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REVIEW

Pulse CO-oximetry – Clinical impact in the emergency department

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SUMMARY

Pulse CO-oximetry is now widely available in a variety of situations in critical and emergency medicine. This technology allows the continuous and non-invasive determination of haemoglobin, carboxyhaemoglobin, methaemoglobin, oxygen content and the Pleth Variability Index and is as an essential supplementary monitoring tool in emergency, critical and peri-operative settings. However, the operator must be aware of the inherent limitations of this technique.

1. Introduction

Pulse oximeters were developed in the 1980s[1] and are now used as for clinical evaluation, monitoring and diagnosis, either at the bedside or at the point-of-care (POC). This may be in a variety of clinical settings, such as the emergency room and peri-operative and critical care, and may include both spot checks and clinical evaluation.[2,3] There have been many advances in recent years and pulse oximeter technology now not only measures oxygen saturation (SpO_2) pulse rate (PR) and perfusion Index (PI),[4] but also allows non-invasive continuous or spot check determination of carboxyhaemoglobin (SpCO), methaemoglobin (SpMet), oxygen content (SpCO) and the Pleth Variability Index (PVI) (Fig. 1).[3,5]

Non-invasive haemoglobin measurement is of particular interest, as it allows the real-time detection of acute changes in haemoglobin concentrations, and rapid triage of patients in the emergency department. It also helps physicians to optimise fluid management in peri-operative and intensive care settings.[3,6]

Moreover, SpCO helps physicians in screening for occult carbon monoxide intoxication and the PVI can be used to assess the volume status of critically ill, mechanically ventilated patients.[7]

Conventional pulse oximetry is based on the specific characteristics of oxygenated and deoxygenated haemoglobin at two wavelengths (red and infrared). Absorption of light at these wavelengths differs significantly between oxygenated and deoxygenated haemoglobin. The ratio of the absorption in the red and infrared is converted to the percentage of oxyhaemoglobin.[4,8] The new generation of pulse oximeters have been designed to minimise problems with patient movement, low tissue perfusion and excessive ambient light.[4,8,9] Motion artefacts can be incorrectly recorded as a pulse signal.

Additionally, venous blood movement when the patient moves or breathes can lead to over- or underestimation of SpO_2 and pulse rates.[10] Masimo Signal Extraction Technology (SET) pulse oximetry uses the traditional red and infrared photoplethysmographic waveforms, with four special algorithms, including radiofrequency and light shielded optical sensors, digital signal processing and adaptive filtration. This allows the isolation of individual "saturation components" in the optical pathway and the distinction between arterial and venous signals during motion and low perfusion. In this respect, the highest O_2 is demonstrated as SpO_2.[10]

Masimo Rainbow technology (Masimo Rainbow SET, Masimo, Irvine, CA) uses multiple (more than 7) wavelengths and specific signal processing algorithms. This enables the device to isolate, identify and quantify various haemoglobin species and measure SpHb, carboxyhaemoglobin and methaemoglobin, in addition to oxyhaemoglobin and pulse rate.[11]

2. Haemoglobin assessment

2.1. Methods of haemoglobin determination

Laboratory haemoglobin measurement is traditionally the gold standard for the estimation of haemoglobin concentrations, as recommended by the International Committee for Standardization in Haematology. The method of reference for haemoglobin determination is currently the photometric cyanmethaemoglobin method[12] and, although this method is accurate, it has some

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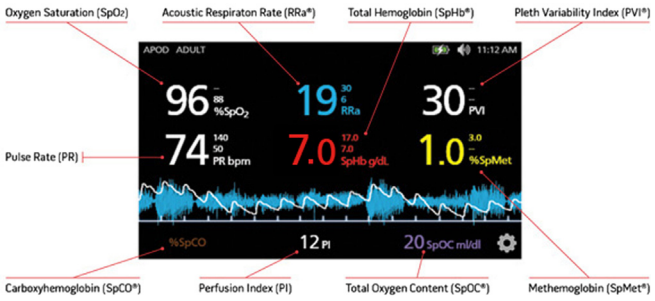

Fig. 1. Pulse CO-oximetry allows the monitoring of total haemoglobin, carboxyhaemoglobin, methaemoglobin, oxygen content, PI and PVI.

limitations. Laboratory measurements are invasive, potentially expose health professionals to biohazards, are costly, pose a potential contamination risk and the results are not immediately available. The measurements may lead to iatrogenic blood losses, due to repeated measurements.[12–14]

Vanzetti described a method for measuring Hb concentration using the azide- methaemoglobin reaction and photometry absorbance.[15,16] This led to the development of point-of-care devices, such as HemoCue, which allows immediate haemoglobin determination with smaller blood samples than with classical laboratory measurements (usually capillary samples).[12]

