Hemodynamics in self-healing human bruises assessed by combined optical spectroscopy and pulsed photothermal radiometry

Marin A[(1)], Majaron B[(1,2)*]

(1) Faculty of Mathematics and Physics, University of Ljubljana, Slovenia
(2) Department of Complex Matter, Jožef Stefan Institute, Ljubljana, Slovenia

*Corresponding author's email: boris.majaron@ijs.si

Assessment of bruise age in forensic investigations is based on characteristic skin discoloration, due to dynamical processes involving mass diffusion and biochemical transformation of the extravasated hemoglobin into various by-products. However, the current protocol relies exclusively on visual inspection and assessment of discoloration by a medical expert. Aiming toward development of an objective approach for aging of bruises, we have augmented our recently introduced methodology for noninvasive analysis of skin structure and composition, which combines diffuse reflectance spectroscopy (DRS) in visible spectral range and pulsed photothermal radiometry (PPTR). The latter involves irradiation of the test site with a milisecond light pulse at $\lambda = 532$ nm, emitted from a medical-grade laser (DualisVP, Fotona, Slovenia). The subsequent transient change of Planck's emission from the skin surface is acquired with a fast MWIR camera (FLIR SC7500, $\lambda = 3.5–5.1$ µm) at 1000 fps [1].

Data from both techniques are analyzed simultaneously using a numerical model of light and heat transport in human skin, represented by four characteristic layers [1]. In contrast with the previous report, the model used here includes two additional chromophores, β-carotene and bilirubin, and adjustable thickness of the papillary dermal layer. In addition, the analyses of bruises rely on baseline values of skin properties, assessed from measurements of a nearby intact site [2,3,4].

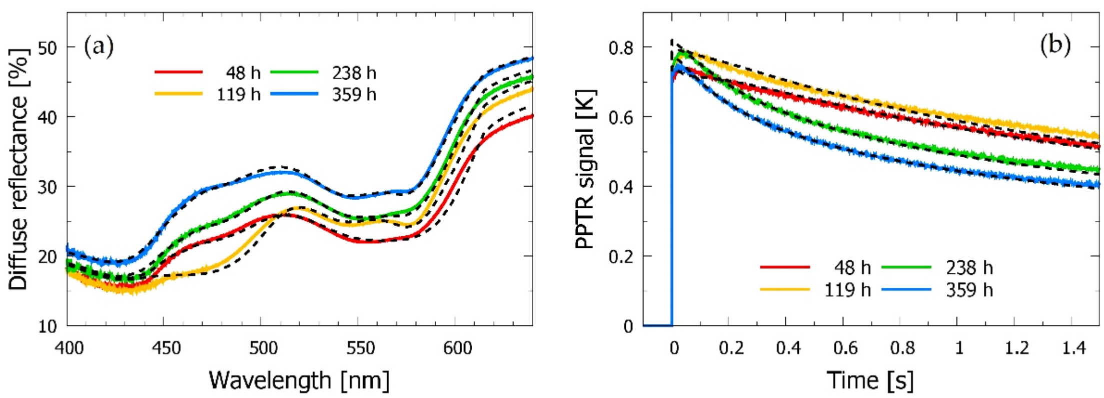

Fig. 1. DRS spectra (a) and PPTR signals (b) obtained from a bruised skin site at different times after the injury (see the legends). Dashed lines represent the best fitting model predictions.

The results obtained from measurements performed in three volunteers over a period of 16 days indicate a dramatic increase of the blood content in the reticular dermis and reduction of its oxygenation level in first days after injury. This is followed by gradual emergence of bilirubin, a long-lived by-product of the hemoglobin decomposition. Eventually, all model parameters relax towards the values characteristic

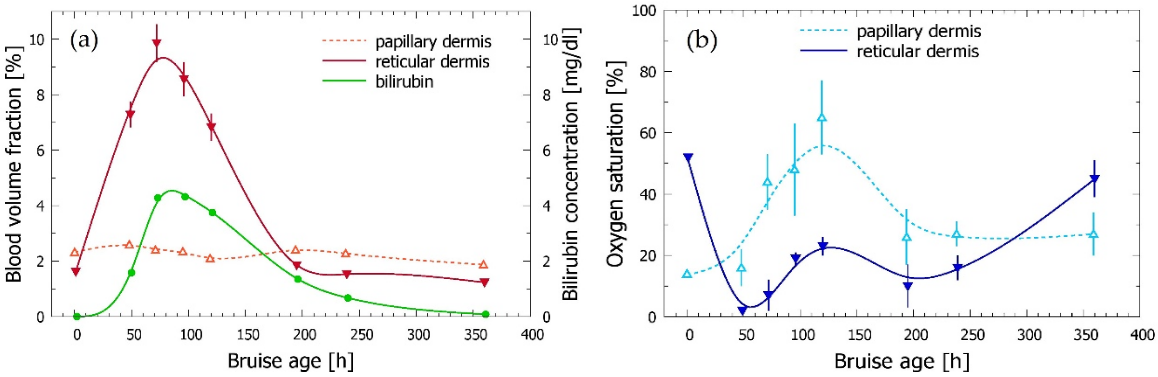

Fig. 2. The assessed dynamics of blood and bilirubin contents (a), and oxygenation level of blood (b) in the papillary and reticular dermis over 15 days after the injury.

for intact skin [3,4]. Moreover, all assessed values and characteristic time intervals are consistent with available literature data.

We will also present and discuss our attempts to match the assessed hemodynamics with a modified version of an earlier proposed analytical model of bruise dynamics with a small number of free parameters, such as the hemoglobin mass diffusivity and characteristic time for its decomposition, depth and duration of blood spillage, etc. [5,6].

We are hopeful that the presented methodology and acquired information may provide a basis for development of a future methodology for objective and robust assessment of the time of injury in forensic investigations.

Acknowledgments – This research was supported by the Slovenian Research Agency (grants P1-0192 and P1-0389). The laser used for PPTR measurements was loaned to us by Fotona, d.o.o. (Ljubljana, Slovenia).

References

[1] N. Verdel A. Marin, M. Milanič, B. Majaron, Physiological and structural characterization of human skin in vivo using combined photothermal radiometry and diffuse reflectance spectroscopy, Biomed. Opt. Express 10 (2019) 944–960. https://doi.org/10.1364/BOE.10.000944.

[2] A. Marin, N. Verdel, M. Milanič, B. Majaron, Influence of healthy skin baseline on bruise dynamics parameters as assessed by optical methods, Proc. SPIE 11075 (2019) 110751O. https://doi.org/10.1117/12.2527083.

[3] A. Marin, N. Verdel, B. Majaron, Hemodynamics in traumatic bruises assessed by diffuse reflectance spectroscopy and photothermal radiometry, Proc. SPIE 11211 (2020) 112110Z. doi.org/10.1117/12.2545876.

[4] A. Marin, N. Verdel, M. Milanič, B. Majaron, Noninvasive monitoring of dynamical processes in bruised human skin using diffuse reflectance spectroscopy and pulsed photothermal radiometry, Sensors 21 (2021) 302. https://doi.org/10.3390/s21010302

[5] L.L. Randeberg, O.A. Haugen, R. Haaverstad, L.O. Svaasand, A novel approach to age determination of traumatic injuries by reflectance spectroscopy, Lasers Surg. Med. 38 (2006) 277–289. doi.org/10.1002/lsm.20301.

[6] L. Vidovič, M. Milanič, B. Majaron, Objective characterization of bruise evolution using photothermal depth profiling and Monte Carlo modeling, J. Biomed. Opt. 20 (2015) 017001. doi.org/10.1117/1.jbo.20.1.017001.