

NIRS (near-infrared spectroscopy) measurement of peripheral tissue oxygenation using the Nonin Equanox 7600 is not disturbed in helicopter-EMS (HEMS) environment.

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SUMMARY

NIRS (near-infrared spectroscopy) is a promising technique to monitor regional tissue oxygenation in critically ill patients, possibly also in helicopter EMS (HEMS) patients. From the study results presented we conclude that NIRS can be safely embedded into an existing HEMS system (safe device mounting, no relevant disturbance of the HEMS avionics). Furthermore, our data support the conclusion that HEMS environment *per se* does not systematically affect the tested NIRS system (Nonin Equanox 7600). Thus, we suggest that NIRS may become an attractive option to monitor tissue oxygenation in EMS, including the HEMS settings.

INTRODUCTION

Preservation and restoration of adequate tissue oxygenation is pivotal in critically injured and critically ill patients [1]. Patho-physiologically, a drop in regional microvascular perfusion and consequently regional tissue oxygenation in distinct, vulnerable vascular beds occurs earlier than in other vascular beds and on the systemic circulatory level. This is particularly the case in vascular regions supporting -by intense vasoconstriction- the centralization pattern of the circulation during circulatory distress. Examples are the splanchnic region and also the peripheral tissues (e.g., skeletal muscle), showing intense vasoconstriction during circulatory distress, thereby facilitating redistribution of blood volume and blood flow to the so-called vital organs, i.e., the heart and the brain. Thus, the splanchnic region and the peripheral circulation (e.g., skeletal muscles) appear suitable sentinel tissues to allow an early detection of perfusion and oxygenation distress, even before these disturbances become apparent in the so-called vital organs or at the systemic circulatory level (e.g., drop in blood pressure). For decades, these non-vital tissues were somewhat neglected in critical care, and interest was focused on the vital organs. However, it is becoming increasingly apparent that in patients initially surviving (e.g., due to adequate basic and advanced life support [2], [3])

such a *first hit* (e.g., major trauma), ongoing hypoperfusion and hypoxxygenation of the non-vital organs plays a crucial role to trigger or fuel the *second hit*, e.g., sepsis or multi organ failure after initial survival. Besides this conceptual change in the understanding of the role of the non-vital organs in the critically ill or traumatized patients, there were traditional limits of methodology to monitor the perfusion and oxygenation of these peripheral tissues. Routine technologies to measure tissue oxygenation were not available and experimental methods can not be transferred simply to the bed side. On the level of the splanchnic region, our research group has performed extensive research to elucidate the role of regional perfusion and oxygenation in anesthesia and intensive care settings and in models of shock and shock therapy [1]. The research tools used are applicable in the experimental setting and/or with subjects positioned relatively stable (e.g., in cooperative volunteers, or patients under anesthesia). However, when focusing on patients moving or being moved more vigorously, alternative techniques to measure regional perfusion and/or oxygenation are required. Relevant scenarios might be the preclinical setting, but also the intra- and interhospital transport of patients. A suitable option to measure regional oxygenation of such a sentinel tissue, in this particular case the skeletal muscles of the extremities, is NIRS. With NIRS, patients can be monitored even when moving or being moved, i.e., it is less sensitive to motion artifacts than other techniques available. NIRS measures composite tissue oxygenation, including hemoglobin oxygenation within smaller arteries, veins and the capillaries. The NIRS measurements are methodologically independent from blood flow pulsatility, in contrast to standard pulse oxymetry, and NIRS may thus be particularly beneficial in patients with low peripheral perfusion status, e.g., during hypovolemia, hypothermia or vasopressor therapy. From the selection of NIRS devices currently available, the Nonin Equanox 7600 system appeared an attractive option for our HEMS setting, given its drop-test robustness, small and light weight design, 3 hour battery life and reported ambient light and electromagnetic artifact tolerance.

