Age-Related Changes in Male Forearm Skin-to-Fat Tissue Dielectric Constant at 300 MHz

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Background

Prior research suggests that tissue dielectric constant (TDC) values are useful to assess localized skin water in females for early diagnosing breast cancer treatment-related lymphedema and TDC values in young adults have shown gender differences. However, no TDC data is available for older males or have the effects of aging studied despite known shifts in water state and other skin age-related changes.

Introduction

Prior studies used measurements of skin tissue dielectric constant (TDC) at 300 MHz to characterize and compare young adult male and female skin properties to a skin depth of 1.5 mm. The results demonstrated a 13% greater TDC value in males and concluded that such measurements are useful but one must consider this difference in experimental design and data interpretation. Skin TDC values largely depend on water content and are used to characterize the presence and extent of edema or lymphoedema. It is unknown if values obtained in this young adult population carry over into older ages. This is especially relevant to TDC data for males as most prior data are based on female evaluations. There are several reasons why it is important to consider possible male age-related TDC differences and why such differences are expected.

Relevancies

Aging increases the likelihood of prostate and breast cancer. Treatment of both conditions entails surgery and radiation and can lead to treatment-related lymphedema. Male breast cancer has a uni-modal age of onset at about 70 years and has a more severe cancer staging at the time of diagnosis. Such high cancer stages at diagnosis often require aggressive treatment regimens, thereby increasing the likelihood of post-treatment lymphedema. Since, undiagnosed lymphedema worsens with time, the earlier that it is detected and treated the better the outcome. Prior work targeted early detection using TDC measurements only on female breast cancer related lymphedema as TDC values are directly related to skin water content, thereby registering changes in tissue water. Aging is also associated with intrinsic and UV-induced skin changes that alter skin structural properties, mechanical properties, as well as water content and state; thereby likely affecting TDC values. As the skin ages, water is no longer bound to proteins and other macromolecules, and begins to adopt a more mobile or "free" state. Water in this free state is associated with higher dielectric constant thus potentially resulting in a higher TDC value as skin ages.

What is Tissue Dielectric Constant?

Dielectric constant or relative permittivity is a dimensionless number equal to the ratio of tissue permittivity to vacuum permittivity. Because TDC values mainly depend on tissue water content, the value and its change may give rise to water content as well as change in content. TDC values at a frequency of 300 MHz are sensitive to both free and bound water. Measuring of the bound water component is important as up to 80–90% of young adult skin water content is bound although this percentage may decrease substantially with aging. In practice, we utilized the MoistureMeterD (figure1) which generates and transmits a very low power 300 MHz signal into the skin. Part of the signal is absorbed by tissue water, and the remaining signal is reflected back into the MoistureMeterD which calculates the TDC based off of reflection coefficient. Changing the diameter of the probe changes the effective depth of measurement.

Goals of the Study

We aim to test the hypothesis that there is an age-dependence increase in TDC which can be detectable at various depths below the skin surface. A second aim was to provide initial reference TDC ranges suitable for use with young and especially older men as no such data is currently available for older males.

TDC Measurement

TDC measurements were made with the MoistureMeterD (figure1). This device measures TDC by touching skin with a small hand-held probe for about 10s. Four probes ranging in diameter from 10mm to 0.5mm were used, giving an effective measurement depth of 0.5, 1.5, 2.5 and 5.0 mm. Measurements were taken with subjects seated with arms resting palms up on a lap pillow after they had been resting for at least 5 min. Measurement sites were both volar forearms 6 cm distal to the antecubital fossa. Probe placement was such to avoid any visible surface veins in areas virtually free of heavy hair growth. Measurements were alternated between each arm until three values per arm were obtained for each depth. After all TDC measurements were completed, the girth of the forearms at the previously measured TDC sites were measured using a tape measure. Biceps girth was also measured in the same way 8 cm proximal to the antecubital fossa. The subjects were then asked to remove their shoes and socks and to stand on a scale for the purpose of measuring their weight and various body composition parameters via 50KHz bioimpedance measurements. Subjects stood barefoot on the scale during which time they gripped an electrode in each hand. Parameters measured can be found in Table 1. Total and segmental percentages were determined using specific algorithms within the device based on the whole body and segmental bioimpedance values.

