



## A new approach for the estimation of body composition: infrared interactance<sup>1,2</sup>

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**ABSTRACT** A new method for the estimation of body composition in humans, called infrared interactance, is discussed. Infrared interactance is based on the principles of light absorption, reflection, and near-infrared spectroscopy. Body composition (percentage fat) was estimated in 53 adults (23 to 65 yr of age) by infrared interactance and compared to results from deuterium oxide dilution ( $r = 0.94$ ), skinfold ( $r = 0.90$ ), and ultrasound ( $r = 0.89$ ) measurements. The method is safe, noninvasive, rapid, easy to use, and may prove useful to predict percentage body fat, especially in the obese. *Am J Clin Nutr* 1984;40:1123–1130.

**KEY WORDS** Human body composition, total body water, skinfold measurements, ultrasound measurement, near infrared spectroscopy, obesity

### Introduction

Interlaboratory comparison of human energy expenditure and other metabolic data depends upon accurate determination of body weight (1), fat-free mass, lean body mass, and/or total body fat (2, 3). A number of methods for measuring fat-free mass, lean body mass, or total body fat exist and include hydrostatic weighing (4, 5), total body potassium determinations (6, 7), deuterium oxide dilution ( $D_2O$ ) (8, 9), skinfold (SF) (10, 11) or ultrasound (US) (12, 13) measurements, total body electrical conductivity (14–16), and total body impedance (17, 18). We report herein the results of a preliminary study using a new method infrared interactance (IRI). This method is rapid, safe, noninvasive, and may be useful in research and in clinical and field situations.

Earlier research conducted at the USDA Beltsville Agriculture Research Center in the area of near infrared reflectance and transmittance (19–21) has led to the development of the infrared interactance method.

### Methods

Twenty adult males and thirty-three adult females were studied (Table 1). They were part of an ongoing

nutrition study at the Beltsville Human Nutrition Research Center. Their weights had been maintained on a diet of constant nutrient composition for 13 wk. All were deemed healthy by physical and biochemical evaluations. Written, informed consent was obtained. The research protocol was reviewed and approved by the Human Studies Committees of the USDA Agricultural Research Service, Georgetown University, and the University of Maryland, College Park.

Spectral measurements were made using a computerized spectrophotometer model 6250, built by Neotec Instruments Division of Pacific Scientific, Silver Spring, MD. The instrument uses a single beam rapid scanning monochromator (linear scan from 600 to 2500 nm) and a fiber optic probe. The instrument was operated in the transmittance mode. Scans were made over the midrange wavelengths (700 to 1100 nm). The fiber optic probe conducted the radiation from the monochromator to the selected site on the body and collected the

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interactive radiation and conducted it to the detector. The probe was surrounded by a piece of black felt (approximately 15 cm in diameter with an approximately 2 cm diameter hole in the center which fitted around the end of the probe) to preclude the possibility of other radiation entering each specific site.

The instrument was standardized by measuring a signal from a reference Teflon block (1 cm thick) before scanning each subject. The instrument computed interactance ( $I$ ) at each wavelength by dividing the signal obtained at each site by the signal from the reflectance standard ( $I = E_s/E_r$ ; where  $E_s$  = energy received from subject, and  $E_r$  = energy received from the reference). All data were processed to  $\log(I/I)$  to be similar to absorption spectra plotted as  $\log(I/T)$ . Earlier work in analysis of agricultural foodstuffs (22) has shown that  $\log(I/T)$  varies linearly with concentration of a specific absorber in a mixture with other materials.

The method of data treatment used to analyze the spectra used the ratio of two second derivatives of the  $\log(I/I)$  data obtained at two different wavelengths. The mathematical transformation to the second derivative of  $\log(I/I)$  is standard in near-infrared spectroscopy and is done to reduce effects on reflectance spectra of such variables as particle size and temperature. The use of ratios of two second derivatives of  $\log(I/I)$  data obtained at two different wavelengths is also widely used for estimating the composition of other materials (19–21). The treatment of the data is described in detail in earlier publications (21, 22).

