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Abstract. Beta dispersion is found in living tissue in the kilohertz – megahertz range and is caused by the cellular structure of biological materials with low frequency properties caused by cell membranes. Alpha dispersion is found in the hertz range and the causes are not so well known. Alpha dispersions are the first to disappear when tissue dies. Tissue data have often been based upon excised specimen from animals and are therefore not necessarily representative for human tissue alpha dispersions. Here we present data obtained with non-invasive skin surface electrodes for different segments of the living human body. We found alpha dispersions in all cases; the ankle-wrist results had the smallest. Large alpha dispersions were found where the distance between the electrodes and muscle masses was small, e.g. on the calf. Further studies on electrode technique and reciprocity, electrode positioning, statistical variations, gender, age and bodily constitutions are necessary in order to reveal more about the alpha dispersion, its appearance and disappearance.

1. Introduction

Schwan [1] introduced three dispersion mechanisms (α, β, γ) to characterize the anomalous electric properties of biomaterials[1]. He linked the β dispersion with the cellular structure of biological materials with low frequency properties caused by cell membranes. He proposed that the α dispersion was due to surface admittance (lateral to the membrane surface). If this is correct the alpha dispersion should be less dependent on the intracellular content but more dependent on the complex membrane surface structures. α dispersion is more sensitive to age and environmental factors than β dispersion [1].

Basically the dispersion concept was defined according to the mechanism causing dispersion. If the generating mechanisms are different it is important to know what dispersion type measured data belongs to. Alpha dispersion can be found down to below 1 Hz and up to 100 kHz [1]. But the mechanisms behind dispersions are often unclear or unknown, and the dispersion grouping has also been based upon simply a defined frequency range. Loosening the link to mechanisms weakens the concept of dispersions and some its usefulness for bioimpedance research may get lost.

It is the purpose of this paper to look for and characterize alpha dispersions in human in-vivo and in-situ data.

2. Method

The following tissue volumes were examined with a 4-electrode technique: The forearm for the short distance to small muscle masses. The thigh for the short distance to large muscle masses and the calf for the shortest distance to large muscle masses; the "whole body" heel-to-wrist segment; the forehead for the small muscles masses and short distance to the low conductivity skull. The 4 electrodes were positioned

[1] Alpha in this paper is the name of a dispersion, but still it is sometimes confused with the alpha angle in Cole and Cole-Cole equations.

on a straight line on the chosen skin area. No skin preparations were used, and the electrodes had a more than 15 min contact period before measurements started.

Two types of AgCl electrodes were used: 1) Solid gel contact disk of radius 1,25 cm and skin contact area 4,9 cm^2 (Tyco, Kendall, KittyCat model 1050NPSM small). The solid gel surface adhered directly to the skin. The solid gel together with a cloth ring formed the rim of the electrode. Used for all results except those shown on figure 1 right and figure 3 left. 2) Wet gel model with skin wetted area ≈3 cm^2 and an outer plaster ring (Ambu Medicotest Blue Sensor model Q-00-A).

Transfer complex impedance was measured with a Solartron 1260/1294 system in the frequency range from 1 (or 0,1) Hz to 1 MHz. The current carrying (CC) pair was excited with a constant voltage of 0,5 or 1 V rms. With 1 V rms excitation voltage the excitation current was about 15 μA at the lowest frequencies, increasing to about 1 mA at the highest frequencies. Throughout the frequency spectrum the current was too small to be sensed by the test person. This excitation modus is preferred because the current level is adapted to linearity and current perception thresholds: the lower the frequency the lower the current density threshold of non-linearity [2] and perception [3].

The complex admittance locus curve was shown in the Wessel plane [4] and visually inspected for dispersions in the form of circular arcs. Y-plots were preferred to Z-plots because of the better balance between the size of the alpha and beta arcs.