Subjects

Male volunteers (N = 60) were divided into three age groups (young, older, and oldest referred to as A, B, and C respectively) of 20 subjects each with the rationale for age groupings to have three non-overlapping age groups. Group age ranges were for young, 22–25; for older, 26–56; and for oldest, 62–92 years, with corresponding group mean ages (mean±SD) of 24.0±0.9, 40.0±12.9 and 71.0±8.0, respectively. Due to grouping rationale a greater variation in ages within the 'older' group was present. Subjects were evaluated after the research nature of the study was explained to them, and they had signed an informed consent that was previously approved by the University IRB. Exclusionary criteria for participation were if subjects had any known skin condition affecting forearm skin, any open wound on either arm or any prior arm trauma that might have affected tissue water or previous breast cancer treatment, or lymph node resection for any purpose or had a cardiac pacemaker. No subjects who volunteered were excluded.

Figure 1: MoistureMeterD

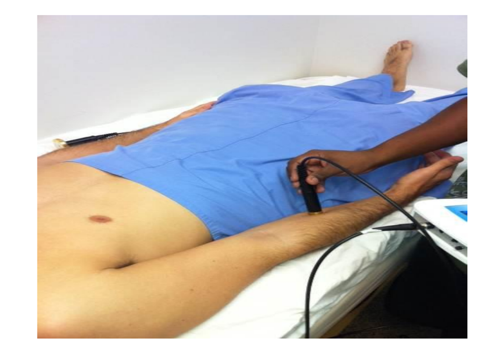

Figure 2: Forearm TDC Measurement

Results

Body Composition Parameters

Table 1 summarizes the main body composition parameters for each age group. Except for total weight and BMI values, the oldest group was significantly different in comparison to the young or young and older groups with the oldest group having less total body water percentage, arm girths, and muscle mass and greater whole body and arm fat percentages.

	A	B	C	P-Value
Age (years)	24.0	40.0	71.0	<0.001
Weight (Kg)	81.8	89.9	80.6	0.072
BMI (Kg/m2)	25.2	28.0	26.8	0.098
Body Water (%)	59.1	55.4	53.7	<0.010
Body Fat (%)	16.5	22.0	25.0	<0.010
Arm Fat (%)	17.0	21.2	23.2	<0.010
MM Arms (Lbs)	8.1	8.3	6.7	<0.001
MM Total (Lbs)	141.4	144.8	125.9	<0.001
Girth Forearm (cm)	27.1	28.3	26.0	<0.01
Girth Biceps (cm)	29.6	30.2	27.5	<0.01

Table 1: Body Composition Parameters

TDC Absolute Values

Figure 2 summarizes the age and depth dependence of measured TDC values for each of the age groups. For each age group, TDC arm average values decreased with increasing effective measurement depth (P < 0.001). With respect to age-related differences, only TDC values measured to a depth of 0.5 mm proved to be significantly age dependent with a significantly greater value for the oldest age group (P < 0.01).

TDC Depth (mm)	A	B	C	Combined Group	2.5 SD Threshold
0.5	0.985 ±0.073	1.010 ±0.082	1.005 ±0.075	1.000 ±0.076	1.19
1.5	0.992 ±0.058	1.017 ±0.076	1.010 ±0.070	1.006 ±0.068	1.18
2.5	0.989 ±0.072	1.028 ±0.105	0.996 ±0.079	0.988 ±0.093	1.22
5.0	0.948 ±0.098	1.023 ±0.125	0.985 ±0.105	0.985 ±0.105	1.25

Table 2: I-AR Values are ratios of TDC values (mean SD) of dominant to non-dominant forearms

TDC Ratios

In contrast to the depth dependence of TDC values, inter-arm ratios (I-AR) were not dependent on depth or age with all ratio values summarized in Table 2 with no difference in ratios among age groups for any depth or any difference in ratios among depths for each age group. By including the data for all 60 subjects, an overall I-AR based on 60 subjects could be determined with values shown in Table 1. From these data, a conservative threshold ratio for detecting the presence of unilateral edema or lymphedema can be calculated by adding to the overall mean ratio a value of 2 5 SD. Threshold ratios calculated in this way range from 1.18 to 1.25 as shown in Table 2.

