. Multiple regression analysis using zero order, first order, and second order Fourier coefficients as predictor variables of FFM, TBW and total body potassium (TBK) gave correlation coefficient, r^2, of 0.932, 0.961 and 0.891 with SEE of 1.43 Kg, 1.57 L and 11g respectively (35). These results indicate that the second generation TOBEC has the potential for increased predictive accuracy in estimating body composition. Its drawback is the lack of validation in patients undergoing weight or compositional changes and in patient with abnormal water electrolyte distributions.



2. A second generation TOBEC instrument.

3. Neutron Activation Analysis (NAA)

NAA is an analytical technique based on nuclear reaction with various elements such as calcium (Ca), sodium (Na), chloride (Cl). phosphorus (P) and nitrogen (N) of human body by creating unstable isotopes, e.g. ^{45}Ca and ^{15}N. In this method a moderated beam of fast neutrons is delivered to the subject that creates unstable isotopes. These unstable isotopes revert to stable condition by emitting one or more gamma rays of characteristic energy. A human subject is placed carefully with respect to a detector array in a highly shielded facility and the radiation from the subject is detected by the gamma radiospectrum of the emissions. The energy level identifies a particular element while the level of activity indicates its abundance.

The first application of NAA to the assessment of human body composition was the determination of total body calcium (TBCa) (36-33). The precision of the repeated TBCa de. termination is 2.5% over a 4-5 year period (39) that makes this method suitable for lontitudinal studies. Specific procedures have also been developed to normalize body calcium levels in patients with motabolic bone disease (40).

Measurements of total body nitrogen (TBN) by using promtgamma technique (41,42) have led to the recognition of the clinical usefulness of body nitrogen in body composition assessment. This method quantitates TBN absolutely by using body hydrogen as an internal standard. The procedure requires 20 minute neutron exposure and counting period and has a calculated whole body radiation dose of 26 mrem. Determinations of absolute TBN values allow the estimation of muscle and non-muscle mass and their protein contents by using the mathematical models of Burkinshaw (43). Use of these data along with bone mineral mass from the TBCa measurements permits the calculation of total body fat. Most information on the body composition can be obtained by NAA than any available techniques. Unfortunately, factors, such as high cost, the need for skilled operator, lack of mobility and most of all the use of ionizing rediation, severely limit the routine application of NAA in body compositional studies.

4. Computerized Tomography (CT)

In this, method a collimated X-ray source and detectors are aligned at opposite poles of a circular gantry. A human subject, lying on a movable platform, is advanced through the

control aperature of the gantry. As the X-ray beam is rotated around the designated area, information about the intensity of the attenuated X-ray beam is recorded and stored. The computer then constructs the two-dimensional cross-sectional images. Each CT image is a matrix of pixels, each about 1 mm X 1 mm, arranged in rows and columns. The depth of the slice thickness varies from 1 mm to 10 mm. The magnitude of the X-ray beam attenuation is reflected in the degree of pixel shading. Lower densities appear black and higher densities are white with air and bone at the low and high ends of absorption respectively. Thus high image contrast can be observed between bone, adipose (fat) and fat free tissues.

Various approaches have been tried with this CT method to analyze human body composition (44). These approaches have been used to assess changes in muscle and adipose tissue in malnutrition (45) and to describe cross-sectional difference in abdominal fat distribution during aging (46,47). The adipose and fat free tissues can be determined from the number of pixels in a slice of CT. However, tomographic pixels derived from an area of adipose tissue represent not only neutral fat but also protein matrix. Thus the assessment of absolute amount of fat mass can not be accurate enough. The CT method has been helpful in diagnosing organ tumers (48), fatty liver (49) and tissue iron content (59). Factors that limit the use of this techuique are similar to NAA.

5, Nuclear Magnetic Resonance (NMR)

Whereas CT and NAA techniques have inherent radiation problems, a new and sophisticated method with great potential for the safe, non-invasive and direct assessment of human body composition is Magnetic Resonance Imaging (MRI) and Spectroscopy (MRS). Both MRI and MRS are actually based on the same basic principles of Nuclear Magnetic Resonance (NMR), Since common people in the western countries are usually afraid of the word "Nuclear", hence the terminology is MRI/MRS to suit the public sentiment. NMR is basically a form of absorption spectrescopy based on the properties of nuclei that possess a net spin and associated magnetic field to precess or resonate at particular frequencies which can be detected with the appropriately positioned magnetic fields and receiving coils (51). The frequency at which a magnetic nucleus resonates is described by the following equation