The IRI method was assessed as a possible tool for determining % body fat by comparison with data derived from total body water as estimated by the  $D_2O$  technique (23, 24). Interactance spectra were measured at each of five anatomically well-defined sites (10) which are used for prediction of body fat by SF and US measurements (triceps [T], biceps [B], subscapular [SC], suprailiac [SI], and thigh [TH]). Twenty scans were made for each site (requiring a total of approximately 13 s) and automatically averaged by the instrument. About 3 min were required to measure and store the data from all five sites on each subject. The resultant five spectra (one averaged scan for each of the five sites) for each subject were stored on the computer disc. By averaging the spectra from the five sites, an average spectrum was computed for each of the 53 individuals and data from these average spectra were used for calculations. At each wavelength of the spectrum, the correlation (across all 53 subjects) between the ratio of the second derivative of  $\log(I/I)$  at that wavelength, expressed as a ratio of the same value determined at each other wavelength, and fat content (as estimated by  $D_2O$  dilution) was determined. Based on the correlations obtained, the optimum wavelengths for use in calculating the ratios were found to be 916 and 1026 nm.

TABLE 1  
Characteristics of subjects studied

	n	Age yr	Wt kg	Ht cm
Males ( $\bar{x} \pm SD$ )	20	41 $\pm$ 11	79 $\pm$ 11	176 $\pm$ 7
Females ( $\bar{x} \pm SD$ )	33	43 $\pm$ 14	61 $\pm$ 14	164 $\pm$ 7

To test the ability of the IRI method to predict body fat on an unknown population, data from two-thirds (36) of the subjects were used to develop a calibration (prediction) equation. This equation was then used to predict the % body fat of the other "test" subjects [the subjects were ranked by % body fat, from lowest to highest, and every third subject (3, 6, 9, etc) was used as a "test" subject].

Total body fat was also predicted from SF measurements (T, B, SC, SI) using the body density equations of Durnin and Womersley (10) and ultrasonic (ultrasound) measurements (T, B, SC, SI, TH) using the Body Composition Meter (Ithaca Instruments, Ithaca, NY) and regression equations published by Volz and Ostrove (13) for body density and Brozek's (5) equation for body fat.

## Results

As can be seen from the spectra in Figure 1 the pure fat absorption band is at 930 nm and the pure water absorption band is at 970 nm. These same bands are apparent in the triceps interactance spectra from the arms of two subjects [one male (low fat) and one female (high fat); Fig 1]. The average near-infrared interactance spectra ( $\log I/I$ ) of the 20 men for each site are shown in Figure 2, while the average spectra for each site of the 33 women are shown in Figure 3.

The five spectra for a male subject who was found to have 12.7% fat by deuterium oxide dilution are shown in Figure 4 and the five spectra for a female subject with 45.9% body fat are shown in Figure 5. Since similar spectra were obtained for subjects of different sex but with similar estimated % body fats, the differences in the spectra shown in Figures 4 and 5 are not a sex effect but reflect differences in body composition.

For all 53 subjects, the relationship between % body fat, as predicted by the  $D_2O$  dilution technique and as predicted from the average spectra (IRI data) was % body fat =  $53.64 - 20.72 [(second\ derivative(916\ nm)) \div (second\ derivative(1026\ nm))]$  with a SE of estimate of 3.0% bodyfat. The correlation coefficients between % body fat as predicted by the IRI method and as estimated by the  $D_2O$  dilution technique were 0.84, 0.95, and 0.94 for males, females, and males plus females, respectively ( $p < 0.01$  for all three values). As a point of interest, for the two subjects whose spectra are shown in Figures 4 and 5, the IRI-predicted body fats were

