Current Use of Noninvasive Hemoglobin Monitoring in Anesthesia

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Published online: 17 July 2014
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Abstract Modern technology enables clinicians to assess hemoglobin levels noninvasively and continuously. Some instruments also provide concentrations of other types of hemoglobin, such as methemoglobin and carboxyhemoglobin. Such information obtained immediately and noninvasively can be helpful in the management of critically ill patients or those undergoing surgery with bleeding. However, the accuracy of noninvasive hemoglobin measurements should be evaluated before clinical application, particularly for transfusion decisions. Clinicians should be aware of the performance of continuous noninvasive hemoglobin monitoring devices during anesthesia and of the various factors that influence their accuracy. This review considers the accuracy of current continuous noninvasive hemoglobin monitoring and its clinical use.

Keywords Noninvasive · Hemoglobin · Transfusion

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Introduction

Continuous noninvasive hemoglobin monitoring devices allow clinicians to identify hemoglobin levels, one of the determinants of oxygen delivery to the tissue, without sampling or delay. The concept of “hemoglobin monitoring” is possible because of the continuous and noninvasive characteristics of the device. Hemoglobin levels can be monitored continuously similar to blood pressure and heart rate during anesthesia. This may help clinicians detect occult bleeding or prepare for a transfusion. A surgical procedure itself can cause acute and massive bleeding that may threaten the patient’s oxygen delivery. When hemoglobin decreases to $<6\text{--}7$ g/dL, a transfusion is usually recommended. The accuracy of the noninvasive hemoglobin value (SpHb) should be guaranteed in patients who need a transfusion. Various clinical factors can affect measurement accuracy during diverse clinical conditions. Therefore, it is prerequisite to understand factors that affect accuracy for proper use of a noninvasive hemoglobin monitoring system. In this review, we consider the current use of noninvasive hemoglobin monitoring systems and various conditions influencing their accuracy.

Currently Available Devices for Noninvasive Hemoglobin Monitoring

Masimo Corporation

A noninvasive hemoglobin monitoring device was developed from a pulse oximeter. Pulse oximetry measures oxygen saturation noninvasively using red (660 nm) and infrared (950 nm) light-emitting diodes. However, inaccuracy usually occurs in the presence of dyshemoglobins

(carboxyhemoglobin or methemoglobin) or at a low hemoglobin concentration [1, 2]. In 2005, Masimo Corporation released the Rad-57 device, which uses multiple wavelengths of light and pulse CO-oximetry technology. The eight wavelengths in the 500–1,300 nm range enable the measurement of fractional hemoglobin. Transmitted light has different optical densities at different wavelengths, which are analyzed and converted to a digital signal using a proprietary algorithm [2]. This technology was extended in 2008 to measurement of total hemoglobin concentration. Currently available devices are the Radical-7, a continuous monitoring bedside device, and the Pronto-7, a handheld spot-check device [3•]. Most studies have focused on the performance of these noninvasive hemoglobin measurement devices manufactured by Masimo Corporation. New software and probes to improve the accuracy of measurements are currently under development.

OrSense Products

The Rainbow technology has been revealed as inaccurate under poor perfusion conditions [4]; OrSense developed another noninvasive hemoglobin monitoring devices to overcome this limitation, the NBM-200 and NBM-200MP (OrSense, NesZiona, Israel). NBM-200 is spot-check device and analyze pulse rate and hemoglobin value. It uses differential light absorption before and after blood flow obstruction in a finger using a ring-shaped finger sensor that is temporarily squeezed to over-systolic pressure [4, 5]. This technology is known as occlusion spectroscopy and has been used to noninvasively measure glucose concentration. The release of blood flow after occlusion generates a strong optical signal that is tenfold greater than the pulse signal [6]. The lights in wavelength ranging from 600 to 950 nm are emitted from the ten spectrally stabilized emitters and detected within sensor, and the hemoglobin concentration can be measured by analyzing the signals at these wavelengths [7]. NBM-200MP additionally displays plethysmography and oxygen saturation of hemoglobin, based on the association of low-perfusion oximetry combined with occlusion spectroscopy [4]. Several studies of the OrSense products have been conducted, but have shown inconsistent results with a wide variation in biases. In addition, limited data involve unstable patients with bleeding. Therefore, further studies are required if this device is to be used in clinical practice, particularly in unstable patients with bleeding.

