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Comparison of haemoglobin measurement methods in the operating theatre

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Editor's key points

- This study compared the accuracy of four bedside methods for haemoglobin (Hb) assessment [non-invasive and continuous haemoglobin measurement with Pulse CO-Oximetry (SpHb), arterial blood measurement by satellite CO-Oximetry (HbSat), and HemoCue arterial (HcueArt) and capillary (HcueCap) blood] with a laboratory haematology analyser (LHA).
- HcueArt is closest to LHA even when Hb concentrations change rapidly.
- HbSat provided values in close agreement LHA but requires sample preparation and handling.
- SpHb is less invasive, less accurate, but measures continuously.
- When absolute accuracy is essential then invasive measurements are needed to confirm SpHb or HcueCap values before transfusion.

Background. Various methods of haemoglobin (Hb) measurement are available to guide transfusion including several methods that allow for measurement at the bedside. This study directly compared their absolute and trend accuracy compared with values from the central lab (reference method).

Methods. Adult patients undergoing surgery with expected blood loss wore a rainbow ReSposable sensor connected to a Radical-7 Pulse CO-Oximeter (SpHb). Arterial samples were analysed with a haematology analyser (HbLab), a satellite CO-Oximeter (HbSat), and a point-of-care haemoglobinometer (HemoCue; HcueArt). Concomitantly, ear capillary blood was tested using the same haemoglobinometer (HcueCap). Absolute accuracy and the clinical significance of error were assessed with Bland–Altman plots and three-zone error grids. Trend analysis was performed using a modified polar plot, testing both directionality and magnitude of Hb changes compared with the reference.

Results. Two hundred and nineteen measurements from 53 patients with HbLab ranging between 6.8 and 16.3 g dl^{-1} (4.2 and 10.1 mmol $litre^{-1}$) were recorded. Compared with the reference method, bias (precision) was 0.2 (0.2) g dl^{-1} [0.1 (0.1) mmol $litre^{-1}$] for HcueArt, 0.8 (0.3) g dl^{-1} [0.5 (0.2) mmol $litre^{-1}$] for HbSat, 0.5 (0.5) g dl^{-1} [0.3 (0.3) mmol $litre^{-1}$] for HcueCap and 1.0 (1.2) g dl^{-1} [0.6 (0.7) mmol $litre^{-1}$] for SpHb. None of the devices tested would have led to unnecessary or delayed transfusion according to 2006 ASA transfusion criteria. Trend accuracy was better for HcueArt and HbSat than for HcueCap and SpHb.

Conclusion. Bedside Hb measurement methods differ in their agreement to a laboratory haematology analyser but none would have led to transfusion errors.

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Keywords: anaemia; blood transfusions; haemoglobinometry; haemorrhage/surgery; point-of-care systems

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Anaesthetists need tools to monitor haemoglobin (Hb) quickly and accurately in order to avoid delayed transfusions, which can result in patient death,[1] and unnecessary transfusions which increase patient morbidity.[2 3] For this purpose, several invasive methods of estimating Hb at the bedside such as satellite CO-Oximeters and point-of-care haemoglobinometers have been developed. Although they provide rapid measurement of Hb, they still require a blood sample, and therefore allow only intermittent monitoring. Pulse CO-Oximetry provides continuous and non-invasive monitoring of Hb with a multiple wavelength optical sensor. Several studies have compared the point-to-point accuracy of Pulse CO-Oximetry in emergency departments,[4 5] intensive care units (ICUs),[6–9] and operating theatres[10–18] but few have evaluated trend accuracy in comparison with other invasive bedside devices.

This study aims to determine the absolute and trend accuracy of four bedside methods for Hb assessment [non-invasive and continuous Hb measurement with Pulse CO-Oximetry (SpHb), arterial blood measurement by satellite CO-Oximetry (HbSat), and HemoCue measurement with arterial (HcueArt) and capillary blood (HcueCap)] during surgery at high risk of bleeding, compared with a laboratory haematology analyser as the reference method.

Methods

This prospective observational study was conducted at the University Hospital of Poitiers, France. After obtaining ethics committee approval (Comité de Protection des Personnes Ouest III; Eudract ID RCB: 2009-AO1144-53) and informed consent, adult patients undergoing major surgery with expected significant blood loss were recruited.

Patients with suspected methaemoglobinemia, carbon oxide poisoning or hyperbilirubinaemia, and those undergoing emergency surgery were excluded.

