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Assessment of Local Tissue Water in the Arms and Trunk of Breast Cancer Survivors With and Without Upper Extremity Lymphedema: Local tissue water in breast cancer survivors

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Abstract

Given the paucity of information on local tissue water (LTW) in the upper extremity and trunk of women after breast cancer surgery, the purpose of this study was to compare tissue dielectric constant (TDC) values between the affected and unaffected sides of breast cancer survivors with and without upper extremity lymphedema (LE). Differences in LTW were assessed using the TDC method for three sites in the upper limbs, three sites in the lateral thorax, and two sites on the back. Additional measures included: demographic and clinical characteristics, arm circumference, and bioimpedance analysis. For the 112 survivors without LE, no differences in TDC values were found between affected and unaffected sides for the first dorsal web space, ventral forearm and upper arm, and upper and lower back. Compared to the unaffected side, TDC values were significantly higher on the affected side for the upper, mid, and lower lateral thorax. For the 78 survivors with LE, compared to the unaffected side, TDC was significantly higher on the affected side for all of the sites evaluated except the hand web space. Our findings support the use of the TDC method to detect differences in upper extremity and truncal edema in survivors with LE following breast cancer treatment. Measurement of LTW may provide a useful method to determine truncal as well extremity LE. The ability to detect early signs of truncal edema may lead to pre-emptive interventions in breast cancer survivors.

Keywords

breast cancer; cancer survivors; lymphedema; local tissue water; tissue dielectric constant

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INTRODUCTION

While upper extremity lymphedema (LE) is a well-documented problem following breast cancer surgery (Paskett et al., 2012; DiSipio et al., 2013), less is known about the occurrence and severity of truncal edema (e.g., chest, shoulder, back) following breast cancer. A limited amount of research suggests that truncal LE is associated with painful and non-painful swelling, shoulder discomfort, feelings of fullness and heaviness, and low back pain (Williams 2006; Williams et al., 2004). In addition, truncal LE has a negative impact on women's ability to function and their quality of life (QOL) (Williams 2006; Williams et al., 2004). The ability to detect early signs of truncal lymphedema may lead to pre-emptive interventions (Stout Gergich et al., 2008; Shah et al., 2016).

However, the determination of truncal LE is challenging because assessment guidelines and diagnostic criteria do not exist. Therefore, women's reports of truncal LE may be ignored or minimized (Jeffs 2006). While findings from one study suggested that skin calipers can be used (Roberts et al., 1995), this method is not reliable for measuring truncal LE in obese women or in women after radiation therapy (Williams et al., 2002). In addition, methods that rely on bilateral comparisons or circumferential measures to assess LE are not appropriate for truncal LE.

An alternative approach to evaluate truncal LE is to measure local tissue water (LTW). Measurement of the tissue dielectric constant (TDC) can be used to quantify the amount of LTW in the skin and subcutis. The TDC method applies a high frequency electromagnetic (EM) field of 300 MHz, through a coaxial probe, to the skin and subcutaneous tissue. The majority of EM energy is absorbed by tissue water and the remainder is reflected back into a coaxial line. The reflected EM wave provides information about the water content of the tissue (Nuutinen et al., 2004). In areas of high water content, more EM energy is absorbed and the EM energy reflected back is reduced. The TDC value that is calculated from the reflected wave, is directly proportional to the tissue water content, and is inversely proportional to the reflected EM energy. The TDC value serves as an index of LTW to varying depths below the epidermis (Nuutinen et al., 2004). Tissue water measurement depth (i.e., 0.5 millimeters (mm) to 5.0 mm) is determined by the dimensions of the coaxial probe; with effective depths of up to 2.5 mm reported in the literature (Mayrovitz et al., 2009). Given that LE initially develops in the dermal layers of the skin and subcutaneous tissue, the TDC may be a sensitive method to detect early changes in local tissue water content in the trunk of women after breast cancer surgery (Mayrovitz et al., 2009).

