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Gender differences in facial skin dielectric constant measured at 300 MHz

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Background/purpose: Skin tissue dielectric constant (TDC) measurements at 300 MHz provide non-invasive data on free and bound tissue water. TDC-data is available for some body sites, but most is for female forearm. Contrastingly, there are no data on face-skin or comparative data between genders. Our goals were to obtain facial-TDC reference values and determine if TDC-values differ between genders.

Methods: TDC was measured at forehead, cheek, and forearm in 60 young adults (30 men) to a 1.5-mm depth. Measured TDC-values were compared with TDC-values calculated using skin-thickness data.

Results: Measured TDC-values ranged from 39.6 ± 2.9 at male-forehead to 28.2 ± 2.4 at female forearm and were significantly different ($P < 0.001$) among each site in the order forehead > cheek >forearm. Male TDC-values were greater than female TDC-values ($P < 0.01$) with differences from 5.6% at forehead to 11.3% at forearm. Calculated TDC-values incorporating site and gender skin-thickness differences yielded TDC-values at the most 3% different from measured values.

Conclusion: Gender differences should be considered in clinical studies in which men and women are included in a common study population with respect to experimental design and data interpretation. This is especially true if absolute TDC-values are of interest rather than changes in TDC-values on the same subject subsequent secondary to an intervention.

Key words: face skin – dielectric constant – skin water – skin thickness – skin hydration – skin moisturization

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Tissue dielectric constant (TDC) measurements at a frequency of 300 MHz via the coaxial line reflection method (1–5) provide non-invasive data on free and bound skin local tissue water to effective measurement depths of 0.5–5.0 mm. The method has been used to determine TDC values with skin irritation (6), skin irradiation (7), hemodialysis (8), post cardiac surgery (9), weight loss(10), menstrual cycle (11) and lymphedema (12,13). TDC measurement regions have included breast (7), leg (9,14), thorax, and upper arm (15) but most studies have used the female forearm (12,16,17), mainly for its importance in matters related to arm lymphedema. A region not previously characterized via skin dielectric measurements is the face. There are various conditions and circumstances for which facial skin water and its change is of clinical interest (18–25) and for which rapid local non-invasive TDC measurements might be useful with respect to assessing facial skin protection strategies (26). Previous work using other biophysical measurements, including transepidermal water loss (TEWL) and stratum corneum capacitance, have shown variations in values among facial skin sites (27,28) and regional differences in facial skin thickness (29) and blood flow (30). However, normal TDC reference values for the face and their variance have not been previously reported. Because of a greater skin thickness in men in certain anatomic areas (31–37) one might hypothesize the presence of male–female differences in skin tissue water as assessed by TDC. Indeed, some evidence of a gender difference in TDC values has recently been reported for forearm TDC values (38) with the possibility of variations among different forearm locations (39). Thus, the goals of this study were to obtain normative facial TDC reference data to determine if facial TDC values differed between genders and to determine if TDC values differ among measured anatomic sites.

Methods

Subjects

Sixty volunteer subjects participated in this study (30 men and 30 women) and were evaluated after signing an Institutional Review Board approved informed consent. Requirements for participation were that subjects be at least 18-years old and have no self-reported or visual evidence of any abnormal skin condition at the time of evaluation. Men were required to be clean shaven at least 4 h prior to their scheduled evaluation. Women were required to refrain from using body lotions or creams on their evaluation day. Ages of men vs. women were (mean ± SD) not significantly different (25.6 ± 2.9 vs. 26.3 ± 4.4 years, P = 0.51). Body mass index (BMI) of men vs. women was also not significantly different (25.3 ± 4.3 vs. 24.5 ± 4.2 Kg/m^2, P = 0.435). Table 1 summarizes pertinent physical features of male and female subjects..

TDC measurement device

The device used to measure TDC was the MoistureMeter-D (Delfin Technologies Ltd, Kuopio, Finland). It consists of a cylindrical probe connected to a control unit that displays the TDC value when the probe is placed in contact with skin. The physics and operating principles have been well described (1,2,4,5,40). In brief, a 300 MHz signal is generated within the control unit and transmitted to tissue via the probe that is in contact with skin. The probe acts as an open-ended coaxial transmission line (1,4). The portion of the incident electromagnetic wave that is reflected depends in part on the dielectric constant of the tissue, which itself depends on the amount of free and bound water in the tissue volume through which the wave passes. Reflected wave information is processed within a control unit and the dielectric constant is displayed. For reference, pure water at a temperature of 34°C has a value of about 75.2. The effective measurement depth depends on probe dimensions, with larger spacing between inner and outer conductors corresponding to greater penetration depths. In the present study, a probe with an effective measurement depth of 1.5 mm was used. This probe has an outside diameter of 20 mm with 3 mm spacing between inner and outer concentric conductors.

