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The effect of digital nerve block on the accuracy of hemoglobin monitoring during surgery: A randomized clinical trial

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Abstract: *Background***:** The decision to transfuse blood products to patients during surgery is critical, due to the potential complications and costs of transfusion. Measuring hemoglobin level by spectrophotometry (SpHb) plays an important role in making this decision. The accuracy of SpHb depends on the finger perfusion. Since digital nerve blocks (DNB) can enhance blood circulation, we aimed at investigating DNB effects on the accuracy of SpHb.

Methods: Patients undergoing spine surgery were randomly assigned to two groups. Group A received DNB in the left hand, and group B received DNB in the right hand. In each group, the other hand was considered as the control. Rainbow adult ReSposable sensors were attached to the patients' both hands. Before surgical incision and every 1.5 hours, the SpHb values of both hands and the perfusion index were recorded. Concomitantly, arterial blood samples were drawn and sent to the lab for hemoglobin concentration measurement. This served as the gold standard for assessing hemoglobin levels (labHb). We used a mixed-effects generalized linear model to test the effect of independent variables on the difference between SpHb and labHb at each time point.

Results: The SpHb displayed higher hemoglobin levels than those assessed by the lab. For lower labHb values, the SpHb-labHb differences were larger. A one-unit decrease in labHb increased the difference between SpHb and labHb by 0.56 g dL^{-1}, which was statistically significant. DNB significantly increased the difference between SpHb and labHb by 0.42 g dL^{-1}. The effect of DNB on the difference between SpHb and labHb was significant up to three hours after the beginning of surgery (0.58 g dL^{-1} difference between blocked and non-blocked hands).

Conclusion: This study shows that, when hemoglobin levels are low, the accuracy of spectrophotometry decreases. Although DNB increases finger perfusion, it leads to an overestimation of hemoglobin levels by SpHb.

Keywords: blood transfusion; hemoglobin, spectrophotometry; accuracy; digital nerve block; bupivacaine.

Introduction

The decision to transfuse blood products to patients during surgery is important for an anesthesiologist. Due to potential complications and the costs of providing blood products, transfusion should be done carefully (1-3). Measuring hemoglobin levels during the surgery plays an important role in making this decision. Non-invasive hemoglobin monitoring by spectrophotometry (SpHb) allows physicians to estimate hemoglobin levels promptly at the patient's bedside (4-6). However, the potential difference between the estimated hemoglobin level and the standard laboratory method of hemoglobin assessment (labHb) makes it difficult to decide on blood transfusion indication accurately and confidently (3).

Since SpHb has been available in the operating room, several studies have evaluated its accuracy. Although the mean difference between SpHb and lab data (labHb) has been reported as relatively acceptable in a number of studies (3-7), there are still concerns regarding this issue. It is unclear whether the difference between SpHb and labHb would be the same whatever the hemoglobin level, or would vary at the extremes of hemoglobin levels (6, 8). Also, after significant blood loss or even following blood administration during surgery, the average difference between SpHb and laboratory might change (5, 9). A few studies have suggested that the accuracy of SpHb could change over time from the beginning till the end of the surgical procedure (5, 10).

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Aligned with the studies that have evaluated the accuracy of SpHb, other investigations have attempted to increase SpHb accuracy by enhancing the circulation of the organ on which the SpHb probe is placed. Digital nerve block (DNB) has been proposed as a method to increase perfusion and, thus, to improve SpHb accuracy (11-13). While previous studies on the effect of DNB demonstrated some positive outcomes, they did not measure or report all important perfusion indices and did not include variables such as hemoglobin level and time of anesthesia in their evaluations (11, 12). Investigations performed on healthy individuals (12) or awake patients (13) (rather than patients undergoing surgery with general anesthesia) and the lack of a concurrent control group (11) might have limited the generalizability of their findings, and resulted in uncertain interpretations.

