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Effect of Continuous Non-Invasive Hemoglobin Monitoring on Blood Transfusion and Mortality in Hip Surgeries: A Randomized Controlled Study

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ABSTRACT

Objective: This study aimed to determine the effect of non-invasive hemoglobin (SpHb) measurement on blood transfusion decisions in patients undergoing hip surgery and to analyze the effect of these decisions on mortality.

Materials and Methods: Fifty-two patients (ASA I–III, ≥60 years) undergoing hip surgery were randomized into the SpHb or conventional (CONV) group for transfusion management. Hemoglobin (Hb) levels were recorded before induction, at transfusion decision points, immediately after transfusion, and after recovery. Postoperative survival was monitored at 1 and 3 months.

Results: The SpHb group maintained significantly higher Hb levels at the first transfusion decision point, after transfusion, and during recovery (p=0.001, p=0.012, p=0.001). Partial oxygen pressure (PaO_2) was also higher in the SpHb group at the corresponding time points. The CONV group required significantly more blood transfusions (p=0.025) and had longer hospital stays (p=0.043). Although 3-month mortality was numerically lower in the SpHb group than in the CONV group (11.53% vs. 19.23%), no statistically significant difference was detected in this pilot-sized cohort (p>0.05).

Conclusion: According to our findings, SpHb monitoring during hip surgery may be a useful tool for enabling earlier transfusion decisions, which could help prevent significant Hb declines. In our study cohort, this strategy was associated with a trend toward fewer transfusion requirements, shorter hospital stays, and better perioperative oxygenation.

Keywords: Hemoglobins, hemorrhage, hip fractures, intraoperative, monitoring, mortality.

INTRODUCTION

Blood loss is a major cause of morbidity and mortality. In cases of excessive bleeding, the amount of bleeding should be calculated immediately, tests should be completed within a short time, and treatment

should be started.[1] Hip and revision hip arthroplasty surgeries are performed frequently worldwide, and studies have reported that 18–65% of these operations require blood transfusion.[2]

Blood replacement has several complications in addition to its benefits, including providing oxygen supply to tissues and preventing deterioration of organ perfusion.[3] Complications include allergic reactions, transfusion-related circulatory overload, infections, transfusion-related acute lung injury, and thromboembolism. It is also associated with several adverse conditions, including delayed wound healing, acute kidney injury, sepsis, prolonged hospitalization, and mortality.[2–4]

Laboratory-measured complete blood count (CBC) hemoglobin (Hb) level is the primary parameter used to guide transfusion decisions in bleeding operations. However, continuous and non-invasive technologies, such as fingertip probe monitoring, have gained prominence. Bedside non-invasive hemoglobin (SpHb) monitoring offers rapid data collection and allows continuous assessment without additional invasive interventions.[5]

In this study, we examined the differences between blood transfusion decisions made using standard methods and those based on SpHb monitoring in patients undergoing hip surgery. We predicted that SpHb-monitored patients would have lower mortality rates and improved clinical outcomes.

The primary aim of this study was to compare blood transfusion decisions based on SpHb monitoring with those based on conventional methods in patients undergoing hip surgery. Secondarily, it aimed to investigate the effects of these decisions on perioperative oxygenation, length of hospital stay, and mortality. We hypothesized that SpHb-monitored patients would have decreased mortality rates and improved clinical outcomes.

KEY MESSAGES

- Continuous non-invasive hemoglobin (SpHb) monitoring enables earlier transfusion decisions by identifying critical hemoglobin thresholds more accurately than conventional methods in surgeries associated with high bleeding risk.
- The use of SpHb monitoring in hip surgery significantly reduces the total number of red blood cell units transfused and shortens the length of hospital stay.
- Although SpHb monitoring improves perioperative oxygenation and transfusion management, 30-day and 90-day mortality rates remain similar to those associated with conventional transfusion decision-making methods

MATERIALS AND METHODS

Study Place and Design

Following ethical approval from the Zonguldak Bülent Ecevit University, this prospective randomized controlled study was conducted in accordance with the Declaration of Helsinki and registered at ClinicalTrials.gov (NCT04785274). Patient recruitment and the clinical phase took place between April and December 2021.

