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FOREARM AND BICEPS CIRCUMFERENTIAL VARIATIONS IN SKIN TISSUE DIELECTRIC CONSTANT AND FIRMNESS

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ABSTRACT

Tissue dielectric constant (TDC) and skin firmness assessed via indentation force (FORCE) help quantify lymphedema and track changes. We sought to determine potential differences in these parameters dependent on arm circumferential locations. Thus, TDC and FORCE were measured in 40 healthy women at medial, anterior and lateral locations on forearm and biceps. In five other women with unilateral lymphedema (68.6±7.6 years), TDC was measured at corresponding circumferential forearm positions. Measurements were done in triplicate using compact noninvasive devices. Results for healthy women (23.8±2.7 years) showed forearm medial TDC values (26.7±2.2) were less than anterior (28.0±2.4) or lateral (28.0±2.5) positions (p<0.001). Lymphedema patients had elevated values but similar medial-anterior-lateral patterns (33.7±8.0, 39.8±10.2 and 42.9±10.0). Biceps medial TDC values (24.1±2.2) were also less than either anterior (27.0±2.1) or lateral (28.2±3.3). Contrastingly, medial FORCE values at forearm and biceps were less than at anterior and lateral locations (p<0.001) and increased in the order of medial-anterior-lateral on forearm (p<0.001). The present findings provide reference values for both TDC and FORCE of commonly measured arm sites with specificity as to circumferential variations. This observed variation indicates the need for care in locating measurement positions for tracking patients with lymphedema.

Keywords: lymphedema assessment, lymphedema measurement, tissue dielectric constant, skin firmness, arm skin water reference values

Breast cancer-related lymphedema (BCRL) occurs as an unfortunate complication of breast cancer treatments including surgery, radiation therapy, and chemotherapy resulting in destruction of lymphatic pathways causing a range of changes including swelling, pain, and decreased functionality (1). Lymphedema can be present for years before becoming clinically noticeable and early detection and treatment can reduce associated costs and severe complications of the disorder. Upper limb lymphedema can significantly impact work and livelihood (2) and it is reasonable to suggest that regularly screening patients for BCRL can help with the optimal management of the post-breast cancer condition (3) since earlier detection and treatment of lymphedema are reported to correlate with better outcomes (4).

The question as to which method is best to screen for BCRL and/or track its change with time or treatment is an open one with various methods available, each with its own set of advantages. To assess fluid content changes, arm volumes can be measured with tape (5-7), electronically (8-13), via bioimpedance spectroscopy (14-18), water displacement

(7,8,19-21), imaging methods (22-24), or with tissue dielectric constant (TDC) measurements (25-31). There are also questions and different views as to what quantitative values properly define lymphedema thresholds (32-36). However, among these various methods, only with TDC measurements is it possible to make selective localized tissue water assessments. As applied to measurements on arms, it has been shown that there are variations in TDC values dependent on the longitudinal location of the measurement when made on the anterior arm surface (37,38). However, except for anterior and medial forearm TDC measurements limited to a forearm site (39), there is essentially no systematic information on the extent of variation of TDC values with respect to the position of their circumferential measurement at a fixed longitudinal forearm and upper arm sites of clinical interest. Since such TDC measurements are sometimes used to identify and track lymphedema changes, this information would be valuable to determine the care with which the specific measurement location needs to be specified, especially in a busy clinical environment. Aside from the need to characterize tissue water as a feature of lymphedema, there is also the issue of changes in tissue texture over time or with treatment. One approach is via tonometry (40-43) and another is by assessing tissue firmness by measuring the indentation force to a fixed indentation depth using various methods (44-49). However, as in the case of arm TDC measurements, the circumferential variation in arm indentation force (FORCE) is also unknown and such knowledge would be useful in the context of identifying and tracking developing lymphedema-related fibrosis. Thus, the primary goal of the present research was to characterize the normal range and circumferential variability of TDC and FORCE parameters present at the forearm and upper arm sites in young healthy women as a first step in providing both basic information and useful reference ranges.

