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Race-related differences in tissue dielectric constant measured noninvasively at 300 MHz in male and female skin at multiple sites and depths

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Background/Purpose: We hypothesized that reported race-related differences in skin properties cause skin and skin-to-fat water differences among races that are measureable by skin tissue dielectric constant (TDC) values that depend strongly on water content. Our first aim was to test this hypothesis. Also, since inter-side TDC ratios are used to assess edema and lymphedema, the second aim was to test if TDC ratios are race-dependent. The third aim was to determine the extent to which TDC depends on total body water (TBW) and fat (TBF).

Methods: Tissue dielectric constant was measured to 1.5 or 5.0 mm depths bilaterally on chest, forearm and ankle in 100 young (19-39 years) adults with 10 male and 10 female per self-expressed race. Races were African-American, Asian, Asian-Indian, Caucasian and Hispanic groups. TBW and TBF were measured using bioimpedance.

Results: Tissue dielectric constant values decreased from chest to forearm to ankle ($P<.001$) independent of race with most values greater for males but with inter-arm TDC ratios independent of gender, site, depth, or race. For females, forearm TDC values differed among races ($P<.01$) with Asian and Asian-Indian values tending to be least. For males, chest TDC values differed among races ($P<.01$) mainly due to large African-American TDC values. For the composite group, TDC was strongly ($P<.001$) positively correlated with TBW and negatively correlated with TBF.

Conclusions: Tissue dielectric constant dependence on race of the type herein uncovered should be considered in assessing skin hydration comparisons that include different race or ethnic subjects. Further, the demonstrated relationship between TDC and body composition should be considered as an important covariate. However, despite these variations, the inter-arm TDC ratio remains robust as a potential indicator of unilateral tissue water changes.

KEYWORDS

edema, race-related skin differences, skin dielectric constant, skin ethnicity, skin water

1 | INTRODUCTION

Racial or ethnic differences of some skin conditions have been the subject of prior reports[1] with some findings of racial differences in skin contradictory.[2] Interest in characterizing skin property differences among racial groups is in part related to the concept that elucidation of differences may facilitate more selective skin protection strategies and treatments. One skin feature of interest is skin water content.

Prior measurements of forearm stratum corneum (SC) dryness among ethnic groups of women (African-American, Caucasian, Chinese and Mexican) showed no significant difference in dryness among young adults.[3] Measured forearm skin thickness (epidermal + dermal) in these populations also revealed no significant racially related differences.[4] Absence of SC hydration, however, does not preclude the possibility of racially related differences in water features within deeper skin structures. Thus, our primary aim was to investigate this possibility using skin tissue dielectric constant (TDC) values that are largely dependent on tissue water content.[5] Accordingly, TDC measurements were done in young adults comprised of five self-described racial groups (African-American, Asian, Asian-Indian, Caucasian, and Hispanic) with 20 subjects per group. Because of gender differences[6,7], each group included 10 males and 10 females. Further, to test for potential linkages of skin water to body composition parameters, total body water (TBW) and total body fat (TBF) were also evaluated.

2 | METHODS

2.1 | Subjects

One hundred young adults participated after signing an approved consent form. Recruitment was designed to achieve 10 males and 10 females in each of the following self-reported racial groups; African-American, Asian, Asian-Indian, Caucasian, and Hispanic. Entry requirements were that they (1) were between 18 and 39 years, (2) had no known dermatologic condition, (3) had not had any major trauma or surgery to upper or lower extremities and (4) were not taking any medications. Participants were asked not to apply body lotions or creams to body parts to be measured on the experiment day. Body composition parameters, that included TBF percentage and TBW percentages, were measured standing and supine as described subsequently. Also, total body bioimpedance (TBZ) was measured supine and arm fat percentage (AFP) was measured standing. Supine blood pressures (SBP) were taken with a mercury sphygmomanometer. The major features of these five groups are shown in Table 1. Males vs females had significantly (P<.001) greater SBP, height, weight, BMI and TBW and significantly (P<.001) less TBF and TBZ values. Five males (10%) and three females (6%) were left-handed; the rest were right-handed. Two male left-handers were Caucasian, two were African-American and one was Hispanic. For females, one left-hander was African-American and two were Asian.