Quality control

In the Wessel plane plots most admittance loci of figures 1-3 showed negative phase at the highest frequencies. Positive phase impedance (negative admittance) at high frequencies is often found in 4-electrode systems [5]. In the results presented here it is linked with the impedance contribution of the self-inductance of the measured volume and the leads combined with the low transfer impedance values measured. The range of linearity was examined and maximum excitation voltage applied to the CC electrodes was 1 V rms (3V for figure 1 right side). Bode diagrams (not shown here) were controlled with the Kramers-Kronig rule [4] (falling impedance with increasing frequency shall correspond to negative phase angles and visa versa). All results were Kramers-Kronig compatible. Reciprocity was controlled by swapping the PU and CC pairs to check that the same spectra were obtained. Reciprocity failed at the lowest frequencies, the reason for this is not clear and will be pursued further.

3. Results

Forearm

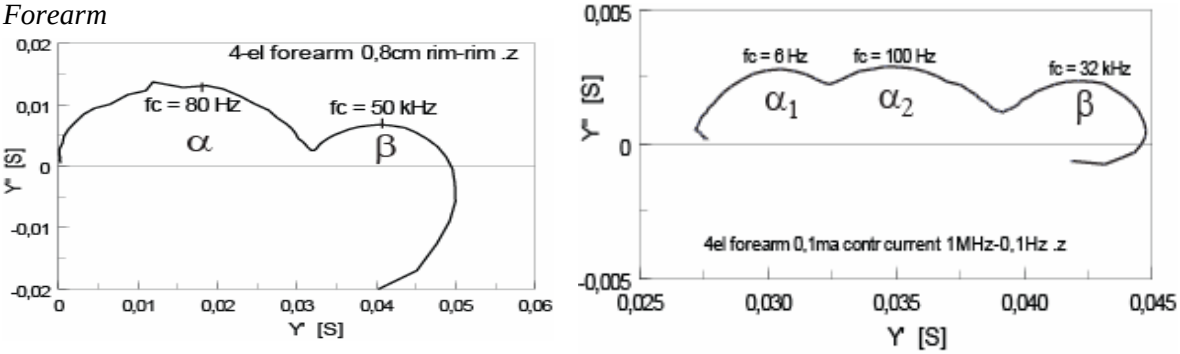

Figure 1 Wessel plane Y-plots. PU and CC pairs in line at the ventral side of the forearm. Left: equal 3,3 cm center to center distance. Right: equal 5 cm center to center distance, wet gel electrodes.

Figure 1 left illustrates the noisier curve form often found at lower frequencies in the alpha region. The low-frequency part of the alpha segment approaches the origin, illustrating small DC conductance as often found when an electrode line is not parallel to e.g. muscle fiber directions (anisotropy).

The plot to the right was obtained driving the instrumentation in controlled current mode at 100 μA. Two clear alpha dispersions at 6 Hz and 100 Hz are seen.

Thigh and ankle-to-wrist segments

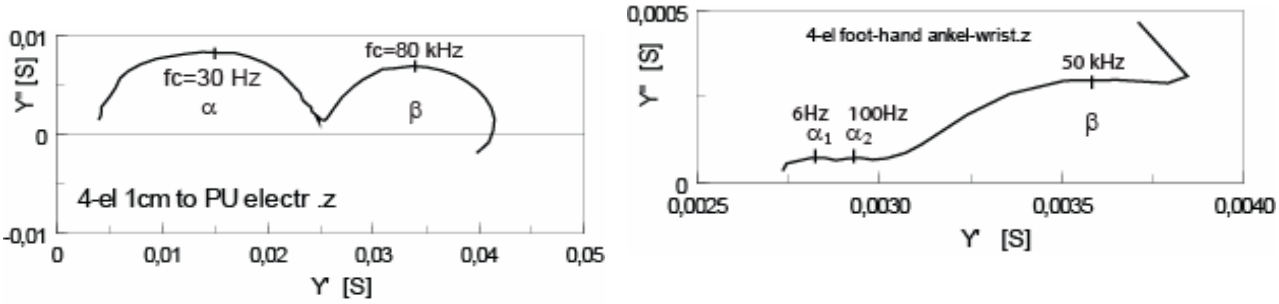

Figure 2 Wessel plane Y-plots. Left: PU and CC pairs placed at top of the thigh, PU electrodes 6 cm apart and CC electrodes at 1 cm rim-to-rim distance from the PU electrodes. Right: PU pair ankle-wrist, CC pair heel-hand.