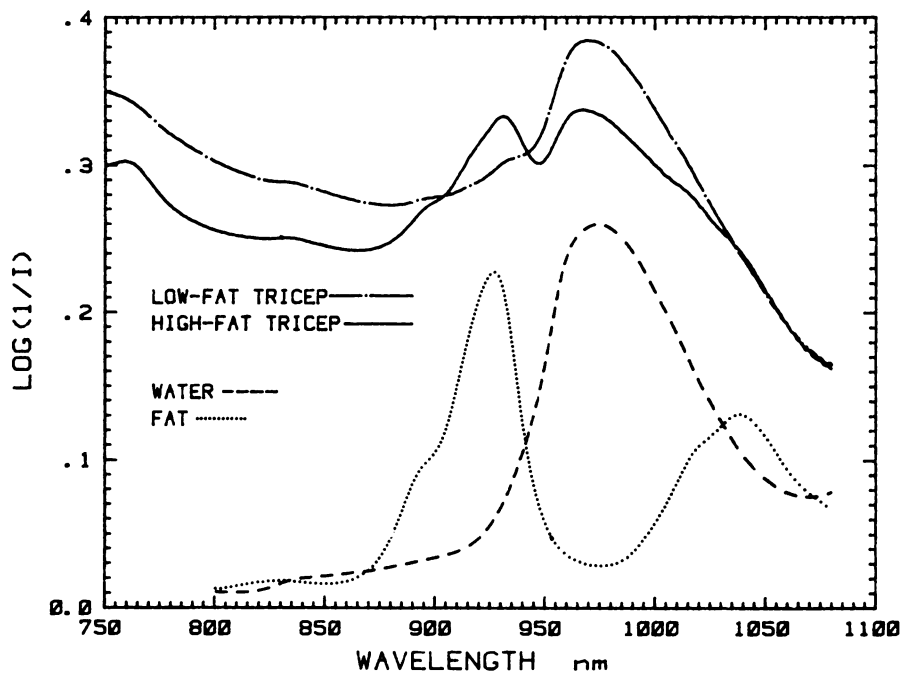


FIG 1. Near-infrared spectra from samples of pure pork fat and distilled water and from the triceps region of the arms of two subjects [one male (low-fat), and one female (high-fat)].

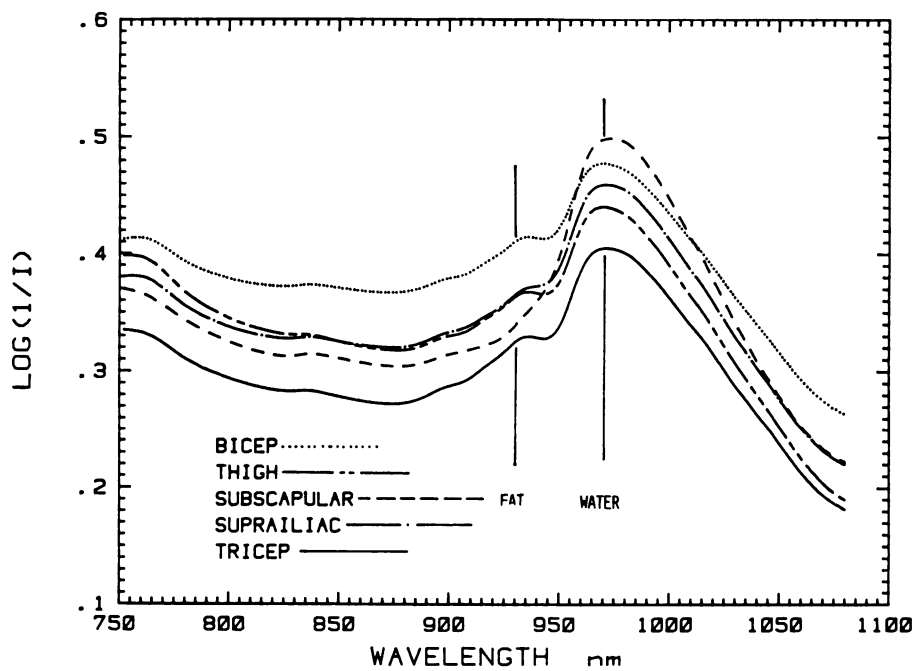


FIG 2. Near-infrared spectra for men (average spectra for five sites).

