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Delay in detection and treatment of perioperative anemia in hip fracture surgery and its impact on postoperative outcomes

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ABSTRACT

Background: Elderly patients with hip fractures are at high risk for perioperative anemia as a result of fracture- and surgery-related blood loss. The detection of anemia is dependent on intermittent blood samples and therefore might be delayed, potentially leading to a significant delay in transfusion. This study aimed to investigate the possible delay in perioperative anemia detection, accumulated perioperative anemia-associated burden, peripheral perfusion, and their association with patient outcomes in elderly patients with hip fracture.

Methods: Elderly patients with acute hip fracture scheduled for surgery were enrolled in this prospective study from August 2016 to December 2016. All patients were monitored continuously for hemoglobin concentration (SpHb) and perfusion index (PI) with the Radical-7® Pulse CO-Oximeter® and Rainbow® R1 Adhesive Multi-parameter Sensors (Masimo Corp., Irvine, CA, US) from 12 h presurgery to 24 h postsurgery.

Results: Fifty-one patients were enrolled, and 41 were included in the final analyses. Mean delay in the detection of low Hb (<10 g/dL) using intermittent blood samples, when compared with SpHb, was 1.07 h (standard deviation, ±2.84 h). Median perioperative cumulated time with low SpHb (<10 g/dL for at least one min) was 25 min (interquartile range [IQR]: 21–690). There was a significant association between perioperative time with low SpHb and the occurrence of postoperative delirium (median cumulated time with low SpHb: 162 min in patients with delirium vs 22 min in patients without delirium, P = 0.034) and a nonsignificant trend for an association between perioperative time with low SpHb and 90-day mortality or medical complications (median cumulated time with low SpHb: 119 min for patients with mortality or severe complication vs 22 min for patients without mortality or severe complication, P = 0.104). PI values during the perioperative period were not significantly associated with patient outcomes. Cumulated time with low PI (<0.5) preoperatively (but not perioperatively) was significantly associated with the occurrence of postoperative delirium (P = 0.047).

Conclusions: This study showed a delay in transfusion threshold detection, and the presence of significant associations between low SpHb or time with low SpHb and postoperative outcomes.

Introduction

Perioperative anemia is common in elderly patients undergoing emergency surgery and has been identified as an independent risk factor for morbidity and mortality in non-cardiac surgery patients [1–9]. Acute blood loss induces hypovolemia and reduces red cell blood mass, after which fluid resuscitation and restoration of circulating volume presents as anemia with a low blood hemoglobin (Hb) concentration. Patients with hip fractures often suffer from perioperative anemia as the blood loss from the fracture and surgery is significant and continuous throughout the entire perioperative period [2–5,10,11]. The high 30-day mortality rate and high incidence of postoperative delirium have both been associated with anemia [12–14].

Laboratory Hb values from intermittent blood sampling are used to detect anemia in patients with hip fractures and determine the need for red blood cell (RBC) transfusions [15–17]. However, these values show a poor correlation with circulating blood volume during acute blood loss and reflect hemoglobin levels only at the time of blood sampling. Because laboratory Hb values are available only intermittently, significant delays in the detection of anemia and correction through RBC transfusion potentially may occur, aggravating the effects of anemia and hypovolemia.

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Continuous, non-invasive monitoring of capillary hemoglobin concentrations (SpHb) is now possible with Pulse CO-Oximetry technology and multi-wavelength sensors. This technique measures capillary hemoglobin in real time, and its use might potentially help prevent a delay in RBC transfusions in hip surgery patients.

As trauma patients react to blood loss by undergoing peripheral vasoconstriction in order to maintain their central blood volume, conventional hemodynamic measures such as blood pressure and heart rate are poor indicators of low to moderate blood loss [18–20]. However, some evidence suggests that markers of inadequate peripheral perfusion are early indicators of hypovolemia [21,22]. Therefore, it is possible that measurement of peripheral perfusion, as well as pHb, could provide useful clinical information as to the presence of hypovolemic anemia.

