Measuring the electrical impedance of mouse brain cortex

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Introduction

The structure and connectivity of brain tissue is likely to influence its conductivity through the movement of ions intra- and extra-cellularly. By measuring conductivity, we can therefore make inferences about the tissue structure and function. For example, it has been suggested that conductivity could be a marker of impending seizure activity [1]. While measurements *in vivo* have been fairly common [2, 3], there have been few measurements made *in vitro*. We report on such measurements here.

Measurements

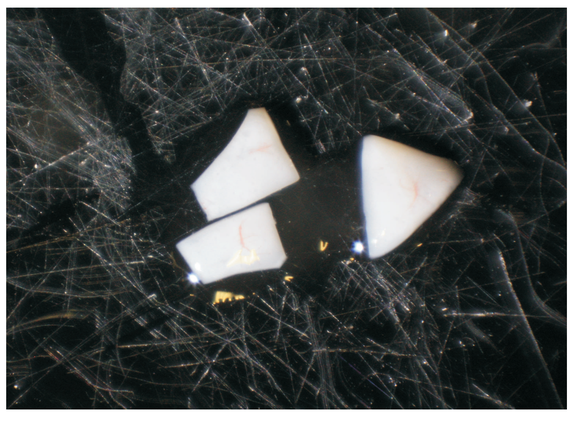
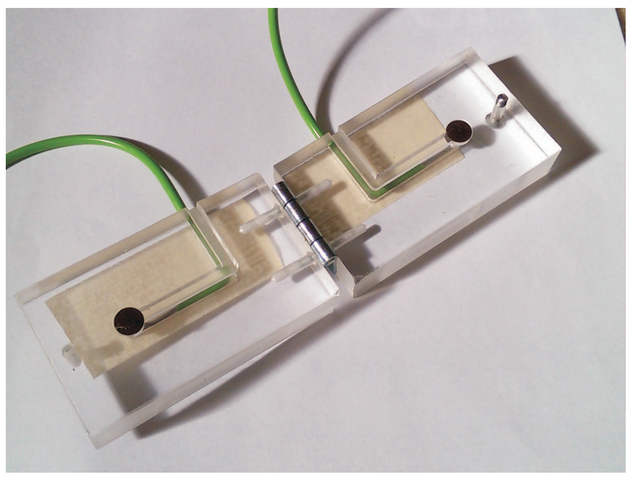


Figure 1. A photograph of cortical sections.

Preparation. Mouse brain slices of thickness 400 μm were prepared on a vibratome (Campden Instruments, U.K.) using standard procedures [4]. The slices were bathed in artificial cerebrospinal fluid (ACSF) to keep them alive. Slices were removed and sections of cortex approximately 2 mm$\times$2 mm were cut with a razor blade (Fig. 1).

They were photographed through a calibrated microscope and their areas identified with software (NIS-Elements BR).

Electrodes. Excess ACSF was removed from a section with tissue paper and the section placed within a sandwich device consisting of two Ag/AgCl electrodes (Fig. 2) separated by 400 μm. These are made from silver rod, chloridized chemically.



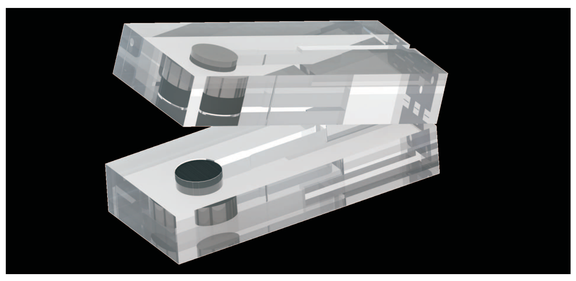


Figure 2. The sandwich device: design (above) and as built (left).

Temperature control. The temperature of the sandwich was held at 25°C using a Peltier device, heat pipe and Arduino-based PID control system. Thermocouples were placed inside and on the outer-surface of the sandwich.

Impedance measurement. Impedance was measured for frequencies (f) of 20 Hz to 2 MHz using an Agilent E4980A four-point impedance monitor in a shielded room. The bulk resistivity and permittivity characteristics of the i-th section, z_i (Ω m), can be calculated from the measured impedance Z_i using the thickness d (=400 μm) and area A_i:

$$z_i(f) = \frac{Z_i(f)d}{A_i}. \qquad (1)$$

Modelling

We consider a model based on the Cole-Cole model of dispersion using non-linear capacitative elements (Fig. 3). The bulk impedance z of the circuit as a function of angular frequency $\omega = 2\pi f$ is given by:

$$z(\omega) = R_1 + \frac{R_2}{1+(j\omega R_2 C_2)^{\beta_2}} + \frac{R_3}{1+(j\omega R_3 C_3)^{\beta_3}}. \qquad (2)$$

Two R-C units are required to model two regions of dispersion.

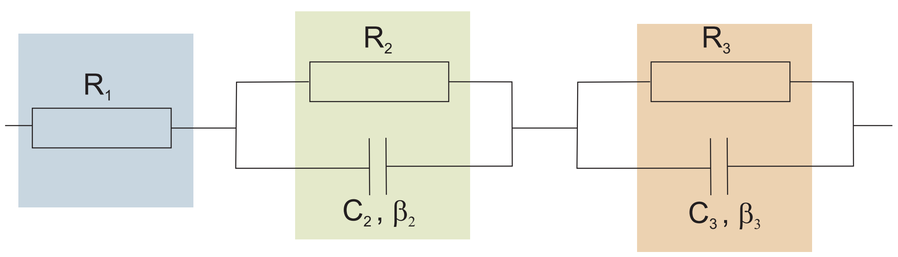


Figure 3. The circuit model using two Cole-Cole elements.

