A New Model of Pulse Oximetry: Two-Dimensional Pulsation†

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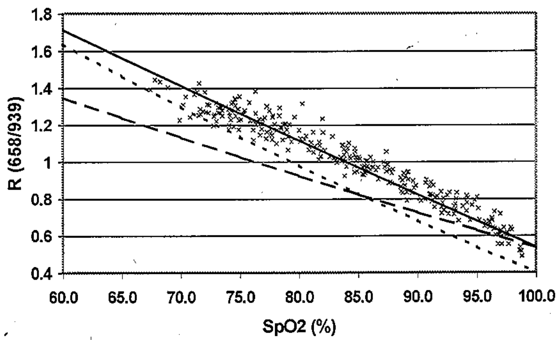
Introduction: We developed a two-dimensional pulsation model of pulse oximetry. Instead of a one-dimensional single layer as in the conventional theory, the arteries pulsate in two dimensions taking into account the effect of probing light that does not pass through the arteries. Computer simulation results based on this model agree well with human test results.

Model: The arteries are modeled with a rectangular cross-section with horizontal width of W_a and vertical thickness (optical pathlength) l_a. Tissues outside of the artery are in an area lateral to the artery with width of W_T and the same thickness as the artery. Assuming the input optical power illuminates the artery and the tissue uniformly, the transmitted power, P, is composed of two parts, one that passes through the artery and one that does not. When the artery pulsates, the optical pathlength and the widths of the artery and the tissue change simultaneously. As a result, we derived the following equation for the relative change of transmitted optical power, equivalent to the change of optical density, dA, in the conventional theory.

$$dA = \frac{dP}{P} = -\frac{\exp(-g_T l_a) - \exp(-g_a l_a)(1 - g_a l_a)}{W_r \exp(-g_T l_a) + \exp(g_a l_a)} \frac{dl_a}{l_a}.$$

In the equation, $W_r = W_T / W_a$ is the ratio of the widths of the two areas, g_T is the extinction of tissues outside the artery, and g_a the extinction of the artery due to O_2Hb and RHb absorptions, the blood oxygen saturation s, and scattering of the blood. The ratio, R, of dA at two different wavelengths, where the relative pathlength change, dl_a / l_a, is cancelled, is a function of s, and this function defines the calibration curve, R-SpO_2. In R, we have two parameters, l_a and Wr, that are not present in the conventional model and that represent human variations.

Results: Data sets (×) of R-SpO_2 of thirteen human subjects were collected at wavelengths of 658 and 939 nm. Computer simulations of this two-dimensional pulsation model (solid line —) and the conventional one-dimensional pulsation model with (dashed line – – –) and without (dotted line ---) scattering were done at the same wavelengths as shown in the figure. In the simulation, $l_a = 0.8$ cm and $Wr = 0.5$.



Conclusions: The two-dimensional pulsation model gives a specific form of effects of tissue outside the arteries in pulse oximetry. This model provides us the theoretical calibration curve that more closely matches the empirical data than the conventional model and can extend to very low saturation.

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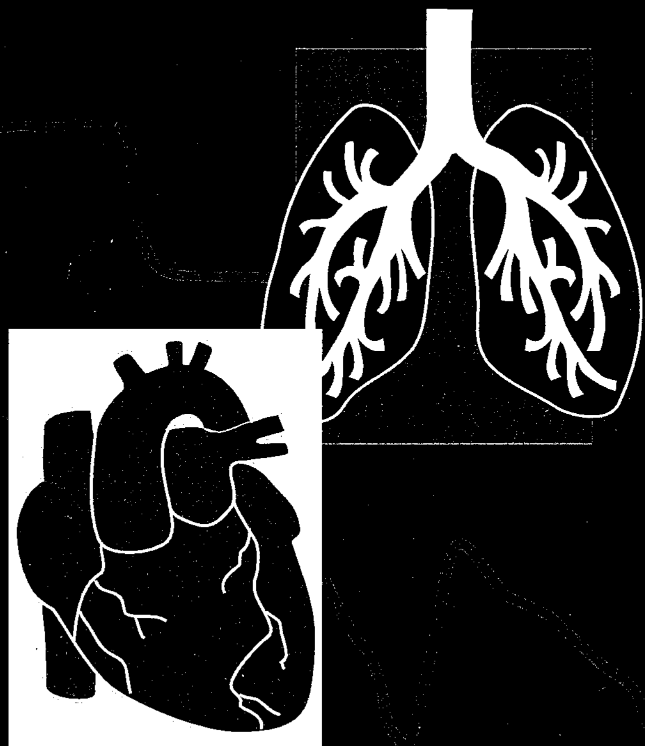

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