TDC Depth (mm)	A	B	C
0.5	-0.438 (0.05)	-0.366 (0.11)	-0.564 (0.010)
1.5	-0.450 (0.04)	-0.481 (0.03)	-0.545 (0.013)
2.5	-0.648 (0.002)	-0.519 (0.019)	-0.643 (0.002)
5.0	-0.745 (0.001)	-0.639 (0.002)	-0.720 (0.001)

Table 3: Correlation Coefficients between TDC values, total body fat percentages, and associated (P-Value)

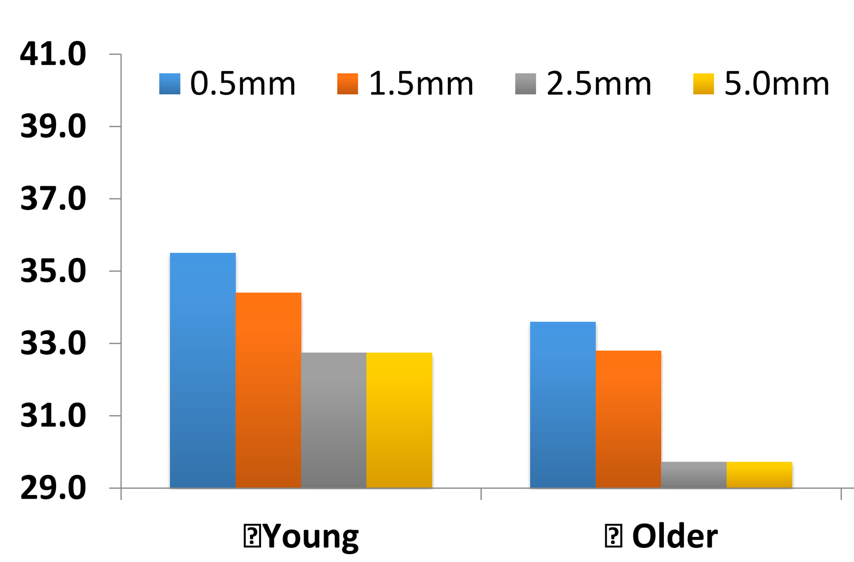

Figure 4: TDC Values by Age group

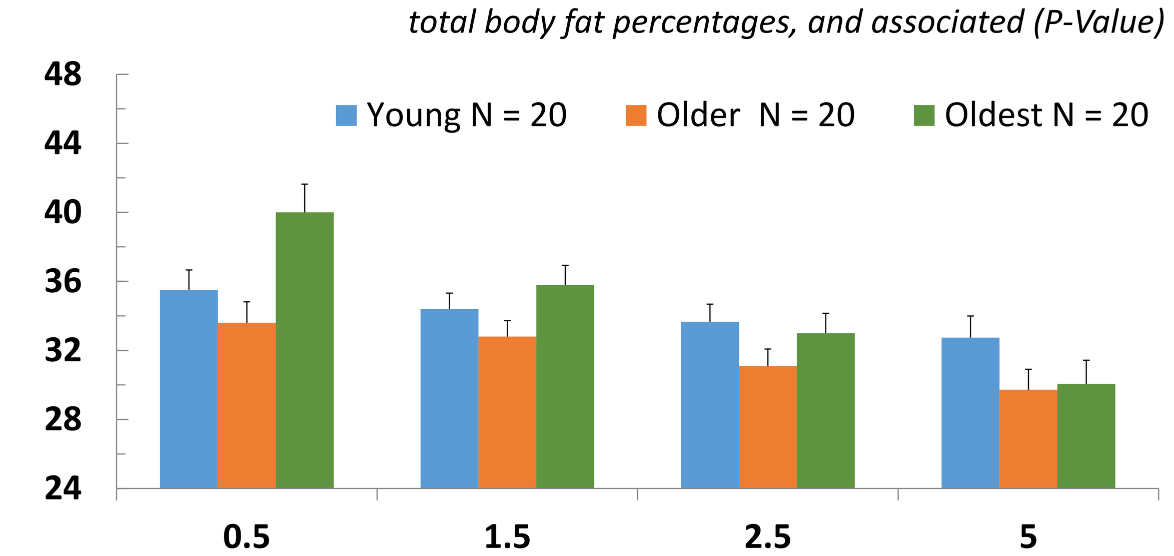

Figure 3: TDC Values by depth and age group.

TDC Dependence on Measurement Depth

Absolute TDC values decreased significantly with depth. This is expected since glycosaminoglycans, that have their greatest number just beneath the epidermis, have their concentration decrease with increasing skin depth. These proteins can bind up to 1000 times their volume in water. Also epidermal skin has at least twice the amount of mobile water as dermal skin. As TDC values are based on % of free and bound water, a decreasing TDC value is expected. With greater depths, more subcutaneous fat contributes to the measurement and a lower TDC is generated with increasing depth in the forearm.

TDC Age-Related Dependence

One new finding is that age-related differences in TDC occur only in the oldest group and only within the skin depth of 0.5 mm (Fig. 3). This depth includes dermal regions in which age-related shifts in water state from mostly bound to increasing amounts of free water content has been reported. This shift depends on the fact that in young skin water exists mainly in a bound state attached to proteins, but as skin ages altered protein folding causes water to bind to itself. Thus, our finding are consistent with such a water state shift as mobile water has a greater dielectric constant than does bound water. The fact that a greater TDC value is evident only to a depth of 0.5 mm may be due to including increasing amounts of low water content fat with depth. TDC measurements to a depth of 0.5 mm would include the epidermis and part of the dermis, but measurements to 1.5 mm and below include dermis and include increasing % of hypodermis with its low water content fat. The expected increase in TDC