**Skin Model 1**

\[ I(\lambda) = I_0(\lambda) \cdot R_d(\lambda) \cdot e^{-2\varepsilon_m(\lambda)c_m/l_m - 2\varepsilon_h(\lambda)c_h/l_h} \]

**Skin Model 2**

\[ I_{TOT} = I_0(R_1 + T_1^2 \cdot R_2 + T_1^2 \cdot T_2^2 \cdot R_3 + T_1^2 \cdot T_2^2 \cdot T_3^2 \cdot R_4) \]
Epidermis

- The total optical absorption coefficient ($\mu_{a.epi}$) of the epidermis depends on a minor baseline skin absorption and a dominant melanin absorption due to the melanosomes in the epidermis.
- Baseline absorption coefficient of melaninless epidermis
- Absorption coefficient of a single melanosome
- Volume fraction of melanosomes in epidermis
- Net epidermal absorption coefficient

**Epidermis**

\[
\mu_{a.epi}(\lambda) = (f_{.mel})(\mu_{a.mel}) + (1 - f_{.mel})(\mu_{a.skinbaseline})
\]

<table>
<thead>
<tr>
<th>Skin type</th>
<th>Fraction melanin</th>
</tr>
</thead>
<tbody>
<tr>
<td>light-skinned adults</td>
<td>$f_{.mel} = 1.3\text{-}6.3%$</td>
</tr>
<tr>
<td>moderately pigmented adults</td>
<td>$f_{.mel} = 11\text{-}16%$</td>
</tr>
<tr>
<td>darkly pigmented adults</td>
<td>$f_{.mel} = 18\text{-}43%$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>wavelength [nm]</th>
<th>$\mu_{a.skinbaseline}$ [cm$^{-1}$]</th>
<th>$\mu_{a.mel}$ [cm$^{-1}$]</th>
<th>$\mu_{a.epi}$ [cm$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>694 nm</td>
<td>0.268</td>
<td>228</td>
<td>23</td>
</tr>
<tr>
<td>755 nm</td>
<td>0.254</td>
<td>172</td>
<td>17</td>
</tr>
<tr>
<td>1064 nm</td>
<td>0.244</td>
<td>55</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Bloodless rat skin

\[
\mu_{a.skinbaseline}(\lambda) = 0.244 + 85.3\exp(-(\lambda - 154)/66.2) \text{ [cm}^{-1}\text{]}
\]

Neonatal skin

\[
\mu_{a.skinbaseline}(\lambda) = (7.84\times10^8)(\lambda^{-3.255}) \text{ [cm}^{-1}\text{]}
\]

Based on vaporization

at the ruby laser wavelength (694 nm) $\mu_{a.mel} = 230$ cm$^{-1}$
at the alexandrite laser wavelength (755 nm) $\mu_{a.mel} = 170$ cm$^{-1}$
at the NdYAG laser wavelength (1064 nm) $\mu_{a.mel} = 55$ cm$^{-1}$
Absorption coefficient of epidermis

![Graph showing absorption coefficient for epidermis](image)

Scattering coefficient of the epidermis

- There are some differences between the scattering coefficient of the epidermis $\mu_{s,\text{epi}}$ and of the dermis, $\mu_{s,\text{derm}}$, but not large.
  - $\mu_{s,\text{epi}}$ is set equal to $\mu_{s,\text{derm}}$

- The second major scattering property of a tissue is its anisotropy, $g$, with typical values of $g$ in the range of 0.7-0.95 for skin tissue, and vary with wavelength.
  - $\mu_{s',\text{epi}} = (\mu_{s,\text{epi}})(1-g)$

Dermis

- The total optical absorption coefficient ($\mu_{a,\text{derm}}$) of the dermis depends on a minor baseline skin absorption and a dominant hemoglobin absorption due to the cutaneous blood perfusion.
  - Baseline absorption coefficient of bloodless dermis
  - Absorption coefficient of whole blood

Absorption coefficient of whole blood

![Graph showing absorption coefficient for whole blood](image)
Absorption coefficient of whole blood

at isosbestic point,

\[ \mu_a = 0.023 \text{ mM} \cdot 0.09 \text{ mm}^{-1} / \text{ mM} = 0.002 \text{ mm}^{-1} \]

Mean free absorption pathlength = 500 mm

Dermis

• The total optical absorption coefficient (\(\mu_{a,dern}\)) if the dermis is perfused with blood
  • Absorption coefficient of dermis perfused with blood
    • \(\mu_{a,dern} = (\Gamma_{blood})(\mu_{a,blood}) + (1 - \Gamma_{blood})(\mu_{a,skin baseline})\)

Dermis

• The reduced scattering of dermis, \(\mu_s'_{derm}\),
  • is a combination of the contributions due to Mie scattering by the large cylindrical dermal collagen fibers and the Rayleigh limit scattering by the small-scale structure associated with the collagen fibers and other cellular structures
  • Using Mie theory, one can calculate the scattering coefficient, \(\mu_{s,dern}\), and the anisotropy, \(g_{dern}\), then calculate the \(\mu_s'_{dern}\).
  • The epidermis with its keratin fibers appears to behave somewhat like dermis, and \(\mu_s'_{epi}\) is tentatively approximated by the \(\mu_s'_{dern}\).

Scattering coefficients of dermis

\[ \mu_{s,Mie,fibers}(\lambda) = (2 \times 10^5)(\lambda^{-1.5}) \text{ [cm}^{-1}] \]

\[ \mu_{s,Rayleigh}(\lambda) = (2 \times 10^{12})(\lambda^{-4}) \text{ [cm}^{-1}] \]

\[ \mu_s(\lambda) = \mu_{s,Rayleigh}(\lambda) + \mu_{s,Mie,fibers}(\lambda) \]
CONCLUSION

• The absorption is described in terms of melanin and hemoglobin absorption and proportional to the volume fractions of melanosomes and whole blood, with a slight baseline skin absorption.

• The dermal scattering is described in terms of the relative contributions of Mie and Rayleigh scattering due to collagen fibers.

• The epidermal scattering, which is affected by its keratin fibers, is sufficiently close to that of dermis and sufficiently thin to not be critical.