To date, most of the studies that used TDC have assessed healthy women (Mayrovitz, Corbitt, et al. 2017; Mayrovitz, Fasen, et al. 2017) and upper extremity swelling in women with and without breast cancer-related LE (Mayrovitz et al., 2015a,b; Mayrovitz et al., 2014; Mayrovitz et al., 2008a,b; Lahtinen et al., 2015; Bakar et al., 2018). Findings from these studies suggest that TDC can reliably detect inter-limb differences in LTW in women at risk for and with LE (Mayrovitz et al. 2015a; Mayrovitz et al., 2014; Bakar et al., 2018; Lahtinen et al., 2015). For example, in women who had LE for less than one year following breast cancer surgery, TDC values were significantly higher in the affected versus the unaffected upper arm and forearm (Lahtinen et al., 2015). In another study of women after breast

cancer surgery (Bakar et al., 2018), women with LE demonstrated a higher ratio of affected versus unaffected upper arm LTW%, compared to women without LE.

While a small, but growing body of evidence suggests that TDC can be used to assess upper extremity LE (Mayrovitz et al., 2015a; Mayrovitz et al., 2014; Bakar et al., 2018; Lahtinen et al., 2015), limited data exist on its use for the measurement of truncal LE in breast cancer survivors. In fact, only two studies reported truncal TDC values in women after breast cancer surgery (Bakar et al., 2018; Mayrovitz et al., 2015b). In the first study that evaluated LTW in the lateral thorax of women pre- to 24 months after breast cancer surgery (Mayrovitz et al., 2015b), mean thoracic TDC values were significantly higher on the affected compared to the unaffected side at 6 months after surgery and remained significantly higher at 12, 18, and 24 months. In the second study that evaluated edema in the lateral thorax in women with and without upper extremity LE two to five years after breast cancer surgery (Bakar et al., 2018), no between group differences were found on the operated side. Moreover, no differences in LTW% ratios for the lateral thorax (affected/unaffected sides) were found in women with and without upper extremity LE. Findings from these two studies are limited by small sample sizes, high attrition rates, and minimal information on demographic and clinical characteristics.

Given the limited information on LTW in the upper extremity and trunk of women after breast cancer surgery, the purpose of this study was to compare TDC values between the affected (i.e., side of breast cancer treatment) and unaffected sides at 3 upper extremity and 5 truncal sites, in breast cancer survivors with and without a clinical diagnosis of upper extremity LE at enrollment into the study. We hypothesized that in survivors without LE, no differences in TDC values would be found between the affected and unaffected sides at any sites in the upper extremity or trunk. However, in survivors with LE, we hypothesized that TDC values would be higher in the affected compared to the unaffected side for all of the upper extremity and trunk measurement sites.

METHODS

Survivors

This study is part of a larger, ongoing study that is evaluating phenotypic and genomic risk factors for LE in women who underwent breast cancer surgery. Survivors were recruited from throughout the San Francisco Bay area using the following strategies: direct referral from clinicians; direct mailing to survivors who were identified through targeted searches of our medical center's electronic health record; newspaper advertisements; e-mails to participants in the Dr. Susan Love Research Foundation's Army of Women® Program; e-mails to support group members; postings on breast cancer and survivorship web sites; presentations at support group meetings; and snowball sampling through referrals from survivors.

Women were eligible if they: were ≥18 years of age, had undergone breast cancer surgery; had completed breast cancer treatment (i.e., surgery, radiation therapy, neoadjuvant or adjuvant chemotherapy) at least six months previously (excluding endocrine or targeted therapy); were able to read, write, and understand English; and were mentally and physically

able to participate in the study. Survivors were excluded if they had a history of bilateral breast cancer; had a current infection or lymphangitis; had a neuromuscular condition that would affect upper extremity or overall level of physical function; had primary LE; had a condition that precluded measurement of LE; or were pregnant. Survivors with bilateral mastectomies were included only if they had a diagnosis of LE and no history of lymph node removal on the unaffected side. Survivors reported a diagnosis of LE during the telephone screening. The research nurse asked the survivor if she was diagnosed with breast cancer-related LE. The research nurse confirmed the LE diagnosis as part of the medical record review.