Putting these three aspects together, i.e., the dual role of peripheral tissue as sentinel organ but also as pathophysiologically relevant tissue on the one hand and the possibility to measure tissue oxygenation by NIRS in moving/moved patients preclinically, we intended to implement NIRS into the regional HEMS service [4]. Therefore, following study steps or study questions were addressed:

- 1.) Possibility to adequately mount the NIRS system in the HEMS helicopter.

- 2.) Study, if helicopter devices (e.g., avionics) are disturbed by the NIRS system.
- 3.) Study, if the NIRS system is disturbed by the HEMS environment.

MATERIALS, METHODS & MAIN RESULTS

The study was performed at the HEMS of the Level-1 Trauma Center North-West-Netherlands, associated with and situated at the VUmc university medical center, Amsterdam, The Netherlands.

1.) Mounting of the Nonin Equanox NIRS monitor system in the helicopter: In preparation of this project, the necessary permissions were granted by the responsibly HEMS authorities after clarification of the relevant technical details (e.g., NIRS monitor/sensor weight, possible sources of radiation, characteristics of the inbuilt wireless Bluetooth system). The following step was to define a safe and ergonomically appropriate place within the helicopter to place the Equanox NIRS monitor and the required sensors. After various tests to mount the system on the mid-console between the pilot and co-pilot seat (which obstructed the already limited front view possibilities of the emergency physician from his seat in the patient cabin), and at the rear side of the pilot seat in front of the emergency physician (which appeared not safe in case of turbulences), the optimal position for the device was found to be at the rear wall of the patient compartment.

2.) Are helicopter devices disturbed by the NIRS system ?

With permission granted to perform the next study step, we thoroughly tested the possibility that the NIRS device could disturb helicopter systems, including the GPS based routing system. First, these tests were done with the helicopter on the ground (standard helicopter base location on the roof deck of the hospital), secondly with the helicopter airborne. None of the helicopter crew members noticed any disturbances or malfunctions of the helicopter systems, attributable to the tested NIRS device.

3.) Is the NIRS system disturbed by the HEMS environment ?

To study if the Nonin Equanox 7600 NIRS device is disturbed by the HEMS environment, e.g., helicopter engine start-up / shut-down, or cabin vibrations, we performed the following tests: Healthy, unpaid volunteers (n=6 measurements, with informed consent) were recruited and positioned into the rear, patient compartment of the helicopter. We selected healthy volunteers under the assumption that uncompromised individuals would show a more stable baseline tissue oxygenation, compared to patients. Adult size NIRS sensors (8000CA, Nonin Equanox) were placed on the dominant forearm of the volunteers. After a stabilization period of several minutes, allowing for stabilization of the

baseline measurements (the 'baseline' period), the two helicopter engines were started subsequently. Recordings were continued in the following engine running period on the ground and during flight (the 'engine' period). After final helicopter engine shut down, the recordings were continued for several minutes (the 'post' period). The main results of this study step are: Although the individual baseline values differed (inter-individual variability, range about 75%-85%), we were able to obtain and maintain readings on all subjects and we did not observe a systematic effect of the HEMS environment on the measurement, e.g., by engine start-up or shut-down.

DISCUSSION & CONCLUSION

From the study results presented we conclude that Nonin Equanox 7600 NIRS can be safely embedded into an existing HEMS system (safe device mounting, no relevant disturbance of the HEMS system). Furthermore, our data support the conclusion that HEMS environment *per se* does not systematically affect the tested NIRS system and thus NIRS measurements. Thus, we suggest that NIRS may become an attractive option to monitor tissue oxygenation in EMS, including HEMS settings. With focus on peripheral (i.e., skeletal muscular) tissue oxygenation monitoring, NIRS may serve to more early detect patients that remain incompletely resuscitated or are deteriorating, even in situations when systemic variables (e.g., blood pressure) or surrogates of vital organ function (e.g., ECG recordings) are still within accepted normal limits. Thus NIRS may help to detect patients at risk and may assist to guide therapy. Further studies will have to demonstrate, how NIRS monitoring can improve (H)EMS therapy and ultimately (H)EMS outcome.

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