2.2 | Tissue dielectric constant measurements

The dielectric constant (relative permittivity) is a dimensionless number equal to the ratio of tissue permittivity to permittivity of a vacuum. Since TDC values mainly depend on tissue water, TDC values are indices of water content. For reference, the dielectric constant of distilled water at 32°C is about 76. The device used (MoistureMeterD, MMD, Delfin Technologies, Kuoppio Finland) measures TDC at a frequency of 300 MHz and is therefore sensitive to both free and bound water. Measuring of the bound water component is important since 75-90%

TABLE 1 Characteristics of subjects

	Female (N=50)					Male (N=50)				
	Caucasian	A-A	Hispanic	Asian	Asian-Indian	Caucasian	A-A	Hispanic	Asian	Asian-Indian
Age (years)	26.7±5.0	27.2±2.7	26.4±3.3	26.9±2.2	25.6±1.9	25.7±2.1	25.7±3.4	27.6±3.7	27.2±3.2	24.9±2.6
[a]Height (in)	65.6±3.5	65.9±3.9	64.8±3.9	63.0±3.7	62.3±4.9	71.1±2.2	70.0±1.9	67.9±5.5	67.5±2.2	68.2±3.1
[a]BMI (Kg/m^2)	21.7±3.1	24.3±3.6	23.6±2.8	22.0±3.8	23.4±6.5	24.9±2.6	25.7±4.3	27.7±2.5	23.2±2.4	26.2±6.7
[a]TBF (%) stn	25.6±6.9	31.1±7.5	31.2±6.4	25.1±5.8	28.9±8.2	15.0±4.5	16.6±6.7	17.0±5.8	12.5±4.6	19.3±6.8
[a]TBF (%) sup	21.5±6.2	27.1±6.5	24.8±4.5	22.4±4.1	27.3±5.5	12.8±3.4	14.2±5.9	14.6±5.3	10.5±2.9	15.6±6.0
[a]TBW (%) stn	55.0±4.6	51.2±5.1	53.2±5.4	54.9±3.9	52.3±5.5	60.3±3.5	60.1±5.9	59.1±4.8	63.6±4.3	57.0±5.6
[a]TBW (%) sup	56.6±7.9	51.3±5.9	54.2±6.4	56.3±5.0	51.9±6.5	61.1±2.9	60.7±5.4	57.9±7.8	65.9±4.1	58.9±5.3
[a]AFP (%) stn	24.8±8.0	30.4±7.2	29.3±6.5	27.2±6.3	28.1±8.0	15.6±3.6	16.4±5.2	17.0±5.4	13.2±3.6	17.7±7.0
[a]TBZ (Ohms) sup	583±44	572±69	567±60	604±77	673±77*	443±43	447±67	437±51	445±48	494±50
[a]Systolic (mm Hg)	113.7±7.8	112.6±10.7	107.0±5.0	107.7±7.5	109.6±7.5	118.3±10.6	117.0±8.2	120.2±7.1	116.2±8.7	122.8±11.3
Diastolic (mm Hg)	63.6±4.7	69.4±10.4	69.8±6.8	67.8±7.1	66.8±7.8	66.2±6.5	67.6±8.4	71.0±6.8	67.0±5.3	68.6±7.6

Table entries are mean±SD.

A-A: African-American; stn: standing; sup: supine; BMI: body mass index; TBF: total body fat %; TBW: total body water %; AFP: arm fat % (average of both arms); TBZ: total body bioimpedance measured at 50 KHz, systolic and diastolic are supine blood pressures.

[a]Denotes an overall significant difference between females and males P<.001. There were no significant differences among races except for female TBZ (P = .005) attributable to the female Asian-Indian group having greater TBZ values than Caucasian, African-American and Hispanic groups (P<.05) but not greater than the Asian group.

of young adult skin water content is bound[8] although water percentage may decrease with aging.[9] In use, the device generates and transmits a very low power signal into a coaxial probe, acting as an open-ended transmission line, that is in contact with the skin (Figure 1). Touching the skin activates the device that measures skin or skin-to-fat TDC to effective depths ranging from 0.5 to 5.0 mm depending on probe size. A single measurement takes less than 10 seconds. Effective measurement depth is the depth at which the electric field decreases to 1/e of its surface field. We used probes with effective depths of 1.5 and 5.0 mm with outer diameters of 21 and 55 mm, respectively. Probes are calibrated against ethanol-water mixture concentrations of known dielectric constant values.[10]