Study Procedures

The study was approved by the Institutional Review Board at the University of California, San Francisco. All survivors provided written consent prior to evaluation. Medical records were reviewed for disease and treatment information and history of LE diagnosis. Dr. Smoot (a lymphedema therapist and physical therapist) taught the research nurses how to perform all of the objective measures. Inter-rater reliability, among the four research nurses, was evaluated at a single session every six months. All of the anatomic sites were assessed and the measurements were repeated until an inter-rater reliability of ≥.80 was achieved among all of the research nurses. The testing was done with a volunteer acting as a study participant in a simulated study examination room. Each nurse performed the objective measures on the same volunteer. Every 6 months, Dr. Smoot observed each of the nurse's assessments and provided feedback. Inter-class correlations were calculated for each of the measures using SPSS version 23 (IBM Corporation, Armonk, NY).

Subjective measures—Demographic questionnaire obtained information on age, marital status, education, ethnicity, employment status, living situation, activity level, and financial status. Karnofsky Performance Status (KPS) scale was used to evaluate functional status using a self-report scale that ranged from 30 (I feel severely disabled and need to be hospitalized) to 100 (I feel normal; I have no complaints or symptoms) (Karnofsky 1949). Self-Administered Comorbidity Questionnaire (SCQ) was used to assess comorbidities (Sangha et al. 2003). Survivors were categorized into LE and non-LE groups based on the self-reported response to the question "since breast cancer surgery, have you received a diagnosis of LE in your arm" (yes = LE group; no=non-LE group). This subjective report was confirmed through a medical record review.

Objective measures

Measurement of LTW: LTW was evaluated using the TDC method (MoistureMeterD Compact; Delfin Technologies LTD, Kuopio Finland). MoistureMeterD is a handheld noninvasive portable device that consists of an electronic control unit and an integrated probe that evaluates LTW to a depth of 2.5 mm (Lahtinen et al. 2015). Measurement depth is dependent on the dimensions of the device probe. Absolute TDC values decrease with increased depth of measurement. However, Mayrovitz reported that interlimb TDC ratios of affected to unaffected limbs were not significantly different across depths (Mayrovitz, Weingrad, and Lopez, 2015b). Since the same device was used for all of the assessments, measurement depth was consistent across all of the sites and study participants. Using an

interlimb TDC ratio of 1.2, the sensitivity and specificity was found to be 65% and 94%, respectively, using a diagnostic reference standard of ≥2 cm interlimb circumference difference (Bakar et al., 2018).

TDC Measurement Sites: The "Protocol for Measurement of Breast, Flank, Upper Back, and Arm Using Delfin MoisturemeterD Compact" (copyright 2015, with permission from Dr. Reefman) was used to identify the test sites. The Protocol templates provided by Dr. Reefman (The Hague University of Applied Sciences, The Netherlands) were used to standardize the assessments across women with various body types (Abstract presented at the 25th National Lymphedema Network World Congress of Lymphology, San Francisco. 2015. Manuscript in Preparation per personal communication with Dr. Reefman). Bilateral assessments were done for the upper limbs and thorax. Three locations were evaluated in the upper limbs, namely: the first dorsal web space, 6 cm distal to the antecubital fossa crease on the ventro-medial arm, and 8 cm proximal to the antecubital fossa crease on the ventro-medial surface (Supplemental Figure 1). Three sites were evaluated bilaterally in the lateral thorax using templates based on length of thorax (Supplemental Figure 2a). Two sites were evaluated bilaterally on the back using the template based on thorax length and girth (Supplemental Figure 2b).

TDC Measurement Procedure: Prior to testing, survivors were positioned supine for at least 10 minutes on a padded examination table with a small pillow under their head. All sites were measured starting on the right side. Single measures at each of the six sites were taken in sequence (i.e., dorsal web space, lower arm, upper arm, and three lateral thorax sites (see Supplemental Figure 1 and 2a for pictures of locations) and then repeated one time before moving to the left side. The Moisture MeterD probe was placed in contact with the skin and constant and even gentle pressure was applied for 3 to 4 seconds. An audible tone indicated when the measurement was complete. The order of measurements was as follows: hand, forearm, upper arm, upper, mid, and lateral thorax. Procedures were then repeated on the left side. To evaluate the back locations, survivors sat upright on the exam table. The survivors were in a sitting position for approximately five minutes prior to the assessment. Any visible moisture was toweled off by the research nurse prior to the TDC evaluation.