Figure 2 left side shows a clear dispersion with the alpha dispersion having a sufficient DC conductance to make it probable that the electrode positioning line was parallel to the muscle fibers. Right side is from a large segment approaching a "whole body" segment comprising one arm, one leg and a part of the abdomen. The dispersions are small, the alpha dispersions hardly discernible.

Calf and forehead

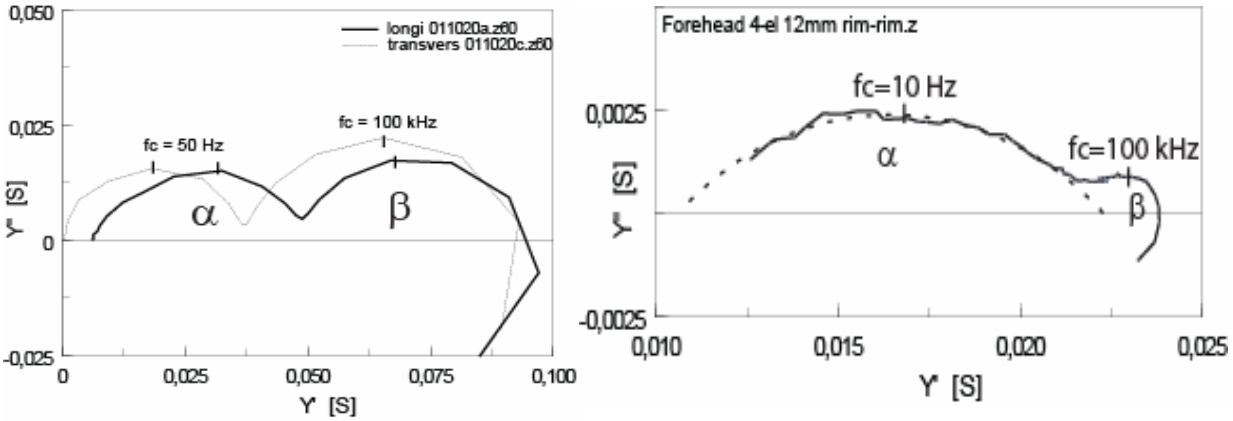

Figure 3 Wessel plane Y-plots. Left: Calf longitudinal: 4 wet electrodes in a line parallel to the muscle fiber direction. Calf perpendicular: 4 electrodes in a line transversal to the muscle fiber direction. Right: Forehead: Solid gel electrodes in line with equal 1,2 cm rim-to-rim distance.

On figure 3 left side the differences between the longitudinal and transversal dispersions are small: they have similar characteristic frequencies, the similar imaginary maximum values and the similar real value increments. The important difference is that the transversal curve has moved to the left approaching the

origin at the lowest frequencies, compatible with the often found low DC conductance in transversal measurements.

Figure 3 right side shows a result obtained with 4 electrodes positioned on the forehead with rim-to-rim distances of 1,2 cm. Excitation amplitude was 500 mV rms, and the low frequency part is noisy and a calculated regression circular arc is therefore included in the diagram for easier determination of the characteristic frequency.

4. Discussion and conclusions

Our results are in agreement with the notion that all living tissues have beta dispersions caused by their membranes. Our results with in-vivo non-invasive skin 4-electrode technique did show that all the measured cases also had at least one alpha dispersion even if they could be very small. It is well known and seen as slightly enigmatic that whole blood has beta- and gamma-dispersion, but no alpha dispersion [6]. Martinsen et al [7] measured impedance of haddock muscles for a period of 13 hours after the fish had been sacrificed. Most of the alpha dispersion disappeared after a few hours, while in the same period the low frequency end of the beta-dispersion increased. This is in agreement with our notion that alpha- and beta-dispersions are generated by different mechanisms, but both are related to the cell membranes of living tissue. Beta dispersion used for body composition measurements are based upon the well defined Maxwell-Wagner mechanism. Much of the work with body composition has been based upon beta-dispersion, and it is a question whether alpha dispersion actually gives additional information or on the contrary is just a disturbance for such measurements. Further studies on electrode technique and reciprocity, electrode positioning, statistical variations, gender, age and bodily constitutions are necessary in order to reveal more about the alpha dispersion, its appearance and disappearance.

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