In sum, non-invasive monitoring could help us making better and timely decisions about the indication of blood transfusion during surgery. However, the accuracy of monitoring methods could be a potential drawback. In an effort to measure and increase the SpHb monitoring accuracy, we hypothesized that DNB would improve hemoglobin estimates accuracy by enhancing blood circulation. Hence, the specific objective of this study was to investigate the effects of DNB on the accuracy of SpHb. For this purpose, we measured the difference between SpHb and labHb as the primary outcome, and the perfusion index (PI) and Pleth Variability Index (PVI) of patients' hands as the secondary outcomes. We attempted to overcome the above-mentioned shortcomings by designing a controlled trial, including patients undergoing surgery with a chance of massive blood loss, using a long-acting anesthetic for DNB, and exploring the effects of different variables altogether on SpHb accuracy.

Methods

Study setting and participants

We identified the patients who were admitted to Sina Hospital, affiliated with Tehran University of Medical Sciences (TUMS), for non-emergency spine surgery. We included those patients who were 18 years of age or older and had grade three or lower American Society of Anesthesiologists (ASA) Physical Status. We excluded patients who had emergency surgery or had ASA 4 or higher, as well as the ones suffering from anatomic or vascular disorders that caused problems in attaching the SpHb sensor. We explained the study's aim and methods as well as the possible complications and risks to the eligible patients. Those who were fully willing to participate in the research were asked to complete a written informed consent form and then were enrolled in the study.

Patients were randomly assigned to two groups using a random number generator computer program (allocation ratio 1:1). Group A received DNB in the left hand, and group B received DNB in the right hand. The allocation was concealed from both participants and investigators. The investigators who recorded outcomes and who analyzed data were blinded to the group allocation. Only one of the investigators who performed DNB was aware of the groups.

Management of Anesthesia

All patients were attached to ECG, end-tidal CO_2, non-invasive blood pressure monitoring, and bispectral index (BIS) monitoring. Every participant received midazolam 0.05 mg Kg^{-1} and fentanyl 2-3 µg Kg^{-1} as premedication. Anesthesia induction was achieved using atracurium 0.5 mg Kg^{-1}, thiopental sodium 5 mg Kg^{-1}, and lidocaine 1.5 mg Kg^{-1}. Following anesthesia induction, an arterial line was inserted in the left radial artery to monitor blood pressure and draw blood samples. Allen's test was performed before the procedure to ensure adequate perfusion. All patients had surgery in the prone position. Isoflurane and a continuous infusion of remifentanil 0.2 µg Kg^{-1} h^{-1} were used for anesthesia maintenance.

We calculated the maximum allowable blood loss before the operation, and visually estimated it during the surgery. When blood loss reached the maximum allowable amount, or the patient's SpHb dropped to less than the minimum acceptable level (8 to 10 g dL^{-1}), blood transfusion would start. The exact minimum acceptable hemoglobin level was determined individually for each patient, at the beginning of the operation, based on their cardiovascular status and underlying diseases.

At the end of surgery, the muscle relaxant effect was reversed by neostigmine 50 µg Kg^{-1} and atropine 20 µg Kg^{-1}. After tracheal tube removal, patients were transferred to the post-anesthesia care unit.

Digital nerve block and hemoglobin monitoring

After anesthetic induction, two Rainbow adult ReSposable sensors (Rainbow® R2-25, Rev K) were attached to the third finger of patients' both hands, and each sensor was attached to a monitor.

DNB was performed by injecting two ml of 0.25% bupivacaine at the base of the medial and lateral sides of the finger that was attached to the sensor (1 mL on each side of the base). Patient allocation to Groups A and B was concealed, and the researcher responsible for data collection was blinded to the randomization process.

Measuring the outcomes

At the beginning of the procedure (before surgical incision), both hands' SpHb values were recorded. At the same time, an arterial blood sample was drawn and sent to the laboratory to measure the hemoglobin level (labHb). The difference between SpHb and labHb at each time point was the primary outcome of the study. The secondary outcomes included the perfusion index (PI) and Pleth Variability Index (PVI), that were documented for both hands.

The above-mentioned process mentioned was repeated once every 1.5 hours during the operation till its end. The amount of intravenous intake and patient's blood loss during surgery was also recorded. In addition to the above measures, the patient's hemodynamic status, including invasive blood pressure (iBP) and pulse rate (PR), were recorded.