Randomization was performed using the closed-envelope method by an independent anesthesiologist. Both the patients and the statistician were blinded to group allocation.

Ethics Approval

Following ethical approval from the Zonguldak Bülent Ecevit University Non-Interventional Clinical Research Ethics Committee (Approval Number: 2020/24, Date: 16.12.2020), this prospective randomized controlled study was initiated.

Patients and Data Collection

Written informed consent was obtained from all patients before surgery. Sixty patients aged ≥60 years in the American Society of Anesthesiology Physical Status (ASA PS) I–III risk group, who were expected to have blood loss of more than 10%–20% of the total blood volume and were scheduled for hip surgery in the operating room of Zonguldak Bülent Ecevit University Medical Faculty Hospital, were included in the study.

Hemodynamic data, including mean arterial pressure (MAP), heart rate (HR), and peripheral oxygen saturation (SpO_2), as well as pleth variability index (PVI), partial oxygen pressure (PaO_2), and body temperature, were recorded at intervals. Hospital stay length was recorded at discharge, and 1-month and 3-month survival data were collected via telephone interviews.

Diagnostic Criteria

In the SpHb group, bedside non-invasive hemoglobin (SpHb) measurements were performed using the Radical-7 Pulse CO-Oximeter™ fingertip sensor probe (Masimo Corp., USA).

In Group CONV, the permissible amount of blood loss was calculated for a hemoglobin (Hb) value ≤9 g/dL (hematocrit [Hct]: 27%).

Definitions

In Group CONV, the permissible amount of blood loss was calculated for an Hb value ≤9 g/dL (Hct: 27%). In this calculation, the loss of red blood cell volume (RBCV)=RBCVpreop–RBCV27% formula was used. Permissible blood loss was calculated as loss of RBCV×3.[6]

During the operation, the bloody sponges and compresses were weighed again, and the amount of bleeding was calculated. In this calculation, 1 g of blood was considered equivalent to 1 mL.

Measurements available at common predefined time points for the full cohort were defined as primary longitudinal outcomes and analyzed using a linear mixed-effects model with fixed effects for group, time, and group×time interaction, and a random intercept for patient. Measurements observed only in subsets of patients during additional transfusion-related stages were defined as event-based secondary outcomes and analyzed separately as exploratory analyses. These event-based observations were not included in the main longitudinal model because they were not available for all participants and depended on the occurrence of a clinical event.

Inclusion Criteria

Written informed consent was obtained from all patients before surgery. Sixty patients aged ≥60 years in the American Society of Anesthesiology Physical Status (ASA PS) I–III risk group, who were expected to have blood loss of more than 10%–20% of the total blood volume and were scheduled for hip surgery in the operating room of Zonguldak Bülent Ecevit University Medical Faculty Hospital, were included in the study.

Exclusion Criteria

The exclusion criteria were the presence of arrhythmia, severe heart failure, uncontrolled diabetes mellitus, hypothermia, hyperbilirubinemia, jaundice, sepsis, need for inotropic support, lung resection, existing blood disease, allergy to the study drugs, and rejection.

Clinical, Surgical, and Laboratory Investigations

Routine monitoring was performed and recorded as baseline values. Intra-arterial cannulation of the radial artery was established in all patients for continuous blood pressure monitoring and blood gas analysis, alongside baseline hemogram monitoring. Baseline complete blood count hemoglobin (CBC-Hb) was recorded before induction.

Standardized anesthetic depth was maintained by delivering sevoflurane (1 minimum alveolar concentration [MAC] in 50% O_2/air) and continuous remifentanil infusion (0.1–0.3 µg/kg/min), targeting a bispectral index (BIS) value within the range of 40%–60%. Volume-controlled ventilation was initiated (tidal volume [TV]: 8 mL/kg; respiratory frequency was increased if end-tidal carbon dioxide [$EtCO_2$] was >45 mmHg).

