A theoretical and experimental study of the optical properties of in vivo skin

J. W. FEATHER, J. B. DAWSON, D. J. BARKER and J. A. COTTERILL

INTRODUCTION

Many studies have been made of skin colour\textsuperscript{1–3} but to date few of these techniques have been applied clinically; when some index of colour change is required an arbitrary subjective grading system is usually used.

We propose that by presenting the spectrum of light reflected from the surface in an appropriate form, the pigments and structures within skin which give rise to its colour may be identified and quantified. This approach is based on a simplified model of skin as a layered, light transmitting, absorbing and scattering structure and on a parameter which is the logarithm to the base 10 of the inverse of the reflectance (LIR) of the skin. From the wavelength dependence of the parameter (i.e. the LIR spectrum) indices may be derived which correlate closely with subjective impressions of erythema, blanching and pigmentation. In the model it is assumed that three layers containing fibrous protein, melanin and haemoglobin respectively, lie on a base of collagen and fat (Figure 30.1). These layers are assumed to transmit, absorb and scatter light in accordance with formulae originally developed to describe the optical properties of diffusely reflecting powders\textsuperscript{4}. From these formulae it may be shown that when scattering within a layer is small, and where $T$ is transmittance, $R$ is reflectance, $k$ is 2 (fraction of light absorbed/unit path length in layer) and $d$ is the thickness of layer, then $T \rightarrow e^{-kd}$ and $R \rightarrow 0$.

The intensity ($I$) of light reflected from a layered structure is the sum of the contributions from each layer:

$$I = I_0(R_1 + T_1^2 R_2 + T_1^2 T_2^2 R_3 + T_1^2 T_2^2 T_3^2 R_4)$$

where $I_0$ is the incident intensity.

In the simplest case it is assumed that the reflectance of the upper three layers approaches zero, hence:

$$I = I_0 T_1^2 T_2^2 T_3^2 R_4$$
and thus the reflectance of skin is: \[ R_s = \frac{I}{I_0} = T_1^2 T_2^2 T_3^2 R_4 \]

It follows that the value of LIR for skin \textit{in vivo} is approximately \[ \log (T_1^2 T_2^2 T_3^2 R_4)^{-1} \]. By substituting \( T = e^{-kd} = 10^{-A/2} \), where \( A \) is a parameter corresponding to absorbance in transmission spectrophotometry, a simplified expression for the LIR of skin \((L)\) is obtained:

\[ L = A_1 + A_2 + A_3 - \log R_4 \]

where \( A_1, A_2 \) and \( A_3 \) are the absorbance equivalent parameters for the layers of fibrous protein, melanin, haemoglobin respectively, and \( R_4 \) \((\geq 0.9)\) is the reflectance of the collagen and fat layer. According to this expression we have a system in which the logarithm of the inverse of the reflectance is simply the sum of the absorbances of the skin’s constituent layers. To examine the validity of this system it was necessary to construct an instrument for the measurement of the LIR spectra of skin \textit{in vivo}.

**INSTRUMENTATION**

A schematic diagram of the instrument is shown in Figure 30.2. Fibre optics transmit light from a tungsten filament lamp to the skin and then to a monochromator for spectral analysis. The fibre optics are mounted in a blackened metal viewing head supported on a counter-balanced arm. The head rests gently on the skin with the fibre optics at an angle of 45° to the surface to avoid direct specular reflection. The transmitting and receiving fibres were