Arm Circumference: Circumferential measurements of both upper extremities were done twice, using a spring-loaded tape measure at 10 centimeter (cm) intervals from ulnar styloid of the wrist up to a total distance of 40 cm (Cornish et al., 2001). Volume was calculated using the formula for the volume of a truncated cone

$$\left(V = 1/12\Pi\, \Sigma h\left(C_1^{\,2} + C_1C_2 + C_2^{\,2}\right)\right)$$

(Sander et al., 2002)

Bioelectrical impedance analysis (BIA): To ensure adequate hydration, patients were required to avoid: exercise other that casual walking on the day of the visit, as well as alcoholic beverages, strenuous exercise, and hot tub or sauna for 24 hours prior to the visit. BIA measurements of both upper limbs were done using established procedures (Hayes et

al., 2005; Cornish et al. 2001; Cornish et al. 2000). Using the Quantum X Bioelectrical Impedance Device (RJL Systems, Clinton Township, MI), measurement electrodes were placed on the skin at either end of the 40-cm length over which the circumference measurements were made and the drive electrodes were placed 8 to 10 cm distal to these measurement electrodes. Two readings of resistance from each limb were averaged.

Data analysis

Data were analyzed using SPSS version 23 (IBM Corporation, Armonk, NY). Separate analyses were done for survivors with and without LE. Descriptive statistics and frequency distributions were calculated for demographic and clinical characteristics. Means and standard deviations (SD) were calculated for TDC values and LTW. The MoistureMeterD Compact automatically converts the TDC value into LTW%. Therefore, to be able to compare our findings with previous studies (Bakar et al., 2018), TDC values were calculated from LTW% (Nuutinen et al., 2004; Mayrovitz et al., 2016) using the following formula:

$$\mathrm{LTW\%} = 100\% \times (\mathrm{TDC\text{-}1})/77.5.$$

The TDC value is proportional to the tissue water content. Higher LTW% indicates higher water content. Mean differences in TDC values and 95% confidence intervals (CI) between the affected and unaffected sides were calculated. Paired t tests were used to evaluate for differences between the affected and unaffected sides. A p-value of <0.05 was considered statistically significant. The TDC ratio (affected side/unaffected side) was calculated for the paired TDC values to compare our findings with previous studies (Bakar et al., 2018; Mayrovitz et al., 2015b).

RESULTS

Characteristics of survivors without LE

Demographic and clinical characteristics of the survivors without LE are summarized in Table 1. Survivors without LE were 60.5 (±10.0) years of age and 7.0 (±6.7) years from their initial breast cancer diagnosis. Of the 112 survivors, 55.0% were diagnosed with breast cancer on their dominant side, 73.9% had breast conservation surgery, 83.0% had a sentinel lymph node biopsy (SNLB), and 27.7% had an axillary lymph node dissection (ALND). Differences in limb volume between the affected and unaffected limbs were −1.2 (±84.3) milliliters and bioimpedance resistance ratio was 0.995 (±0.043).

TDC values in survivors without LE

For survivors without LE, no differences in TDC values were found between the affected and unaffected sides for the first dorsal web space, ventral forearm and upper arm, and upper and lower back (Table 2). Compared to the unaffected side, TDC values were significantly higher on the affected side for the upper, mid, and lower lateral thorax (all, $p<.001$). The TDC ratios of the affected/unaffected side ranged from 1.00 (±0.09) in the ventral forearm to 1.155 (±0.258) in the mid and lower lateral thorax.

Characteristics of survivors with LE

Demographic and clinical characteristics of the survivors with a history of LE are summarized in Table 3. Women with LE were 60.3 (±8.9) years of age and 8.6 (±6.6) years from their initial breast cancer diagnosis. Of the 78 survivors with LE, 51.9% were diagnosed with breast cancer on their dominant side, 57.1% had breast conservation surgery, 64.1% had a SNLB, and 73.1% had an ALND. Differences in limb volume between the affected and unaffected limbs were 194.1 (±331.8) milliliters and bioimpedance resistance ratio was 1.2 (±0.3).