Our objective in this study was to investigate the delay in the detection of anemia in elderly hip surgery patients when assessed using laboratory Hb values from intermittent blood sampling compared with SpHb, or with continuous measurement of the perfusion index (PI), and to evaluate possible associations of the delay with patient outcomes. Furthermore, we investigated the associations between the cumulated perioperative burden of anemia (measured by SpHb) and conventionally measured intermittent Hb, and the associations of SpHb, Hb, and PI with postoperative delirium and mortality or severe complications.

Methods

Study design

We conducted an observational prospective study in University Hospital, Hvidovre, Capital region, Denmark. The study protocol was approved by the regional ethics committee (H-15012731) and the Danish Data Protection agency (AHH-2015-097, nr: 04237). The study was registered prior to patient enrollment at ClinicalTrials.gov (registry no. NCT02838706, Principal investigator: Christopher Clemmesen, Date of registration: July 20, 2016). Written informed consent was obtained from all subjects. This manuscript adheres to the applicable STROBE guidelines.

Patients

From August 2016 to December 2016 all patients with acute hip fracture scheduled for surgery in University Hospital were screened for inclusion in the study after arrival in the emergency department. To be eligible for inclusion, patients had to be aged 65 years or older, have a hip fracture, speak and understand Danish, have a Danish social security number, provide informed oral and written consent, and have no contraindications for receiving preoperative epidural analgesia. Patients with an allergy to bandages in the adhesive sensor were excluded.

Anesthesia, surgery, and perioperative management

All patients scheduled for surgery for hip fracture surgery were evaluated, and if possible, the anesthetist performing the pre-anesthetic assessment participated in the patient evaluation.

All patients followed our standard procedure for surgery, anesthesia, and perioperative procedures. After admission to the emergency department, patients received a fascia iliaca compartment blockade. A possible hip fracture was confirmed by x-ray and patients were transferred to the postoperative care unit for preoperative epidural analgesia. After a test dose of 3 mL lidocaine 2% with epinephrine, to exclude spinal or intravascular placement of catheter, a bolus of 5 mL bupivacaine 0.25% and 1 mg of morphine was given. Epidural analgesia was initiated with 4 mL/h of bupivacaine 0.25% and 50 μg/mL morphine. In most cases, patients underwent surgery within 24 h of admission. In the operating theater, a bolus of 10 mL of lidocaine 2% in increments of 5 mL was administered in the epidural catheter. Light sedation induced with propofol 10–40 μg/kg/min was given upon patient request. Patients with insufficient preoperative epidural at surgical time out received general anesthesia with propofol 3–5 mg/kg/h, remifentanil 0.3–1.0 μg/kg/h, sufentanil 0.1–0.2 μg/kg, and toradol 30 mg intravenously during the postoperative period. After surgery, all patients were treated according to a well-defined multimodal fast-track rehabilitation regimen that included daily screening for delirium in the specialized hip fracture unit.

Standard blood samples for laboratory Hb measurement were obtained at admission, every morning after surgery, and whenever patients had clinical signs of anemia. The treatment regimen included a liberal transfusion trigger of 10 g/dL Hb based on laboratory Hb values. There was a focus on early transfusion after detection of anemia in order to facilitate early anemia correction.

The hip fracture unit follows standard non-pharmacologic procedures to prevent delirium. This includes early mobilization, improved nutrition according to a dietician's program, sleep improvement, medication review, and a pre- and postoperative assessment by the hip fracture unit cardiologist. The standard initial pharmacologic treatment for postoperative delirium consists of haloperidol (if contraindicated, then olanzapine). A delirium-specialized liaison psychiatric team consisting of a psychiatrist and specialized trained nurse was affiliated with the unit and saw some of the more complicated cases with delirium.

Standard postoperative analgesia included epidural bupivacaine 0.125% and morphine 50 μg/mL at 4 mL/h (until the fourth postoperative day), acetaminophen 1 g every 6 h, and rescue analgesia with morphine 5 mg (patients without an epidural catheter received morphine 5–10 mg PO every 6 h). All patients were evaluated on days 1–3 after surgery and daily on weekdays thereafter by a physiotherapist in order to commence with physiotherapy and a mobilization program based on day-to-day and habitual levels of function.

