REFLECTANCE SPECTROPHOTOMETRY

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INTRODUCTION & METHODS

The microcirculation is the essential vascular compartment where blood-transported O_2 is finally delivered to the O_2-consuming cells. Therefore it is of utmost importance that microcirculatory oxygenation is adequate to balance loco-regional metabolic demands.

A non-invasive, optical technique to measure microcirculatory oxygenation is reflectance spectroscopy (also called remission spectroscopy or -photometry). In brief, beams from a light source (e.g., from a high pressure xenon lamp) are guided to the tissue of interest (e.g., *via* a flexible glass fibre cable), this light interacts with the illuminated tissue and a fraction of the light is ultimately re-collected and sent back *via* the light-guide to the analysing monitor system. The interaction of light within the tissue of interest includes wavelength-dependent absorption at haemoglobin molecules, which depends on the degree of haemoglobin oxygenation, allowing calculation of the microcirculatory haemoglobin O_2-saturation (μHbO_2) from the collected spectra. Herein the microcirculatory oxygenation measured resembles a composite oxygenation marker from microcirculatory arterioles, capillaries and venoles. It thus reflects the loco-regional O_2-balance between O_2-delivery and O_2-consumption, and thus microcirculatory O_2-availability. Consequently, increased O_2-delivery (e.g., increased microcirculatory perfusion) or decreased O_2-consumption (e.g., by hypothermia) would increase μHbO_2, whereas decreased O_2-delivery (e.g., hypoperfusion) or increased O_2-consumption (e.g., hyper-metabolism) would decrease μHbO_2.

Advantages of reflection spectrophotometry. Reflectance spectroscopy is a non-invasive optical technique, not requiring any toxic dyes (like Pd-porphyrine techniques) or traumatic instrumentation (like Clark-type PO_2-needle electrodes or microdialysis catheters). Thus, spectroscopy appears advantageous in bench-to-bedside research, because this method can be applied both in animal experiments and also in patients. In addition, the measurement may be classified as *continuous*, whereas the traditional technique of tonometry, particularly saline tonometry, require prolonged equilibration times.

In current systems, the technique of reflection spectroscopy may be combined with techniques of laser Doppler flowmetry (LDF), allowing the simultaneous assessment of microcirculatory oxygenation and microcirculatory blood flow.

Which spot to measure? Given the heterogeneity of the microcirculation between and within organs, one has to predefine a meaningful spot to measure microcirculatory oxygenation. Obviously, to monitor microcirculatory oxygenation during (or after) certain localized surgical procedures, the measurement spot is defined by the surgical procedure itself: After transplantation of a free musculo-cutaneous flap, monitoring the microcirculatory oxygenation of skin of the transplant allows detection of arteriolar inflow reduction and/or venous outflow problems, leading to venous congestion of the transplant. Thus, function of the non-accessible arteriolar and venous anastomoses can be deduced from a non-invasive surface measurement. In contrast to the routine assessment using clinical signs (skin colour, skin temperature and tissue swelling), this technique is more objective, better to be quantified and allows for a continuous measurements.

However, in the disciplines of anaesthesia, critical care and emergency medicine, it is often not a single organ where oxygenation is endangered, but the entire body (e.g., by cardio-circulatory distress, including shock). Thus, the selection of the optimal measurement spot is not as obvious as exemplified for surgical procedures. Traditionally it is argued, that focusing the monitoring on so-called vital organs (e.g., heart or brain) is advantageous herein, since hypoxygenation particularly of these organs would lead to disastrous consequences for patient

outcome. Although the latter statement *per se* is obviously correct, it misses the crucial aspect that the so-called vital organs are well protected from circulatory distress and react relatively late in the sequence of circulatory distress. Reasons for this rather robust oxygenation of the so-called vital organs are a well developed local autoregulation of perfusion and a preferential perfusion in states of circulatory centralization.

Thus, we argue that monitoring of organs or tissues explicitly *not* belonging to the so-called vital organs appears more advantageous, because these remote organs would react more early in states of circulatory distress and thus could serve as sentinel organs. Following this argumentation, this early detection of disturbances of microcirculatory oxygenation in remote organs supports rapid suspicion, rapid diagnosis and ideally rapid correction of the patient condition, even markedly before signs of tissue hypoxygenation occur in the so-called vital organs. This would allow the switch from a *reactive* concept of therapy to a more *proactive* therapy concept of tissue oxygenation. This is fully in line with concepts of the *golden hour of shock*, nominating the factor of time and timing as crucial in the setting of acute care.

The splanchnic region possesses several items that render it an excellent candidate as measurement spot for microcirculatory oxygenation in this setting. As *non-vital* organs, the splanchnic organs participate strongly in the process of circulatory centralisation, e.g., *via* intense splanchnic vasoconstriction. This response occurs early in the sequence of cardio-circulatory distress, e.g., haemorrhage or other forms of hypovolaemia. Within the splanchnic region, the gastrointestinal tract is principally accessible *via* natural orifices, e.g., orally or rectally. The oral route has been established for gastric tonometry, a traditional method to assess the adequacy of regional perfusion/oxygenation. Although the technique of tonometry is hampered with multiple methodological problems, the gastric mucosa remains an attractive measurement site for microcirculatory oxygenation, e.g., as non-traumatic accessible part of the splanchnic region.

RESULTS & DISCUSSION

As discussed, we selected the gastric mucosa as preferred measurement spot for most of our studies so far. Since the impact of anaesthesia relevant pathologies (e.g., anaemia or haemorrhage) and anaesthesiological interventions on the microcirculatory gastromucosal oxygenation were unclear, we performed a series of studies on this subject, both experimental and clinical. For brevity of this abstract, the general key findings from our studies may be summarized as follows:

1. In various (models of) pathologies, microcirculatory oxygenation may react earlier than systemic markers.
2. Even the direction of changes may differ between the systemic circulation and the regional microcirculation.
3. Therapeutic options improving the systemic circulation do not necessarily improve regional microcirculation.
4. Therapeutic options exist, that (so far in animal experiments) selectively improve gastro-mucosal microcirculatory oxygenation, i.e., without marked impact on systemic circulation.

A major task within anaesthesia, critical care and emergency medicine is to ensure adequate oxygenation of the patient. Consequently, we should extend care from ensuring blood oxygenation (as routinely monitored by standard pulse oxymetry) to ultimately ensuring cellular oxygenation. This task can be supported by using techniques to more directly measure tissue oxygenation, e.g., by reflection spectrophotometry. Besides technical progress (e.g., need for smaller devices applicable in clinical practice) a number of principal questions still remain unsolved, e.g., addressing critical or goal values of microcirculatory oxygenation. Further, the therapies aiming at improvement of the microcirculation are far from established and thus demand further research.

REFERENCES

An extended list of references can be obtained from the authors, *via*: L.Schwarte@vumc.nl.