TDC values in survivors with LE

In the survivors with LE, no differences in TDC values were found between the affected and unaffected sides for hand web space (Table 4). Compared to the unaffected side, TDC values were significantly higher on the affected side for ventral forearm and upper arm; upper, mid, and lower lateral thorax (all, $p<.001$); and upper and lower back (both, $p<.05$). The TDC ratios of the affected/unaffected side ranged from 1.02 (±0.07) in the upper and lower back to 1.29 (±0.36) in the ventral forearm.

DISCUSSION

This study is the first to report TDC and LTW findings from multiple sites in the upper limbs and trunk in women with and without upper extremity LE following breast cancer surgery. In our assessment of LTW, we evaluated three sites in the upper limbs, three sites in the lateral thorax, and two sites in the back. Based on consultation with a number of LE therapists, these sites were chosen because they were noted to be most common sites for truncal edema. The findings from this study support our a priori hypothesis that in survivors with upper extremity LE, LTW% and TDC values would be higher on the affected side for all of the upper limb and truncal sites tested. In women without LE, no statistically significant differences were found between the affected and unaffected sides for any of the sites tested in the upper limbs or back. However, for all of the lateral thorax sites, TDC values were higher for the affected compared to the unaffected side.

Compared to one study that reported TDC values for the ventral forearm of women with LE (i.e., 42.9 ± 8.2 affected limb versus 26.0 ± 4.0, unaffected limb) (Mayrovitz et al. 2014), our TDC values were slightly lower for the affected limb (35.62 ± 10.03) and slightly higher for the unaffected limb (28.04 ± 4.56). Because time since surgery and type of surgery were not reported (Mayrovitz et al., 2014), the exact reasons for these differences cannot be determined. However, one can hypothesize that the lower TDC values in the lower limbs may reflect less severe LE in the affected limbs. Given that the average affected-unaffected arm volume difference among women with a history of LE in our study was below 200 ml, this explanation is plausible. The authors suggested that a ratio of ≥1.2 could be used as a threshold to detect pre-clinical LE, based on a change of 3 standard deviations from mean dominant/non-dominant TDC ratio of their non-lymphedematous participants. Of note, in our study, the mean TDC ratio for the ventral forearm was above this threshold in the LE group (1.29 ± 0.36), but not in the non-LE group (1.00 ± 0.09).

In another study that evaluated LTW using the TDC method in 32 breast cancer survivors with and 31 without upper extremity LE (Bakar et al., 2018), the ventral forearm, the ventral upper arm, and the lateral thorax were assessed. For the non-LE group, our LTW% findings were slightly lower than theirs for both the affected and unaffected sides. However, for the women with LE, our average LTW% measurements were 2 to 8 percentage points higher. These inconsistent findings may be related to differences in time since surgery and/or severity of upper limb swelling in the LE group.

Surprisingly, for the lateral thorax, Bakar et al (2018) reported the highest LTW% on the affected side of the non-LE group. In contrast and consistent with our hypothesis, we found the highest thorax values for the affected side of the survivors with LE. Interestingly, LTW% and TDC values in the thorax were higher for the affected side of our survivors without LE. The increased TDC values for the affected thorax of women who did not have upper extremity LE suggests that truncal LE may occur in the absence of, or as a precursor to, upper extremity LE. This finding warrants additional study.

Because of the challenges with accurate assessment of truncal edema, it is difficult to estimate occurrence rates for their condition. In a telephone survey of 148 women post breast cancer treatment (Bosompra et al., 2002), 10% of women reported swelling in the back, 10% in the anterior chest wall, 14% in the lateral chest well, 14% in the remaining breast tissue, and 22% in the axilla. One barrier to accurate assessment of truncal edema is the inability to perform side to side comparisons using measures of total volume such as water displacement, perometry, or circumferential assessment. In addition, preoperative to postoperative comparisons using total volume measures are challenging because of the anatomic changes in the breast following cancer surgery. While bioimpedance devices are capable of differentiating intracellular and extracellular fluid volume, they cannot segment the mass of the trunk for side to side comparisons. In addition, neither bioimpedence nor total limb volume measures provide a localized measure of fluid volume. Therefore, additional measures are needed that allow for localized assessment of early volume changes in the skin and subcutaneous tissues of the limb, as well as for volume changes in the skin and subcutaneous tissues of the trunk. The TDC method may help address some of these challenges. Moreover, serial measures of TDC require that the measures be done at consistent locations. The use of an established protocol (see methods section) provides a method to ensure valid and reliable measurements over time and across women of varying anatomic sizes.

