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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<th>Journal:</th>
<th><em>Skin Research and Technology</em></th>
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<td>Draft</td>
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<td>Manuscript Type:</td>
<td>Original Article</td>
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<td>Date Submitted by the Author:</td>
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<td>Complete List of Authors: Mayrovitz, Harvey; Nova Southeastern University, Physiology Mahtani, Sharien; Nova Southeastern University, College of Osteopathic Medicine Machaelos, Louis; Nova Southeastern University, College of Osteopathic Medicine Pitts, Eric; Nova Southeastern University, College of Osteopathic Medicine</td>
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<td>Keywords: skin dielectric constant, skin water, edema, skin ethnicity, lymphedema</td>
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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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Key words
Skin dielectric constant, skin water, edema, skin ethnicity, race-related skin differences

Running Title: Race-related differences in skin dielectric constant
ABSTRACT

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. One aim was to test this hypothesis. Also, since inter-side TDC ratios are used to assess edema and lymphedema, a second aim was to test if TDC ratios are race-dependent. A third aim was to determine the extent to which TDC depends on total body water (TBW) and fat (TBF).

Methods: TDC 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: TDC values decreased from chest to forearm to ankle (p<0.001) 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<0.01) with Asian and Asian-Indian values tending to be least. For males chest TDC values differed among races (p<0.01) mainly due to large African-American TDC values. For the composite group TDC was strongly (p<0.001) positively correlated with TBW and negatively correlated with TBF.

Conclusions: TDC 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.
INTRODUCTION

Racial or ethnic differences of some skin conditions has been the subject of several prior reports (1-3) with some findings of racial differences in skin features and pathophysiology contradictory (4, 5). Interest in characterizing skin property differences among racial groups is in part related to the concept that elucidation of such differences if present may facilitate more selective skin protection strategies and treatment approaches if and when treatment is needed. One such skin feature of interest in this regard is skin water content. Prior measurements of forearm skin stratum corneum (SC) dryness among four ethnic groups of women (African American, Caucasian, Chinese and Mexican) revealed no significant differences in dryness among young adults (6). Measurements of forearm skin thickness (epidermal + dermal) in these populations also revealed no significant racially-related differences (7). The absence of SC hydration however does not preclude the possibility of racially-related differences in water features within deeper skin structures. Thus the primary aim of this study was to investigate this possibility using measurements of the skin tissue dielectric constant (TDC) the values of which are largely dependent on water content of the tissue volume included in the measurement (8, 9). For this purpose TDC measurements were done to effective skin depths of 1.5 mm and 5.0 mm at three anatomical sites 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 known differences between genders (10, 11) each group included 10 males and 10 females. Further, to test for potential linkages of skin water to body composition parameters, total body water and total body fat were also evaluated in all subjects.
METHODS

Subjects

A total of 100 young adults participated in this research study after each had the study
explained to them and they voluntarily signed a consent form that was previously approved by
the university’s institutional review board. Recruitment was designed to achieve 10 male and
10 female young adult subjects in each of the following self-reported racial groups; African-
American, Asian, Asian-Indian, Caucasian and Hispanic. Entry requirements were that 1) they
were between 18 and 39 years, 2) they had no known dermatologic condition, 3) they had not
had any major trauma or surgery to the upper or lower extremities and 4) they were not taking
any medications. All participants were advised to not apply body lotions or creams to parts of
the body to be measured on the day of the measurement session. Each participant’s body
composition parameters, that included total body fat percentage (TBF) and total body water
percentages (TBW), were measured in a standing and supine position as described
subsequently. In addition each subject’s total body bioimpedance (TBZ) was measured supine
and their arm fat percentage (AFP) was measured standing. Supine blood pressures were taken
with a mercury sphygmomanometer. The major features of these five groups are shown for
females and males in Table 1. As a group, males vs. females had significantly (p<0.001) greater
systolic blood pressure, height, weight, BMI and total body water percentage and significantly
(p<0.001) less total body fat percentage and bioimpedance values. Five males (10%) and 3
females (6%) declared they were left handed whereas the rest declared their dominant hand
was their right hand. Two male left hander’s were Caucasian, two were African-American and
one was Hispanic. For females, one left hander was African-American and two were Asian.
**Tissue Dielectric Constant (TDC) 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 in this study (MoistureMeterD, MMD, Delfin Technologies, Kuoppio Finland) measures TDC at a frequency of 300 MHz and is therefore sensitive to both free and bound water (12). Measuring of the bound water component is important since 75-90% of young adult skin water content is of the bound form (13) although the percentage of water may decrease with aging (14). In use the device generates and transmits a very low power signal into a coaxial probe that is in contact with the skin (Figure 1). The probe acts as an open-ended coaxial transmission line (15). Touching the skin activates the device that measures skin or skin-to-fat TDC to effective depths ranging from 0.5 mm to 5.0 mm depending on the probe size used. A single measurement takes less than 10 seconds.