Statistical analysis

We analyzed the data using the Stata program (StataCorp. Release 13.1. College Station, TX: StataCorp LP.; 2013). Descriptive indices, including frequency, percentage, range, mean, and standard deviation were used to report the data. A $P < 0.05$ was considered statistically significant in all tests. We used the Bland-Altman recommended graph to display the SpHb-labHb differences versus their average values (14). We used a mixed-effects generalized linear model to test the effect of independent variables on the difference between SpHb and labHb at each time point. The observations at each time point were treated as nested within the individual level. Lab Hb and PI in the models were normalized to their corresponding baseline averages of 10 and 2, respectively.

Ethical considerations

The protocol of this study was approved by the ethics committee of Tehran University of Medical Sciences (No. IR.TUMS.VCR.REC.1395.110). Patients could leave the study, with or without any reason, at any stage of the project. The trial was registered prior to patient enrollment at clinicaltrials.gov (NCT02908412). During the research, the

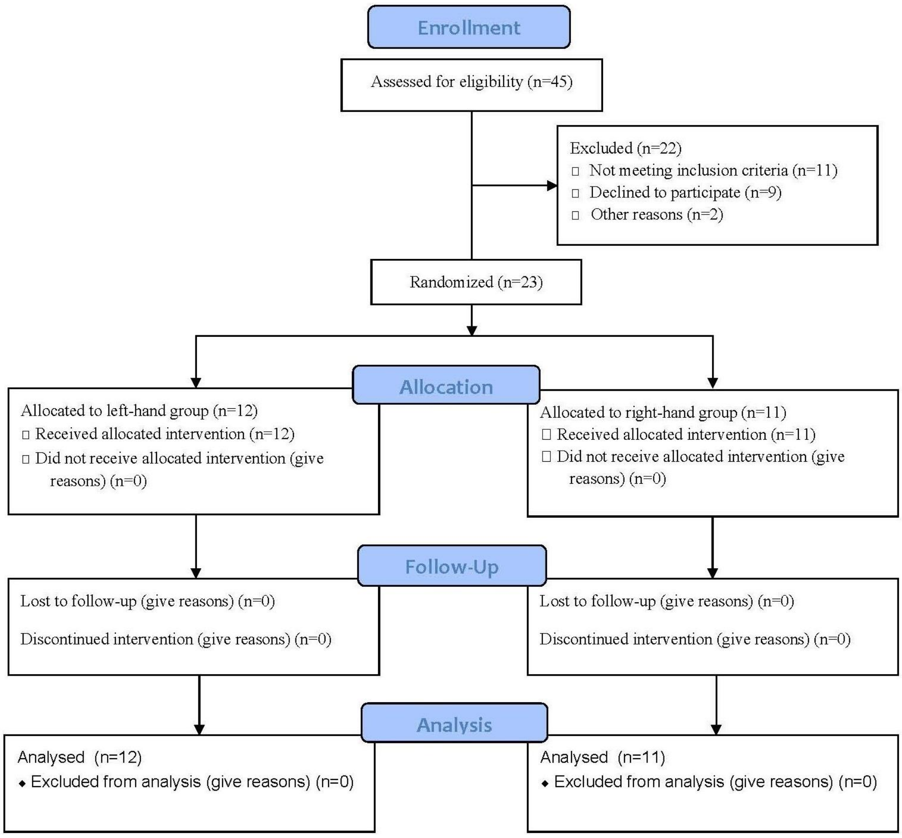

Fig.1. — CONSORT flow diagram.

names and identities of the patients under study were kept confidential. No additional charges were imposed on the patients.

Results

This trial is reported according to CONSORT recommendations (Fig. 1).

Patients' characteristics

Twenty-three patients were included in the study, out of whom 18 (78%) were female. The participants were between 18 and 64 years old with a mean age (SD) of 45.1 (15.3) years, and their weights ranged between 45 and 90 kg with a mean (SD) of 66.7 (12.0) kg. Eleven and 12 patients were assigned to the left-hand and the right-hand groups, respectively. Blood transfusion was provided to four patients, three of whom received one unit of packed red cells, and one received two. The participants' demographic characteristics and data at baseline (before surgery) are summarized in Table 1.