Pleth variability index (PVI) was utilized for intraoperative dynamic fluid monitoring, with a threshold of >15% indicating fluid responsiveness and requiring 100–250 mL of saline loading, aiming to maintain PVI <15%.[7]

In the non-invasive hemoglobin (SpHb) group, bedside non-invasive SpHb measurements were performed using the Radical-7 Pulse CO-Oximeter™ fingertip sensor probe (Masimo Corp., USA). The fingers were wrapped to prevent the sensor from being exposed to light. Blood transfusion was not performed until the SpHb value was measured and was ≤9. Throughout the operation, when the SpHb value was ≤9, 1 unit of red blood cells (RBCs) was administered intravenously and recorded.

SpHb, PVI, and blood gas measurements were performed and recorded before anesthesia induction, after induction, at the first transfusion decision time, immediately after the first transfusion, at the second and third transfusion decision times according to the bleeding condition, and immediately after transfusion. Measurements obtained at later transfusion-related stages were event-dependent and were available only in patients who required additional transfusion.

Dry sponges and compresses were weighed preoperatively and reweighed intraoperatively after blood exposure to calculate blood loss. Blood on the drapes and floor was estimated, and total blood loss was determined by combining aspirator volume with sponge and compress weights. Patients received 1 unit of RBCs when the allowable blood loss threshold was reached.

Statistical Analysis

Sample size was calculated a priori using G*Power based on pilot data (12 patients/group; conventional [CONV] hemoglobin [Hb]: 9.62±0.47; SpHb: 9.04±0.51). With 99% confidence and 95% power, ≥26 patients per group were required; 60 patients were enrolled to account for potential data loss.

Outcomes were classified as primary longitudinal outcomes, measured at predefined time points in all patients, and event-based secondary outcomes, observed only in subsets during transfusion-related stages. Longitudinal data were analyzed using a linear mixed-effects model with fixed effects for group, time, and group×time interaction, and a random patient intercept. Event-based outcomes were analyzed separately as exploratory analyses on an available-case basis.

Continuous variables were expressed as mean±standard deviation (SD) or median (min–max), and categorical variables were expressed as frequency (%). Comparisons were performed using Student's t-test or the Mann–Whitney U test for continuous variables and the Pearson chi-square test or Fisher-Freeman-Halton test for categorical variables. A p-value of <0.05 was considered significant.

RESULTS

A total of 52 patients were randomized into the study following the exclusion of 8 individuals, 3 who did not fulfill the inclusion criteria and 5 who opted out, from an initial pool of 60 candidates (Fig. 1). The demographic distribution comprised 69.2% females and 30.8% males, with a mean age of 75.48±10.63 years (range: 60–93 years). Hemodynamic parameters, including heart rate (HR), peripheral oxygen saturation (SpO_2), mean arterial pressure (MAP), and pleth variability index (PVI), showed no statistically significant differences between the groups at any of the assessed time points (p>0.05). This stability was observed consistently from baseline (pre-surgery) through the induction phase, at all intraoperative intervals (from 10 to 180 minutes), and during the post-anesthesia recovery period.

In terms of perioperative fluid management, no statistically significant differences were observed between the cohorts regarding total fluid administration or urine output (p>0.05). However, Group CONV exhibited a markedly higher volume of estimated intraoperative blood loss compared with the other group, a finding that reached statistical significance (p<0.001; Table 1).

Following the baseline and perioperative descriptive analyses, outcome results were structured according to measurement type. Measurements available at common time points for the full cohort were evaluated as primary longitudinal outcomes, whereas later transfusion-related measurements observed only in smaller patient subsets were presented separately as event-based exploratory outcomes. Accordingly, primary longitudinal analyses were based on linear mixed-effects models, and event-based subgroup findings were interpreted cautiously.