Haemospect

Haemospect (MBR Optical Systems, Herdecke, Federal Republic of Germany) is a spectroscopic device that uses

visible and near-infrared lights. It was developed from the Mediscan 2000 system and was first marketed in 2008. The Haemospect sensor has light-emitting and -detecting silica fibers that are 250 μm apart. Halogenated white light is used and the reflected light is analyzed for spectra in the 350–1,020 nm range. Then, the system calculates the concentration and path length of light between the light-emitting and -receiving fibers using the non-linear Levenberg–Marquardt fitting algorithm, and the hemoglobin concentration is calculated. Although two studies showed a good correlation with actual total hemoglobin (tHb) in pediatric patients [8, 9], limited data are available regarding its use during anesthesia.

Evaluation of the Accuracy of Noninvasive Hemoglobin Monitoring

During clinical practice, various conditions and patient factors can affect the accuracy of noninvasive hemoglobin measurement. These factors are perfusion state, the hemoglobin level itself, a large volume shift, type of infused fluid, and age of the patient. Many studies have used the correlation coefficient, bias, precision, and limits of agreement (LOA) to evaluate the accuracy of devices. However, none of these methods can perfectly evaluate accuracy from the clinical perspective.

The correlation coefficient indicates simply the strength and direction of the linear relationship between two variables but provides no information on the clinical implication of a specific value. Bias is the degree of closeness to the actual value and is defined as the average of paired differences for all measurements. Precision is the degree to which repeated measurements yield identical results under unchanged conditions and is manifested as the standard deviation of the difference in paired measurements. The LOA represent the dispersion of data around the bias line, which is calculated from the bias ± 1.96 standard deviations.

Although bias is used widely to compare two devices, low bias does not necessarily infer an accurate instrument [10•]. Even if data are distributed widely from the actual value but the spread above and below 0 is approximately identical, the bias is 0. Absolute bias is occasionally used to reduce this problem. In addition, the Bland–Altman analysis is designed to measure fixed, not proportional, bias. Therefore, if there is a relationship between the tHb and SpHb, LOA are not reliable [10•].

A simple method to analyze trending ability is based on regression analysis and concordance, and was first described by Perrino et al. [11]. It is used when evaluating the accuracy of cardiac output (CO) monitoring. The test ΔCO

was plotted against the reference ΔCO on a four-quadrant scatter plot [12]. The concordance rate was simply a measure of the number of data points that fell into one of the two quadrants of agreement. Another method to evaluate trending is a polar plot, which is described in Critchley's review [12].

Because the clinical meaning of SpHb accuracy differs according to tHb level, the clinical error grid has been applied to evaluate the accuracy of SpHb [13•, 14, 15•]. This method was first used to evaluate blood glucose monitoring devices. Hemoglobin and blood glucose levels have similar aspects in terms of the clinical meaning of values that differ from the real values (when the values are out of the normal range, the meaning of its value is greater). A clinical error grid is a practical method of evaluating the clinical significance of SpHb.

Accuracy in Various Clinical Situations

During clinical practice, SpHb can be applied to patients of different ages (adults, children, infants, or neonates) in various locations [operating room, intensive care unit (ICU), emergency room, or outpatient ward], during different surgical procedures, in healthy or ill individuals, and under different physiological conditions (poor peripheral perfusion, active bleeding, or rapid fluid administration). Understanding the performance of noninvasive hemoglobin monitoring devices under diverse conditions facilitates their use during anesthesia.

