

## Estimation of Dielectric Constant from CPE Parameters for Human Skin

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Models invoking Constant-Phase Elements (CPE) are often used to fit impedance data arising from a broad range of experimental systems. While the physical origins of the CPE are controversial, a bigger problem remains the interpretation of impedance data in terms of physically meaningful properties such as capacitance, from which one may obtain the dielectric constant or thickness.

The impedance response for skin typically shows CPE behavior, as is shown in Figure 1 for a representative piece of skin before and after perforation with a 26 gauge needle.<sup>1,2</sup>

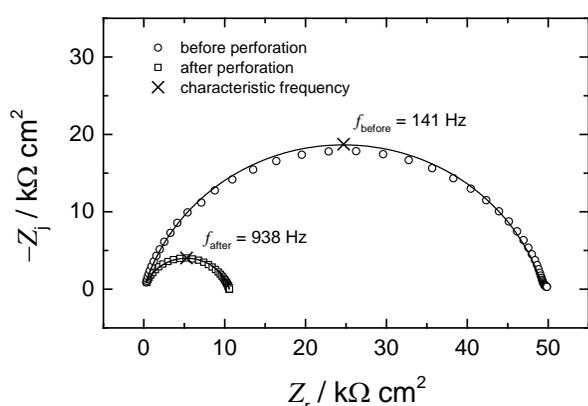


Figure 1. Impedance response for a representative piece of skin before and after perforation with a 26 gauge needle.

Several formulas have been used to extract skin capacitance from CPE parameters. The expression reported by Hsu and Mansfeld<sup>3</sup>

$$C_{\text{eff}} = \frac{\epsilon\epsilon_0}{\delta} = Q^{1/\alpha} R_p^{(1-\alpha)/\alpha} \quad (1)$$

can be associated with a normal distribution of time constants,<sup>4</sup> but the parameter values obtained are often physically unreasonable. Oh and Guy<sup>5-6</sup> used a modification of equation (1) which can be expressed as

$$C_{\text{eff}} = \frac{\epsilon\epsilon_0}{\delta} = Q^{1/\alpha} R_p^{(1-\alpha)/\alpha} \frac{\sin(\alpha\pi/2)}{1 + \cos(\alpha\pi/2)} \quad (2)$$

A similar expression

$$C_{\text{eff}} = \frac{\epsilon\epsilon_0}{\delta} = Q^{1/\alpha} R_p^{(1-\alpha)/\alpha} \sin(\alpha\pi/2) \quad (3)$$

was derived by Shoar Abouzari et al. for interpretation of the impedance response of lithium borate network glass.<sup>7</sup>

Under the assumption that the normal distribution of time constants could be attributed to a distribution of resistivity with a uniform dielectric constant, Hirschorn et al.<sup>8,9</sup> found

$$C_{\text{eff}} = \frac{\epsilon\epsilon_0}{\delta} = (gQ)^{1/\alpha} (\delta\rho_\delta)^{(1-\alpha)/\alpha} \quad (4)$$

where  $\rho_\delta$  is the lower limit of the resistivity evaluated at  $x = \delta$  and  $g$  is a known function of  $\alpha$ . In a subsequent paper, Musiani et al.<sup>10</sup> showed that, for systems showing

CPE behavior, a distribution of dielectric constant does not change the inferred distribution of resistivity, and equation (4) still applies, with  $\epsilon$  evaluated at  $x = \delta$ . The dielectric constant can be expressed as

$$\epsilon = \frac{(\delta Qg)^{1/\alpha} \rho_\delta^{(1-\alpha)/\alpha}}{\epsilon_0} \quad (5)$$

Two key parameters are the thickness  $\delta$ , taken here to be the thickness of the stratum corneum (15  $\mu\text{m}$ ), and the resistivity  $\rho_\delta$ , taken to be that of the phosphate-buffered saline (55  $\Omega\text{cm}$ ) in which the skin was immersed.

The dielectric constant estimated for the skin before and after perforation is shown in Table 1. The dielectric constant is not expected to change as a result of perforation. The values obtained by equations (1), (2), and (3) are much larger than the dielectric constant of water and also differ substantially before and after perforation. In contrast, the value obtained using equation (5) was unaffected by perforation. The values obtained by equation (5) can be compared to the range of values (29-53) obtained in different studies by a technique which measures absorption and reflection of electromagnetic energy at a radiofrequency of 300 MHz.<sup>11,12</sup>

Table 1. Average skin dielectric constant before and after the skin was perforated by a 26 gauge needle for seven experiments. Values reflect the average for seven separate experiments.

	before	after
Equation (1)	444 $\pm$ 65	256 $\pm$ 34
Equation (2)	334 $\pm$ 46	192 $\pm$ 24
Equation (3)	426 $\pm$ 61	245 $\pm$ 32
Equation (5)	23 $\pm$ 3	20 $\pm$ 3

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