Multispectral Imaging Technologies for Skin Assessment

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Medical research lines

**Neonatology**
- Monitoring
- LCS

**Spectroscopy in oncology**
- head and neck cancer
- esophagus
  Probe based refl spectroscopy

**Nanotechnology in oncology**
- upconversion NP’s for diagnosis and treatment

**Spectral imaging in ophthalmology**
Forensic research lines

**Bruises**
- Child abuse/domestic violence
- Reflectance Spectroscopy

**Localization & analysis of biological traces**
- Is it Blood?
- Blood Stain Age
- Reflectance Spectroscopy

**Fingerprints**
- Latent fingerprint visualization
- Spectral Camera

**Thermal Body Cooling**
- Determine time of death
- New computer model
- Validation measurements

Collaboration:
- Ted Bijvoets, Politie Kennemerland, Ed van Zalen, FSO noord-west, Marcel de Puit, NFI

Collaboration:
- Daan Botter, Harry van Venrooij, Bernice Oude Grotebevelsborg, NFI
Background

➢ **Child abuse (USA):**
  - estimated 9,000,000 cases per year
  - in 2003 900,000 convictions

➢ **Indicators of child abuse:**
  - Child is scared
  - Unconvincing explanation
  - Wounds inconsistent with developmental skills
  - Location of the bruises on the body
  - **Color (age) of the bruises**
Color of bruise

<table>
<thead>
<tr>
<th>Color of Bruise</th>
<th>Age of Bruise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red (Swollen, tender)</td>
<td>0 - 2 days</td>
</tr>
<tr>
<td>Blue, purple</td>
<td>2 - 5 days</td>
</tr>
<tr>
<td>Green</td>
<td>5 - 7 days</td>
</tr>
<tr>
<td>Yellow</td>
<td>7 - 10 days</td>
</tr>
<tr>
<td>Brown</td>
<td>10 - 14 days</td>
</tr>
<tr>
<td>No further evidence of bruising</td>
<td>2 - 4 weeks</td>
</tr>
</tbody>
</table>

* From Protocol Child abuse in AMC hospital Amsterdam

Need for determination of age of bruises
Age determination based on visual inspection not possible
This presentation

We will work towards a method for ageing bruised which combines spectral imaging with a mathematical simulation model.

Challenges to address:
- To understand formation and healing processes in a bruise.
- Identify the predictable processes in a bruise.
  → By performing spectral measurements
  → By designing a spatial and time resolved model

Ideally, the method will be a combination of the two
Color of bruise influenced by:

- Depth
- Size
- Shape
- Density of skin
- Skin color
- Observer

Model

Spectroscopy
Previous Work

FULL ARTICLE

Characterization of vascular structures and skin bruises using hyperspectral imaging, image analysis and diffusion theory

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Key words: diagnostic imaging, computer-assisted image processing, contusions, near-infrared spectroscopy

PACS: 87.64.—t, 87.85.−d, 87.85.Pq, 89.20.Mn

Hyperspectral imaging, image analysis and diffusion theory were used to visualize skin vasculature and to monitor the development of fresh skin bruises. Bruises were inflicted in a porcine model, and the development of the hemorrhage was monitored using white light hyperspectral imaging (400–1000 nm). Hyperspectral images from human volunteers were also included in the study. Statistical image analysis was used to classify bruised regions and to visualize the skin vasculature. Biopsies were collected from the animals to reveal the true depth of the bruising. A three-layer diffusion model and an analytic hemoglobin transport model were used to model the reflectance spectra from the images. The results show that hyperspectral images contain depth information, and that the approximate depth and extent of bruises can be retrieved using a combination of statistical image analysis and diffusion theory. This technique also shows potential to visualize vascular structures in human skin.