For the primary longitudinal partial oxygen pressure (PaO_2) outcomes, there were no statistically significant differences between the groups at baseline or at the first red blood cell (RBC) transfusion decision time (p>0.05). PaO_2 values measured after completion of the first transfusion were significantly higher in the SpHb group (p=0.015). Linear mixed-effects model analysis demonstrated a significant overall time effect (F=116.692, df=2, 94.663; p<0.001) and group effect (F=9.085, df=1, 123.703; p=0.003), whereas the group×time interaction was not statistically significant (F=0.877, df=2, 94.663; p=0.419) (Table 2a). Event-based transfusion-related PaO_2 measurements are presented separately in Table 2b.

For the primary longitudinal complete blood count hemoglobin (CBC-Hb) outcomes, baseline hemoglobin levels were similar between the groups (p>0.05). CBC-Hb values measured at the first RBC transfusion decision, after completion of the first transfusion, and after extubation were significantly higher in the SpHb group than in the conventional group (p=0.001, p=0.012, and p=0.001, respectively). Linear mixed-effects model analysis showed a significant overall time effect (F=76.536, df=3, 89.403; p<0.001) and group effect (F=27.337, df=1, 120.214; p<0.001), whereas the group×time interaction was not statistically significant (F=0.661, df=3, 89.403; p=0.519), indicating that the overall trajectory of hemoglobin change over time did not differ significantly between the groups (Table 3a). Event-based transfusion-related CBC-Hb measurements are presented separately in Table 3b and should be interpreted as exploratory.

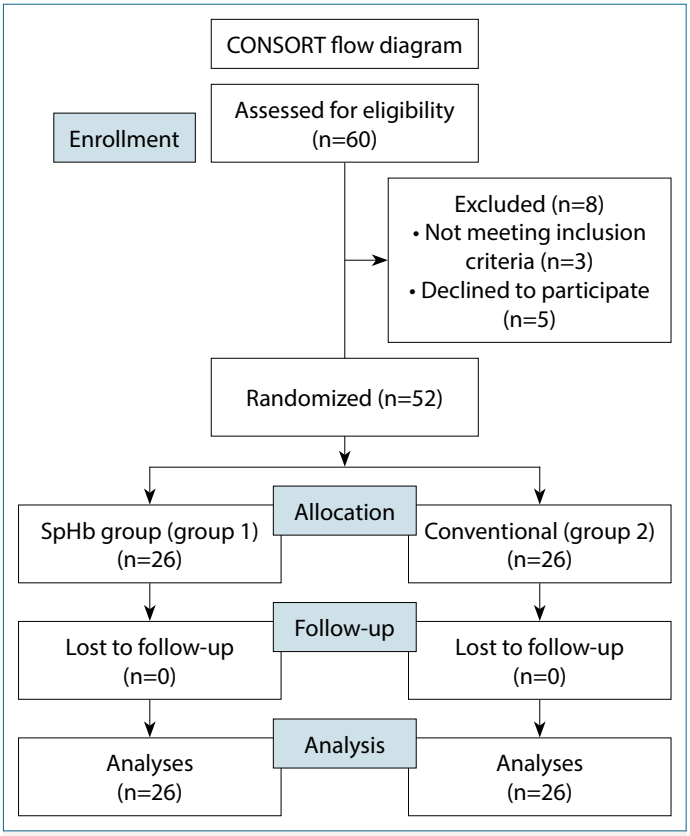

Figure 1. Consolidated standards of reporting trials (CONSORT) flow diagram.

When SpHb and CBC-Hb measurements were compared in the SpHb group, there were no statistically significant differences between the first RBC transfusion decision time and after the first RBC transfusion, the second RBC transfusion decision time and after the first RBC transfusion, or the recovery time of CBC-Hb and SpHb measurements (Fig. 2) (p>0.05).