The operating principle depends on the fact that that part of the 300 MHz signal transmitted from the probe to the skin is absorbed, mainly by tissue water, and part is reflected back to a control unit. From this returning signal the complex reflection coefficient is automatically calculated (8, 16) and the dielectric constant is determined (17, 18). Effective measurement depth is defined as the depth at which the 300 MHz electric field decreases to 1/e of its surface field. In this study probes with effective depths of 1.5 and 5.0 mm with outer diameters of 21 mm and 55 mm respectively were used (Figure 1). Reflections of the transmitted signal depend on the complex permittivity of the tissue which in turn depend on signal frequency and the dielectric constant (the real part of the complex permittivity) and the
conductivity of the tissue with which the probe is in contact. At 300 MHz the contribution of conductivity to the overall value of the permittivity is small and the TDC is mainly determined by water molecules (free and bound). More details including validation and repeatability data are described in the literature (9, 19, 20). Each probe is calibrated against ethanol-water mixture concentrations each of known dielectric constant (19).

**Measurement Procedures**

TDC was measured with subjects’ supine and arms resting palms up at their sides (Figure 1). Prior to lying, they removed their shoes and socks and stood on a scale to measure their weight and body composition parameters via bioimpedance measurements at a frequency of 50 KHz (InnerScan Body Composition Monitor, Tanita model BC558). They stood barefoot on the scale for about 15 seconds while they gripped an electrode in each hand (Figure 2A). Parameters measured were percentages of total body water (TBW) and total body fat (TBF) and arm fat percentages (AFP) determined by specific algorithms within the device. Subjects then lied supine on a padded and electrically insulated examination table whereupon electrodes were applied for the measurement of supine body composition parameters (Figure 2B) using the BodyStat 1500 system (Body Stat Ltd, Isle of Man, UK). Parameters measured in the supine position were TBW and TBF and additionally total body bioimpedance (TBZ). The supine body composition measurements were initiated after 10 minutes of supine rest. During those 10 minutes the sites for subsequent TDC measurement were marked with a surgical pen. The sites (shown in figure 1) were A) the subclavicular area at the 2nd 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). TDC measurements were
bilateral in the order of chest to arm to ankle with each site measured in triplicate. Probes were placed to avoid visible surface veins in areas virtually free of heavy hair growth. Measurements between right and left sides were alternated until three values per side were obtained. The average of the three measurements was used to characterize the TDC value of each side. This procedure was done for each of the two effective measurement depths.

**Analysis**

TDC 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 analysis of variance (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 using regression analysis with TDC values as the dependent variable and measured body composition parameters as independent predictors. For the 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, USA) was used as the statistical analysis software.
RESULTS

**TDC values by site (Table 2)**

**Females:** Results (Table 2) showed that for females (N=50) TDC values on each body side and their average differed significantly by site (p<0.001). 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 chest TDC values were 15% greater than at forearm and 36% greater than at ankle. At 5.0 mm, chest TDC values were also about 15% greater than at forearm.