Primary outcomes

As shown in Table 2 (model 1), a one-unit decrease in labHb increased the difference between SpHb and labHb by 0.56 g dL^{-1}, which was statistically significant. It shows that, when hemoglobin levels are low (e.g., in case of blood loss), the values of SpHb decrease to a smaller extent than labHb. There was also a positive association between DNB and SpHb-labHb difference (model 1 in Table 2), which was statistically significant. This finding means that SpHb was, on average, 0.42 g dL^{-1} higher than labHb in the blocked fingers as compared to the non-blocked fingers.

The interaction between labHb and DNB was not statistically significant, suggesting that the effect of blocking on the SpHb-labHb difference was not dependent on the laboratory hemoglobin level. The intercept of the model (1.87 g dL^{-1}) represents the SpHb-labHb difference in the non-blocked hand of a patient with a 10 g dL^{-1} hemoglobin level. Its positive value indicates that SpHb is higher than the lab values at baseline.

In Figure 2, the Bland Altman graph shows the SpHb-labHb difference against their mean. The middle line is the mean difference, and the two upper and lower lines represent the confidence interval of the difference. Consistent with the regression model findings, SpHb always over-estimates hemoglobin levels, but this difference increases when labHb is lower.

We assessed the effect of including PI values and their interaction with DNB in the generalized linear mixed-effects model (model 2 in Table 2) to

Table 1

Characteristics of patients

Characteristics		Participants (n=23)
Age (years), mean (SD)		45.09 (15.30)
Weight (Kg), mean (SD)		66.73 (12.02)
Female (percentage)		18 (78%)
Left hand blocked (percentage)		11 (47%)
ConcurrentDiseases (percentage)	Diabetes mellitus	2 (8.7%)
	Hypertension	2 (8.7%)
	Ischemic heart dis.	3 (13%)
Hgb (g/dl), mean (SD)		11.85 (1.80)
Heart (rate bps), mean (SD)		71.60 (10.54)
Systolic (BP mmHg), mean (SD)		104.43 (13.45)
Diastolic (BP mmHg), mean (SD)		64.69 (10.52)
Duration of surgical procedure (hours), mean (SD)		4.02 (1.45)
IV intake (ml), mean (SD)		2395.65 (1124.92)
Blood loss(ml), mean (SD)		574.78 (561.88)

SD: standard deviation.

Table 2

The effect of blocking, adjusted for normalized value of lab Hb, on the SpHb-labHb difference at each time point

Variables	Definition	Model 1	Model 2
		Coefficient (SE)	Coefficient (SE)
Normalized labHb (labHb-10)	The effect of increase in labHb on the difference between SpHb and labHb (in g/dl)	-0.56 (0.07)***	-0.6 (0.07)***
Blocking (blocked vs. non-blocked)	The effect of blocking on the difference between SpHb and labHb	0.42 (0.14)**	0.36 (0.17)
The interaction between Blocking and normalized labHb	The joint effect of blocking and increase in labHb on the difference between SpHb and labHb	0.023 (0.07)	0.06 (0.07)
Normalized PI (PI-2)	The effect of increase in PI on the difference between SpHb and labHb	-	0.11 (0.11)
The interaction between PI and normalized labHb	The joint effect of increase in PI and labHb on the difference between SpHb and labHb	-	-0.14 (0.12)
Intercept	The average difference between SpHb and labHb in non-blocked finger in a person with labHb of 10 g/dl (and PI of 2 units: model 2)	1.87 (0.24)***	1.95 (0.25)***

P<0.05: *; p<0.01: **; p<0.001: ***; labHb: laboratory hemoglobin; PI: perfusion index; SE: standard error; SpHb: spectrophotometric hemoglobin; The variance of the SpHb and labHb difference that was explained by model 1 was 0.64(0.08) and by model 2 was 0.64(0.08) ; The residual variance of the SpHb and labHb difference in model 1 was 1.04(0.35) and in model 2 was 1.02(0.35).