Bruised skin classified by spectral angle mapping
Fiber based spectroscopy

- Follow 1 bruise in time
- Measure spectral content in 3 locations bruise + healthy skin
- Fit hemoglobin + bilirubin
# Bruises of known age, measured once

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>74</td>
</tr>
<tr>
<td>Average Age</td>
<td>35.0 y (9-78 y)</td>
</tr>
<tr>
<td>Fitzgerald skin type</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2 (2.7%)</td>
</tr>
<tr>
<td>2</td>
<td>21 (28.4%)</td>
</tr>
<tr>
<td>3</td>
<td>30 (40.5%)</td>
</tr>
<tr>
<td>4</td>
<td>12 (16.2%)</td>
</tr>
<tr>
<td>5</td>
<td>3 (4.1%)</td>
</tr>
<tr>
<td>6</td>
<td>6 (8.1%)</td>
</tr>
<tr>
<td>Use of alcohol at time of origin</td>
<td>18 (13.3%)</td>
</tr>
<tr>
<td>Use of blood thinners</td>
<td>2 (1.5%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bruises</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of bruises</td>
<td>123</td>
</tr>
<tr>
<td>Average age of bruise at measurement</td>
<td>4.1 d (0.7-13.6 d)</td>
</tr>
<tr>
<td>Average size</td>
<td>629 mm² (±31 mm²)</td>
</tr>
<tr>
<td>Body location</td>
<td></td>
</tr>
<tr>
<td>Group 1 Medial side of arm</td>
<td>30 (22.9%)</td>
</tr>
<tr>
<td>Group 2 Lateral side of arm</td>
<td>42 (32.1%)</td>
</tr>
<tr>
<td>Group 3 Lateral side of leg</td>
<td>51 (38.9%)</td>
</tr>
</tbody>
</table>
Fit procedure

Fit:
- Correction of the spectra for wavelength dependable pathlength
- Lambert-Beer + scattering
- Healthy skin used as reference
Fit coefficients in time
Fit coefficients in time: 1 bruise

A. Single bruise measured in time

\[ \frac{\alpha_{Hb}}{\alpha_{Bili}} \]

- **Edge**
- **Centre**
Fit coefficients in time: 42 different bruises measured once

- Grouped according to location: lateral arm

B. 42 lateral bruises of different ages measured once

- Edge
- Center
So we can conclude

- Bruises grouped by location show similar behaviour... but the individual measurement is still very difficult

- We need some model to do custom-made modeling
Bruise model

- Schematic skin model
- Finite difference model in time
- Diffusion (Darcy + Fick), Conversion (Michaelis-Menten enzyme kinetics), Clearance

Diagram:
- A: Schematic skin model with layers
- B: Finite difference model in time showing diffusion
- C: Diffusion with conversion and clearance processes
## Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Biological Range</th>
</tr>
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<tr>
<td>Hydraulic conductivity, $K$ ($t=0$)</td>
<td>$5 \times 10^{-9}$ m$^4$/Nh</td>
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<tr>
<td>Pressure difference, $dp$</td>
<td>$2.6 \times 10^2$ N/m$^2$</td>
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<tr>
<td>Diffusivity Hemoglobin, $D_{Hb}$</td>
<td>$1 \times 10^{-9}$ - $1 \times 10^{-7}$ m$^2$/h</td>
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<tr>
<td>Diffusivity Bilirubin, $D_B$</td>
<td>$4 \times 10^{-9}$ - $4 \times 10^{-7}$ m$^2$/h</td>
</tr>
<tr>
<td>Affinity, $K_m$</td>
<td>0.24 μM</td>
</tr>
<tr>
<td>Speed of conversion, $V_{max}$</td>
<td>3.4 μmol/h/mgHO</td>
</tr>
<tr>
<td>Concentration of HO</td>
<td>0.1-10 mg/L</td>
</tr>
<tr>
<td>Clearance of Bilirubin, $\tau_B$</td>
<td>50-400 h</td>
</tr>
<tr>
<td>Dermal thickness, $x$</td>
<td>500-2000 μm, dependent on body site</td>
</tr>
<tr>
<td>Size and shape of initial blood pool (mm)</td>
<td>2 – 100 mm, dependent on size of bruise</td>
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<td>Starting concentration of hemoglobin (g/L)</td>
<td>150 g/L</td>
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Bruise model

Diffusivity Hb & Bili; $D_{\text{Hb}}$ & $D_{\text{B}}$
Hb $\rightarrow$ Bili conversion via enzyme; [HO]
Clearance time Bili; $\tau_{\text{B}}$
The idea

Measure the concentrations of Hb and Bili in the bruise

Do an initial guess of the physiological parameters

Perform the simulations

Adjust the parameters

Match?