METHODS

Subjects

A total of 40 women between 18-31 years of age 23.8 ± 2.7 years (mean ± SD) and five women with unilateral arm lymphedema (68.6 ± 7.6 years, lymphedema duration of 1-3 years) participated. The study was explained to all participants after which they signed an Institutional Review Board approved consent form. For the main study, participants' entry required that they were between 18-35 years of age and have no abnormal skin condition(s) and/or history of diabetes (any form). Entry requirements for the lymphedema patients were that they had unilateral arm lymphedema, were in the process of receiving active lymphedema treatment and were scheduled for lymphedema treatment.

Measurements

TDC measurements were done with a handheld device (LymphScanner, Delfin Technologies, Kuopio Finland). This device is similar to a compact device used previously (39) but has some additional features not used in this study. TDC values are largely dependent on the amount of skin water within the measured local volume. The effective measurement depth is between 2.0 mm - 2.5 mm thereby including epidermis and dermis in its measurement volume. The device functions as an open-ended transmission line (50-52) in which a low-level 300MHz signal is transmitted when in contact with skin for about 5 seconds. The reflected component is used to determine TDC values that are expressed in absolute terms (tissue permittivity) or as water percentage. TDC measurements were obtained from the forearm and upper arm of healthy subjects and on forearm of patients with unilateral lymphedema. Tissue Indentation force (FORCE) was determined using the SkinFibroMeter (45, 53) (Delfin Technologies, Kuopio Finland). This handheld device measures skin tissue firmness by determining the force required to indent skin to 1.25 mm. In use, a 2 mm diameter semi-spherical diameter indentor deforms the skin inwardly with the resultant force recorded and displayed on a window on the front of the device. The device has internal sensors that accept values only within prescribed limits of force and velocity. So, if an applied force is too large or applied too rapidly or too slowly, internal software prompts the user to repeat the measurement until data is obtained within the set device limitations. A single recorded value is obtained as the average of five acceptable sequential measurements made rapidly in succession. These FORCE measurements were only made on the forearm and upper arm of the 40 healthy women due to device accessibility.

Procedures

The healthy young subjects were students from the Health Professions Division at Nova Southeastern University recruited on campus for this study. Those who agreed to participate and satisfied entry criteria were scheduled for an appointment day and time. At that time, they were seated in a chair with their non-dominant arm resting in front of them on a padded table. Lymphedema subjects were evaluated on their scheduled clinic appointment date. For the main healthy group (N=40) target measurement sites were on the non-dominant arm whereas measurements on the lymphedema subjects (N=5) were on their lymphedematous arm. Target measurement arm sites were marked at three positions on the forearm and three positions on the biceps with a surgical pen as shown in *Fig. 1* for a healthy subject. Forearm sites were 5 cm distal to the antecubital fossa on the lateral (outer), anterior (top), and medial (inner) aspects. Bicep (upper) arm sites were 8 cm proximal to the antecubital fossa on the outer, top, and inner aspects. The medial (inner) aspects of both sites represent the least sun exposure, whereas outer sites (lateral) represent the most sun exposure. TDC followed by tissue indentation force (FORCE) was the order of specific measurements for both forearm and biceps. Measurements were taken sequentially at forearm in the order of lateral to anterior to medial with each done sequentially. After one sequential set was completed a 2nd and then a 3rd was completed until triplicate measurements per position were achieved. Following

Fig. 1. Measurement sites and positions. The forearm site was 5 cm distal to the antecubital fossa with measurement positions on the medial (FM), anterior (FA) and lateral (FL) positions. The upper arm bicep site was 8 cm proximal to the antecubital fossa on the medial (BM), anterior (BA) and lateral (BL) positions. The medial aspects of both sites represent the least sun exposure, whereas outer (lateral) sites represent areas with the most sun exposure.

completion of the forearm measurements, the same procedure was completed for the biceps measurements.

