

# Single-Frequency LCR Databridge Impedance Measurements as Surrogate Measures for the Integrity of Human Skin

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Percutaneous absorption data are required for risk assessments of potentially toxic chemicals. In-vitro measurements of human skin can be used to avoid testing on human volunteers or animals. However, the collection and handling of excised skin can introduce damage, which may affect the percutaneous absorption measurements. Therefore, testing whether the barrier function of skin samples has sufficient integrity for meaningful measurements of in-vitro chemical permeability is common and usually required when data are generated for regulatory purposes. Measurement of skin impedance is faster and less expensive than measuring tritiated water permeation. For the same reason, in-vitro impedance measurements are also used to identify chemicals and chemical mixtures that cause irreversible (or corrosive) damage to the skin.

Impedance measurements of in-vitro skin samples are commonly determined using an LCR Databridge. According to their manufacturers, these instruments measure inductance (L), capacitance (C) or resistance (R) in either a parallel (PAR) or series (SER) mode determined at one of two user-selected frequencies, usually 100 or 1000 Hz. Nearly always, the reported resistance values measured by PAR and SER modes (i.e.,  $R_{PAR}$  and  $R_{SER}$ , respectively) at a given frequency are different. Also,  $R_{PAR}$  and  $R_{SER}$ , determined at different frequencies, are different, clearly indicating that these instruments do not report the DC skin resistance. In this work,<sup>1</sup> a large quantity of skin impedance data was used to demonstrate the relationships among the LCR Databridge results and skin resistivity or integrity.

Under the assumption that the impedance of skin can be expressed as that corresponding to the circuit presented in Figure 1, the Databridge values can be expressed as

$$R_{PAR} = \frac{R_e + R + \frac{(RQR_e\omega^\alpha)^2}{R + R_e} + 2QRR_e\omega^2 \cos\left(\frac{\alpha\pi}{2}\right)}{1 + \frac{R_e(QR\omega^\alpha)^2}{(R + R_e)} + QR\omega^\alpha \cos\left(\frac{\alpha\pi}{2}\right)} \quad (1)$$

$$R_{SER} = R_e + \frac{R + R^2Q\omega^\alpha \cos\left(\frac{\alpha\pi}{2}\right)}{1 + (RQ\omega^\alpha)^2 + 2RQ\omega^\alpha \cos\left(\frac{\alpha\pi}{2}\right)} \quad (2)$$

$$C_{PAR} = \frac{QR^2\omega \sin\left(\frac{\alpha\pi}{2}\right)}{R_e + R + \frac{(RQR_e\omega^\alpha)^2}{R + R_e} + 2QRR_e\omega^2 \cos\left(\frac{\alpha\pi}{2}\right)} \quad (3)$$

and

$$C_{SER} = \frac{1 + (RQ\omega^\alpha)^2 + 2RQ\omega^\alpha \cos\left(\frac{\alpha\pi}{2}\right)}{-R^2Q\omega^{2\alpha} \sin\left(\frac{\alpha\pi}{2}\right)} \quad (4)$$

The parameters defined by equations (1-4) were used to provide comparisons to impedance data for human skin. A sample comparison, presented in Figure 2, shows that series capacitance values measured at a frequency of 100 Hz are strongly correlated to the DC skin resistance in a predictable way. Similar comparisons were made for  $R_{PAR}$ ,  $R_{SER}$  and  $C_{PAR}$  at frequencies of 100 Hz and 1,000 Hz.

This work shows that measurements of  $R_{PAR}$  and  $C_{SER}$  at 100 Hz may be used as surrogate measures for skin resistivity to assess the integrity of human skin samples. While the sensitivity to skin resistance of  $R_{PAR}$  measured at low frequency is consistent with results presented in the literature, a surprising result of the present study is that the capacitance  $C_{SER}$  measured at low frequency provides an even better surrogate for skin resistivity.

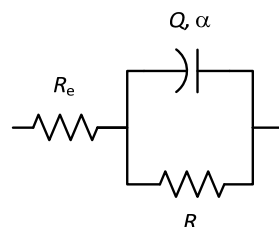


Figure 1. Electrical circuit corresponding to human skin.

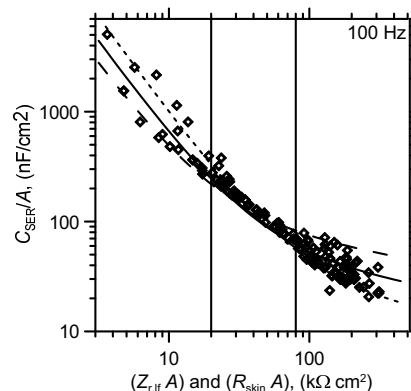


Figure 2. Symbols represent the area-normalized values of  $C_{SER}$  calculated from the complex impedance of 145 cadaver skin samples as a function of the corresponding low-frequency asymptote for the real part of the impedance. The lines represent model predictions. Details are presented by White et al.<sup>1</sup>

## References

1. E. A. White, M. E. Orazem, A. L. Bunge, "A Critical Analysis of Single-Frequency LCR Databridge Impedance Measurements of Human Skin," *Toxicol. in Vitro* (2011), in press.

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