The 40th-minute temperature values in the CONV group were significantly higher than those in the first group (p=0.042).

Table 1. Demographic and procedural data

Variables	Group SpHb	Group CONV	p
Sex			0.548[a]
Female, n (%)	17 (65.4)	19 (73.1)	
Male, n (%)	9 (34.6)	7 (26.9)	
Age, years	71.5 (60–93)	80.5 (61–92)	0.521[b]
Baseline Hb, g/dL	11.2 (8.4–13.2)	10.2 (9.2–12.7)	0.072[c]
Intraoperative input and output			
Crystalloid, mL	2000 (1000–3000)	2000 (1000–4000)	0.069[b]
Urine output, mL	307 (43–572)	295 (57–532)	0.993[b]
Estimated blood loss, mL	490 (200–850)	750 (475–1200)	<0.001[b]
Duration of surgery, h	2.72±0.86	3.14±1.50	0.237[c]
Duration of anesthesia, h	3.08±0.89	3.63±1.56	0.149[c]

Values are presented as mean±SD, median (min–max), or number (%). [a]p-values were calculated using the Pearson chi-square test. [b]p-values were calculated using the Mann–Whitney U test. [c]p-values were calculated using Student's t-test.

The temperature at the 40th minute was 36.45±0.26°C in Group SpHb and 36.59±0.22°C in Group CONV. The other measurements showed no significant differences between the groups (p>0.05).

The total RBC transfusion count in the CONV group was significantly higher than that in the SpHb group (p=0.025). The average blood transfusion volume was 1.65±0.89 units in Group SpHb and 2.42±1.36 units in Group CONV (Table 4).

The length of hospital stay for patients in the CONV group was significantly longer than that for patients in the SpHb group (p=0.043). The length of hospital stay was 5 (2–19) days in Group SpHb and 9 (2–60) days in Group CONV (Table 4).

In terms of mortality, 38.5% (n=5) of the deceased patients died in the first month, and 61.5% (n=8) died in the third month. Although the 3-month mortality rate in the CONV group (19.23%) was nearly double that in the SpHb group (11.53%), no statistically significant difference was detected in this pilot-sized cohort (p>0.05). No differences were observed between the groups in terms of surgical duration or duration of anesthesia (p>0.05) (Table 4).

DISCUSSION

Our results demonstrated that bleeding management using non-invasive hemoglobin (SpHb) data significantly contributed to a decrease in the need for blood transfusions, increased perioperative oxygenation, and reduced hospital stay duration in patients undergoing hip surgery. Consistent with our hypothesis, SpHb monitoring allowed more precise transfusion decisions compared with conventional methods.

In our study, the primary longitudinal analysis showed that partial oxygen pressure (PaO_2) values were higher in the SpHb group after completion of the first transfusion. Although later transfusion-related PaO_2 measurements also tended to be higher in the SpHb group, these observations were event-based and derived from smaller patient subsets; therefore, they should be interpreted cautiously. We believe that the higher perioperative oxygenation observed in the SpHb group may be related to earlier transfusion decisions enabled by continuous hemoglobin monitoring.

Hart et al.[2] reported that high bleeding occurred during total hip prosthesis surgeries and that 75% of these patients received blood transfusions. For these reasons, in our study, we selected hip surgery cases in which we anticipated a loss of 10%–20% of the patients' total blood volume to make a decision on blood transfusion using non-invasive hemoglobin (Hb) measurement values.