Data collection and outcome measures

Data were collected using the Radical-7® Pulse CO-Oximeter® and Rainbow® R1 Adhesive Multi-parameter Sensors (Masimo Corp., Irvine, CA, US). SpHb, PI, oxygen saturation (SpO_2), and pulse rate (PR) were recorded continuously every two seconds. The sensor was placed on the second, third, or fourth finger of the patient's non-dominant hand and was shielded from ambient light. If possible, the sensors remained on the patients from admission and initial resuscitation until the third postoperative day. The sensors were briefly disconnected only when they were inconvenient for patient care (such as during personal hygiene) and daily when the sensor bandage was changed. With the exception of the SpO_2 value, the monitor was blinded for all study participants, care providers, and attending physicians and nurses in order to prevent SpHb and PI values from guiding transfusion and other clinical decisions.

Outcome measures were defined a priori. The study outcome was the impact of any delay in the diagnosis of perioperative anemia (defined as Hb below the transfusion threshold of 10 g/dL) and patient outcome. The was defined by the association between the occurrence or duration of anemia (measured with laboratory Hb values or SpHb) with patient outcomes, and the association of low PI values (defined as $PI < 0.5$) with patient outcomes. Patient outcomes of interest were postoperative delirium and 90-day mortality or a severe complication such as cerebrovascular accident, acute myocardial infarction, arrhythmia, pneumonia, respiratory insufficiency, pulmonary embolus, deep venous thrombosis, acute kidney failure, or septicemia.

To detect possible postoperative delirium, we used the Brief Confusion Assessment Method (bCAM). Patients were screened with bCAM once daily for the first three postoperative days. Patients with a positive bCAM score were evaluated according to criteria of the Diagnostic and Statistical Manual of Mental Disorders IV for possible delirium.

To our knowledge, this is the first study to investigate a possible delay in diagnosing of anemia with SpHb among elderly patients with hip fracture. Therefore, no prior data existed to calculate a sample size. In order to investigate the impact of duration of time spend below transfusion threshold on outcome we used delirium for power analysis since time spend below threshold is uninvestigated. We estimated a incidence of delirium of 40% from previous studies and assumed that we needed at least 50% of this or 20% incidence to have enough patients for a meaningful comparison. As such we needed to include at least 43 patients with a power of 0.8 and a significance of 0.05. Therefore, we decided included 50 patients to account for missing data.

The originally planned study period lasted from inclusion (immediately after admittance) until the third postoperative day. However, due to frequent data inconsistencies in the postoperative period in the surgical wards resulting in lack of data, we chose to narrow the period of SpHb and the PI measurements. This decision was made after initial examination of continuous data, before analysis of outcomes and correlations. We divided the perioperative period into three periods: (1) preoperatively (the last 12 h before surgery); (2) intra-operatively (during the surgery); and (3) postoperatively (the first 24 h after surgery). Low Hb was defined as a value <10 g/dL, which was the departmental trigger to initiate transfusion. Low SpHb was defined as a value <10 g/dL maintained for a minimum of one minute. Delay in anemia detection was defined as the time lag (in whole h) between a low SpHb value and the next low Hb from blood sampling. We also investigated the association between the median PI value during the entire measurement period and outcomes. We defined low PI as a value continuously <0.5 for a minimum of one minute.

Statistical analysis

Statistical analysis was performed using SPSS for Windows software, version 22.0 (IBM Corp., Armonk, NY) and GraphPad Prism 7 for Windows software (GraphPad Software Inc., La Jolla, CA). Categorical data are presented as counts with percentage, and the Fisher exact test or the chi-square test was used to evaluate differences between groups. The continuous SpHb and PI data were not normally distributed, as assessed by inspection of Q-Q plots, histograms of frequencies, and Kolmogorov-Smirnov tests. Therefore, these data are presented as median with interquartile range (IQR), and differences between groups were analyzed with the nonparametric Mann-Whitney U signed-rank test. In all analyses, a *P* value <.05 was considered statistically significant.