Pediatric Patients

SpHb data in pediatric patients are limited. Various pediatric sensors for Masimo devices are available, which are based on patient weight (Rainbow R20 is for 10–50 kg, Rainbow R125L is for <3 kg, and the Rainbow R120L is for 3–30 kg). The degree of SpHb accuracy in pediatric patients who underwent neurosurgery or preoperative phlebotomy is similar to that of adults [16, 17]. In neonates, the benefit of SpHb may be greater than in adults or large children because neonates have a limited blood volume. Even a small blood sample can cause anemia if Hb measurements are repeated. One report in a neonatal ICU showed a clinically acceptable accuracy and correlation with tHb [18]. However, the accuracy and usefulness of the Radical-7 are questionable in multivisceral pediatric transplant patients [19]. In summary, although SpHb offers a clinically acceptable correlation with tHb and the benefit of a continuous trend monitor, critical decisions should not be made in pediatric patients based on this device alone.

Location

Operating Room

The correlation coefficient during vascular surgery is lower than during other types of surgery [20]. The type of surgery can influence the accuracy of a noninvasive hemoglobin monitoring device; moreover, intraoperative physiology may also affect its performance.

Potentially Hemorrhagic Abdominal or Pelvic Surgery Applegate et al. [21•] evaluated the performance of the Radical-7 in gynecologic, urologic, and general abdominal surgeries with mean estimated blood loss of 760 mL. That study of 91 surgical patients showed a weak correlation between SpHb and tHb. In addition, SpHb was out of 1 g/dL of tHb in 48.6 % of the measurement pairs. Those authors found that several characteristics influenced bias. The bias was larger in patients with blood loss >1,000 mL, hemoglobin <9.0 g/dL, or any intraoperative transfusion, whereas the bias was reduced during deep anesthesia. Increased bias in patients who require a transfusion may be an obstacle to use of SpHb monitoring for the decision to perform a transfusion.

The accuracy of the Radical-7 was compared with that of HemoCue (cHb) in a study of patients scheduled for potentially hemorrhagic major urologic surgery [22]. The correlation coefficient was lower and LOA were wider for the Radical-7 than those for the cHb. In addition, the percentage of outliers (defined as the absolute bias >1 g/dL) for the Radical-7 was significantly higher than that for the cHb (46 vs. 16 %, $P < 0.05$). Therefore, the authors concluded that SpHb monitoring with the Radical-7 gives a lower reading than that of the cHb in terms of assessing hemoglobin concentration during hemorrhagic surgery. The accuracy of noninvasive continuous hemoglobin monitoring is lower in patients with bleeding than in healthy individuals.

Cesarean Section (CS) Butwick et al. [23] evaluated the accuracy of the Radical-7 in 50 healthy term patients undergoing elective CS under neuroaxial anesthesia. Measurements were obtained at the following time points: baseline (before preload during the preoperative period), during the immediate postoperative period (within 10 min of arrival in recovery), and 24 h after completion of surgery. The bias series and LOA are demonstrated in Table 1. SpHb tended to be higher than tHb with a greatest difference 24-h post-CS. Considering that no patient experienced significant obstetric hemorrhage, the variable bias and wide LOAs may limit the clinical utility of the Radical-7 for assessing tHb and making transfusion decisions in patients undergoing elective CS.

Table 1 Accuracy of continuous noninvasive hemoglobin monitoring in previous studies