**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<0.001) with both chest and forearm being 27% greater than at the ankle. But, at 5.0 mm chest TDC values were significantly (p<0.001) less (10.7%) than at forearm.

**TDC values by side (Table 2)**

Despite the 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 the forearm to 1.010 ± 0.125 at the ankle and for a depth of 5.0 mm TDC inter-side ratios ranged between 1.050 ± 0.080 at the chest and 1.020 ± 0.080 at the forearm. A similar small range in this ratio among sites and depths is observed for females (Table 2). The uniformity in this inter-side ratio suggests a relative side-to-side symmetry in TDC values among normal, non-edematous conditions.
**TDC values by gender (Table 2)**

The uniformity in these inter-arm TDC ratios between genders was true despite the fact that some differences in absolute TDC values between genders were found. Significant gender differences in absolute TDC values were found only at the 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<0.001) and 5.0 mm (25.3 ± 4.3 vs. 35.4 ± 7.1, p<0.001).

**TDC values by race (Table 3)**

**Females:** Similar to the 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. Analysis of variations in TDC values among races at each site revealed an overall significant difference (p<0.01) among races only at the forearm at measurement depths of 1.5 mm and 5.0 mm. Follow-up analyses indicated the dominant difference was attributable to a significantly larger TDC value of the Caucasian group in comparison to the Asian-Indian group (p<0.05). Although none of the other sites or measurement depths revealed an overall significant difference among the five racial groups, it appeared that TDC values of the Asian and Asian-Indian groups tended to be lower than corresponding Caucasian values.

**Males:** TDC values showed a significant monotonic decrease from chest to arm to ankle (p<0.001) for African American, Asian and Asian-Indians but had no site-race dependence for Caucasians and Hispanics. Analysis of variations in TDC values among races at each site revealed an overall significant difference (p<0.01) among races at the chest for measurement depths of 1.5 mm and 5.0 mm and at the ankle for a 1.5 mm depth. Follow-up analyses for these sites
The dominant difference at the chest was attributable to the significantly larger TDC value of the African-American group with respect to both Caucasian and Asian-Indians (p<0.01). Contrastingly, the dominant difference at the ankle was attributable to the significantly larger TDC value of the Caucasian group with respect to all other groups (p<0.01).

Correlations among body composition parameters (Table 4)

TDC values measured to at 1.5 mm (TDC15) and 5.0 mm (TDC50) had significant positive correlations with total body water percentage (TBW) and significant negative correlations with total body fat percentage (TBF) for both males and females at chest and forearm sites. At the ankle, TDC values showed no significant correlation with either TBW or TBF. In these correlation analyses, TBW and TBF values used were the average of the values obtained standing and supine.

Analysis of variance 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 Pearson correlation coefficients between forearm TDC50 and TBW and TBF for females were 0.576 and -0.569 respectively, and corresponding values for males were 0.595 and -0.624. Linear regression equations describing the association between forearm TDC and TBW and TBF for females were 0.576 and -0.59 respectively, corresponding to the forearm and supine TBW and TBF were highly correlated (r = 0.869) as were standing and supine TBF (r=0.911). The overall correlation coefficient between TDC50 and TBW (figure 3A) is 0.710 and for TBF (figure 3B) is 0.773. This indicates that about 50%-60% of the variation in TDC50 among subjects is explainable based on the observed TBW and TBF.

Correlations between TDC values and either total body bioimpedance (TBZ) or arm fat percentage (AFP) were always less than those between TBW or TBF. For both genders the strongest correlations were at 5.0 mm depth at the forearm, with Pearson correlation coefficients between forearm TDC50 and TBW and TBF for females were 0.576 and -0.59 respectively, corresponding to the forearm and supine TBW and TBF were highly correlated (r = 0.869) as were standing and supine TBF (r=0.911). The overall correlation coefficient between TDC50 and TBW (figure 3A) is 0.710 and for TBF (figure 3B) is 0.773. This indicates that about 50%-60% of the variation in TDC50 among subjects is explainable based on the observed TBW and TBF.