Results

From August to December 2016, 225 patients with hip fracture were screened for inclusion in the study. Fifty-one patients were included in the study, and 42 patients were included in the final analyses (Fig. 1). These patients consisted of 25 women (59.5%) and 17 men (40.5%) with a median age of 78 years (SD +/-8). Baseline characteristics of the patients are listed in Table 1.

Delay in detection of perioperative anemia

During the measurement period, 20 of the 42 patients had at least one event of a laboratory Hb value <10 g/dL. A low SpHb value was detected concurrently, or prior to obtaining a low laboratory Hb value, in 15 patients. In three patients, there were insufficient data to estimate delay, and in four patients SpHb values were not <10 g/dL even though the laboratory Hb value was <10 g/dL. All patients with insufficient SpHb data or with SpHb values that had not been <10 g/dL at the time when the blood samples with a low Hb concentration were obtained were regarded as having no delay in low Hb detection. When compared with the timing of the detection of anemia with SpHb, for the 20 patients with a laboratory Hb value <10 g/dL, the mean (± standard deviation) delay in the detection of low Hb using blood samples was 1.07 ± 2.84 h.

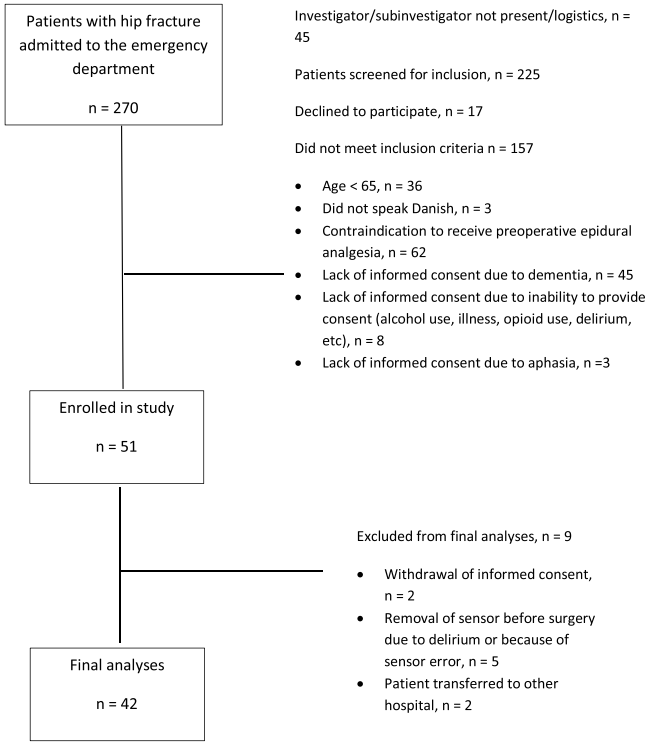

Fig. 1. Enrollment.

Eight patients had at least 1 h and up to 12 h of delay in the detection of the transfusion threshold trigger. All 20 patients with an event of low pHb received blood transfusions.

Association between Anemia and patient outcomes

We investigated the association between an event of low laboratory Hb during the measurement period and negative clinical outcomes (the occurrence of delirium or 90-day mortality/severe complications). At the time of admission, only three patients (7%) had a low laboratory Hb value. Twenty patients (50%) had a low laboratory Hb value at the time of surgery, and 25 patients (60%) had a low laboratory Hb value at some point during the study. There was no significant association between an event of low Hb and negative postoperative outcomes (Table 2).