Table 3

Effect of blocking over time on the SpHb-labHb difference

Variables		Definition	Model 3	Model 4
			Coefficient (SE)	Coefficient (SE)
Time		The difference between SpHb and labHb (in g/dl):		
	1.5 h	-1.5 h after surgery compared to baseline in non-blocked hand	0.91 (0.25)***	0.45 (0.23)
	3 h	-3 h after surgery compared to baseline in non-blocked hand	0.64 (0.27)*	-0.06 (0.27)
	4.5 h	-4 h after surgery compared to baseline in non-blocked hand	1.79 (0.4)***	0.55 (0.42)
	6 h	-6 h after surgery compared to baseline in non-blocked hand	1.42 (0.48)**	0.27 (0.47)
	7.5 h	-7.5 h after surgery compared to baseline in non-blocked hand	0.89 (0.9)	-0.48 (0.85)
Interaction between time and blocking		The difference between SpHb and labHb in blocked vs nonblocked:		
	Baseline	-At baseline	0.37 (0.25)	0.37 (0.22)
	1.5	-1.5 h after surgery	0.35 (0.25)	0.35 (0.22)
	3	-3 h after surgery	0.58 (0.28)*	0.58 (0.25)*
	4.5	-4.5 h after surgery	0.63 (0.48)	0.63 (0.44)
	6	-6 h after surgery	0.35 (0.6)	0.35 (0.54)
	7.5	-7.5 h after surgery	0.8 (1.2)	0.8 (1.08)
Normalized labHb (labHb-10)		The difference between SpHb and labHb at baseline by one unit increase in labHb	-	-0.48 (0.08)***
Intercept (time 0)		The difference between SpHb and labHb at baseline in a person with labHb of 10 g/dl	0.72 (0.29)*	1.62 (0.3)***

P<0.05: *; p<0.01: **; p<0.001: ***; labHb: laboratory hemoglobin; SE: standard error; SpHb: spectrophotometric hemoglobin; The variance of the SpHb and labHb difference that was explained by model 3 was 0.72 (0.09) and by model 4 was 0.59 (0.07); The residual variance of the SpHb and labHb difference in model 3 was 1.33 (0.43) and in model 4 was 0.98 (0.33).

predict the SpHb-labHb difference. The effect of PI on the SpHb-labHb difference was not statistically significant.

In order to assess the effect of time on the association between DNB and the SpHb-labHb difference, we developed another generalized

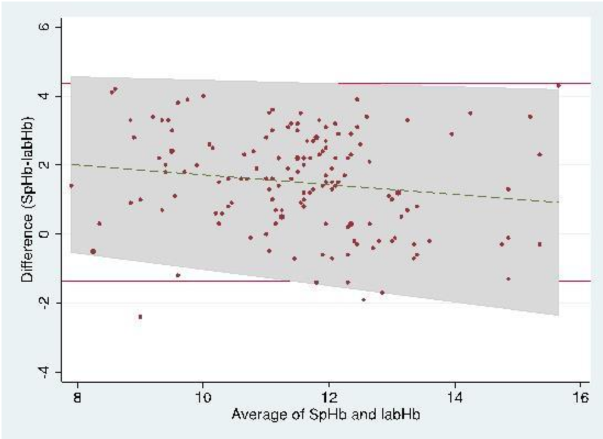

Fig. 2. — The Bland Altman graph of the SpHb-labHb difference compared to their mean.

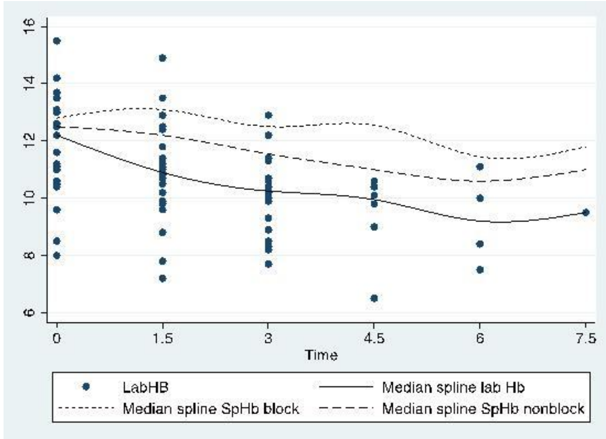

Fig. 3. — labHb and SpHb changes in blocked and non-blocked hands over time.

linear mixed-effects model (model 3 in Table 3), including dummy variables for time-points and their interaction with DNB. The patient was considered a random variable. As shown in model 3 of Table 3, the SpHb-labHb difference was compared to the baseline values in the non-blocked hand at each time point. At all times, the SpHb-labHb difference was significantly higher than at baseline. DNB increased the SpHb-labHb difference at all times, but this difference was significant only 3 hours after the beginning of surgery. The SpHb-labHb difference was largest at 3 and 4.5 hours after the beginning of surgery. For example, 3 hours after surgery, SpHb was 0.64 g dL^{-1} higher than labHb in the non-blocked hands. In blocked hands, the SpHb was even higher than the labHb (approximately 1.22 g dL^{-1}).