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DISCUSSION

A primary aim of the present study was to investigate and characterize the extent of skin tissue water differences among five different racial groups. The principal method chosen for these evaluations was the measurement of the skin tissue dielectric constant at 300 MHz, the value of which is largely dependent on the sum of free and bound water within the measured volume (8, 16, 18, 21). This method is noninvasive, quick and has been used in many prior studies in which the assessment of skin or skin-to-fat tissue water was of interest (22-36).

To help provide further information and a more generalized assessment three anatomical sites were chosen for evaluation; chest, forearm and ankle region. The forearm was chosen since it is a very common site for skin evaluations and because it has also been used for a variety of TDC-related studies, mostly in Caucasian females (26, 34, 35, 37, 38) with some assessments in Caucasian males (10, 11, 39). The ankle site was chosen since it is a preferential area for tissue edema in several clinical conditions such as congestive heart failure and chronic venous insufficiency. In this regard it was thought that normal range values, as would be developed in the present study, might serve as reference values if TDC measurements were adopted as screening measures in these or other conditions. The chest site was chosen because it is an anatomic area that 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 in some cases, 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 effective measurement depths, 1.5 mm and 5.0 mm for the TDC measurements was based on the following considerations. The 1.5 mm depth
was chosen based on data for skin thickness (7, 40, 41) that indicates that 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 (10, 11).

**Subject and Group Feature Comparisons**

The female and male groups were well matched with respect to age but differed with
respect to almost all other measured parameters with males having a greater total body water
percentage, a greater systolic blood pressure, a greater body mass index and a lesser total body
fat percentage and overall bioimpedance value. Contrastingly within genders there was
essentially no significant difference in these parameters among races. The one exception was a
slightly greater total bioimpedance value observed in the female Asian-Indian group.

**TDC Values by Gender, Site and Side**

**TDC by Gender:** Considering each gender group, significant differences between genders were
found only at the forearm where TDC measurements at both 1.5 mm and 5.0 mm measurement
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 (42). 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 (10) and herein measured. It is important
to note that absolute TDC values apply to the age group under which the measurements were
made since differences attributable to age have been reported (43).
TDC by Site: Significant differences in TDC values among sites that were demonstrated for both genders emphasize the need to consider anatomical location when assessing absolute TDC values among groups. For females, there was a monotonic decrease in TDC values from chest to forearm to ankle. The decrease from forearm to ankle at a measurement depth of 1.5 mm is consistent with prior measurements in a group of 32 women (29) but no TDC data on the chest is 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 the chest this new finding further emphasizes that when doing anatomical site comparisons between genders due consideration of both gender and site are 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 (9, 19); \[ PW\% = \frac{100(TDC_m)}{TDC_{100}} \] 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. Under the measuring conditions similar to used in the present study average ankle skin temperatures is about 31°C (29) corresponding to a value for \( TDC_{100} \) of about 76 (19). For average 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. All of these PW% are less than might be predicted for dermis of young individuals since values of 70% or more have been reported (13, 14). 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.
TDC by Side: Because there was no significant difference in absolute TDC values between sides at any site or depth for either gender or by race, the inter-side ratio of TDC values (dominant / non-dominant) could provide an index from which unilateral edema might be detected. For that purpose one could define an abnormally high ratio indicating an increase in tissue water when the ratio exceeds the reference ratio (table 2) by some multiple of the standard deviation (SD) with the choice of which multiple to use depending on the degree of conservativeness desired. A similar approach has been applied for the possible detection of early onset lymphedema of the arm in mainly Caucasian females (34, 37, 38, 44) 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 (26).
**TDC values by race**