TABLE 1. Subjects

	Men (*N* = 30)	Women (*N* = 30)	*P*-value
Age (years)	25.6 ± 2.9	26.3 ± 4.4	0.512
Height (m)	1.78 ± 0.11	1.62 ± 0.08	<0.001
Weight (Kg)	79.8 ± 12.2	64.3 ± 13.6	<0.001
BMI (Kg/m^2)	25.4 ± 4.3	24.5 ± 4.2	0.435
Underweight	1 (3.3%)	1 (3.3%)	
Normal weight	15 (50%)	17 (56.6%)	
Overweight	9 (30%)	7 (23.3%)	
Obese	5 (16.7%)	5 (16.7%)	
Right hand dominant	29/30 (96.7%)	29/30 (96.7%)	

Entries are mean ± SD.
Underweight = BMI <18.5 Kg/m^2.
Normal weight = BMI 18.5–24.9 Kg/m^2.
Overweight = BMI 25–29.9 Kg/m^2.
Obese = BMI $\geq$30 Kg/m^2.
Hand dominance is subject self-reported.

TDC measurement procedure

Measurements were done with subjects supine and were started after a 15-min acclimation rest interval. Facial TDC measurements were made on the forehead, 2 cm above the left eye brow and on the left cheek at the level of the lip measured 4 cm from its left edge. In addition, TDC was measured on the left anterior forearm midline 8 cm distal to the antecubital crease. Each site to be measured was marked with a dot to serve as a reference center point for probe placement. A single measurement was obtained by placing the probe in contact with the skin and held in position using gentle pressure. After about 10 s an audible signal indicated completion of the measurement. Second and then third measurements were made at the same sites with 60 s elapsing between the start of subsequent measurements yielding triplicate sequential measurements at each site. The average of these three measurements was calculated and used to characterize the TDC value at that site. Skin temperatures at the TDC measurement sites were determined using a non-contact infrared thermometer. Temperature and relative humidity of the room in which evaluations were done were (mean ± SD) 25.4 ± 1.3°C and 34.5 ± 4.0% at measurement sequence start and 25.0 ± 1.0°C and 34.6 ± 3.8% at the end of the measurement sequence.

Analysis

Comparisons of TDC values among sites were done for each gender separately using analysis of variance with the three sites (forehead, cheek and forearm) as factors included in the model. Tests for gender differences in TDC values at each site were done using independent t-tests. A *P*-value less than 0.05 was *a priori* set as the threshold level for a significant difference between groups and among sites.

Results

Comparisons of TDC values among sites showed an overall significant difference ($P < 0.001$) between sites for both men and women (Table 2) with TDC values at forehead greater than at cheek ($P < 0.001$) and values at cheek greater than at forearm ($P < 0.001$). Percentage differences in TDC values between forehead and forearm for men vs. women were 29.0 ± 10.8% vs. 32.5 ± 10.8%, $P = 0.219$ and between forehead and cheek were (10.0 ± 14.0% vs. 15.3 ± 14.9%, $P = 0.243$). Analysis of male vs. female difference at each site showed that TDC values of male skin were significantly greater than TDC values for corresponding sites of females skin at each measured site (Table 2). Average male TDC values exceeded female values by 5.6% at forehead, 9.5% at cheek and 11.3% at forearm.

Discussion

An easily used non-invasive method to assess skin tissue dielectric constant (TDC) provides a useful tool to investigate physiologically and clinically related conditions in which changes in tissue water or the tissue dielectric constant itself are of interest. Although a variety of applications of this method have been described (7,9,11,12,17,41,42) there have been no reports characterizing facial skin TDC values and only one report describing male–female TDC differences (38). As skin thickness (epidermis + dermis) of men tends to be greater than for women (31–34,37) possible skin thickness effects on TDC values is unclear. Thus, the present study was undertaken to characterize facial TDC values and to determine if there were associated male–female differences in skin TDC.