2.3 | Measurement procedures

Tissue dielectric constant was measured with subjects' supine and arms resting at their sides. Prior to lying, they removed shoes and socks and stood on a scale to measure weight and body composition parameters via bioimpedance at a frequency of 50 KHz (InnerScan Body Composition Monitor, Tanita model BC558, The Competitive Edge, Vancouver, WA, USA). Parameters measured were percentages of TBW and TBF and AFP determined by device-specific algorithms. Subjects then lied supine whereupon electrodes were applied to measure supine body composition parameters using the BodyStat 1500 system (Body Stat Ltd, Isle of Man, UK). Supine parameters measured were TBW and TBF and TBZ. Measurements were initiated after 10 minutes of supine rest. During those 10 minutes, sites for subsequent TDC measurement were marked with a surgical pen. Sites (Figure 1) were (A) the subclavicular area at the second intercostal space midclavicularly (chest), (B) the anterior forearm 8 cm distal to the antecubital crease (forearm), and (C) 2.5 cm posterior and slightly inferior to the medial malleolus area (ankle). Bilateral TDC measurements were made in triplicate from chest to arm to ankle. Probes were placed to avoid visible surface veins in areas virtually free of heavy hair growth. Measurements of right and left sides were alternated until three values per side were obtained. Averages of these three were used to characterize TDC values of each side.

2.4 | Analysis

Tissue dielectric constant values among races were compared using a general linear model (GLM) with race as the between-subjects factor and measurement site (chest, arm, and ankle) as the repeated (within) factor for 1.5 mm TDC measurements and chest and arm as repeated measures for the 5.0 mm depth. Follow-up analysis to test for specific differences among races by site was based on ANOVA. In all analyses, each sex was considered separately. TDC values among sites for each gender group (N=50 each) were compared using a GLM with site as the repeated measure. Possible relationships between TDC values and body composition parameters were tested by regression analysis with TDC as the dependent variable and body composition parameters as independent predictors. For parameters measured by both body composition devices (TBW and TBF), the separately determined values were averaged for use in the regression analysis. SPSS v16 (IBM, New York, NY, USA) was the statistical analysis software.

3 | RESULTS

3.1 | TDC values by site

3.1.1 | Females

Results (Table 2) showed that for females (N=50) TDC values on each body side and their average differed significantly by site ($P<.001$). TDC values at 1.5 mm decreased from chest to forearm to ankle and decreased from chest to forearm at 5.0 mm depth. At 1.5 mm depth,