Limitations

Several limitations warrant consideration. We did not factor in dominance in our analysis of between-limb comparisons of TDC values. In a recent study of the effect of handedness in healthy female adults (Mayrovitz, Fasen, et al., 2017), limb dominance had no effect on TDC values or ratios. Second, limited information is available on the optimal assessment sites. We chose all but one site based on current literature (Mayrovitz, Fasen, et al., 2017; Mayrovitz et al., 2015a,b; Weingrad and Davey 2014; Mayrovitz et al., 2008a), clinical experience, and consultation with LE therapists. Of note, the choice of the first dorsal web space may not be the ideal location to evaluate hand LTW. Additional sites in the hand

warrant evaluation to determine the optimal location for the assessment of LTW in this location. The back measurements were done approximately five minutes after the survivors changed from a supine to a seated position. It is possible that the TDC values for the back were elevated due to increased moisture from lying supine for approximately one hour. This position shift should be taken into account when comparing our findings to results from future studies.

Conclusion

Our findings support the use of the TDC method to detect differences in LTW% in survivors with upper extremity LE following breast cancer treatment. Differences were detected at several locations in the arm and trunk. In addition, differences were found in the lateral thorax of survivors without LE. While our findings warrant replication, measurement of TDC may be a useful method to determine truncal as well extremity LE in breast cancer survivors.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Table 1.

Demographic and Clinical Characteristics of Survivors Without Breast Cancer Related Lymphedema (n=112)

Characteristic	Mean (SD)
Age (years)	60.5 (10.0)
Education (years)	16.7 (2.3)
Body mass index (kg/m^2)	25.9 (5.2)
Karnofsky Performance Status score	93.9 (7.9)
Self-Administered Comorbidity Questionnaire score	2.7 (2.8)
Time since cancer diagnosis (years)	7.0 (6.7)
Time since initial breast cancer surgery (years)	6.9 (6.7)
Number of lymph nodes removed	6.1 (7.3)
Number of positive lymph nodes	0.8 (1.9)
Upper extremity volume difference between limbs (affected – unaffected, ml)	−1.2 (84.3)
Bioimpedance ratio (affected/unaffected)	0.995 (0.043)
	% (n)
Ethnicity White Non-white	 78.6 (88) 21.4 (24)
Married or partnered (% yes)	66.1 (74)
Lives alone (% yes)	23.2 (26)
Working for pay (% yes)	63.4 (71)
Income < $30,000 $30,000 to <$70,000 $70,000 to < $100,000 ≥ $100,000	 9.2 (9) 21.4 (21) 20.4 (20) 49.0 (48)
Exercise on a regular basis (% yes)	75.0 (84)
Smoking, current or history of (% yes)	27.7 (31)
Affected side the same as dominant side (% yes)	55.0 (61)
Received neoadjuvant CTX (% yes)	21.7 (23)
Type of initial breast surgery * Breast conservation Mastectomy	 73.9 (82) 26.1 (29)
Sentinel lymph node biopsy (% yes)	83.0 (93)
Axillary lymph node dissection (% yes)	27.7 (31)
Reconstruction to the affected breast at initial surgery (% yes)	11.6 (13)
Additional breast surgeries after initial surgery (% yes)	27.7 (31)
Reconstruction to the affected breast after initial surgery (% yes)	12.5 (14)
Stage of disease per postoperative report Stage 0 Stage I Stage II Stage III or IV	 11.1 (11) 47.5 (47) 33.3 (33) 8.1 (8)
Estrogen receptor positive (% yes)	77.8 (84)
Progesterone receptor positive (% yes)	63.0 (68)

Characteristic	Mean (SD)
Human epidermal growth factor receptor-2 (% negative)	19.4 (21)
Received adjuvant CTX (% yes)	52.8 (56)
Received external beam radiation therapy (% yes)	73.2 (82)

* n=111 for type of surgery. One survivor had only a breast biopsy and axillary lymph node dissection.