A major new finding specifically with respect to race-related differences in TDC values was the nature of the differences in TDC values among the five races studied. TDC measurements made to a depth of 1.5 mm, which mainly includes epidermal and dermal properties, showed overall significant differences in females, but only at the forearm. At this site the largest difference was between Caucasians and Asian-Indians with Caucasian values 10% greater. A similar difference pattern was observed at a measurement depth of 5.0 mm where the Caucasian TDC value was 23% greater. Because the forearm is often a site measured in women in conjunction with a variety of skin-related issues, it seems clear from the present findings that race-dependent differences must be taken into account. 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 (7, 40) although ethnic-related differences in skin structural components may be involved as reported for Caucasian and African-American skin (45).

In contrast to the pattern of racial differences in TDC in females, the pattern in males revealed significant differences among races at chest and ankle but not at forearm. The main determinant for chest differences among races was attributable 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 one or more previously described differences between African-American and Caucasian skin including an increased number of apocrine and apoecrine glands compared to Caucasian skin (4) and other differences (2). However the present results do not allow further understanding of the involved mechanisms.
TDC Values in Relation to Body Composition Parameters

Total body water percentages (TBW) and total body fat percentages (TBF) were assessed with subjects standing and supine using two different devices. The reason for including both measurements was the unique characteristics of each device. The device used for the assessment in a standing position allowed for the determination of the primary parameters (TBW and TBF) as well as a separate simultaneous additional assessment of arm fat percentage (AFP). The device used for the assessment in a supine position allowed for the determination of the primary parameters as well as an independent assessment of the total body bioimpedance value (TBZ), a measurement not available in the other device. These two additional parameters (AFP and TBZ) were of interest and were evaluated because of the potentially useful information they provide.

In the case of AFP, it was initially thought that because of the lower water content of fat as compared to skin and muscle, that if there were a body fat parameter upon which forearm TDC values would be most dependent it would most likely be the arm fat percentage. However the regression analyses showed that the inverse correlation between TDC values and fat percentage was strongest when total body fat was used. This would suggest that when body composition parameters are to be used as covariates for TDC assessment the use of segmental values such as for the arm are not needed. Since segmental body fat assessment devices that evaluate limbs and torso separately are not as widespread as those that do total body fat this suggests a much wider selection is possible.

The reason for examining TBZ as a parameter was because it is the direct measurement that is made by 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<0.001) 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 as shown in figure 3. 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 total body fat 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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Table 1. Characteristics of Subjects: 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. § Denotes an overall significant difference between females and males p<0.001.

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<table>
<thead>
<tr>
<th></th>
<th>Female (N =50)</th>
<th>Male (N =50)</th>
<th>ALL (N=100)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TDC (1.5 mm Depth)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dom</td>
<td>Non-Dom</td>
<td>Ratio</td>
</tr>
<tr>
<td>Chest</td>
<td>37.5±3.6(\dag)</td>
<td>37.0±3.5(\dag)</td>
<td>1.015±0.097</td>
</tr>
<tr>
<td>Forearm</td>
<td>32.2±3.0(\dag)</td>
<td>32.4±2.7(\dag)</td>
<td>0.993±0.062</td>
</tr>
<tr>
<td>Ankle</td>
<td>27.2±4.0(\dag)</td>
<td>27.4±3.8(\dag)</td>
<td>0.999±0.134</td>
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<tr>
<td></td>
<td>TDC (5.0 mm Depth)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Dom</td>
<td>Non-Dom</td>
<td>Ratio</td>
</tr>
<tr>
<td>Chest</td>
<td>29.6±4.0(\dag)</td>
<td>28.4±3.5(\dag)</td>
<td>1.042±0.050</td>
</tr>
<tr>
<td>Forearm</td>
<td>25.4±4.6(\dag)</td>
<td>25.2±4.3(\dag)</td>
<td>0.993±0.062</td>
</tr>
</tbody>
</table>