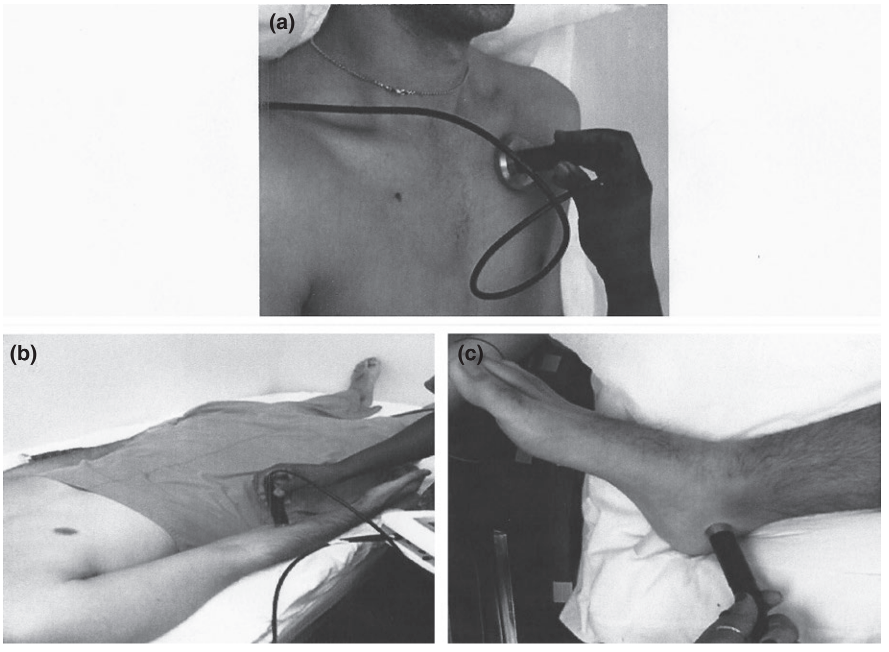

FIGURE 1 Sites of tissue dielectric constant (TDC) measurement. All TDC measurements were bilateral with subject supine; (A) Chest measurement using the 5.0 mm depth probe, (B) Forearm measurement using the 1.5 mm depth probe, (C) Ankle measurement with the 1.5 mm depth probe

TABLE 2 TDC values by site and side

	Female (N=50)				Male (N=50)				All (N=100)
	Dom	Non-Dom	Ratio	TDC_{AVG}	Dom	Non-Dom	Ratio	TDC_{AVG}	Ratio
TDC (1.5 mm depth)									
Chest	37.5±3.6[a]	37.0±3.5[a]	1.015±0.097	37.2±3.3[a]	36.8±6.8	37.1±6.1	0.995±0.094	37.0±6.3	1.005±0.096
Forearm	32.2±3.0[a]	32.4±2.7[a]	0.993±0.062	32.3±2.7[a]	37.0±3.8	37.0±4.4	1.002±0.058	37.0±3.9[b]	0.998±0.059
Ankle	27.2±4.0[a]	27.4±3.8[a]	0.999±0.134	27.3±3.6[a]	29.3±6.8[a]	28.9±7.1[a]	1.021±0.125	29.1±6.8[a]	1.010±0.125
TDC (5.0 mm depth)									
Chest	29.6±4.0[a]	28.4±3.5[a]	1.042±0.050	29.0±3.7[a]	32.3±7.1[a]	30.8±7.2[a]	1.057±0.080	31.6±7.0[a]	1.050±0.080
Forearm	25.4±4.6[a]	25.2±4.3[a]	0.993±0.062	25.3±4.3[a]	36.0±7.4[a]	34.9±7.2[a]	1.002±0.058	35.4±7.1[a,b]	1.020±0.080

Table entries are mean TDC values±SD for effective measurement depths of 1.5 and 5.0 mm at all measured sites.
Dom and Non-Dom are self-reported dominant and non-dominant hands. Ratio is the Dom to Non-Dom TDC ratio; TDC_{AVG} is the average of Dom and Non-Dom values.
[a]TDC values were significantly different (*P*<.001) among sites for corresponding depths. TDC values did not significantly differ between sides at any site or depth.
[b]TDC average values were significantly different (*P*<.001) between genders only at the forearm. The dominant hand was the right hand in 94% of females and 90% of males.

chest TDC values were 15% greater than at forearm and 36% greater than at ankle. At 5.0 mm depth, chest TDC values were also about 15% greater than at forearm.

3.1.2 | Males

For males (N=50), the pattern among sites was different from females. At 1.5 mm, chest and forearm TDC values were not significantly different but both were greater than ankle TDC values (*P*<.001) with both chest and forearm being 27% greater than at the ankle. But at 5.0 mm, chest TDC values were significantly (*P*<.001) less (10.7%) than at forearm.

3.2 | TDC values by side

Despite observed TDC differences among sites within each gender, there was no significant difference in TDC values between dominant and non-dominant side values for either gender. Further, TDC ratios, computed as dominant/non-dominant side values, were similar among sites, depths, races, and genders. For males measured to a depth of 1.5 mm, these ratios ranged from 0.998±0.059 at forearm to 1.010±0.125 at ankle and for a depth of 5.0 mm TDC inter-side ratios ranged between 1.050±0.080 at chest and 1.020±0.080 at forearm. A similar narrow range in this ratio among sites and depths is observed for females (Table 2). Uniformity in this inter-side ratio suggests a relative side-to-side symmetry in TDC values among normal, non-edematous conditions.

3.3 | TDC values by gender

Uniformity in inter-arm TDC ratios between genders was true although some differences in absolute TDC values between genders were found (Table 2). Significant gender differences in absolute TDC values were found only at forearm where female values were less than male values at depths of 1.5 mm (32.3±2.7 vs 37.0±3.9, *P*<.001) and 5.0 mm (25.3±4.3 vs 35.4±7.1, *P*<.001).