In Table 3, we added normalized labHb to the above-mentioned model (model 4) to adjust the effect of time on the difference between SpHb and labHb based on the Hb levels. In this model, a one-unit decrease in labHb increases the difference between SpHb and labHb by 0.48 g dL^{-1}. However, after adjustment for labHb level, SpHb was not significantly higher than labHb in the non-blocked hands. There was still a significant difference between the blocked and non-blocked hands, 3 hours after the beginning of the surgery.

Figure 3 shows the labHb and SpHb changes (in blocked and non-blocked hands) over time. The line was fitted with the median spline technique. The labHb line shows the gradual reduction of hemoglobin level during the surgery. The difference between SpHb and labHb increases as compared to the baseline. Consistent with the regression models findings, the difference between SpHb in the blocked and non-blocked hands increases over time and maximizes at 3 and 4.5 hours after the beginning of the surgery.

Table 4

Perfusion Index (PI) difference and Peleth Variation Index (PVI) between blocked and non-blocked hand

Time (hour)	Number of patients	Index	Mean difference	Standard error	Confidence interval (95%)		P value
Baseline	23	PI	1.14	0.39	0.33	1.96	0.008
		PVI	-2.49	1.39	-5.38	0.39	0.087
1.5	23	PI	1.19	0.29	0.58	1.79	0.001
		PVI	-3.86	1.26	-6.49	-1.24	0.006
3	17	PI	1.32	0.27	0.74	1.91	0.000
		PVI	-0.22	2.72	-6.00	5.55	0.936
4.5	5	PI	2.00	0.49	0.73	3.26	0.010
		PVI	-5.40	2.29	-11.76	0.96	0.078
6	4	PI	2.27	0.77	-0.20	4.75	0.062
		PVI	-3.00	1.08	-6.43	0.43	0.069

Secondary outcomes

At 1.5, 3, and 4.5 hours after the beginning of surgery, there was a statistically significant difference between the PI values in the two hands (Table 4). At all times, the PI value in the blocked hand was higher than in the non-blocked hand. PI changes over time in the two hands are shown in Figure 4. At all times, the PVI value in the blocked hand was lower than in the non-blocked hand, which was statistically significant 1.5 hours after the beginning surgery (Table 4).

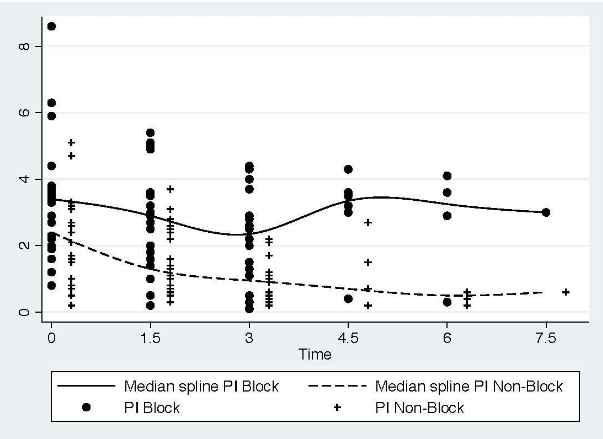

Fig. 4. — Perfusion Index (PI) change during surgery in blocked and non-blocked hand.

Discussion

This clinical trial evaluated the accuracy of non-invasive hemoglobin monitoring by spectrophotometry with or without bupivacaine DNB in patients undergoing spine surgery. The factors that significantly contributed to the SpHb-labHb difference, indicating monitoring accuracy, were DNB and labHb level. To be more specific, the SpHb-labHb difference was larger in case of DNB and when labHb was low. The time elapsed since the beginning of the procedure had no significant impact on SpHb-labHb difference. According our results, DNB leads to an increase in PI, which did not affect monitoring accuracy.