The gold standard method for measuring Hb is a complete blood count performed in the laboratory.[8] However, the most significant disadvantages of this method are its invasiveness, the time required to obtain results, including collecting the blood sample, delivering it to the laboratory, and processing it, and the risk of infection associated with repeated procedures.[9] On the other hand, intravenous fluid replacement is also administered to patients during the operation. Excessive or insufficient fluid replacement can lead to hemoconcentration, thereby leading to incorrect Hb measurement results.[10] We standardized fluid replacement to prevent potential hemodilution or hemoconcentration, and pleth variability index (PVI) monitoring was consequently performed in all patients.[7] In our study, no significant difference was found

Table 2a. Comparison of PaO_2 measurements at primary longitudinal time points: Linear mixed-effects model analysis

Measurement, mmHg	n	Group SpHb Mean±SD	Group SpHb EMM (95% CI)	n	Group CONV Mean±SD	Group CONV EMM (95% CI)	Between group p
Baseline	26	105.31±24.32	105.3 (57.4–153.2)	26	97.64±23.67	97.6 (49.8–145.5)	0.264[b]
First RBC transfusion decision	26	172.51±41.01	172.5 (122.8–222.2)	26	153.27±43.09	153.3 (103.6–202.9)	0.105[b]
After completion of the first transfusion	26	191.36±29.55	191.4 (143.0–239.7)	26	170.51±30.32	170.5 (122.2–218.8)	0.015[b]
Linear mixed-effects model: Fixed effects (Type III Tests, Kenward–Roger df)							
Effect		**F**	**Numerator df**		**Denominator df**	**p**	
Time		116.692	2		94.663	<0.001	
Group (SpHb vs. CONV)		9.085	1		123.703	0.003	
Group×time interaction		0.877	2		94.663	0.419	
Overall between-group comparison (LMM estimated marginal means, averaged over time)							
Group		**Overall EMM mmHg**	**95% CI**		**Mean difference (SpHb–CONV)**	**p**	
SpHb		156.4	108.9–203.9		+15.9 mmHg	0.003	
CONV		140.5	93.0–188.0				

Observed values are presented as mean±SD, and model-based values are presented as estimated marginal means (EMM) with 95% confidence intervals (CIs). RBC: red blood cell; CONV: conventional monitoring; SpHb: non-invasive hemoglobin monitoring. Between-group p-values shown for each primary time point were obtained using independent-samples Student's t-tests and are provided as descriptive time point-specific comparisons of observed values. In addition, the primary longitudinal time points were analyzed using a linear mixed-effects model with fixed effects for group, time, and group×time interaction, and a random intercept for each patient. The corresponding Type III tests and overall between-group comparison are presented in the lower panels of the table. [b]Student's t-test.

Table 2b. PaO_2 measurements at event-based secondary time points: Exploratory analyses

Measurement, mmHg	n (SpHb)	Group SpHb, mean±SD or median (min–max)	n (CONV)	Group CONV, mean±SD or median (min–max)	Between group p
Second transfusion: Event-based exploratory analysis (SpHb n=8; CONV n=16)					
Second RBC transfusion decision	8	199.5 (168–222)	16	159.5 (98–208)	0.027[a]
After completion of the second transfusion	8	204.63±27.42	16	168.06±33.95	0.015[b]
Third transfusion: Descriptive analysis only (SpHb n=1; CONV n=4)					
Third RBC transfusion decision	1	191.0	4	182.5±38.49	–
After completion of the third transfusion	1	201.0	4	182.5±37.78	–

Values are presented as mean±SD or median (min–max), as appropriate; single observations are shown as observed values only. RBC: red blood cell; CONV: conventional monitoring; SpHb: non-invasive hemoglobin monitoring. Event-based secondary time points were analyzed separately and should be interpreted as exploratory because of the small and unbalanced subgroup sizes. [a]Mann–Whitney U test; [b]Student's t-test.

between the PVI scores and the amount of fluid administered to the patients in either group during the perioperative period.

Non-invasive approaches and monitoring strategies have gained considerable popularity worldwide.[11] SpHb monitoring is the most widely used technique among these methods.[12] The primary objectives of our research were to observe the Hb trend during the blood replacement procedure to prevent excessive blood transfusions and to identify dramatic decreases in Hb levels early, allowing immediate choices regarding transfusions.