During surgery, 24 patients (57%) had an event of low SpHb, and 35 patients (83%) had at least one event of low SpHb during the measurement period (Table 2). Among patients with an event of low SpHb, the median time with low SpHb was 25 min (IQR: 21–690). In evaluations of the association between the cumulated time with low SpHb values and patient outcomes, we found a significant association between cumulated time with low SpHb and postoperative delirium: the median cumulated time with low SpHb values was 162 min (IQR: 30–819) for patients with postoperative delirium versus 22 min (IQR: 4–137) for patients without postoperative delirium ($P = 0.034$, Table 2). There was also a trend for a longer cumulated time of low SpHb in patients with 90-day mortality or

Table 1
Patient characteristic, perioperative and outcome data. Values are mean (SD), median (IQR) or number (%).

Variable	All patients
Age, years, mean (SD)	78 (±8)
Sex, male/female, n (%).	17/23 (42.5%/57.5%)
ASA, n (%):	
I	1 (2.5%)
II	25 (62.5%)
III	13 (32.5%)
IV	1 (2.5%)
Type of fracture, n (%):	
Femoral neck	22 (55.0%)
Pertrochanteric	15 (37.5%)
Subtrochanteric	3 (7.5%)
Low prefracture function, NMS (0–6), n (%).	11 (27.5%)
High prefracture function, NMS (7–9), n (%).	29 (72.5%)
Low mental status, (0–6), n (%).	3 (7.5%)
High mental status, (7–9), n (%).	37 (92.5%)
Type of surgery, n (%):	
Hanssons pins	6 (15.0%)
Hemiarthroplasty	14 (32.5%)
Sliding Hip Screw	1 (2.5%)
Intramedullary Nail	29 (47.5%)
Total Hip Arthroplasty	1 (2.5%)
Blood loss in ml during surgery, median (IQR).	300 (150-443)
Type of anesthesia*, n (%):	
General	2 (5.0%)
Epidural	19 (47.5%)
Epidural with propofol sedation	19 (47.5%)
Duration surgery, hh.mm, median (IQR).	1:08 (0:49:1:31)
Length of stay, days, mean (SD).	14 (±13)
Hours delay in detection of perioperative anemia, mean (SD).	1:07 (SD ± 2.84).
Patients received transfusion in measuring period, n (%)	20 (47.6%)
Postoperative delirium, n (%).	16 (40%)
90-day all-cause mortality, n (%).	3 (7.5%)
90-day all-cause mortality or severe complications, n (%)**	15 (35.0%)

ASA, American Society of Anesthesiologists Physical Status; BMI, body mass index, NMS; New Mobility Score (0–9).
* All patients were planned to epidural anaesthesia. If the pre-operative epidural was insufficient at Time-out of surgery the type of anaesthesia was converted General anesthesia.
** Severe complications were: cerebrovascular accident, acute myocardial infarction, arrhythmia, pneumonia, respiratory insufficiency, pulmonary embolus, deep venous thrombosis, acute kidney failure or septicaemia.

Table 2
Perioperative pHb and SpHb. Values are count (percent) and median (IQR).

	All patients (N = 42)	Delir = yes (N = 16)	Delir = no (N = 26)	P value	Dead at 90 days or severe complications (n = 15)	Alive at 90 days and no severe complications (n = 27)	P value
PHb							
Admission low pHb**	3	2	1	0.547	1	2	1.000
Low pHb at some point*	25	12	14	0.197	9	17	0.850
SpHb							
Event of low SpHb during surgery*	24 (57%)	12 (75%)	12 (50%)	0.067	11 (73%)	13 (48%)	0.193
Event of low SpHb pre, intra or post**	35 (83%)	16 (100%)	19 (73%)	0.033	14 (93%)	21 (78%)	0.390
Time with low SpHb							
Cumulated median (IQR) time with low SpHb***	49 (8–419)	162 (30–819)	22 (4–137)	0.034	119 (49–325)	22 (4–514)	0.104
During surgery median (IQR) time with low SpHb***	8 (0–55)	21 (1–82)	0 (0–26)	0.113	20 (0–70)	0 (0–51)	0.146

* Chi-square.
** Fisher's exact.
*** Non-parametric MannW.

severe complication; however, this association was not statistically significant. The median cumulated time with low SpHb was 119 min (IQR: 49–325) for patients with 90-day mortality or severe complication versus 22 min (IQR: 4–514) for patients without 90-day mortality or severe complication ($P = 0.104$, Table 2).