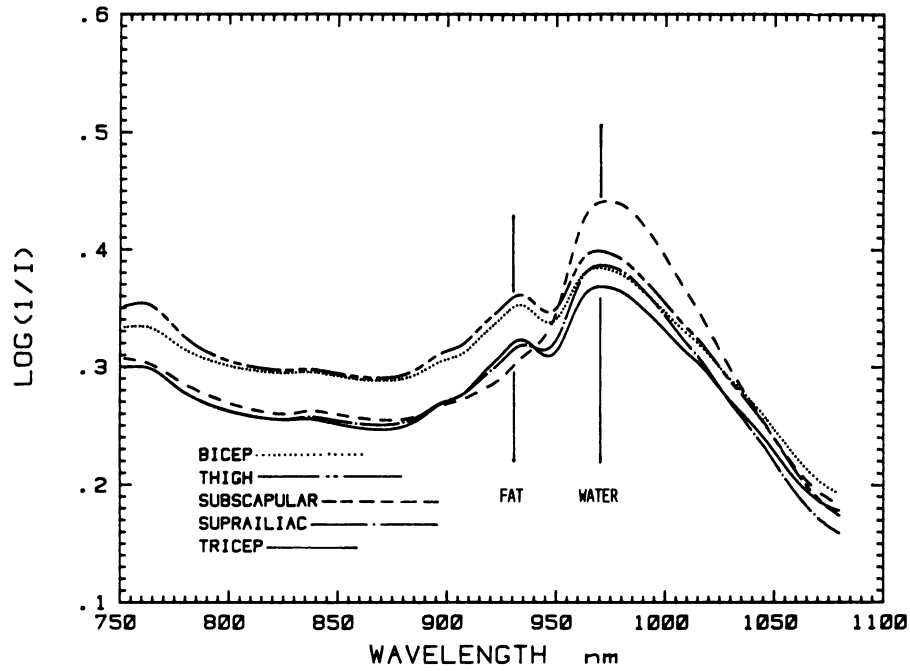


FIG 3. Near-infrared spectra for women (average spectra for five sites).

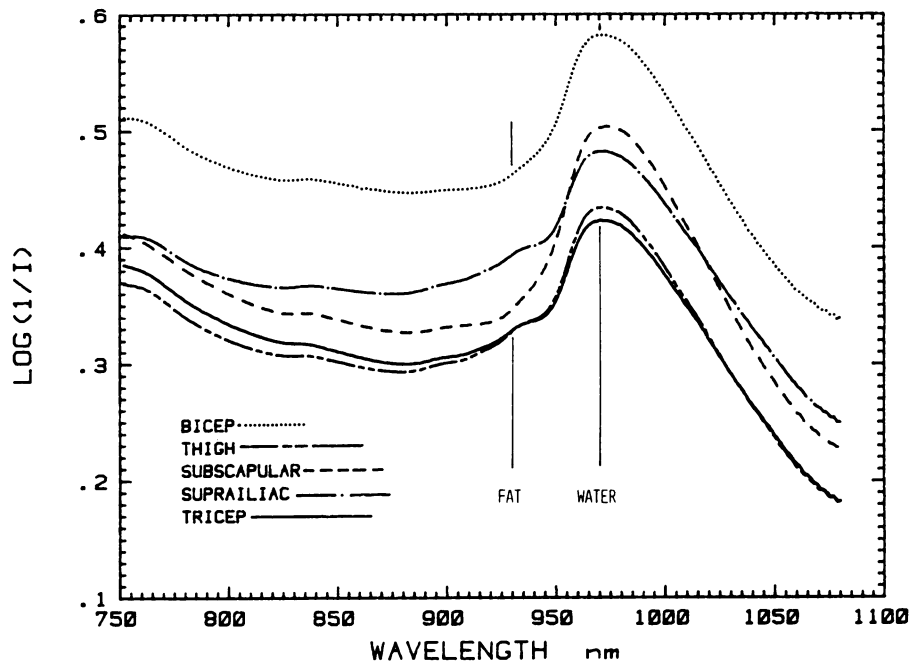


FIG 4. Spectra at five sites from a subject (male) with 12.7% body fat as estimated by the D<sub>2</sub>O dilution method.