References	Location/patients	Device/probe or software version	Correlation coefficient	Bias (95 % CI) (g/dL)	Precision (g/dL)	LOA (g/dL)	Influencing factor
Park et al. [16]	OR/neurosurgery, pediatric patients	Rad 7/rev E	0.53	0.90 (0.48–1.32)	1.35	–1.74 to 3.54	tHb
Dewhirst et al. [17]	OR/phlebotomy, pediatric patients	Rad 7/rev E	0.68	0.1	1.5	–2.8 to 3.1	
Causey et al. [20]	OR/vascular surgeries	Rad 7/rev C	0.77	0.29 (0.08–0.49)	–	–	Type of surgery
Applegate et al. [21•]	OR/pelvic surgery	Rad 7/rev E	0.69	0.50	1.44	–2.3 to 3.3	Blood loss >1,000 mL, tHb, transfusion, deep anesthesia
Lamhaut et al. [22]	OR/urologic surgery	Rad 7/rev C	0.77	–0.02 ± 1.39	1.11	–2.75 to 2.70	
Butwick et al. [23]	OR/CS, baseline	Rad 7/rev E	–	1.22 (0.89–1.54)	1.05	–0.9 to 0.33	
Butwick et al. [23]	OR/CS, immediately post-CS	Rad 7/rev E	–	0.14 (–0.18 to 0.46)	1.56	–2.35 to 2.56	
Butwick et al. [23]	OR/CS, 24 h post-CS	Rad 7/rev E	–	1.36 (1.04–1.68)	0.85	–0.55 to 3.27	
Berkow et al. [24]	OR/spine surgery	Rad 7/rev E	–	–0.3	1.00	–2.4 to 1.7	SIQ
Miller et al. [25]	OR/spine surgery	Rad 7/rev E	–	0.26	–	–3.24 to 3.77	PI, tHb
Isosu et al. [41]	OR/vascular surgeries	Rad 7/rev C	0.76	0.2	1.5	–2.8 to 3.1	PI, in vivo adjustment
Gayat et al. [5]	ER	NBM-200MP	0.69	0.21 (0.02–0.39)	–	–3.01 to 3.42	tHb, PI
Gayat et al. [26]	ER	Pronto-7/rev B	0.8	0.56 (0.41–0.69)	–	–1.84 to 2.94	tHb, age
Sjostrand et al. [27]	ER	Rad 7/rev B	0.53	1.80 (1.50–2.10)	–	–3.3 to 6.9	SpO ₂ , tHb
Jung et al. [18]	ICU/neonates	Rad 7/rev E	–	–0.47 (–0.62 to 0.32)	–	–2.75 to 1.81	PI, SIQ
Causey et al. [20]	ICU/SICU	Rad 7/rev C	0.76	0.86	–	–2.54 to 4.26	tHb
Frasca et al. [29]	ICU/SICU	Rad 7/rev E	0.67	0.05 (–0.22 to 0.31)	–	–	
Nguyen et al. [31]	ICU/cardiac	Rad 7/rev E	0.79	0.00	0.50	–1.0 to 0.9	
Nguyen et al. [31]	ICU/cardiac	Rad 7/rev E	0.33	–1.3 (–1.9 to –0.7)	–	–4.6 to 2.1	PI
Joseph et al. [30]	ICU/trauma	Rad 7	0.52	–1.7 (–2.3 to –1.1)	–	–5.7 to 2.3	PI
Coquin et al. [32•]	ICU/GI bleeding	Rad 7	0.67	1.0	–	–	
Coquin et al. [4]	ICU/GI bleeding	NBM-200MP	0.55	1.0 ± 1.9	1.8	–2.7 to 4.7	Norepinephrine
Macknet et al. [33]	Healthy	Rad 7	0.71	–0.4 ± 2.0	1.6	–3.5 to 4.3	Vasopressor infusion
Shah et al. [34]	Healthy	Pronto-7	0.69	–0.15	0.92	–	–
Kim et al. [35]	Healthy/blood donors	NBM-200	0.69	–0.1 ± 1.1	–	–2.3 to 2.1	
Belardinelli et al. [36]	Healthy/blood donors	NBM-200	0.69	0.08 ± 1.11	1.38	–2.10 to 2.33	–
		Pronto-7	0.29	0.29	0.98	–1.64 to 2.21	
			–0.53	–0.53	1.04	–2.57 to 1.51	

LOA limits of agreement, CI confidence interval, OR operating room, ER emergency room, ICU intensive care unit, CS Cesarean section, SIQ signal sensitivity value, PI perfusion index

Spine Surgery The first study of spinal surgery reported that the Radical-7 has clinically acceptable accuracy [24]. However, a subsequent spinal surgery study showed a relatively large LOA and the effects of various other factors [25]. In Miller's study, the Radical-7, tHb, and cHb were compared. A total of 78 paired Hb samples were collected from 20 patients and analyzed. Overall, 61 % of the SpHb values corresponded with the tHb values by <1.5 g/dL. The authors suggested that SpHb monitoring is expected to facilitate transfusion management by providing additional and continuous data. However, the large LOA and other influencing factors should be considered.

