Optical simulations of skin diagnosis with account of multiple surface scattering events

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ABSTRACT

To fully exploit current optical methods of skin diagnosis, it is desirable to understand the physics underlying photon migration in epithelial tissue[1-3]. A number of approaches have been developed to meet this challenge. Most simulations are based upon the radiative transport theory which describes the sequential transfer of diffuse light through the stack of skin layers[4-5]. These models are computationally intensive and typically rely upon the following assumptions: 1) volume scattering of photons inside the collagen fiber layer is predominant, 2) photons undergo Fresnel reflections on each boundary, 3) scattering can be modeled along each path using prescribed phase functions such as Henyey-Greenstein or Mie[5,6]. Our work simulates photon migration in skin from a different standpoint: using a commercially available optics code, we randomly trace a large number of photons and assign generic absorption and scattering properties to all boundaries, including the ones separating sublayers of collagen fibers. As a result, single and multiple surface scattering events are accounted for. Absorbing inhomogeneities may be included as light obstructions and fluorophores as secondary sources, respectively. This preliminary work is targeted for clinical applications involving skin imaging and spectroscopy.

SUMMARY

We adopt as a starting point the five-layer model of the human skin with the optical parameters outlined in refs.1, 7 and 8. The primary source is a laser diode (λ = 460 nm, 10 mW) coupled to a fiberoptic probe whose end face is brought in normal contact to the top surface of the epidermis. Collagen fibers are modeled as a planar stack of sublayers, uniformly distributed across the dermis thickness. The boundary of each collagen sublayer is treated as a lambertian diffuser with a 100% scattering function. Volume absorption is modeled according to ref. 7 and substituted with the equivalent surface absorption (see below). A large number of photon paths ($N = 2.10^6$) are randomly traced using a built-in Monte-Carlo routine. Single backscattering is included by enabling forward photons to travel once in reverse direction after being incoherently scattered off each collagen sublayer. For illustration purposes, transmitted photons are assumed to reach half of the dermis thickness.
Let Φ represent the light flux incident on a given skin layer of thickness δ. Assuming that there is no specular reflection, the percentages of absorbed, scattered and transmitted flux per boundary are computed from:

$$\%\Phi abs = [1 - \exp(-\mu_a.\delta)].100$$

$$\%\Phi scatt = [1 - \exp(-\mu_s'.\delta)].100$$

$$\%\Phi trans = 100 - (\%\Phi scatt + \%\Phi abs)$$

where μ_a and μ_s' are the absorption and reduced scattering coefficients.
Figs. 1 to 4 show the irradiance map (lumen/mm^2) on the last surface reached by transmitted photons, when a square shape, fully absorbing inhomogeneity is embedded 0.4 mm beneath the epidermis. The size of the inhomogeneity and the probe diameter are chosen as follows:

	Fig. 1	Fig. 2	Fig. 3	Fig. 4
inhomog. (mm x mm)	0.5 x 0.5	1 x 1	2 x 2	2 x 2
probe dia. (mm)	0.5	0.5	0.5	1

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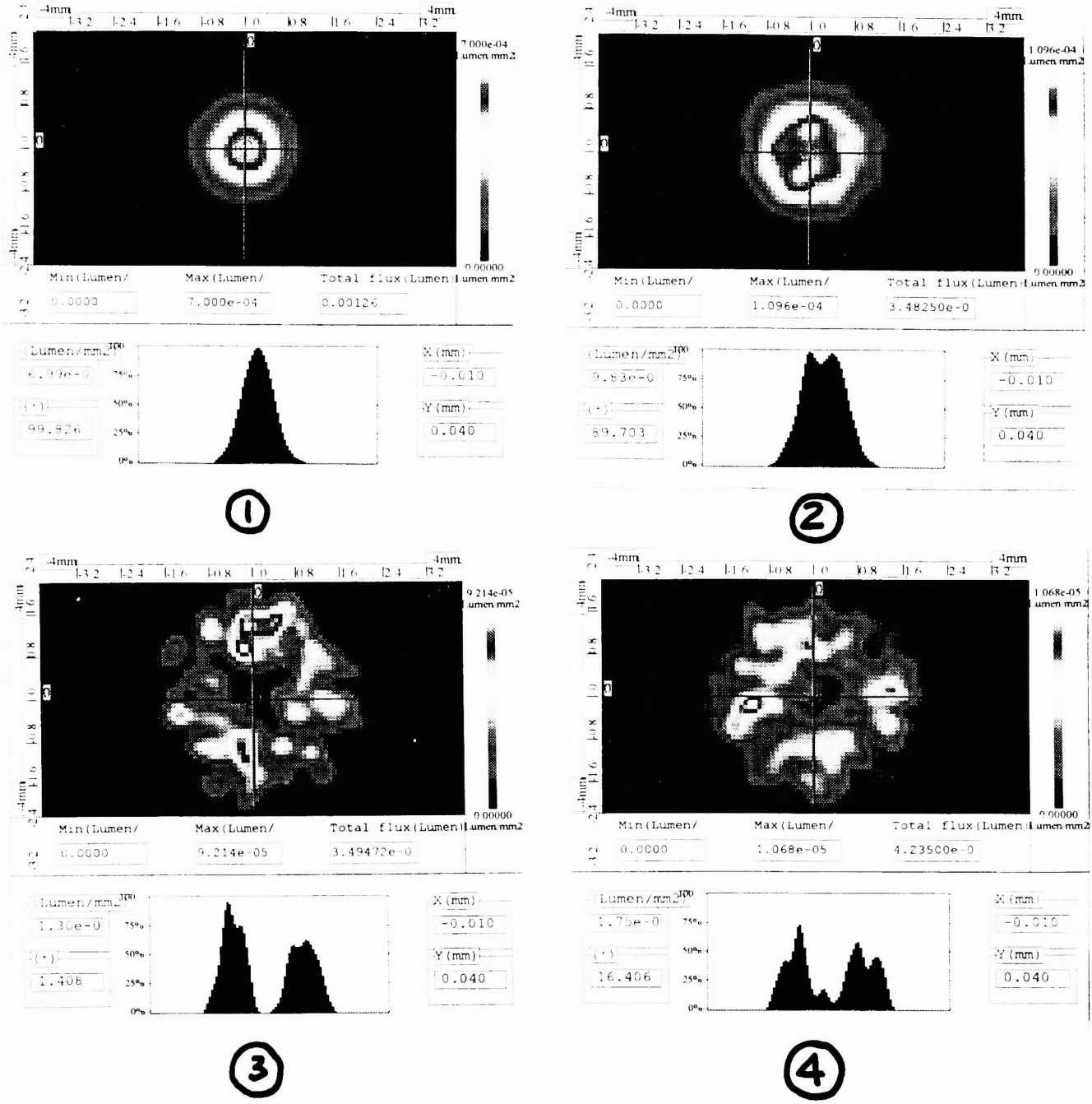

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