The relationship between labHb and SpHb-labHb difference has previously been studied in three investigations that were not using DNB. In a study by Miller et al. on 20 patients who underwent spinal surgery, the correlation between these two variables was negative (10). Similar results were observed in a study by Applegate et al. on 96 patients with abdominal or pelvic surgery (5). This negative relationship between labHb level and SpHb-labHb difference was also seen in our study. However, both above-mentioned studies found that, at high hemoglobin levels, SpHb was lower than labHb, and that, at low hemoglobin levels, SpHb was higher than labHb. In our study, SpHb was always higher than labHb. This result was consistent with the study of Saito et al. on 24 patients who underwent gynecologic or urological surgery (9).

The impact of DNB on the SpHb-labHb difference was evaluated in three studies. Miller et al. (2012) again studied 20 patients undergoing spinal surgery and compared their SpHb with labHb at different times, including baseline, after DNB with lidocaine, and in one-hour intervals during the surgery (11). The differences between SpHb and lab hemoglobin were considered “very accurate” in 37% of cases (11). Since the study had no control group, the authors compared the findings to the results of a previous study in which no DNB had been used, and only 12% of cases were “very accurate” (10). It was concluded that the nerve block could increase both the PI and the SpHb accuracy (11). Miller et al. carried out another study to compare DNB’s effects with two local anesthetics (12). DNB was performed on two identical fingers on both hands of the 12 healthy volunteers using lidocaine on the one hand and bupivacaine on the other one (12). This study showed that both lidocaine and bupivacaine raised the perfusion indices and temperatures of the fingers. Yet the duration and extent of the temperature rise were higher when DNB was performed using bupivacaine. Also, the authors reported that changes in PI were directly correlated with SpHb variations (12). In our study, although DNB caused an increase in the PI, it also increased the SpHb-labHb difference, which means the nerve block with bupivacaine reduced monitoring accuracy. In another study, Bergek et al. blocked the brachial plexus in 20 surgical patients and discovered that SpHb and PI increased by 8% and 188% in the blocked hand, respectively, while PVI decreased by 54%. These changes were consistent with the findings of the present study (13).

Regarding the relationship between PI and the SpHb-labHb difference, no association was found in our study. However, in another research, post-block changes in PI were in line with the SpHb-labHb changes (12). In the study by Saito et al., a slight correlation was reported between SpHb-labHb and PI difference (9). Taking time into account, Miller et al., in their 2011 study, stated that the accuracy of SpHb increased over time (10). However, the findings of our study reflect those of Applegate et al., who concluded that the time lapse and duration of surgery did not affect the accuracy of SpHb (5).

Overall, it can be said that simultaneous examination of all major factors influencing the accuracy of spectrophotometry hemoglobin monitoring, including nerve block, patient's level of hemoglobin, PI, and the time elapsed since the beginning of surgery, is the strength of our study. However, the current study has a number of limitations. First, while injection might impact monitoring accuracy (15), we did not investigate the effect of intravenous infusion of fluid in the hand to which the spectrophotometric probe was connected. Variables such as initiation of blood transfusion and blood transfusion volume were not recorded. Second, the outcomes of regional anesthesia might be different when general anesthesia is not performed. We did not examine the effect of anesthesia induction on the accuracy of monitoring, while general anesthetic induction might affect it (9). The effect of the above-mentioned variables could be considered for further research. Further studies could also assess the effects of other methods, like local warming of the hand, to explore if they can improve SpHb accuracy by increasing organ perfusion. It is worth mentioning that there are other important issues than the accuracy of monitoring when deciding on its utility. In this study, we merely focused on factors attributed to the SpHb accuracy; yet, clinical outcomes and quality of care should also be taken into account. One of the studies that reported the use of non-invasive hemoglobin monitoring during surgery was beneficial had mainly focused on the special care provided to the patients by the punctual initiation of blood transfusion, if required (16).

Conclusions

Based on the findings of this study, when hemoglobin levels are low, the accuracy of spectrophotometry decreases. While digital nerve block increases the finger perfusion, it leads to a decrease in the accuracy of SpHb, and to an overestimation of hemoglobin levels. The effect of fluid intravenous infusion, blood transfusion, and type of anesthesia might affect monitoring accuracy and should be considered in future research.

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