Neurosurgery The accuracy of the Radical-7 during neurosurgery has been evaluated in pediatric patients <12 years old [16]. Overall, the difference in SpHb and tHb was <1.5 g/dL in 87 (73.1 %) measurement pairs. If the patient was in a hypovolemic state, the authors infused either colloid or red blood cells based on their protocol. Subsequently, the changes in SpHb and tHb (Δ SpHb and Δ tHb) before and after volume resuscitation were compared. The concordance rate (a measure of the number of data points that are in one of the two quadrants of agreement) using a four-quadrant plot was 94.4 %, and the correlation coefficient between paired measurements of Δ SpHb and Δ tHb after volume resuscitation was 0.87 ($P < 0.001$, 95 % confidence interval, 0.84–0.92). However, the bias was influenced by the tHb concentration. Although SpHb can be useful as a trend monitor during surgery even immediately after administration of intravascular volume expanders, the clinician should be cautious when SpHb alone is used to make transfusion decisions.

Emergency Room

Noninvasive hemoglobin monitoring is also valuable in emergency care. The first study from the emergency room using the Radical-7 concluded that SpHb is systemically biased and insufficiently reliable to guide transfusion decisions because of the large bias and LOA [26]. SpHb could not be obtained with the Radical-7 in 24 of 300 patients who were significantly older and had lower SpO₂ and diastolic blood pressure. Another study using the Radical-7 in 30 patients with stable hemodynamics in an emergency room demonstrated improved bias and LOAs. Although its accuracy seemed to be improved compared to a previous report, it had difficulty predicting tHb with a single SpHb value [27]. Gayat et al. [5] evaluated the performance of two noninvasive hemoglobin monitoring devices, the Pronto-7 and the NBM-200MP, in 300 patients in a stable condition. Although the NBM-200MP was associated with higher variability and a larger LOA compared to those of the Pronto-7, both devices had large LOA, making their clinical

usefulness debatable. Furthermore, no significant fluid shift condition, blood loss, or active bleeding was observed. In recent study, Moore et al. [28] reported that the Radical-7 device failed to detect Hb values in 34 % of cases and the SpHb showed poor correlation with tHb in severely injured trauma patients in emergency room. More studies that include hemodynamically unstable patients are required for clinical use of noninvasive hemoglobin monitoring systems in the field of emergency care. In addition, the problems associated with movement of the probe in conscious patients should be considered.

ICU

ICU patients have much in common with patients under anesthesia. One study of patients in the general ICU showed that SpHb measured with the Radical-7 has absolute and trending accuracy similar to the widely used invasive cHb [29]. However, in that study, <10 % of the measurements were performed in patients with a hemoglobin <8 g/dL, and no patient was actively bleeding. Other studies on patients with bleeding failed to show high accuracy of the Radical-7. Data were not recorded in severely injured ICU patients 13.5 % of the time. About 58 % of their data pairs had a difference >1 g/dL, and >32 % had a difference >2 g/dL [30]. Another report on 41 cardiac ICU patients showed a poor correlation and wide LOA between SpHb (Radical-7) and tHb [31]. Additionally, 40 % of the patients received norepinephrine. That study compared two versions of the Radical-7 software (V 7.3.0.1 vs. V 7.3.1.1), and found no difference. The authors suggested that noninvasive Hb monitoring technology should be improved before its use in anesthesiology or the intensive care setting. Determining hemoglobin using a noninvasive hemoglobin monitoring device in ICU patients with severe gastrointestinal bleeding appears inaccurate for clinical decision making [4, 32•]. In ICU patients admitted for gastrointestinal hemorrhage, the NBM-200MP lacked accuracy compared with cHb regardless of the measurement site [4]. When a study of the Radical-7 in a similar situation was performed, its clinical performance and accuracy were also not acceptable. The proportion of inaccurate measurements was 56 % for noninvasive hemoglobin monitoring devices compared with 15 % for cHb [32•]. In summary, accuracy seems to decrease in ICU patients with bleeding. Therefore, clinicians should be cautious when interpreting the SpHb value for management of ICU patients.