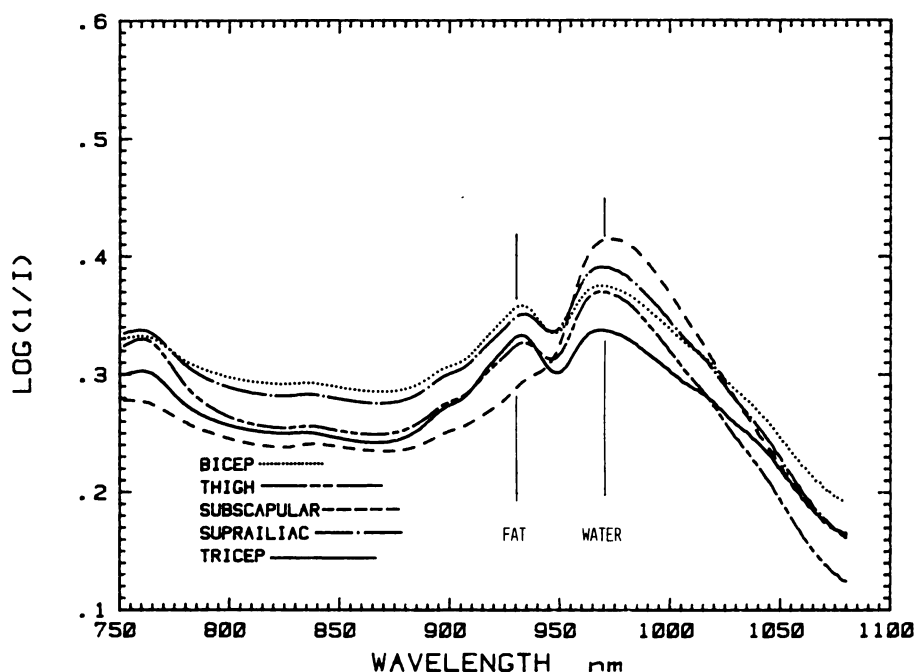


FIG 5. Spectra at five sites from a subject (female) with 45.9% body fat as estimated by the D<sub>2</sub>O dilution method.

13.8% (male subject; Fig 4) and 45.0% (female subject; Fig 5).

The mean ( $\pm$  SD) values for % body fat for all 53 subjects as estimated from IRI, D<sub>2</sub>O, SF, and US are given in Table 2 and correlation coefficients (together with SE of estimate values) between the % body fats as estimated in the males, females, and males plus females by the different methods are given in Table 3. As would be expected, for the estimates obtained from the D<sub>2</sub>O dilution technique and the IRI method, the mean values for % body fat were in agreement. Values predicted from SF measurements were slightly lower (by 1 to 2% body fat) while the estimates derived from US measurements were markedly lower (7 to 8% body fat).

The correlation coefficients between values derived from the D<sub>2</sub>O, SF, and IRI data

were generally high (ie, 0.74 to 0.95). The observed relationships were lower between the values obtained from US measurements and the values obtained by the other methods. However, because of the small number of subjects involved, none of the correlation values listed are significantly different.

The calibration (prediction) equation, when based on 36 subjects, was: % body fat = 55.26 - 22.08 [(second derivative (916 nm)) + (second derivative (1026 nm))];  $r = 0.91$  ( $p < 0.001$ ), SE of estimate = 3.2% body fat. The relationship between IRI-predicted % body fat of the 17 test subjects (as predicted from the equation based on data from the 36 subjects) and % body fat as estimated by the D<sub>2</sub>O dilution technique is shown in Figure 6.

### Discussion

All standard methods (hydrostatic weighing, SF, US, D<sub>2</sub>O) used for estimating body

TABLE 2  
Mean % body fat as estimated by different methods

	IRI	D <sub>2</sub> O	SF	US
Males $\bar{x}$ ( $\pm$ SD)	24.9 (5.5)	24.0 (5.8)	23.0 (5.3)	17.5 (5.3)
Females $\bar{x}$ ( $\pm$ SD)	32.2 (8.4)	32.2 (8.9)	30.7 (6.7)	24.5 (5.4)
Total $\bar{x}$ ( $\pm$ SD)	29.1 (8.0)	29.1 (8.7)	27.8 (7.2)	21.9 (6.2)

TABLE 3  
Correlation coefficients between % total body fat  
as estimated by different methods\*

	IRI			SF			US		
	Males (M)	Females (W)	M + W	Males (M)	Females (W)	M + W	Males (M)	Females (W)	M + W
D <sub>2</sub> O	0.84 (3.3)	0.95 (2.6)	0.94 (3.0)	0.86 (3.1)	0.86 (4.5)	0.89 (4.0)	0.83 (3.3)	0.81 (5.3)	0.84 (4.7)
SF	0.74 (4.1)	0.83 (4.5)	0.86 (4.4)						
US	0.64 (4.6)	0.84 (4.4)	0.84 (4.7)	0.68 (4.0)	0.71 (4.8)	0.78 (4.6)			

\* SE of estimate values (expressed in % body fat) are given in parentheses; all values significant ( $p < 0.01$ ).

