IMPACT OF BODY FAT AND OBESITY ON TISSUE DIELECTRIC CONSTANT (TDC) AS A METHOD TO ASSESS BREAST CANCER TREATMENT-RELATED LYMPHEDEMA (BCRL)

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ABSTRACT

Obesity is linked to the risk of breast cancer and treatment-related lymphedema (BCRL). Thus, knowledge of how obesity, or more specifically total body fat percentage (TBF) and body mass index (BMI), affect measurements that are used to detect or track lymphedema is clinically important. Tissue dielectric constant (TDC) is one measure used to help characterize lymphedema features, detect its presence, and assess treatment-related changes. The goal of this research was to determine the extent to which TDC values depend on TBF and BMI. TDC was measured on both forearms (2.5mm depth) in 250 women (18-72 years) along with TBF (impedance, 50KHz). TBF was 12.2%-54.4% (median=29.3%) and BMI was 14.7Kg/m2-44.3 Kg/m2 (median=22.6 Kg/m2). TDC values and interarm ratios were compared between subgroups that had TBF and BMI values in lower vs. upper quartiles. Subjects in the upper quartile had slightly lower TDC values (1.3 TDC units, p <0.01) that was at most a 5% differential. Contrastingly, TDC interarm ratios were not dependent on TBF or BMI levels. These findings suggest that when tracking lymphedema changes using the TDC method, treatment-related or temporal changes in a woman’s TBF or BMI are unlikely to significantly impact TDC values or their inter-arm ratios.

Keywords: lymphedema, body fat, body mass index, breast cancer, tissue dielectric constant tracking lymphedema, measuring lymphedema

Obesity is linked to breast cancer risk (1-4) and obesity is also linked to the risk of treatment-related lymphedema (BCRL) (5-7). Because of these associations, knowledge as to how obesity, or more generally total body fat percentage (TBF) and body mass index (BMI), affects measures that are used to detect or track lymphedema is of clinical importance. One such measure is the tissue dielectric constant (TDC) that is increasingly used as a tool to help characterize lymphedema features (8,9), detect its presence (10,11), and assess treatment-related changes (12-16). Furthermore, such measurements show practicality in a range of conditions (17-20) and are used to study applied aspects of skin physiology (21-23).

The underlying physics and principle of operation of this technology are well described in the literature (24,25) but there has been no systematic study of the potential impact of TBF or BMI on TDC values and especially how changes in either of these during a course of treatment or simply over time may effect TDC. Because local TDC values are directly related to water content of tissue, a greater relative contribution of low water content
tissues such as fat suggest that patients with higher TBF would have TDC values that are lower than those measured in patients with less TBF. Further, if there were such an inverse relationship between TDC and TBF then when persons under treatment either gain or lose TBF, sequential TDC values used to track lymphedema changes would be confounded by the TBF dependency in an unknown way. Thus, our specific aim was to investigate this issue by determining if there is a significant dependency of absolute TDC values or their interarm ratios on ranges of TBF and BMI in women of a wide age range.

**METHODS**

**Participants**

A total of 250 adult females participated as volunteer subjects after signing an approved Nova Southeastern University (NSU) institutional review board informed consent. Subjects were recruited from medical students, staff, university faculty, and others via word of mouth. To be included subjects needed to: 1) be 18 years or older, 2) have no history of arm trauma that resulted in sustained swelling, 3) be free of any skin condition or open wound on their arm, 4) not be taking any medication known to impact edema, and 5) not have diabetes. Ages of participants ranged from 18 to 72 years with a mean ± SD age of 29.8 ± 11.7 years and a median of 25.0 years. Body mass index (BMI) for the group ranged from 14.7 to 44.3 Kg/m² with a mean ± SD of 23.9 ± 5.0 Kg/m² and a median value of 22.6 Kg/m². Using the standard BMI classification, the percentage of subjects that were obese was 12%, overweight was 19.6%, normal weight was 69%, and underweight was 8.4%.

**Measurements**

TDC values were measured in triplicate on both forearms while subjects were resting supine with arms at their sides with palms up. The measurement site was on the anterior forearm five cm distal to the antecubital fossa. This is a frequently used clinically-related TDC measuring site (9,11,23,26,27). All TDC measurements were made with the MoistureMeterD (Delfin, Kuopio, Finland) using a probe whose measurement includes tissue to an effective depth of 2.5 mm below the skin surface. This probe depth is the most frequently used in studies employing this technology. Temperature and relative humidity of the room in which measurements were done was 22.9 ± 1.6°C and 54.0 ± 6.1% across all experiments. Skin temperature, averaged between dominant and nondominant arms, measured with an infrared thermometer (Exergen, Watertown Main, Model DX501-RS), was 32.1 ± 1.2°C.