3.4 | TDC values by race

3.4.1 | Females

Similar to site dependence of TDC values found for the entire female group, there was significant site dependence for each race separately (Table 3) with TDC values decreasing from chest to forearm to ankle at 1.5 mm and from chest to forearm at 5.0 mm depth. ANOVA of TDC values among races at each site revealed an overall significant difference (*P*<.01) among races only at forearm. Follow-up analyses indicated the major difference was due to a significantly larger TDC value of the Caucasian group compared to the Asian-Indian group (*P*<.05). Although no other site or measurement depth showed an overall significant difference among the five racial groups, it appeared that TDC values of Asian and Asian-Indian groups tended to be lower than corresponding Caucasian values.

3.4.2 | Males

Tissue dielectric constant values showed a significant monotonic decrease from chest to arm to ankle (*P*<.001) for African-American, Asian, and Asian-Indians but no site-race dependence for Caucasians and Hispanics. ANOVA of TDC values among races at each site revealed an overall significant difference (*P*<.01) among races at chest for both measurement depths and at the ankle for a 1.5 mm depth. Follow-up analyses for these sites indicated the major difference at chest was due to a significantly larger TDC value of the African-American group with respect to both Caucasian and Asian-Indians (*P*<.01). Contrastingly, the major difference at ankle was due to a significantly larger TDC value of the Caucasian group with respect to all other groups (*P*<.01).

3.5 | Correlations among body composition parameters

Tissue dielectric constant values measured to 1.5 mm (TDC_{15}) and 5.0 mm (TDC_{50}) had significant positive correlations with TBW and

TABLE 3 TDC values by race

Site/depth	Female (N=50)					Male (N=50)				
	Caucasian	African-American	Hispanic	Asian	Asian-Indian	Caucasian	African-American	Hispanic	Asian	Asian-Indian
[a]CHEST/1.5 mm	37.9±2.5	36.8±3.4	37.9±3.7	37.8±3.3	35.9±3.6	34.1±6.7	42.6±3.8	35.6±5.7	38.9±2.8	33.6±7.1
[b]FOREARM/1.5 mm	33.9±2.8	32.8±3.5	33.2±1.4	31.1±2.3	30.4±1.2	36.9±2.7	39.8±4.2	36.5±5.2	36.6±3.3	35.1±2.8
[a,b]ANKLE/1.5 mm	30.4±4.1	25.8±3.2	27.8±3.1	25.3±3.3	27.0±2.1	36.5±4.6	27.7±7.3	32.2±3.9	26.0±4.7	23.2±3.8
[a]CHEST/5.0 mm	30.4±4.2	30.1±4.2	28.9±3.8	28.6±2.9	26.8±2.4	30.1±5.2	39.5±8.7	28.3±4.9	31.4±4.6±	28.5±5.4
FOREARM/5.0 mm	27.8±5.1	26.6±4.5	24.8±1.7	24.7±5.2	22.6±2.8	34.5±4.8	37.8±9.2	36.2±8.1	36.0±8.0	32.6±4.3

Table entries are mean TDC values±SD for effective measurement depths of 1.5 and 5.0 mm at all measured sites.
For females, TDC values at each depth differed among sites ($P<.001$) and decreased from chest to arm to ankle for each race.
For males, TDC values decreased significantly from chest to arm to ankle ($P<.001$) only for African-American, Asian, and Asian-Indians.
[a]Chest and ankle TDC values differed significantly among races ($P<.01$) for males.
[b]Forearm and ankle TDC values at 1.5 mm differed significantly among races ($P<.01$) for females.

significant negative correlations with TBF for both males and females at chest and forearm sites (Table 4). At the ankle, TDC values showed no significant correlation with either TBW or TBF. In the correlation analyses, TBW and TBF values used were the standing and supine averages. Standing and supine TBW were highly correlated (r=0.869) as were standing and supine TBF (r=0.911). ANOVA showed no significant difference in TBW or TBF among races.