Other Situations

The SpHb value appears to be more accurate in healthy individuals [33, 34]. SpHb measured using the Radical-7 was accurate within 1.0 g/dL compared with that of tHb

measurements in healthy subjects undergoing hemodilution [33]. The Pronto-7 provided accuracy similar to the cHb, invasive point-of-care device, in healthy patients [34]. In contrast, the accuracy was not optimal for blood donor screening.

The use of noninvasive Hb measurement for blood donor screening is controversial. Kim et al. [35] evaluated the usefulness of the NBM-200 for blood donor screening and concluded that wrong decisions could occur when deciding eligibility for blood donation using this device. Another reports of blood donor screening using the NBM-200 are available [36, 37]. Pinto et al. compared performance of fingerstick sampling and NBM-200, and significantly lower level of percentage error was found in NBM-200 compared to reference value (tHb). On the other hand, Belardinelli et al. evaluated the accuracy of the NBM-200 and Pronto-7 and assessed whether they could enhance recruitment and retention of blood donors. However, both devices, particularly the Pronto-7, had lower specificity and sensitivity and the risk of inappropriate donation.

During pregnancy, noninvasive hemoglobin monitoring can provide additional benefit to detect gestational anemia or obstetrical hemorrhage. Hadar et al. [38] evaluated accuracy of NBM-200 in pregnant women. The mean bias and standard deviation of NBM-200 were 0.1 and 0.86 g/dL, and the SpHb strongly correlated to tHb from venous sampling. Thus, authors concluded NBM-200 may serve an important role in obstetrics allowing easy, rapid, and accessible evaluation of hemoglobin.

In another circumstance, such as during hemodialysis, SpHb was used to estimate the changes of blood volume [39]. Although absolute values of SpHb using Radical-7 were poorly correlated with Hb measured by Crit-Line, in-line device that monitors blood volume changes during hemodialysis, the changes of blood volume determined from equation using SpHb showed good correlation with the changes measured by Crit-Line. This study emphasized the trending ability of the SpHb.

Clinical Factors Affecting SpHb Accuracy

The accuracy of SpHb can be influenced by many factors, such as poor peripheral perfusion state, vasoconstrictor infusion, low hemoglobin level, and rapid fluid administration.

Peripheral Perfusion

Perfusion Index (PI) Value Obtaining the SpHb value with a PI <1.4 is not recommended by the Radical-7 manufacturer. The PI value has a definite influence on SpHb accuracy. One study showed that digital nerve block resulting in an increase of digital perfusion can increase PI,

and this can increase accuracy of SpHb [40]. There is a tendency for SpHb to overestimate tHb when the PI is >1.4 [25, 41]. Another report showed a similar pattern when PI was >7.0 [42]. Accuracy increases when the PI value is >2.0, and SpHb underestimates tHb when PI is <2.0 [27]. This pattern was also observed in cardiac ICU patients [31]. SpHb–tHb difference appears to increase with a higher PI (Fig. 1a). Accuracy increases and variability decreases with higher PI values (>4.0) [25]. The NBM-200MP also showed a similar relationship between PI and the SpHb–tHb difference value, but the Pronto-7 value was not influenced by PI [5].

Use of Norepinephrine In addition to accuracy of SpHb, another important issue is data availability. If perfusion to peripheral tissue is poor, data availability can be limited. The number of unavailable measurements related to inadequate perfusion is significantly higher in patients receiving norepinephrine (42 % Radical-7 vs. 15 % cHb) [32•]. Accordingly, vasoconstrictor administration can affect the usefulness of noninvasive hemoglobin monitoring.

Peripheral Vascular Disorders Any condition that obstructs peripheral perfusion can affect the accuracy and availability of data. Vasospastic diseases such as Raynaud's disease also lead to inappropriate SpHb values.