The physics and basic operating principles of TDC measurements are well described in the literature (24,28,29). Briefly, the probe acts as an open-ended coaxial transmission line through which a 300-MHz signal is transmitted. Reflected energy depends on the tissue’s complex permittivity, that depends on the signal frequency and tissue dielectric constant (real part of the permittivity). At 300 MHz, conductance contributes little to permittivity, so TDC is mainly determined by water molecules (free and bound). As a reference, distilled water at 32°C would have a dielectric constant of about 76.

After TDC measurements, subjects sat up for 5 minutes, removed their footwear and stood on a scale for about 10 seconds while gripping a handle-electrode to measure weight and body composition via bioimpedance at 50 KHz (InnerScan Body Composition Monitor, Tanita model BC558). Parameters measured were total body fat percentages (TBF), total body water percentages (TBW) and dominant and nondominant arm fat percentages (AFP). Values were determined by device proprietary algorithms based on the measured impedances.
Analyses

The distribution of each parameter was tested for Normality using the Shapiro-Wilk Test (SWT). Results showed that the distribution of forearm TDC values was not significantly different from Normal (SWT significance >0.2) for dominant, nondominant arms or their combined values. The combined TDC distribution shown in Fig. 1A. In contrast, TBF, TBW, and AFP were rejected as being Normally distributed (SWT significances 0.001 to .003). The TBF distribution is shown in Fig. 1B. Thus, subsequent tests for differences in dominant-to-nondominant sides for TDC values were based on paired t-tests whereas all other comparisons were based on the nonparametric Wilcoxon test. With all tests a p-value <0.05 was taken as a statistically significant difference. To estimate effects of TBF on TDC, subjects with TBF values below and above the TBF median were first compared and then subjects with TBF values in the upper and lower quartiles were compared with nonparametric Mann-Whitney U tests.

RESULTS

Fat and TDC Values

Figure 1 demonstrates the distribution of forearm absolute TDC values and also the total body fat percentage (TBF) distribution. The TDC values for each subject in Fig. 1 are the average of dominant and nondominant side TDC values. Averages, medians, and standard deviations corresponding to all parameters measured are reported in Table 1.

Arm fat percentage (AFP) of the nondominant arm was slightly greater than for the dominant arm (p<0.001). For the full group, the AFP of the nondominant arm was 0.67 ± 1.63 greater than the dominant arm. This corresponds to a 2.2% greater fat percentage. When considering subjects within lower and upper quartiles of TBF, the percentage difference in fat between dominant and nondominant arms was greater for the lower quartile group. Thus, for those subjects with TBF in the lowest quartile (TBF <24.1%) the nondominant arm AFP was 1.13 ± 1.63 greater than the dominant arm. This corresponds to a 5.2% greater fat percentage. Contrasting, for those subjects with TBF in the upper quartile (TBF >35.6%), the nondominant AFP was only 1.1% greater than for the dominant arm. Tissue dielectric constant (TDC) values did not differ between dominant and nondominant arms with an overall dominant/nondominant TDC ratio of 1.006 ± 0.070.
Fat-TDC Effects

Grouping of subjects (125 per subgroup) according to whether their total body fat percentage was below or above the overall group median (29.3%, n=250) allowed for an initial group comparison of associated TDC values. These findings were further distilled by comparing subject’s TDC values between those with total body fat percentages in the lower quartile (12.2% to 24.1%, n=63) with those who had total body fat percentages in the upper quartile (35.6% to 54.4%, n=63). A similar sub-group comparison was done based on the median BMI (22.6 Kg/m²) and its lower quartile range (14.7Kg/m² to 20.6Kg/m², n=63) versus its upper quartile range (26.2Kg/m² to 44.3 Kg/m², n=63). These results, as reported in Table 2, show a small (0.88 TDC units) statistically significant (p=0.006) lower TDC value for subjects whose TBF was above the median. The comparison between lower and upper quartiles of TBF also showed a lesser value for those in the upper quartile (1.3 TDC units, p=0.007). This difference corresponds to an approximately 3.3% lesser TDC value for persons above the median TBF and about 5% lesser TDC values for persons in the upper quartile of TBF. Similar comparisons using the BMI as a cut-point revealed no significant differences in absolute TDC values between persons with total body fat percentages that were low vs. high.