The main new results showed that (1) TDC values obtained on forehead, cheek and forearm skin differed significantly from each other in the order of forehead > cheek > forearm and (2) TDC values were significantly greater in men than women at all sites with percentage differences between genders increasing in the order forearm > cheek > forehead.

Although TDC values depend on tissue water content (8), and the TDC values herein were greater in men than women, it is important to note that the present data should not be interpreted as clearly indicating that the entire difference in TDC values is attributable to differences in water content of male vs. female skin. Reasons for the ambiguity are related to measurement considerations and to considerations of male vs. female differences in skin thickness. Male skin at each of the currently measured sites has been reported to be thicker than female skin (see Table 3) and thus more low water content subcutaneous fat may be included in the TDC measurement volume for women.

TABLE 2. Measured tissue dielectric constant (TDC) values among sites and between genders

Group	Forehead	Cheek	Forearm
Men(N = 30)	39.6 ± 2.7	35.9 ± 4.9	31.5 ± 3.2
Women(N = 30)	37.4 ± 3.3	32.8 ± 3.8	28.3 ± 2.4
P-value	0.001	0.009	<0.001
Difference (%)	[5.6%]	[9.5%]	[11.3%]

Table entries are TDC values (mean ± SD) measured to an effective skin depth of 1.5 mm.
Entries in brackets [] are mean percentage differences between men and women.
Values among sites differed significantly ($P < 0.001$) in the order of forehead > cheek > forearm.
Cheek and forearm values for men were significantly greater than for women.

Methods considerations

With the current method, a probe in contact with the skin measures a tissue dielectric con-

TABLE 3. Skin thickness values from literature

Skin Thickness (mm)	Women	Men
	1.56 (50)	
	1.50 (51)	1.85 (50)
	1.55 (52)	1.85 (51)
	1.70 (29)	
Forehead	[1.58]	[1.85]
	1.45 (51)	1.85 (51)
	1.04 (37)	1.24 (37)
Cheek	[1.25]	[1.55]
	1.08 (50)	1.32 (50)
	0.90 (51)	1.15 (51)
	0.87 (37)	1.17 (37)
	1.05 (52)	
	0.95 (53)	
	0.97 (32)	[1.21]
	0.93 (54)	
Forearm	[0.96]	

Table entries are skin thickness values in mm. Numbers in parentheses () are the reference number.
Numbers in brackets [] are the average of the values for a given site and gender.

stant that depends on the electrical properties of all tissues within the effective measurement depth that has been defined as the depth at which the induced electric field falls to 1/e of its surface value (8). For the probe used in the present study this effective measuring depth is about 1.5 mm and includes skin (epidermis + dermis) and some subcutaneous fat. The thinner the skin, the more is the relative amount of subcutaneous fat that would be included in the measurement. Further, the relative water content of these components is not uniform. Stratum corneum and fat have relatively low water content in comparison to the dermis, but even within the epidermis and dermis water distribution is not uniform. Within the epidermis, the gradual transition from below the corneum to basal cell layers is accompanied by a water content that increases from about 20% to about 70% (43). Within the dermis, superficial papillary and deep reticular regions also differ in their water content (44,45) with an average dermal water fraction of about 70% in contrast to about 10% in subcutaneous fat (46). Thus, the TDC value obtained with the present method reflects to varying degrees the differing water contents within the measurement volume.

Skin thickness considerations

The extent to which site and gender related skin thickness differences could have affected the TDC values in the present study can be estimated using the formula (3,42) derived for a two layer model composed of an upper skin layer and lower fat layer. Accordingly, TDC values were shown to be expressible in terms of skin and fat dielectric constants (ε_s and ε_f), skin thickness (epidermis and dermis) δ, and a probe specific calibration factor q as $TDC = (\varepsilon_s - \varepsilon_f)(1 - e^{-q\delta}) + \varepsilon_f$. Although the main focus of the present study was on the totally measured TDC value as reflective of all measured tissue components, the above relationship can be used to estimate the extent to which site and gender differences in estimated skin thickness may affect the measured TDC value by considering representative parameter values reported in the literature. Previous measurements of dielectric constant values of skin and adipose tissue at 300 MHz (47,48) allow estimation of the dielectric constant values for forearm skin (ε_s) and fat (ε_f) to be 48 and 6, respectively. If it is assumed that for equal water contents ε_s and ε_f are equal for men and women, then the effect of skin thickness differences can be estimated using representative skin thickness values together with the probe-specific calibration factor provided by the device's manufacturer ($q = 0.82$). Skin thickness values based on the literature are shown in Table 3. For each site and gender these values were averaged and used in the TDC equation yielding calculated results as shown in Table 4. Comparison of these calculated values with those measured (Table 2) indicates that the calculated pattern of differences among sites and differences between genders nearly replicate those measured when the calculated TDC values take into account reported skin thickness differences among sites and between genders. Thus, the calculated values are sufficiently close to measured male–female values which indicate that the measured male–female TDC differences could be easily explained on the basis of male–female differences in skin thickness as with male–female differences in tissue water content. To distinguish between these possibilities would require co-measured values of TDC and skin thickness which was not part of the present protocol.