Abbreviations: CTX = chemotherapy; kg = kilograms, m^2 = meter squared, ml = milliliters, SD = standard deviation

Table 2

–Differences in Tissue Dielectric Constants Between Affected and Unaffected Sides of Survivors Without Breast Cancer-Related Lymphedema (n=112)

Testing site	TDC value affected side *(LTW% affected side)*	TDC value unaffected side *(LTW% unaffected side)*	Difference in TDC value between affected and unaffected side	TDC Ratio (affected/unaffected)	Statistic*; p-value
	Mean (SD)	Mean (SD)	Mean (95% CI)	Mean (SD)	
HAND					
First dorsal webspace	30.73 (3.99) *38.36 (5.15)*	30.36 (4.34) *37.88 (5.60)*	0.37 (−0.37, 1.11)	1.02 (0.13)	t=0.98; p=.329
ARM					
Ventral forearm	28.14 (3.13) *35.03 (4.04)*	28.14 (3.12) *35.01 (4.03)*	0.01 (−0.44, 0.46)	1.00 (0.09)	t=0.03; p=.976
Ventral upper arm	24.74 (3.23) *30.64 (4.16)*	24.58 (2.54) *30.43 (3.27)*	0.16 (−0.41, 0.74)	1.01 (0.15)	t=0.56; p=.575
LATERAL THORAX					
Upper lateral thorax	30.10 (3.49) *37.55 (4.50)*	29.03 (3.67) *36.17 (4.74)*	1.08 (0.50, 1.65)	1.04 (0.11)	t=3.70; p<.001
Mid lateral thorax	31.25 (3.69) *39.03 (4.77)*	29.56 (3.40) *36.86 (4.39)*	1.68 (1.17, 2.20)	1.06 (0.10)	t=6.47; p<.001
Lower lateral thorax	33.35 (3.92) *41.75 (5.06)*	31.58 (3.63) *39.46 (4.68)*	1.77 (1.13, 2.41)	1.06 (0.11)	t=5.51; p<.001
BACK					
Upper back	40.86 (3.32) *51.43 (4.29)*	40.79 (3.78) *51.34 (4.87)*	0.07 (−0.32, 0.46)	1.00 (0.05)	t=0.35; p=.724
Lower back	38.78 (3.89) *48.75 (5.02)*	38.67 (4.37) *48.60 (5.64)*	0.11 (−0.36, 0.59)	1.01 (0.07)	t=0.47; p=.636

*paired t-test – difference in TDC values between affected and unaffected sides

Abbreviations: CI = confidence interval, LTW% = local tissue water percent, SD = standard deviation, TDC = tissue dielectric constant

Table 3.

Demographic and Clinical Characteristics of Survivors with Breast Cancer Related Lymphedema (n=78)