For both genders, the strongest correlations were at 5.0 mm depth at the forearm, with slightly less, but still significant correlations at chest. Pearson correlation coefficients between forearm TDC_{50} and TBW and TBF for females were 0.576 and −0.569, respectively. Corresponding values for males were 0.595 and −0.624. Linear regression equations describing the association of forearm TDC values with TBW and TBF at 5.0 mm and associated data points for the full group (N=100) are shown in Figure 2. The overall correlation coefficient between TDC_{50} and TBW (Figure 2A) is 0.710 and for TBF (Figure 2B) is 0.773. This indicates that about 50-60% of the variation in TDC_{50} among subjects is explainable based on the observed TBW and TBF variations, respectively. Correlations between TDC values and either TBZ or AFP were always less than those between TBW or TBF.

4 | DISCUSSION

The main goal of this study was to characterize skin tissue water differences among five racial groups using TDC values at 300 MHz, the value of which largely depends on free and bound water within the measured volume.[5]This method is noninvasive, quick and has been used in prior studies to access skin or skin-to-fat tissue water.[11–13] To provide further information and a more generalized assessment, three anatomical sites were evaluated; chest, forearm, and ankle region. The forearm was chosen since it is a common skin evaluation sites and has been used for many TDC-related studies.[6,7,11,12] The ankle was chosen since it is a preferential area for tissue edema in several clinical conditions such as congestive heart failure and chronic venous insufficiency. It was thought that normal range values might serve as reference values if TDC measurements were adopted as screening measures in these or other conditions. The chest was chosen because it has not previously been characterized in any population. In addition, because of our interest in breast cancer treatment-related lymphedema (BCRL) and its associated chest and trunk edema, we believed that deviations from chest reference values herein obtained for this area might serve as a basis to judge early onset BCRL-related chest edema. The selection of the two TDC measurement depths was based on the following considerations. The 1.5 mm depth was chosen since the 1.5 mm depth measurement would include mostly skin (epidermis and dermis) and little if any hypodermis with its associated subcutaneous fat. The 5.0 mm depth was chosen so as to include as much of the skin-to-fat tissue as possible with the 5.0 mm probe being the largest depth probe available. Finally, the decision to analyze female and male data separately was based on reports indicating that there are intrinsic differences in male and female TDC values.[6,7]

TABLE 4 TDC relationship to total body water (TBW) and total body fat (TBF) percentages

Site	Depth	Independent	Regression Equation (N=100)
Forearm	5.0 mm	TBW	TDC_{F50}=0.935 TBW − 22.6, *r*=.732, *P*<.001
	5.0 mm	TBF	TDC_{F50}=−0.653 TBF + 44.8, *r*=−.761, *P*<.001
	1.5 mm	TBW	TDC_{F15}=0.363 TBW + 14.1, *r*=.539, *P*<.001
	1.5 mm	TBF	TDC_{F15}=−0.262 TBF + 40.5, *r*=−.581, *P*<.001
Chest	5.0 mm	TBW	TDC_{C50}=0.481 TBW + 3.0, *r*=.507, *P*<.001
	5.0 mm	TBF	TDC_{C50} = -0.298 TBF +36.9, *r*=−.468, *P*<.001
	1.5 mm	TBW	TDC_{C15}=0.258 TBW + 22.5, *r*=.314, *P*=.001
	1.5 mm	TBF	TDC_{C15} = -0.137 TBF +40.1, *r*=−.248, *P*=.01

TDC_{F50} and TDC_{F15} are TDC values measured at forearm to depths of 5.0 and 1.5 mm. TDC_{C50} and TDC_{C15} are TDC values measured on chest to depths of 5.0 and 1.5 mm. TBW and TBF are measured with subjects supine.

4.1 | Subject and group feature comparisons

Female and male groups were well matched with respect to age but differed with respect to almost all other parameters with males having a greater TBW, greater systolic blood pressure, greater BMI and lesser TBF and TBZ values. Contrastingly within genders, there was essentially no significant difference in these parameters among races.