PI and patient outcomes

PI values during the perioperative period were not significantly associated with patient outcomes (Table 3). Of the 42 patients included in the final analyses, 27 (64%) had low PI (<0.5) during the study; nine patients had low PI in the 12 h before surgery, 12 patients had low PI during surgery, and 25 patients had low PI during the first 24 h after surgery. Across all patients, the median cumulated time with low PI during the perioperative period was 8 min (IQR 0–59).

The cumulated time with low PI in the 12 h before surgery was significantly associated with the occurrence of postoperative delirium ($P = 0.047$, Table 3). However, the cumulated time with low PI during surgery and during the first 24 h postoperatively

Table 3
Patient outcome and PI. Values are median (IQR).

PI	All patients n = 42	Delirium = yes (n = 16)	Delirium = no (n = 26)	p value	Dead at 90 days or severe complications (n = 15)	Alive at 90 days and no severe complications (n = 27)	p value
Median PI value (IQR)	4.57 (3.43–6.50)	4.29 (2.37–5.32)	5.17 (3.65–7.20)	0.231	4.57 (3.43–5.24)	4.78 (3.40–7.20)	0.547
Cumulated median (IQR) time with low PI*	8 (0–59)	12 (0–119)	3 (0–59)	0.333	9 (0–44)	3 (0–111)	0.776
Preoperative median (IQR) time with low PI*	0 (0–0)	0 (0–5)	0 (0–0)	0.047	0 (0–0)	0 (0–0)	0.546
During surgery median (IQR) time with low PI*	0 (0–6)	0 (0–6)	0 (0–6)	0.782	0 (0–6)	0 (0–9)	0.754
Postoperative median (IQR) time with low PI*	2 (0–59)	3 (0–85)	1 (0–59)	0.406	3 (0–14)	1 (0–91)	0.967

* Median and IQR are round off and stated as minutes. Non-parametric test were performed with values as seconds.

were not significantly associated with the occurrence of postoperative delirium ($P = 0.782$ and 0.406, respectively). There were no significant associations between cumulated time with low PI (preoperatively, during surgery, or postoperatively) with 90-day mortality or severe complication (Table 3).

Discussion

In this prospective observational study, we investigated the burden of anemia and low perfusion among elderly patients with hip fracture, as well as outcomes of postoperative delirium and mortality or a severe complication. The study objective was to asses the impact of a possible delay in detection of blood Hb levels below a liberal transfusion threshold in these patients. We explored the time lag between detection of low Hb as measured by SpHb and by standard blood sampling. In our study, half of the patients received transfusions in the perioperative period. The mean delay in transfusion threshold detection was 1 h among all patients. However, eight patients had a delay of more than one hour, and delays of up to twelve hours occurred, suggesting an extensive delay in transfusion for some patients. The median time with SpHb below transfusion threshold was 49 min (IQR: 8–419). This suggests that despite a rigorous treatment regimen with a liberal transfusion threshold, elderly patients with fracture undergo protracted periods with anemia.

Previous studies using SpHb have focused on the association between laboratory Hb and SpHb values [23,24]. Whether the presence of low SpHb *in itself* is associated with unfavorable patient outcomes has not been investigated previously. In our study, the occurrence of one or more events of low pHb was not significantly associated with patient outcomes. However, we found significant associations between postoperative delirium and both the occurrence of low SpHb and the cumulated time with low SpHb (Table 2). Elderly patients with hip fracture can be hypovolemic and/or dehydrated at admission, and therefore, have hemoconcentration. This is substantiated by our findings that only three patients had a low laboratory Hb concentration at admission, while at the time of surgery, the majority of patients had low Hb as well as low SpHb.