Total Hemoglobin

The differences between SpHb measured by the Radical-7 and the tHb value appear to be inversely correlated with higher tHb [16, 21•, 25] (Fig. 1b). For example, the bias for all measurements was 0.26 g/dL (95 % LOA: –3.24, 3.77), whereas the estimated bias for SpHb values >12 g/dL was –1.64 (95 % LOA: –4.58, 1.29) in patients undergoing spinal surgery [25]. Therefore, SpHb tends to overestimate tHb when tHb is low. This wrong information can lead to the clinician falsely believing that a patient's hemoglobin level is normal even when a transfusion is actually required. The Pronto-7 and NBM-200MP also showed similar results in that biases were inversely correlated with tHb [5]. Another study of the Radical-7 in neonates reported that the accuracy decreases dramatically when the Hb level is >18 g/dL [18].

Fluid

One report found that the accuracy of noninvasive hemoglobin monitoring depends on the type of infused fluid [42]. In healthy volunteers, administration of lactated Ringers' solution increases the SpHb–tHb value by 7 %, whereas starch decreases it by 4.3 %. Another study showed that SpHb tends to change more than tHb during fluid infusion with crystalloid [43].

Fig. 1 The relationship between bias (SpHb–tHb) and perfusion index (PI) or tHb. **a** The bias appears to increase to between 0 and 1 with a higher PI. The values of bias and PI are from Refs. [24, 26, 29]. The trend is illustrated by a nonparametric smoothed regression line. **b** The bias appears to be inversely correlated with higher tHb. The values of bias and tHb are from Refs. [5, 20, 24]

Hemoglobin Synthesis Disorders

Hemoglobin synthesis disorders, such as thalassemia, Hb c, and sickle cell disease, may affect the SpHb value. One study of patients with sickle cell disease using the Pronto-7 demonstrated a moderate correlation with SpHb and tHb [44]. However, that study showed a wide range of bias (–4.8 to 4.5 g/dL), and SpHb values were better correlated when the tHb level was 9–11 g/dL. The authors concluded that this noninvasive method is appropriate for monitoring Hb changes rather than performing spot measurements in an individual.

Improper Application

Improper probe size compared with finger size, improper probe positioning, and motion can influence SpHb values. External fingernail coloring also affects the values. The Pronto-7 uses finger size to select an appropriate sensor size. When the Radical-7 is used, a light shield should be applied to avoid light interference. During general anesthesia, there is no concern regarding the motion of the probe. However, when patients are awake, such as in the emergency room, ICU, or those under spinal anesthesia, movement of the probe can affect the availability and accuracy of data.

Others

Other factors can affect the measurements; these include intravascular dyes (indocyanin or methylene blue), elevated bilirubin, low arterial saturation, and electrical interference.

Clinical Applications and Further Study

SpHb is useful for trend monitoring rather than for transfusion decision making, due to its limited accuracy. Predicting the change in Hb can facilitate preparation for adverse events or a transfusion. The concept of in vivo adjustment can increase the accuracy of performance of SpHb [41]. If the actual tHb is determined by drawing blood at baseline, then the difference between SpHb and tHb at baseline could be used to estimate tHb at other times. The accuracy of SpHb is insufficient to substitute for invasive Hb monitoring. However, it has undeniable advantages of noninvasiveness and continuous and immediate data availability. Most published studies considered the accuracy of devices. However, more data are required if SpHb is to be used to improve clinical outcomes.

Conclusion

Noninvasive continuous hemoglobin monitoring shows promise in terms of improving patient care and outcomes in various healthcare settings. However, many factors influence its accuracy, which must be further improved for use in patients with unstable hemodynamics or with bleeding. We suggest that devices for continuous hemoglobin monitoring can be used as a supplemental tool for monitoring of blood loss during anesthesia. However, SpHb cannot substitute for an invasive Hb measurement until its accuracy is as good as that of the blood-drawn reference value.

Compliance with Ethics Guidelines

Conflict of Interest Ji-Hyun Lee, Yong-Hee Park, and Jin-Tae Kim declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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- Of major importance

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