Anaesthesia was induced with propofol 2.5 mg kg^{-1} and sufentanil 0.3 mg kg^{-1}. Tracheal intubation was facilitated with rocuronium 0.6 mg kg^{-1} and additional rocuronium administration was guided by neuromuscular monitoring during the procedure. Anaesthesia was maintained with desflurane and sufentanil. If necessary, norepinephrine infusion was titrated to obtain a mean arterial pressure >65 mm Hg. Subjects were ventilated using volume-controlled mechanical ventilation (tidal volume: 6–8 ml kg^{-1}) with a mixture of oxygen and air (inspired oxygen fraction, $F_{I_{O_2}}$ 0.50). Respiratory rate was adjusted to maintain normocapnia. No patient received additional epidural anaesthesia or regional anaesthesia.

Patients wore rainbow adult ReSposable sensors (R2–25, Revision E) connected to a Radical-7 Pulse CO-Oximeter, software version 7.6.0.1 (Masimo, Irvine, CA, USA), for continuous and non-invasive measurement of total Hb (SpHb), $S_{p_{O_2}}$, heart rate, and perfusion index, an indicator of localized perfusion. Sensors were applied to the patient according to the directions for use provided by the manufacturer. This included the application of the adhesive portion of the sensor so that the emitter and detector were precisely aligned on the finger. Sensors were covered with opaque shields to prevent optical interference. The sensor position was checked before every reading and readjusted if the adhesive portion became misaligned. If perfusion index was <1%, the sensor was repositioned and recalibrated by switching the monitor off and on. The first SpHb measurement was recorded after the device had been reporting SpHb data for at least 15 min.

For invasive measures of Hb, arterial blood was drawn through a radial arterial catheter placed in the wrist contralateral to the SpHb sensor, for continuous arterial pressure monitoring and intermittent blood analysis. Blood was collected into standard blood collection tubes appropriate for the method of analysis. Reference Hb values (HbLab) were obtained by analysing arterial blood samples at the central laboratory using a Sysmex™ XT-2100i automated haematology analyser (Roche™ Diagnostics, Paris, France). Central laboratory analysers vary by institution but the Sysmex automated haematology analyser is of a type which is typical for many hospital laboratories and has been shown to have good concordance with the cyanmethaemoglobin assay, the international standard for Hb measurement.[19] The confidence limits provided by the manufacturer for the Sysmex analyser are 0.2 g dl^{-1} (0.12 mmol $litre^{-1}$). The same samples were also analysed with a satellite CO-Oximeter (Siemens™ RapidPoint 405, Siemens™, Munich, Germany; HbSat) and a point-of-care haemoglobinometer (HemoCue™, Hb201, Ångelholm, Sweden; HcueArt). Concomitantly, the fourth drop of blood after skin puncture on the ear was obtained for testing of capillary blood with the same HemoCue™ point-of-care device (HcueCap). The anaesthetist was blinded to all Hb values except those of the arterial HemoCue which was used for clinical care.

The Pulse CO-Oximeter is self-calibrating. The Sysmex™ measures Hb by colorimetry using the cyanide-free, sodium lauryl sulphate method, and is calibrated daily according to manufacturer's instructions and good laboratory practice. The Siemens™ RapidPoint CO-Oximeter is calibrated daily under the control of the central laboratory. The HemoCue™ point-of-care device is factory calibrated against the cyanomethaemoglobin method and does not require recalibration.

Simultaneous recording of SpHb, HbLab, HbSat, HcueArt, and HcueCap values were manually collected before surgical incision and then approximately hourly or more often if clinically indicated. Measures ended after completion of the surgical procedure.

Statistical analyses

Categorical data are expressed as number and percentage. Quantitative data are reported as mean values and standard deviation (SD) if normally distributed and as median values and 25th–75th percentiles (25p–75p) if the distribution is non-normal.

Agreement between HbLab (reference method) and Hb values provided by the test devices was performed as described by Bland and Altman.[20] In this study, multiple Hb measurements per patient provided unequal numbers of replicated data in pairs. With such clustered observations, adjustment is necessary, so bias, precision (1 SD) and limits of agreement [bias (1.96 SD)] were adjusted by a component of variance technique (estimating inter-individual and intra-individual variance with non-linear mixed effect model).[21]

Paired Hb values provided by test devices and the reference method were also plotted using the three zones Hb error grid analysis proposed by Morey and colleagues,[22] which takes into account the clinical significance of the difference. The ability of the test devices to follow Hb changes reported by the reference method was analysed by a modified version of the polar plot proposed by Critchley and colleagues[23] for cardiac output monitoring. Variations of Hb between two successive measurements were expressed as relative differences in percentage. Only data points with relative variations of HbLab of >10% between two consecutive measurements were used for analysis (see Supplementary material for description of these two statistical methods).

The association of tested methods absolute accuracy with HbLab levels, and SpHb absolute accuracy with perfusion index and use of vasopressors, were assessed in univariate analysis with Pearson's correlation with variance adjustment for multiple measurements and linear regression, and Student's *t*-test when required. For two-tailed tests, a *P*-value of <0.05 was considered statistically significant. All data