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EDITORIAL ARTICLE

Impedance surprises

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I first started thinking about bioimpedance many years ago in the context of instruments claiming to be able to assess body fat, from measurements of the electrical resistance between hands and feet. The basis of the technique is that the major components of the body are firstly muscle, which has a low resistivity, and then fat which has a high resistivity. If you regard the body as a cylinder then the total resistance will depend upon the length and the area of cross-section of the body and also the average resistivity of the muscle and fat. You can estimate the length and cross-section from body height and weight and hence estimate the average resistivity from which the ratio of fat to muscle can be estimated. The idea is a nice one but one which is full of problems and assumptions. One problem is that our arms are thin whereas our legs are fatter and the trunk is even fatter. As a result our arms typically have a resistance of about 300 ohms, our legs less than 100 ohms and our trunk only about 20 ohms, and yet most of our fat tends to be in our trunk. There are other problems with the technique and lots of ways in which researchers have tried to tackle them but I have only raised the subject in order to put my mind back a few decades to when I first thought about how electricity flows through the body.

I soon discovered that thinking about the body as just having resistance was a simplification, because measured resistances are usually found to decrease with the frequency of the alternating current used to make the measurements, so we should talk about impedance rather than resistance. That raises the question as to why the body has an electrical impedance that falls with increasing frequency. It appears that we contain both resistive and capacitive components. I soon rationalised this in my mind by taking into account that tissue consists of cells and that these are bounded by high resistivity membranes and hence there is a capacitance between the inside and outside of every cell. The capacitance across cell membranes is remarkably high with values of about one micro Farad per square centimetre. The capacitance of cell membranes seems to offer a reasonable explanation as to why bioimpedance falls with increasing frequency – at least in the frequency range from about 100 Hz up to 1 MHz. At much higher frequencies we have to look for other explanations such as molecular absorption.

When I made *in vivo* bioimpedance measurements I found that impedances did indeed usually fall with increasing frequency, but in some cases the impedances seemed to rise slightly, particularly at higher frequencies. My first assumption was that the instrumentation must be at fault but this did not seem to be the case. My second thought was that perhaps there are inductive components to tissue in addition to the resistive and capacitive components. However, there is no obvious source of inductance in the body and in any case the inductances would have to be quite large to explain the increases in impedance that I observed. Eventually I realised that the impedance of a network of resistors and capacitors can indeed exhibit an impedance measurement that rises with frequency. If the network includes three or more RC combinations then the total phase shift at some frequencies will be greater than 180°. An alternating voltage applied between ground and one point of the network can give rise to a larger alternating voltage between another point in the network and ground. I found this to be most surprising but it is correct and it can often explain instabilities in the use of operational amplifiers, where what is thought to be feedback of less than unity is actually greater than unity.

When you start to make bioimpedance measurements you soon uncover surprising results such as the one I have described. There are other surprising aspects of bioimpedance measurements.