Site and gender variations in TDC values

For the young adult population investigated, TDC values were greatest at forehead, intermediate at cheek and least at forearm. At all sites the TDC values were greater for men than women. Female forearm TDC values (28.3 ± 2.4) for the present female group was similar to, but slightly less than the value (31.4 ± 5.2) reported for women with a greater mean age of (51.3 ± 18.0 years) (16). This lower value is consistent with the reported finding that TDC values at measuring depths up to 1.5 mm

TABLE 4. Calculated tissue dielectric constant (TDC) values

Group	Forehead	Cheek	Forearm
Male	38.8	36.2	32.4
Female	36.5	32.9	28.9
Difference (%)	[6.3%]	[10.0%]	[12.3%]

Table entries are TDC values calculated based on the equation $TDC = (\varepsilon_s - \varepsilon_f)(1 - e^{-q\delta}) + \varepsilon_f$ with $\varepsilon_s = 48$, $\varepsilon_f = 6$, q = 0.82.
δ the skin thickness using the average values from Table 3.
Entries in brackets [] are calculated percentage differences between men and women.

increase with increasing age (16). Comparative data for male forearm or facial TDC values are not yet available in the literature.

Other factors that might explain the measured site dependent pattern from forehead to forearm and gender differences in TDC values include possible differentials in skin temperature and stratum corneum hydration. Skin temperatures at corresponding sites (forehead, cheek and forearm) were similar for men and women with combined values (N = 60) at forehead, cheek and forearm being respectively 34.2 ± 0.6°C, 33.5 ± 0.8°C and 32.5 ± 1.1°C. For these temperatures, water's dielectric constant is 75.2 and 75.5 and 75.8, respectively. These differences are small and in the wrong direction to explain the greater forehead and lower forearm TDC values. Skin capacitance measurements, as indices of stratum corneum water, indicate forehead and cheek values are not different (49) suggesting that differences in stratum corneum water are not important factors for the TDC differences observed between face sites.

Summary and Conclusion

Significant differences in TDC values were measured at 300 MHz among forehead, cheek and forearm and at each site between genders with male TDC values greater than female TDC values. These findings alone suggest that when TDC measurements are used in research or clinical studies in which both men and women are included in a common study population, these differences may represent an important consideration in both experiment design and data interpretation. This would be especially true if it were absolute TDC values that were of interest rather than changes in TDC values on the same subject subsequent to time passage or secondary to an intervention. Further, because the calculated TDC values based on differences in reported skin thicknesses yield a site and gender pattern of TDC differences that closely match the average measured TDC values, one should not assume that the values herein reported are completely indicative of differences in skin water content. In fact, the measured male–female TDC differences could as easily be explained on the basis of male–female differences in skin thickness as they could be explained by male–female differences in tissue water content. To distinguish between these possibilities would require co-measured values of TDC and skin thickness which was not part of the present protocol.

As the present findings are based on TDC values obtained to an approximate measurement depth of 1.5 mm, it is unknown whether similar site and male–female differences would be obtained for more shallow or for deeper measurement depths. If the male–female difference herein measured is due to mainly or exclusively because of the smaller skin thickness of females, then the prediction is that such differences would be much reduced or eliminated for measurement depths that only include the epidermis and dermis. Contrastingly if the measured differences are mainly due to differences in skin tissue water then for the same shallow measurements the prediction is that the male–female differences would remain greater, although perhaps not of the same magnitude as herein measured. Future additional investigative efforts to further study these aspects would appear warranted.

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