Table 2. TDC values by site and side

Table entries are mean TDC values ± SD for effective measurement depths of 1.5 mm 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. \(\dag\)TDC values were significantly different (p<0.001) among sites for corresponding depths. TDC values did not significantly differ between sides at any site or depth. \(\dagger\)TDC average values were significantly different (p<0.001) between genders only at the forearm. The dominant hand was the right hand in 94% of females and 90% of males.
<table>
<thead>
<tr>
<th>SITE / DEPTH</th>
<th>FEMALE (N =50)</th>
<th>MALE (N =50)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+CHEST / 1.5 mm</td>
<td>37.9±2.5</td>
<td>36.8±3.4</td>
</tr>
<tr>
<td>*FOREARM / 1.5 mm</td>
<td>33.9±2.8</td>
<td>32.8±3.5</td>
</tr>
<tr>
<td>*,†ANKLE / 1.5 mm</td>
<td>30.4±4.1</td>
<td>25.8±3.2</td>
</tr>
<tr>
<td>†CHEST / 5.0 mm</td>
<td>30.4±4.2</td>
<td>30.1±4.2</td>
</tr>
<tr>
<td>FOREARM / 5.0 mm</td>
<td>27.8±5.1</td>
<td>26.6±4.5</td>
</tr>
</tbody>
</table>

Table 3. TDC Values by Race

Table entries are mean TDC values ± SD for effective measurement depths of 1.5 mm and 5.0 mm at all measured sites.

For females, TDC values at each depth differed among sites (p<0.001) and decreased from chest to arm to ankle for each race.

*Forearm and ankle TDC values at 1.5 mm differed significantly among races (p<0.01) for females.

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FIGURE LEGENDS

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.

Figure 2. Body Composition Measurements

Body composition parameters were measured with subject standing (A) and supine (B). Both measurements included total body water percentage and total body fat percentage. The supine measurement included the absolute whole body impedance measured at a frequency of 50 KHz. The standing measurement included arm fat percentage.

Figure 3. 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.
Figure 1
Figure 2
Figure 3A

A

![Graph showing the relationship between Forearm TDC @ 5.0 mm depth and Total Body Water Percentage (TBW). The equation is TDC₅₀ = 0.869 TBW - 19.3. N=100, r=0.710, p < 0.001.](image)
Figure 3B

TDC<sub>50</sub> = -0.730 TBF + 45.4

N=100, r = 0.773, p < 0.001
<table>
<thead>
<tr>
<th></th>
<th>FEMALE (N =50)</th>
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</tr>
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<tbody>
<tr>
<td></td>
<td>Caucasian</td>
<td>A-A</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>26.7±5.0</td>
<td>27.2±2.7</td>
</tr>
<tr>
<td>§Height (in)</td>
<td>65.6±3.5</td>
<td>65.9±3.9</td>
</tr>
<tr>
<td>§BMI (Kg/m²)</td>
<td>21.7±3.1</td>
<td>24.3±3.6</td>
</tr>
<tr>
<td>§TBF (%) stn</td>
<td>25.6±6.9</td>
<td>31.1±7.5</td>
</tr>
<tr>
<td>§TBF (%) sup</td>
<td>21.5±6.2</td>
<td>27.1±6.5</td>
</tr>
<tr>
<td>§TBW (%) stn</td>
<td>55.0±4.6</td>
<td>51.2±5.1</td>
</tr>
<tr>
<td>§TBW (%) sup</td>
<td>56.6±7.9</td>
<td>51.3±5.9</td>
</tr>
<tr>
<td>§AFP (%) stn</td>
<td>24.8±8.0</td>
<td>30.4±7.2</td>
</tr>
<tr>
<td>§TBZ (Ohms) sup</td>
<td>583±44</td>
<td>572±69</td>
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<td>§Systolic (mmHg)</td>
<td>113.7±7.8</td>
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</tr>
<tr>
<td>Diastolic (mmHg)</td>
<td>63.6±4.7</td>
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254x190mm (96 x 96 DPI)
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