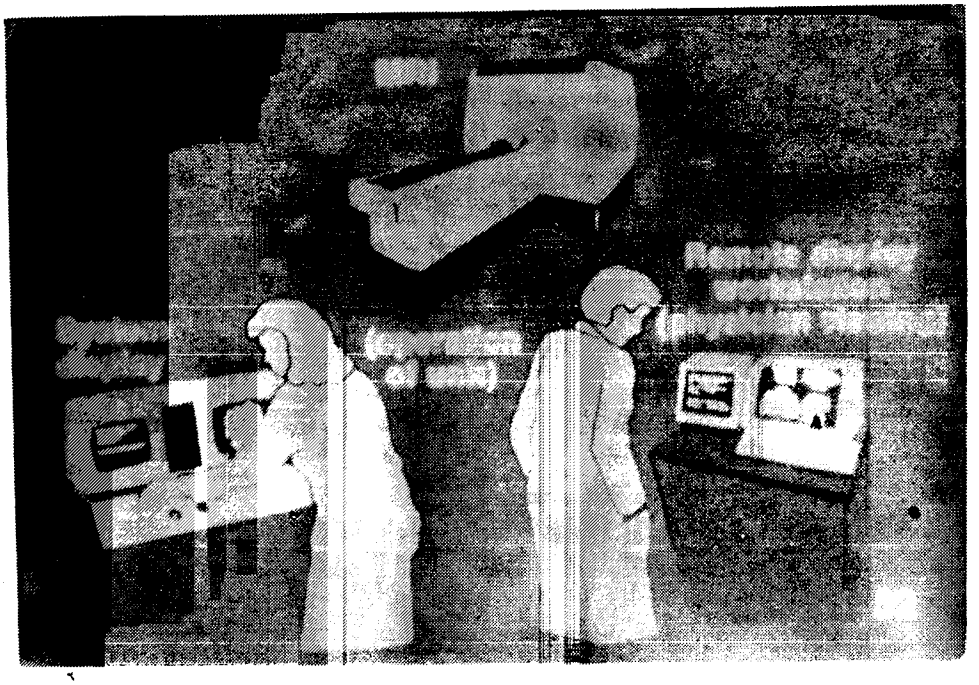
$$\nu = (\text{gamma})Bo/2\pi \qquad [3]$$

Where ν is the resonance frequency, (gamma) is the gyromagnetic ratio for a particular nucleus and Bo is the magnetic field the nucleus is experiencing. The Bo term is what causes the same isotope to resonate at different frequencies depending on its local chemical and magnetic environ-

ments. Several nuclei of biological importance detectable in MRI/MRS experiments include ^{1}H, ^{2}H, ^{13}C, ^{14}N, ^{23}Na, ^{31}P, ^{35}Cl, ^{39}K and ^{43}Ca. Any one of these nuclei, when placed in static magnetic field, attempts to align with the field. If a radiofrequency (rf) wave parturbes this alignment, the axis of the magnetic moment of that nucleus will change its orientation and some of the energy from the rf source will be absorbed. When this rf seurce is turned off, the absorbed energy will be emitted that gives rise the NMR signal and the nucleus or nuclei will relax to its original orientation. To relax to its equilibrium position, the nucleus takes some time which is called Relaxation Time (T). There are two relaxation times: 1) Spin-Lattice or Longitudinal Relaxation Time, T_1, which depends on nuclei's chemical and/or magnetic environments, and 2) Spin-Spin or Transversal Relaxation Time, T_2, which is dominated by the interactions between two or more nuclei and is usually indicated by the linewidth of a resonance signal. Basides these NMR parameters, two other parameters, namely signal intensity and chemical shift dispersion, also play major role in monitoring many chemical and biological events. All these parameters have been used recently to determine TBW in adult human (21) and in baboons (52) non-invassively and accurately.

In recent years, NMR has developed into a highly sophisticated system that generates two and three dimensional images (MRI) of human body. The whole-body MRI system is presented in Figure 3. It consists of a superconducting magnet whose field strength could vary from 0.5 to 2 Tesla, a saddle-shaped rf coil, an interfaced computer system that process data and display images. The images are generated typically at ^{1}H resonace. This is because ^{1}H is most abundant in biological system in the form of water. Both the relaxation times (T_1 and T_2) and chemical shift dispersion properties of ^{1}H are used to construct images (53). In the determination of body compositions by MRI, fat and water can be displayed as two quite distinct entity by virtue of their difference in relaxation and chemical shift values. Another important applicntion of MRI/MRS is to seek specific chemical information from selected regions of the body by using ^{31}P, ^{13}C and ^{1}H resonances. Localised ^{31}P and ^{13}C resonances can provide metabolic information which directly reflects the state of health of the tissue and its responce to therapy (54).

The optimism of future applications of MRI/MRS in body compositional studies is somewhat reduced by the restricted availability and high cost of the system. Nevertheless, the system is an exciting new method that may have profound influence in estimating body energy stores.



3. An integrated MRI/MRS system that can be housed in a modern sophisticated research laboratory or clinic.

Summary

Within the formate of a minireview all the commonly used traditional methods for determining human body copmosition have been described with their possible limitations. The ideal method for assessing body composition be relatively inexpensive, be operated by unskilled technicians and yield highly reproducible and accurate results. In practice, however, there is a compromise between cost, ease of operation and reliability. Keeping these perspectives in mind some newly developed techniques have been discussed. A method or combination of methods for determining body composition should be selected to meet a particular research objective.

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