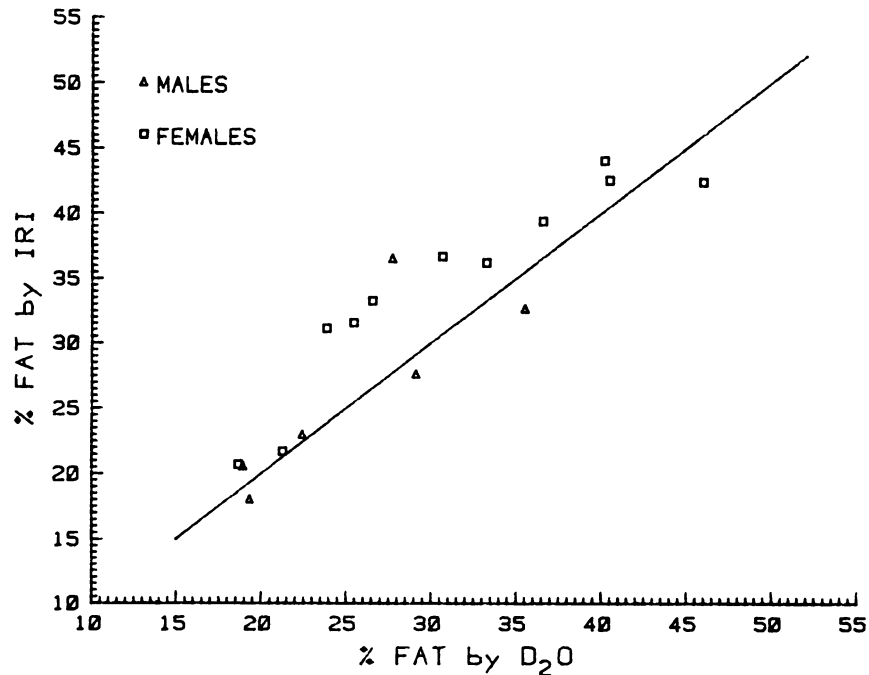


FIG 6. Relationship in 17 subjects between % body fat as predicted by the IRI method and % body fat as predicted by the D<sub>2</sub>O dilution technique. The IRI prediction equation was based on data (IRI and D<sub>2</sub>O) obtained on 36 other subjects (see text). The line shown is the "1:1 line" which would be obtained with 100% agreement between % body fat as predicted by the IRI method and as estimated by the D<sub>2</sub>O dilution technique.

composition are based on assumptions and have their individual limitations (2, 3, 25). The SF and D<sub>2</sub>O techniques (Table 2) gave similar results for % body fat in this study, with US giving consistently lower values.

The shape of an interactance spectrum is a function of the amount of fat, water, and protein present in the sample while the level of the interactance signal is a function of the optical scattering properties of the sample and the geometry of the measuring device. Therefore, the difference in level between the BI curve and the T curve of Figure 2 is caused by differences in scattering properties while the difference in shape between the SC

curve and the T curve results from the difference in composition with the T curve showing higher fat. The difference in curve shapes (eg, between Figs 2 and 3) or the relative magnitudes of the fat and water bands show a higher fat level for the females compared to the males, particularly on the TH and SI spectra. These anatomical differences are well known; however, the higher fat level for females is also in agreement with the average D<sub>2</sub>O values of  $32.2 \pm 9\%$  body fat for females and  $24 \pm 6\%$  body fat for males.

Large variations in the level of the log (1/I) signal were observed between sites and



between individuals (Figs 4 and 5). The cause of these variations is not understood at this time, but the derivative treatment of the data in the data analysis removes some of the effects of these variations as a source of error (22).

Infrared interactance successfully predicted % body fat (Fig 6) in a subgroup of subjects ( $r = 0.91$ ). The "1:1 line" (Fig 6) suggests, however, that in this subgroup population of 17 subjects, the IRI technique slightly overestimated % body fat. In particular, the predicted values for females appear to be systematically high. Measurements on a larger sample are being made, in part to test whether or not this is actually true. If so, different calibration (prediction) equations for males and females might be needed.

Our results suggest that the IRI method may provide a rapid, safe, noninvasive technique for nutritional assessment in individuals and populations. In particular, the method appears to be observer-independent (once anatomical location of the site is completed) and useful in both very lean and obese subjects. However, more studies are needed to further evaluate the method as a technique to measure body composition. ❏

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