Yes

no

We need to measure the surface/ know the starting area ... and optimize the remaining parameters in the model by matching to the measurements

diffusivities

HO concentration

clearance time of bilirubin
Determine the area’s using
- an RGB photograph?
- Use spectral Imaging
Determine input shape from photo

- Select part of bruise

- “Hemoglobin containing pixels” = All pixels falling within the RGB range of this area
Determine areas

- Select 2 parts of bruise
- Hemoglobin area = #hb pixels * pixel size
  Bilirubin area = #bili pixels * pixel size + hb

Bili range
Hb range
Hyperspectral imaging

Measure area of hemoglobin and bilirubin in time
Measure bruise with hyperspectral camera

Bruise age 2 days

- Correct for movement, lighting and curvature of arm
- Overlay all images and obtain spectrum in each pixel
Hyperspectral camera

\[ \mu_{a,Bruise} = offset \]
\[ + x_1 \times \mu_{a,Hb} \]
\[ + x_2 \times \mu_{a,HbO_2} \]
\[ + x_3 \times \mu_{a,BiliBound} \]
\[ + x_4 \times \mu_{a,BiliUnbound} \]
\[ + x_5 \times \mu_{a,Melanin} \]

- Fit all pixels
- Convert to gray scale
- Obtain relative concentration distributions
Obtain areas Hb+Bili

Hemoglobin
Relative concentration image
Bilirubin

Local thresholding:
create binary image
Dilation/erosion
Remove small particles

Obtain Hb + Bili areas

Hemoglobin
Bilirubin
Tunable filter

- Implementation in practice
- Pushbroom scanner

400 – 720 nm

400 – 1000 nm
Pushbroom scanning

(a) Moving sensor platform

Ground pixel area = GSD × GSD
Image swath width

Platform ground velocity = v
Scan line

(b) Two-dimensional focal-plane array with $n_y \times K$ detectors

Objective optics

Collimating optics

Dispersing element

Focusing optics

Entrance slit

Spatial-spectral images from past ground positions
Bruise model

Diffusivity Hb & Bili; $D_{Hb} & D_B$
Hb $\rightarrow$ Bili conversion via enzyme; [HO]
Clearance time Bili; $\tau_B$
New hypothesis

- Information about the age of a bruise is contained in both the area and concentration distribution of hemoglobin and bilirubin and how these change differently with time.
True?

- Determine hemoglobin and bilirubin areas by either method

- Simulate bruise (known age = duration of simulation) with several sets of parameters

- Calculate correlation between simulated and measured Hb and Bili areas for each set of parameters
Measured vs Simulated areas

Medial arm

- Linear fit + 95% Confidence Interval
- 95% Prediction level

![Graphs showing measured vs simulated areas for Medial arm](Image)
Simulate areas using model

- Vary model parameters, optimize
- Simulated age of bruise = 30 min error
Three bruises

This pathophysiology-based procedure determined the age of our first sample bruise with an inaccuracy of
- 0.5 h (2.3%) when the bruise is 0.9 days old, of
- 6 h (12%) when the bruise is 2.2 days old, and
- 9 h (8%) when started at 5 days age

The inaccuracy in age determination for our second sample bruise was
- 2.3 h when the bruise is 3.1 days old,

and for our third sample bruise
- 12 h when the bruise is 2.1 days old
conclusions

- We understand how bruises develop

- By using the model, we can assess tissue physiological parameters

- Accurate, objective age determination is possible!
  - For bruises measured multiple times combined with a
  - RGB camera or an expensive hyperspectral imaging system

- If we assume that the parameters have similar values within groups of arm and leg bruises →
  the same set of values can be applied to model any arm or leg bruise of unknown age, facilitating age determination from one measurement
Thanks

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Ministerie van Economische Zaken,
Landbouw en Innovatie
Pieken in de delta

STW NWO
VIDI vernieuwingsimpuls
Nederlandse Organisatie voor Wetenschappelijk Onderzoek
Future

- So far: area information
- Improved age determination: including concentration distribution
Future

- Concentration distribution greatly influences kinetics

![Graph showing concentration distribution and area over time for different shapes and labels: Bili homogeneous, Bili gauss, Hb homogeneous, Hb gauss.](image)