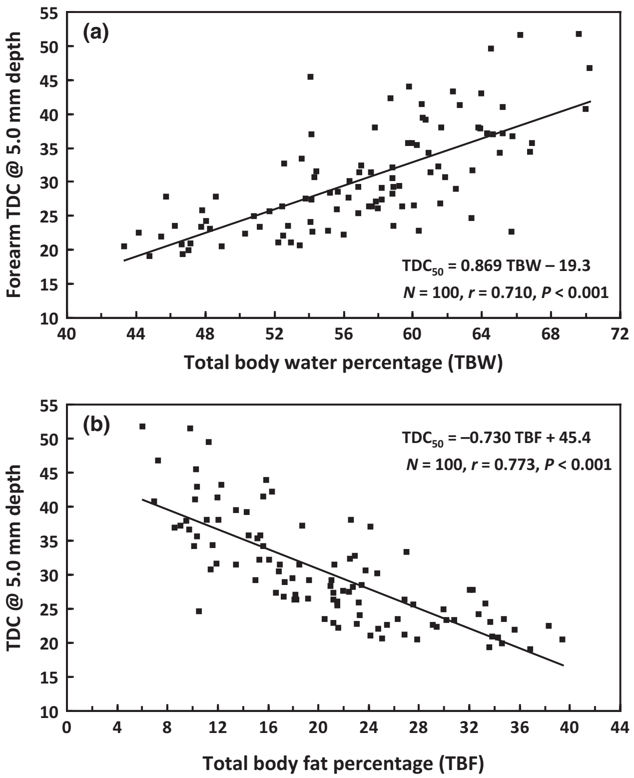

FIGURE 2 TDC dependence on body composition parameters. In (A) and (B) TDC was measured at the forearm to an effective depth of 5.0 mm. Total body water (TBW) and total body fat (TBF) are standing and supine averages. (A) TDC positive correlation with TBW, (B) TDC negative correlation with TBF. Linear regression equations are shown with corresponding Pearson correlation coefficients (*r*) and significance levels. Regressions indicate that 50-60% of TDC variation is explainable based on TBW or TBF variations among subjects

The one exception was a slightly greater TBZ value observed in the female Asian-Indian group.

4.2 | TDC values by gender, site, and side

4.2.1 | TDC by gender

Significant differences between genders were found only at forearm where TDC measurements at 1.5 and 5.0 mm depths were greater in males by 15% and 40%, respectively. These gender-related differences are consistent with previously reported data for mainly Caucasian females and males.[14] It is likely that greater male dermis thickness and lesser low water content fat of the forearm largely explain the greater TDC values previously measured[6] and herein measured.

4.2.2 | TDC by site

Significant differences in TDC values among sites for both genders emphasize the need to consider anatomical location when assessing absolute TDC values. For females, TDC values decreased monotonically from chest to forearm to ankle. The decrease from forearm to ankle at 1.5 mm is consistent with prior measurements[13] but no TDC data on the chest are available for comparison. For males, the ankle site also had the lowest TDC value but no significant difference between forearm and chest was found. As there have been no prior measurements in males on chest, this new finding further emphasizes that when doing anatomical site comparisons between genders due consideration of both gender and site is needed. The significantly lower TDC value at the ankle in both genders suggests that this skin region is among the lowest water content skin tissues evaluated.

An estimate of percentage water (PW%) contained within a measured tissue volume can be made based on the following equation[5,10]; PW%=100(TDC_m)/TDC_{100} in which TDC_m is the measured TDC value and TDC_{100} is the dielectric constant of 100% water at the skin temperature at which the measurement was made. The average ankle skin temperature is about 31°C[13] and the corresponding TDC_{100} value is about 76.[10] For ankle TDC values of 27.3 and 29.1 for females and males (Table 2), PW% is calculated to be respectively 35.9% and 38.3%. These values contrast with water percentages at the chest of

48.9% and 48.7%, respectively. These PW% are less than predicted for young dermis since values of 70% or more are reported.[8,9] The lower than predicted value is due to the inclusion of some amount of the low water content hypodermis fat that contributes to the net TDC measurement.