Low Hb concentrations have been linked to postoperative delirium in elderly patients, possibly as a consequence of decreased cerebral oxygen delivery [25,26]. The pathogenesis of delirium is not completely understood [27]. Delirium can be regarded as acute brain failure due to increased oxygen demand or impaired oxygen supply to the cerebral tissue [28]. To our knowledge, our study is the first to explore and find an association between the time with low SpHb and perioperative/postoperative delirium. Both the duration and depth of perfusion and Hb concentration are believed to be pivotal to the total oxygen supply and associated with perioperative oxygen depth [29]. Therefore, we explored the association between perfusion and patient outcomes.

The PI reflects capillary refill time and can be used to monitor peripheral perfusion [30]. Impaired peripheral perfusion has been shown to be associated with impaired organ perfusion [31]. We did not find an association between PI values and patient outcomes in our study, as PI values were similar in patients with and without delirium and in patients with and without death or a severe complication. The normal range for PI is highly skewed [30], and we chose to use a PI value <0.5 as a cutoff value for low PI. The median cumulated time below this cutoff value was very low (8 min, Table 3). However, the cumulated time with low PI in the preoperative period was significantly associated with the occurrence of postoperative delirium. We did not find any associations between low intraoperative or postoperative PI and outcomes of delirium or mortality/severe complication.

There are several limitations to the study. Most importantly, it was an exploratory pilot study with a small number of patients, and therefore, the results should be interpreted with caution. There were several inconsistencies between the Hb concentration measured in blood samples and SpHb measured continuously. Non-invasive hemoglobin monitoring with the masimo Radical-7® Pulse CO-Oximeter® has proven to have excellent correlation to laboratory hemoglobin in trauma patients. However, there might be some inconsistency in patients with very low peripheral perfusion [32].There are also limitations in the use of pHb to guide transfusion. Laboratory hemoglobin does not always reflect the total circulating hemoglobin mass during acute haemorhage and can be elevated in the hypovolemic anemic patient [17]. SpHb is a different measurement of Hb concentration than pHb. Despite the small sample size, our results suggest that long periods with low SpHb were independently associated with the occurrence of postoperative delirium, and laboratory Hb measurements were not.

Peripheral perfusion measured with PI has not been validated as a global perfusion measurement. Low perfusion in some patients might have caused a lack of signal that led to the exclusion of their data from analysis, because we were not able to discern whether lack of peripheral perfusion signal was caused by low perfusion or by technical issues. Therefore, the duration of low perfusion in the patient population might have been underestimated. Furthermore, sympathetic nervous system activation by stimuli such as pain may influence peripheral perfusion and PI.

Logistical and practical issues resulted in a lack of continuous data recordings in some cases. The initial study protocol called for patients to have the sensor on from admission until the third postoperative day, with patient data recorded every 2 s. using the Radical-7 Pulse CO-Oximeter. Although the period of measurements was narrowed to 12 h before surgery until 24 h after surgery, some patients still had missing continuous monitoring data.

In addition, postoperative delirium is a challenge to measure because of its typically fluctuating course and multifactorial pathogenesis [33]. We chose to use the bCAM to screen patients for delirium once a day for the first three postoperative days. A modified CAM-ICU that was designed to improve sensitivity in non-critically ill patients [34], the bCAM is a highly specific, validated tool used to screen for delirium, and it has previously been translated into Danish [34,35].

In conclusion, we found a delay in transfusion threshold detection on average, and for some patients, the delay was substantial despite the study being done in an optimized perioperative setting in a specialized ward Continuous monitoring with SpHb during the perioperative period revealed that some patients had Hb levels below the prescribed transfusion threshold for a prolonged period. Furthermore, we found a significant association between the presence of low SpHb and postoperative outcomes, and between the cumulated time with low SpHb and postoperative outcomes. Our results suggest that continuous real-time measurements of Hb are better than intermittent laboratory Hb measurements for detection of low Hb levels and have the potential to enhance patient outcomes. Whether or not increased monitoring translates into improved patient outcomes will require further studies.

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This study is registered at www.ClinicalTrials.gov with the identifier NCT02838706.

Declaration of Competing Interest

None.

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