values due to age related changes may be blunted when using a deeper measurement depth. This may explain the non-significant difference in TDC values between age groups at greater depths. It is unlikely that reported ventral forearm dermis thickness reductions would be involved as a preferentially greater reduction of oldest skin thickness would tend to reduce not elevate TDC values at all depths. Another possibility for the selective age-related increase in TDC at the shallowest depth is an age-related loss of lamellar bodies. An associated decrease in total lipid content might increase the TDC due to increased water to lipid ratio only at the most shallow depth. It is also possible that photo-ageing effects, which hasten the transition from mobile to free water, were most dominant in the oldest subjects thus affecting shallower depths.

TDC Dependence on Body Composition

The older group had more whole body and arm fat and less body water and muscle mass than young (Table 1). Data reveals that body composition influences TDC values but does not affect age-related differences. A new finding was that TDC values were highly correlated with body composition and that the strength of the correlations increased with increasing depth (Table 3). The negative correlation between TDC values and total body fat % is consistent with increased contributions of low-water containing fat at greater depths. So, assessments of TDC values in various populations should keep body composition in mind as possible confounding factors.

TDC Inter-Arm Ratios

Another result is the set of reference values for inter-arm TDC ratios for males of various ages (Table 2). Such values are used to assess early breast cancer treatment-related lymphedema in females, with threshold values ranging from 1.2-1.3. Here, male TDC inter-arm ratios did not differ by depth or age group. Results suggest an inter-arm TDC ratio based on 2.5 SD of 1.25 to be taken as a strong likelihood of for sub-clinical edema/lymphedema. This is based on variations from a normal population and needs to be verified. Also, the selection of 2.5 SD is arbitrary but includes 99.5% of cases.