Non-invasive SpHb monitoring may produce inaccurate results in patients with nail polish, motion artifacts, hypotension, arrhythmias, vasoconstrictor medication use, and hyperbilirubinemia.[13] We eliminated the risk of incorrect SpHb probe measurements by excluding these patients from the study. Another disadvantage of these methods is that they are affected by hypothermia. In our study, no difference in temperature was detected between the two groups except for the scores at the 40th minute. At the 40th minute, it was determined to be 36.45±0.26°C in Group SpHb and 36.59±0.22°C in Group CONV (p=0.042). Although a difference was observed in the scores at the 40th minute, we believe that this did not clinically cause hypothermia; therefore, the SpHb measurements were not negatively affected.

Table 3a. Comparison of CBC-Hb measurements at primary longitudinal time points: Linear mixed-effects model analysis

Measurement, g/dL	n	Group SpHb mean±SD	Group SpHb EMM (95% CI)	n	Group CONV mean±SD	Group CONV EMM (95% CI)	Between group p
Baseline	26	11.06±1.26	11.05 (9.73–12.37)	26	10.51±0.85	10.06 (8.74–11.38)	0.072[a]
First RBC transfusion decision	26	8.73±0.55	8.72 (7.45–9.99)	26	8.13±0.59	8.13 (6.86–9.40)	0.001[a]
After completion of the first transfusion	26	9.58±0.90	9.58 (8.28–10.88)	26	8.94±0.85	8.94 (7.64–10.23)	0.012[a]
After extubation	26	9.34±0.69	9.34 (9.06–9.62)	26	8.56±0.67	8.56 (8.29–8.83)	0.001[a]
Linear Mixed-Effects Model: Fixed Effects (Type III Tests, Kenward–Roger df)							
Effect		**F**	**Numerator df**		**Denominator df**	**p**	
Time		76.536	3		89.403	<0.001	
Group (SpHb vs. CONV)		27.337	1		120.214	<0.001	
Group×time interaction		0.661	3		89.403	0.519	
Overall between-group comparison (LMM estimated marginal means, averaged over time)							
Group		**Overall EMM g/dL**	**95% CI**		**Mean difference (SpHb–CONV)**	**p**	
SpHb		9.790	8.524–11.056		+0.745 g/dL	<0.001	
CONV		9.045	7.779–10.311				

Values are presented as mean±SD. EMM: estimated marginal mean; CI: confidence interval; RBC: red blood cell; CBC-Hb: complete blood count hemoglobin; CONV: conventional monitoring group; SpHb: non-invasive hemoglobin monitoring group. Primary longitudinal time points were analyzed using a linear mixed-effects model with fixed effects for group, time, and group×time interaction. [a]p-values were calculated using the independent-samples Student's t-test. Statistical significance was set at p<0.05.

Table 3b. CBC-Hb measurements at event-based secondary time points: Exploratory analyses

Measurement, g/dL	n (SpHb)	Group SpHb, mean±SD or median (min–max)	n (CONV)	Group CONV, mean±SD or median (min–max)	Between group p
Second transfusion: Event-based exploratory analysis (SpHb n=8; CONV n=16)					
Second RBC transfusion decision	8	8.50 (8.10–9.20)	16	8.40 (7.70–9.00)	0.341[b]
After completion of the second transfusion	8	9.77±1.06	16	9.22±0.78	0.174[a]
Third transfusion: Descriptive analysis only (SpHb n=1; CONV n=4)					
Third RBC transfusion decision	1	8.95	4	8.15±0.31	–
After completion of the third transfusion	1	9.85	4	9.62±0.48	–

Values are presented as mean±SD or median (min–max), as appropriate; single observations are presented descriptively. RBC: red blood cell; CONV: conventional monitoring group; SpHb: non-invasive hemoglobin monitoring group. Event-based secondary time points were analyzed separately and should be interpreted as exploratory. [a]Student's t-test; [b]Mann–Whitney U test. Statistical significance was set at p<0.05.

