Electrical Conductivity of Skin Compared to Skin Perfusion Recordings

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ABSTRACT

The electrical impedance between skin-electrodes placed at the intact skin can be a source of artefacts when small electrical voltages such as ECG- and EEG-signals are recorded. This is mainly due to random variations of the electrical properties of the electrode-skin interface. To reduce the effect of these shortcomings, the skin is prepared with conductive paste and sometimes stripped to remove the outer corneous layer of the skin at the sites where the electrodes are placed. That reduces the impedance between the electrode and the skin and subsues disturbing electrical signals emanating from external sources. Numerous electrical models have been presented in the literature in order to relate electrical parameters to physiological and anatomical properties of the skin and to counteract the distortion of electrical signals recorded from the skin surface. To meet these requirements flexible electrodes combined with biochemical sensors have been developed which seem to prepare the way for the future application of skin electrodes as a means of determination of skin parameters.

KEYWORDS

Body Plethysmography, Conductive Tissues, Electrical Models, Electro Cardiography, Electro Encephalography, Skin Perfusion

INTRODUCTION

The skin is the body’s largest organ and serves as a protective cover between the body and the environments. The anatomy of skin is illustrated in Sobotta & Becher (1976) and anatomy and skin functions are described in detail by Archer (2000).

The purpose of the present work is to demonstrate recordings of the electrical impedance between sets of electrodes positioned on specified sites of human skin and compare these results to skin perfusion data retrieved by heat transfer measurements at the same sites.

Measurement of the impedance of living tissue is generally done using a set of surface electrodes placed on the skin and connected to auxiliary circuits for the recording of the voltage between the electrodes and the corresponding current passing from one electrode to the other. The ratio between voltage and current is defined as the impedance $Z$. The type of electrodes used, the frequency and amplitude of the applied electrical current and the extent, anatomy and physiology of the tissue in question have all together influence on $Z$.

Birgersson (2012) measured the Impedance of human skin and developed a mathematical model to ascertain the validity of skin properties found in the literature. Wilson and Spence (1988) accounts for the anatomical and physiological properties of the skin and state a number of skin parameters with relation to heat transfer of skin. Cohen (1977) presents a review of existing data concerning heat

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conduction and the specific heat of excised and in vivo human skin. Johnsen (2010) deals extensively with electrical properties of skin and with the determination of water in keratinized skin tissues.

The outer layer of the skin is the “Epidermis”, which has a protective corneous layer called Stratum Corneum with very low electrical conductivity. Under the epidermis is a layer called the Dermis or Corium, containing the protein Collagen constituting connective tissue fibres. Corium also contains capillary blood- and lymph vessels, sensory organs, sweat glands and nerves providing essential information to the rest of the body which in turn regulates relevant functions of the skin. An example of this “Feed Back” function is the electrodermal activity (EDA) which affects the electrical conductivity of the skin (Critchley, 2002; Johnsen, 2010). Under the Dermis is a layer of subcutaneous fatcells (“Subcutis”) having low electrical conductivity. Impedance recordings can be influenced by underlying tissues such as bones, muscles and greater blood- and lymph vessels.

High electrical conductivity (low impedance) between electrodes and underlying skin and low inherent electrical noise level are important provisions for the recording of electrical signals such as ECG and EEG as described by Smith (1992); Assambo, Baba, Dozio et al. (2007); and Spach, Barr, Havstad et al. (1966). Skin temperature studies have been performed with the aim of retrieving data relevant to Cardiac Out Put presented among others by Schey, Williams and Bucknall (2009).

The present work deals with recordings of the impedance $Z$ between surface electrodes positioned on the skin covering the arched part of the human Musculus Tibialis Anterior and compare the results to skin perfusion data retrieved by means of heat transfer as described by Jarlov and Jensen (2014).

Formulas are developed empirically in order to retrieve the coefficient of electrical conductivity $\sigma$ and the thickness $h$ of the skin from recorded values of the impedance $Z$. For this purpose, numerous experimental recordings of $Z$ measured between electrodes placed on the surface of 0.1 to 0.8 cm thick slices of electrically conductive test material with known $\sigma$ are compared to results obtained from using the formulas.

**IMPEDEANCE MEASUREMENTS**

Figure 1 illustrates sets of surface electrodes with the mutual distance $a$ and diameter $d$. The electrodes are in electrical contact with the surface of a conductive isotropic layer containing an amount of 0.9% sodium chloride solution.

An alternating voltage $U_{AB}$ with the peak to peak value 0.500 Volts between the electrodes generates the current $I$ entering into the layer at one electrode and leaving the layer at the other. The impedance $Z$ can consequently be defined as:

$$Z = U_{AB} / I$$  \hspace{2cm} (1)

This definition of $Z$ must be related to the specific value of $U_{AB}$ because electrolytes behave in a nonlinear way with regard to the amplitude and frequency of the electrical current.

The coefficient of conductivity, $\sigma$, of the material and its thickness, $h$, were measured prior to the recording of $Z$. The measurements of $I$ were performed using a voltage clamp circuit outlined in Appendix 1. $Z$ and $\sigma$ may be complex numbers at high and low frequencies as described by Rosell, Colominas, Riu et al. (1988) because $U_{AB}$ and $I$, when conceived as vectors, exhibit phase angles.

Recordings performed at 1000 cps showed no phase angle as demonstrated in Figure 3, so $Z$ can be regarded as an ohmic (but nonlinear) resistance at this frequency. The material used were layers of goatskin (“Chamois”) prepared with a 0.9% Sodium Chloride (NaCl) solution which has $\sigma = 0.014$ mho cm$^{-1}$. Goatskin, which has a high content of collagen fibres was found to be more
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