Results

Results were obtained from two mice. The first yielded 6 slices and 12 measurable sections; the second gave 5 slices and 9 sections. The experimental results are shown in Fig. 4. The model of Eq. (2) and Fig. 3 is fitted to the results of each of the 21 sections. The distributions of the parameters are shown in Fig. 5. The model fits the results well, particularly for the higher frequency dispersion (left-hand side of Fig. 4c).

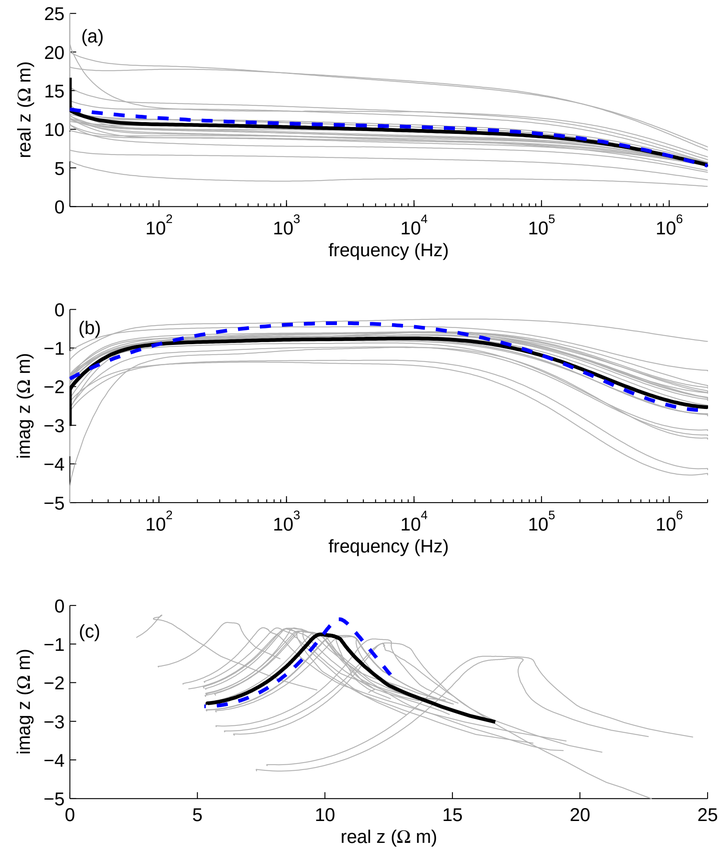


Figure 4. The real (a) and imaginary (b) parts of the bulk impedance (equation 1) as a function of frequency. Plot (c) is a Nyqvist plot of the real part against the imaginary part. The grey lines show each of the 21 cortical sections measured; the thick black line is the mean; the dashed blue line shows the Cole-Cole model fitted to the mean data. Two regions of dispersion are evident, separated by a cusp-like point at about 10 kHz.

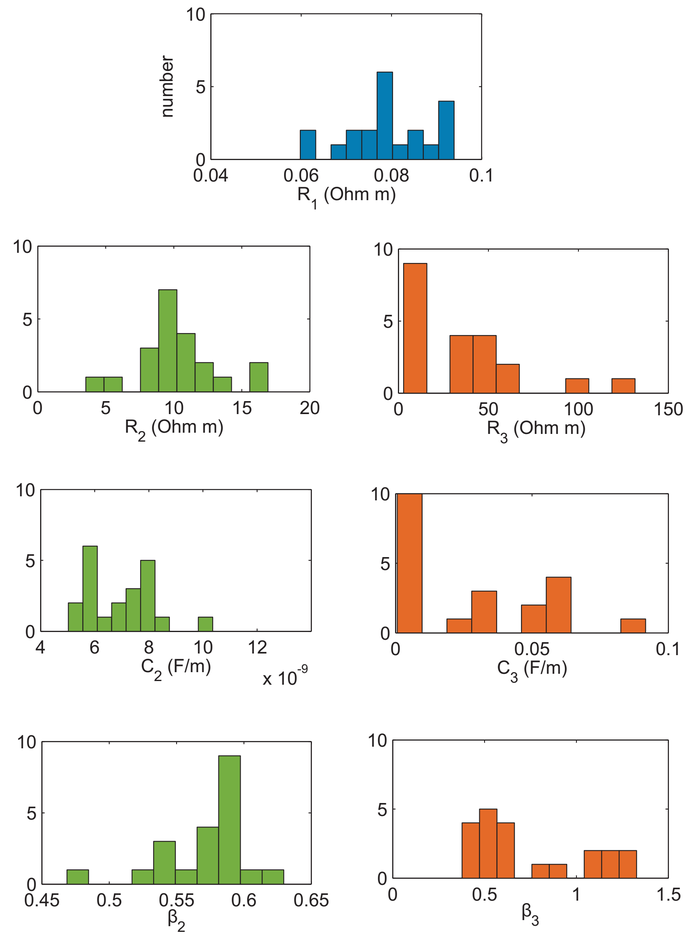


Figure 5. Histograms of the parameters of the circuit model. The green (left column) shows the high frequency dispersion, the orange (right column) the low frequency dispersion. Histograms for the high frequency dispersion (green) have fairly low standard deviation, but this is not the case for the low frequency dispersion (orange).

Conclusion

Results show two regions of dispersion, either side of approximately 10 kHz. The Cole-Cole model, containing non-linear capacitative elements, fits well at the higher frequencies. Physically, these elements are likely to arise due to membrane polarization and migration of ions intra- and extra-cellularly. The quantitative measurements broadly agree with results measured *in vivo*.

References

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