With a new non-invasive, multiwavelength spectrophotometric technology, rapid POC or continuous haemoglobin monitoring is possible.[3,12] This technology is similar to conventional pulse oximetry, and gives an extended analysis of the plethysmographic waveform.[4]

The increasing demand for immediate haemoglobin assessment has led to the development of point of care testing, which offers rapid bedside haemoglobin determination. Numerous studies have addressed the suitability of these devices in several medical settings, such as primary health care settings, during surgery, in intensive care patients and in the emergency department.[17,18] POC devices have several practical advantages. In primary health care settings, these devices may help to identify patients with anaemia who require further investigation and therapy.[19] In natural disasters, POC devices may be the best option for triage, as they are easily transported and require no special laboratory equipment.[18] For example, this can help in choosing the right medical centre.[3] In the emergency department, this technology may help physicians to optimise triage priorities and allow early management and intervention.[3] In blood donor centres, POC devices are used to discriminate between donors who are eligible for donation, to avoid unnecessary deferrals and to optimise blood donor screening.[18] Moreover, in the operating and emergency room and intensive care units, critical time can be saved in patients with crucial haemorrhages.[18,19] In addition, these devices can also be used in patients undergoing chemotherapy and in neonatology.[18,19]

In the emergency department, this technology eliminates delays in transporting samples to the main laboratory, thus supporting triage priorities and decisions on management, intervention and blood transfusion.[3] This is extremely important in patients with active bleeding, such as those with trauma-related haemorrhage, who require close monitoring of bleeding for early surgical management and goal-directed transfusions. This can reduce exposure to blood products, decrease costs and may increase survival.[20,21] Moreover, as these devices are easy to use, they can be applied to the screening of anaemic individuals with occult bleeding who require further investigation and treatment.[19] Additionally, early detection of anaemia may optimise the management of other crucial medical conditions, such as acute coronary syndrome, in which anaemia may worsen the ischaemic process, generate arrhythmias and increase infarction size.[22]

Therefore POC techniques, such as the non-invasive determination of haemoglobin with pulse CO-oximetry, have become a vital supplemental tool in several areas of health care, including pre-hospital, emergency and critical care settings.

2.2. Significance of non-invasive continuous monitoring

Acute bleeding is a crucial problem for physicians in the emergency departments, as well as in the peri-operative and critical care settings. The goal of resuscitation is to preserve tissue perfusion, to optimise global oxygen delivery and to avoid organ ischaemia and potential organ failure.[23,24]

Haemoglobin concentrations are needed to manage hypovolaemia and guide transfusion therapy, but are not always immediately available, and this may influence patient outcome.[2,3]

Recently, the development of non-invasive monitoring methods has allowed the rapid detection of active, possibly occult, bleeding, thus helping to optimise transfusion decisions (Box 2).[14,25]

2.3. SpHb in the emergency department and in outpatient setting

A few studies have investigated the accuracy of non-invasive haemoglobin measurement in the emergency room population and in the outpatient setting (Box 1).

Sjostrand et al. compared the accuracy of pulse CO-oximetry using repetitive controls of venous blood samples from 30 emergency room patients. When all data were included, the bias between 242 pair measurements was −0.47 g/dl (CI -0.39 to −0.09).[26] Raikhel[27] published a prospective observational study that was undertaken to validate measurements by non-invasive pulse CO-oximetry and by capillary measurements, compared with a reference standard. After exclusion of 4 patients, 152 patients were enrolled. The differences between SpHb and capillary Hb and the standards were −0.5 ± 1.0 g/dl and 0.3 ± 1.0 g/dl respectively. The limits of agreement were −2.5–1.5 g/dl for SpHb and −1.7–2.3 g/dl for HemoCue 201. In agreement, Gayat et al.[28] showed that the accuracy of the non-invasive method was better, with a bias close to or lower than 0.5 g/dl compared with previous studies,[25,29,30] and was independently and inversely associated with the true value of haemoglobin. In addition, Shah et al. investigated the accuracy of pulse CO-oximetry compared

Box 1

- Accuracy: Comparison of a method with a tested standard methodology, used to investigate whether the measurement is reliable
- Bias: The mean of all differences between paired measurements for all data points
- Carboxyhaemoglobin: Stable haemoglobin-carbon monoxide complex, that forms in red blood cells upon contact with carbon monoxide
- Methaemoglobin: A form of haemoglobin in which one or more of the four iron atoms is in the ferric (Fe^{+3}) rather than the ferrous state (Fe^{+2}) and therefore cannot bind or transfer oxygen
- Point-of-care devices: Haematology analysers which can provide rapid results using small capillary blood samples
- Fluid responsiveness: The ability of haemodynamically unstable patients to increase stroke volume and cardiac output in response to volume expansion