4.2.3 | TDC by side

Because there was no significant difference in TDC values between sides at any site or depth for either gender or by race, inter-side TDC ratios (dominant/non-dominant) could provide an index from which unilateral edema might be detected. An abnormally high ratio, indicating increased tissue water, could be defined as when the ratio exceeds the reference ratio (Table 2) by some multiple of the standard deviation (SD). The choice of which multiple depends on the degree of conservativeness desired. A similar approach has been applied for the detection of early onset arm lymphedema[11,12] with the current data extending this concept to other races and anatomical sites. According to this approach, deviations from normal reference values (ratios) that exceed a specified threshold are deemed to herald the onset of unilateral edema. Since the present study for the first time has demonstrated that these inter-side ratios do not vary among races, they can now be used accordingly. In practice, the thresholds are usually defined in terms of a multiple (2.0, 2.5, or 3.0) of the SD added to the overall mean of the normal reference group. Because in the present case females and males have been analyzed, there is an option to use gender-specific ratios or to use the composite ratio for each site and depth as tabulated in the last column of Table 2. As an example of using the latter approach, a unilateral forearm edema threshold based on 3.0 SD would be 0.998+3(0.059)=1.18. In applying this approach, it should be emphasized that the inter-side ratios herein determined apply strictly to the age groups evaluated and the extension to older persons should be done carefully. This proviso not withstanding, a forearm threshold of 1.18 is similar to a threshold ratio of 1.20 determined in a large group of older women.[15]

4.3 | TDC values by race

A new finding with respect to race-related differences in TDC values was the difference pattern. TDC values to 1.5 mm, which mainly includes epidermal and dermal properties, showed overall significant differences in females, but only at forearm with the largest difference being Caucasian values 10% greater than Asian-Indians. A similar difference pattern was observed at a depth of 5.0 mm where Caucasian TDC values were 23% greater. Such race-dependent differences must be taken into account when assessing skin conditions. Although an explanation for Caucasian-Asian differences herein observed is speculative, it is unlikely due to skin thickness differences which have been reported to be similar between Caucasian and Asian forearm skin.[4]

In contrast to females, the TDC difference pattern in males showed significant differences among races at chest and ankle but not at forearm. The main determinant for chest differences among races was due to high TDC values of the African-American group at 1.5 and 5.0 mm depths which exceeded Caucasian values by 25% and 31%, respectively. These higher values may be due to differences between African-American and Caucasian skin[2] and but the present results do not allow further understanding of the mechanisms.

4.4 | TDC values in relation to body composition parameters

Total body water and TBF were assessed standing and supine using two different devices. The reason for including both measurements was the unique characteristics of each device. The device used standing assessments allowed TBW and TBF to be measured and also a separate simultaneous assessment of AFP. The device used for supine assessments allowed TBW and TBF to be measured and also allowed an independent assessment of TBZ.

It was initially thought that the lower water content of fat would make forearm TDC values most dependent on AFP. However, regression analyses showed that the inverse correlation between TDC values and fat percentage was strongest when TBF was used. This suggests that segmental arm fat values are not needed as a covariate for TDC assessments.

Total body bioimpedance values were evaluated because it is a parameter that is directly measured most devices that evaluate body composition. Other parameters provided by such devices, including TBW and TBF, are based on specific algorithms that utilize TBZ in various ways. The results of the regression analyses showed that although TDC values were inversely correlated with TBZ with a correlation coefficient of −0.621 (P<.001) at the forearm for a depth of 5.0 mm, this was still less of a correlation than when TBF was used with an overall correlation value of −0.771. This finding further suggests that TBF as compared to the direct value of TBZ is the likely best parameter to be used as a covariate when such is needed. This is fortuitous because many body composition devices do not provide the TBZ parameter and instead only provide derived quantities such as TBF for use.

In conclusion, male and female differences in TDC values among races uncovered in the present study reflect differences in tissue properties that herein are shown to be site-dependent and non-uniform between genders. These outcomes set the stage for further research to probe deeper into the mechanisms or more specific skin features that account for the observed differences. These results also suggest the need for caution in any research study or clinical application in which TDC reference values are extrapolated from one race to another with respect to those anatomical sites herein demonstrated to be somewhat race-specific. Thus, TDC dependence on race of the type herein uncovered should be considered in assessing skin hydration comparisons that include different race or ethnic subjects. Finally, the findings demonstrate a clear correlation between measured TDC values and TBF and body water percentages, a fact that should be considered when comparing TDC values among patients, possibly as an important covariate. However, despite these differences, the inter-arm TDC ratio remains robust as a potential indicator of unilateral tissue water changes.

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