Analysis

TDC and FORCE values were tested to determine normality of their distribution using the Shapiro-Wilk test. Normality was rejected for both measures and analyses were done using nonparametric tests. Comparisons among positions (medial, anterior and lateral) were accomplished using the Friedman test with follow-up tests based on paired Wilcoxon test. Differences between sites (forearm vs. biceps) were also tested using the non-parametric Wilcoxon test. For the follow-up tests of differences between positions at a given site, a significance level corresponding to a p-value <0.01 was used as a threshold for statistical significance.

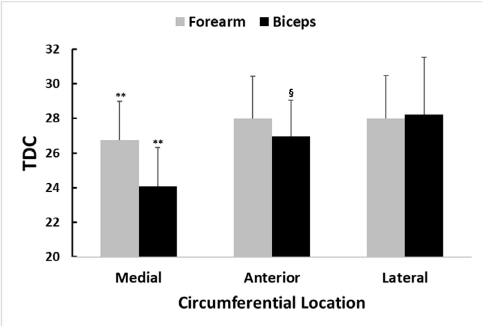

*Fig. 2. TDC values for forearm and biceps. There was an overall statistical difference in TDC values among circumferential positions at the forearm and biceps (p<0.001) for healthy women (N=40). Error bars are SD. ** Indicates medial TDC values less than for anterior and lateral positions for each site (p<0.001). §Indicates anterior bicep TDC values less than at the lateral position (p = 0.002).*

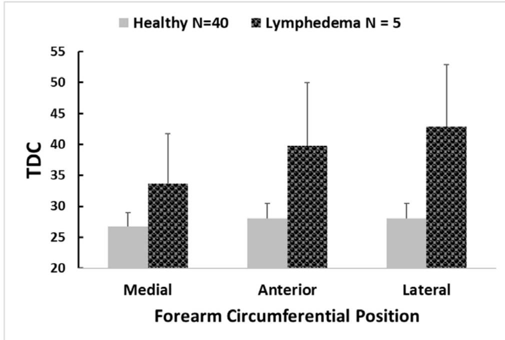

Fig. 3. TDC values for healthy vs. lymphedematous forearms. Patients with arm lymphedema (N=5) show a positional TDC pattern similar to that obtained for the healthy group (N=40) with the smallest TDC values observed at the medial site. Error bars are SD.

RESULTS

TDC Values

TDC values at each position (medial, anterior and lateral) are visualized for forearm and biceps in *Fig. 2* for the 40 women. There was an overall statistical difference in TDC values among positions at forearm (p=0.006) and biceps (p<0.001). Forearm medial TDC values (26.7 ± 2.2) were less than at anterior (28.0 ± 2.4) or lateral (28.0 ± 2.5) positions (p<0.001). Biceps medial TDC values (24.1 ± 2.2) were less than either anterior (27.0 ± 2.1) or lateral (28.2 ± 3.3) positions (p<0.001). TDC differences between anterior and lateral positions were not significant at the forearm. At the biceps, anterior position TDC values were less than at the lateral position (p=0.002). Calculated percentage differences in TDC values between the medial position and the anterior position were 7.0 ± 7.2% at forearm and 14.3 ± 7.3% at biceps. Calculated percentage differences in TDC values between the medial position and the lateral position was 8.3 ± 6.7% at forearm and 20.2 ± 11.4% at biceps. Comparison of these healthy women values with the women with unilateral lymphedema showed a pattern (*Fig. 3*) similar to that obtained for the healthy group but with elevated TDC values at each circumferential