Characteristic	**Mean (SD)**
Age (years)	60.3 (8.9)
Education (years)	16.4 (2.3)
Body mass index (kg/m^2)	26.9 (4.8)
Karnofsky Performance Status score	87.7 (10.0)
Self-Administered Comorbidity Questionnaire score	3.1 (2.7)
Time since cancer diagnosis (years)	8.6 (6.6)
Time since initial breast cancer surgery (years)	8.4 (6.7)
Number of lymph nodes removed	12.8 (8.7)
Number of positive lymph nodes	3.0 (6.3)
Upper extremity volume difference between limbs (affected – unaffected, ml)	194.1 (331.8)
Bioimpedance ratio (affected/unaffected)	1.155 (0.258)
	% (n)
Ethnicity White Non-white	 84.4 (65) 15.6 (12)
Married or partnered (% yes)	57.1 (44)
Lives alone (% yes)	27.3 (21)
Working for pay (% yes)	46.8 (36)
Income < $30,000 $30,000 to <$70,000 $70,000 to < $100,000 ≥ $100,000	 17.1 (12) 24.3 (17) 17.1 (12) 41.4 (29)
Exercise on a regular basis (% yes)	61.0 (47)
Smoking, current or history of (% yes)	23.4 (18)
Affected side the same as dominant side (% yes)	51.9 (40)
Received neoadjuvant CTX (% yes)	22.4 (17)
Type of initial breast surgery Breast conservation Mastectomy	 57.1 (44) 42.9 (33)
Sentinel lymph node biopsy (% yes)	64.1 (50)
Axillary lymph node dissection (% yes)	73.1 (57)
Reconstruction to the affected breast at initial surgery (% yes)	16.7 (13)
Additional breast surgeries after initial surgery (% yes)	25.6 (20)
Reconstruction to the affected breast after initial surgery (% yes)	26.9 (21)
Stage of disease per postoperative report Stage 0 Stage I Stage II Stage III or IV	 2.9 (2) 18.6 (13) 58.6 (41) 20.0 (14)
Estrogen receptor positive (% yes)	73.1 (57)
Progesterone receptor positive (% yes)	53.8 (42)

Characteristic	Mean (SD)
Human epidermal growth factor receptor-2 (% negative)	17.9 (14)
Received adjuvant CTX (% yes)	71.1 (54)
Received external beam radiation therapy (% yes)	76.9 (60)

* n=77 for type of surgery. One survivor had only a breast biopsy and axillary lymph node dissection.

Abbreviations: CTX = chemotherapy; kg = kilograms, m^2 = meter squared, ml = milliliters, SD = standard deviation

Table 4

–Differences in Tissue Dielectric Constants Between Affected and Unaffected Sides of Survivors With Breast Cancer-Related Lymphedema (n=78)

Testing site	TDC Value affected Side *(LTW% affected side)*	TDC value unaffected Side *(LTW% affected side)*	Difference in TDC between affected and unaffected sides	TDC Ratio (affected/unaffected)	Statistic*; p-value
	Mean (SD)	Mean (SD)	Mean (95% CI)	Mean (SD)	
HAND					
First dorsal webspace	31.49 (4.94) *(39.34 (6.37))*	30.73 (4.54) *(38.36 (5.86))*	0.76 (−0.28, 1.80)	1.03 (0.16)	t=1.45; p=.150
UPPER LIMB					
Ventral forearm	35.62 (10.03) *(44.67 (12.94))*	28.04 (4.56) *(34.89 (5.89))*	7.58 (5.28, 9.88)	1.29 (0.36)	t=6.57; p<.001
Ventral upper arm	30.71 (9.31) *(38.34 (12.01))*	24.79 (3.47) *(30.69 (4.48))*	5.93 (3.85, 8.00)	1.25 (0.41)	t=5.69; p<.001
LATERAL THORAX					
Upper lateral thorax	31.03 (2.98) *(38.75 (3.85))*	29.32 (3.78) *(36.54 (4.87))*	1.71 (0.96, 2.46)	1.07 (0.11)	t=4.52; p<.001
Mid lateral thorax	32.44 (3.84) *(40.56 (4.96))*	30.44 (3.84) *(37.99 (4.95))*	2.00 (1.24, 2.75)	1.07 (0.12)	t=5.26; p<.001
Lower lateral thorax	35.65 (4.72) *(44.71 (6.09))*	32.64 (4.40) *(40.83 (5.68))*	3.01 (2.10, 3.92)	1.10 (0.13)	t=6.61; p<.001
BACK					
Upper back	41.75 (3.75) *(52.58 (4.84))*	40.99 (3.88) *(51.60 (5.00))*	0.77 (0.10, 1.43)	1.02 (0.07)	t=2.29; p=.025
Lower back	40.28 (4.24) *(50.69 (5.47))*	39.50 (4.12) *(49.67 (5.31))*	0.78 (0.19, 1.38)	1.02 (0.07)	t=2.61; p=.011

*paired t-test – difference in TDC values between affected and unaffected sides

Abbreviations: CI = confidence interval, LTW% = local tissue water percent, SD = standard deviation, TDC = tissue dielectric constant