DISCUSSION

The principal goal of the present research was to assess the degree to which body fat levels and body mass index might affect measured tissue dielectric constant values because such TDC measurements are used to detect, access, and track breast cancer treatment-related lymphedema (BCRL). The focus on the possible role of fat levels and BMI influencing such measurements derives from the fact that BMI and obesity are disproportionately present in women who develop breast cancer and subsequently lymphedema. Further, during treatment for acquired lymphedema or evaluations made at various times post-surgery, changes in TBF or BMI may occur the impact of which on TDC measures was not known. To supply basic information bearing on this issue a wide range of total body fat percentages (TBF) was determined in a large number of women (250) who were free of lymphedema.

The choice to evaluate healthy women rather than women with BCRL was based on two main considerations. Firstly, it was important to have a sufficiently large range of TBF values to provide suitable comparison ranges. Herein a three-fold range

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**TABLE 1**

<table>
<thead>
<tr>
<th>FAT%</th>
<th>DOM</th>
<th>NDOM</th>
<th>ARMS COMBINED</th>
<th>TOTAL BODY FAT (%)</th>
<th>DOM</th>
<th>NDOM</th>
<th>ARMS COMBINED</th>
<th>DOM/NDOM RATIO</th>
<th>TOTAL BODY WATER (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVG</td>
<td>31.0</td>
<td>31.7**</td>
<td>31.3</td>
<td>30.4</td>
<td>26.1</td>
<td>26.0</td>
<td>26.1</td>
<td>1.007</td>
<td>51.4</td>
</tr>
<tr>
<td>MEDIAN</td>
<td>29.8</td>
<td>30.6</td>
<td>30.3</td>
<td>29.3</td>
<td>25.9</td>
<td>25.8</td>
<td>26.0</td>
<td>1.006</td>
<td>52.1</td>
</tr>
<tr>
<td>SD</td>
<td>8.7</td>
<td>8.4</td>
<td>8.5</td>
<td>8.3</td>
<td>3.0</td>
<td>2.8</td>
<td>2.8</td>
<td>0.070</td>
<td>5.9</td>
</tr>
</tbody>
</table>

Table entries are for 250 female subjects. DOM and NDOM are dominant and nondominant arms respectively. ARMS COMBINED considers both DOM and NDOM and includes 500 arm measurements. ** denotes p < 0.001 vs the DOM ARM.
(14.7 Kg/m² to 44.3 Kg/m²) has been incorporated and evaluated. Secondly, it was important to be able to assess the dependence of interarm TDC ratios on TBF because this ratio is widely used to assess unilateral lymphedema. Such an assessment would not be possible if BCRL was already present.

One new finding demonstrated in this report is that absolute TDC values, measured to an effective depth of 2.5 mm on the anterior forearm, are slightly reduced in persons with higher TBF levels. Since similar measurement depths and anatomical sites are often used for assessments (30), this is a relevant finding. The magnitude of the effect is relatively small, being 1.3 TDC units at most or about 5% less than that measured in women with low-TBF. So, this difference is unlikely to be clinically important when tracking lymphedema changes in patients since there would need to be very large changes in a woman’s TBF for such TBC changes to meaningfully affect sequential TDC measurements. However, there may be situations in which absolute TDC values are being compared between groups where the TBF effect may need to be considered. The fact that TDC values are not significantly affected by BMI but are (slightly) affected by TBF likely indicates that there is more dependence on body composition than simply weight and height.

A second new finding demonstrated that inter-arm TDC ratios were essentially independent of a woman’s TBF. To some extent this may have been an outcome that could have been predicted since it could have been hypothesized that both arms would have similar fat levels thereby rendering the ratio non-affected. However, as shown herein, there is a statistically significant difference in arm fat percentages with the dominant arm having slightly less fat. However, this small difference in arm fat percentage (0.7%) was apparently too small to impact the inter-arm TDC ratio. The above findings apply specifically to the depth and site herein measured although other sites and depths may have similar features.

In conclusion, the present data suggest that when tracking lymphedema changes using the tissue dielectric constant method,
possible temporal changes in a woman’s total body fat percentage or body mass index are unlikely to significantly impact either absolute TDC values or their inter-arm ratios.

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CONFLICT OF INTEREST AND DISCLOSURE

The author declares no competing financial interests exist.

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