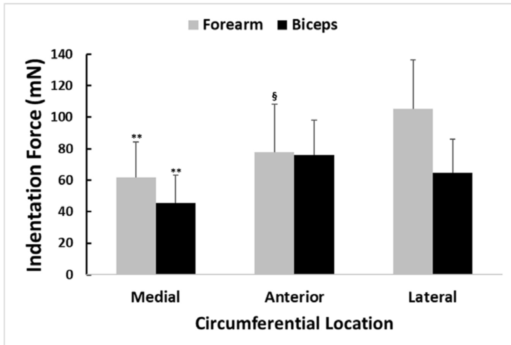

*Fig. 4. FORCE values for forearm and biceps. There was an overall statistical difference in FORCE values among circumferential positions at forearm and biceps (p<0.001) in healthy women (N=40). Error bars are SD. ** Indicates medial FORCE values less than for anterior and lateral positions for each site (p<0.001). §Indicates anterior forearm FORCE values less than at the lateral position (p = 0.001).*

position as compared to the healthy groups data. TDC values of this lymphedematous group for medial, anterior and lateral positions was 33.7 ± 8.0, 39.8 ± 10.2 and 42.9 ± 10.0.

FORCE Values

FORCE values at each position (medial, anterior and lateral) for the healthy women (N=40) are visualized for forearm and biceps in *Fig. 4.* There was an overall statistical difference in FORCE values among circumferential positions at forearm ($p<0.001$) and at bicep ($p<0.001$). At forearm, FORCE at each position differed from each other ($p<0.001$) with the smallest FORCE at the medial position (61.7 ± 22.5) increasing monotonically to the anterior position (77.9 ± 30.3) and to the lateral position (105.2 ± 31.0). Biceps medial FORCE values (45.2 ± 17.7mN) were less than at the anterior position (75.8 ± 22.4 mN) and the lateral position (64.6 ± 21.6 mN). Calculated percentage differences in FORCE values between the medial position and the anterior position were 44.7 ± 55.1% at the forearm and 101.4 ± 117.8% at the biceps. Calculated percentage differences in FORCE values between the medial position and the lateral position were 83.8 ± 68.2% at the forearm and 64.8 ± 63.0% at the biceps.

DISCUSSION

TDC and indentation FORCE offer two different indices useful for assessing lymphedema. TDC provides an index of localized excess fluid whereas FORCE provides an index of tissue property changes. Hence, depending on the stage of lymphedema being evaluated, one or both may be useful to detect or track lymphedema-related changes. When measuring sequentially in a clinical situation, one tries to measure at the same locations but at a minimum, it would be helpful to have an estimate of the range of differences that might occur for variations associated with circumferential placement of the probes. Accordingly, the present study was undertaken to determine the extent of variability of such measurements that might be expected depending on the circumferential arm measurement location and to characterize expected variations in values among arm locations. The results demonstrate that significant statistical variations are present in both TDC and FORCE values with medial locations showing the smallest values as compared to either anterior or lateral aspects. The same basic pattern was present for TDC values measured in a small group of women with unilateral lymphedema. This small group is a limitation of this study and further studies in a larger cohort with lymphedema should be undertaken.

A central emerging question related to these findings is whether the differences in measured values among sites are sufficiently great to call for standardization in reporting and more importantly their impact when used to specify thresholds or track changes over time and treatment in a busy clinical setting. Examination of the greatest relative difference among positions shows for TDC values this occurs between the medial and lateral sites both at forearm and biceps with percentage differences ranging from 8.3% at forearm and 20.2% at biceps. Percentage differences in FORCE are even greater, ranging from 83.8% at forearm to 64.8% at biceps. These differences appear sufficiently great to suggest care should be exercised in comparing or tracking TDC or FORCE changes unless such measurements are made at the same circumferential position. Furthermore, the present specific values for these circumferential locations may be useful in their own right since information of this type would be relevant to maintain consistent, clinically significant values in those being evaluated for lymphedema subsequent to breast cancer treatment. Although the present study focused on circumferential variations at fixed arm sites, other reports (54,55) have indicated variations in TDC values along the arm pointing to the need to consider both longitudinal and circumferential locations.

In conclusion, the present findings provide reference values for both TDC as a measure of fluid and indentation FORCE as a measure of firmness of commonly measured arm sites with specificity as to circumferential variations. This observed variation indicates the need for care in locating measurement positions for tracking lymphedema in a given patient.

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CONFLICT OF INTEREST AND DISCLOSURE

The authors declare no competing financial interests exist.

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