Awada et al.[14] investigated the effect of SpHb monitoring on blood transfusion in neurosurgical surgeries with bleeding. In this study, the group that underwent SpHb monitoring received fewer blood transfusions. The results of the study showed that SpHb monitoring makes it easier to recognize transfusions that need to be applied on time and causes a decrease in the amount of blood replaced in neurosurgical operations with high blood loss. Similarly, in our study, patients monitored with SpHb required fewer transfusions than those managed with conventional methods. The number of transfused red blood cell (RBC) units per patient was significantly lower in the SpHb group than in the CONV group (p=0.025). This finding suggests that continuous SpHb monitoring may have facilitated earlier recognition of downward hemoglobin (Hb) trends and allowed transfusion decisions to be made before hemoglobin levels declined further. The distribution of second- and third-unit transfusions should be interpreted cautiously, as these analyses were based on smaller event-driven subgroups. Although SpHb monitoring has shown promise in transfusion management, laboratory-measured Hb remains the reference standard because the current evidence is limited by methodological constraints and insufficient statistical power.[8,9] Based on our findings, SpHb monitoring may serve as an adjunct tool to detect downward Hb trends

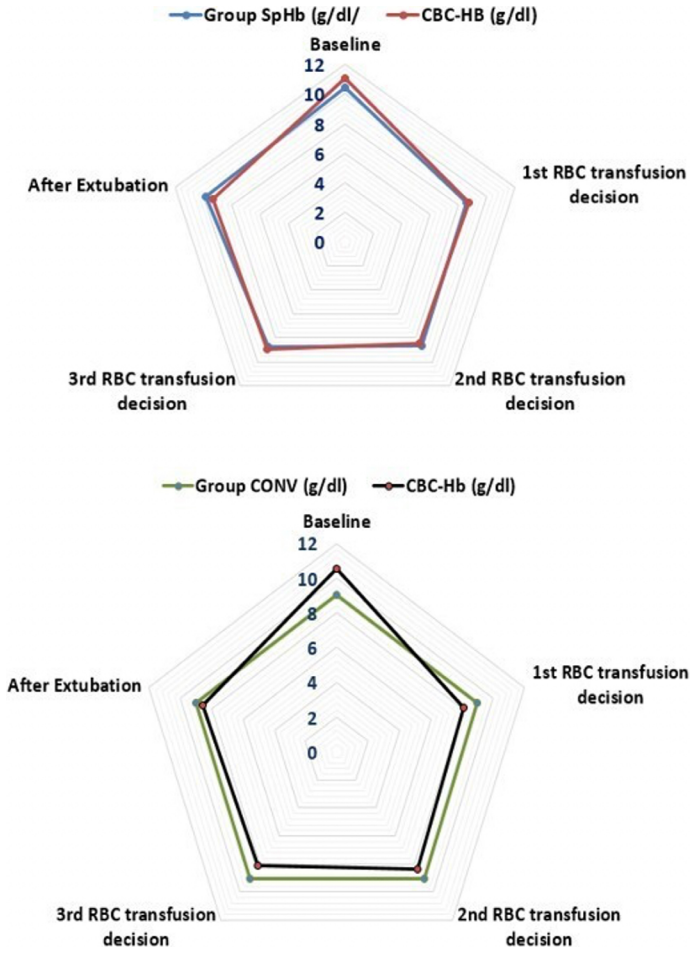

Figure 2. Radar chart design of the groups.

and support earlier transfusion decisions, particularly when Hb approaches the 9 g/dL threshold. Larger randomized controlled trials are needed to better define its clinical utility.

In our study, the length of hospital stay was longer in the conventional group than in the SpHb group (p=0.043). Although hospital stay can be influenced by various factors, such as comorbidities, surgical technique, and postoperative complications, we aimed to control for these variables through our prospective randomized study design. Both groups were comparable in terms of demographic data, American Society of Anesthesiology Physical Status (ASA PS) risk groups, and duration of surgery. Additionally, anesthesia management and fluid therapy were standardized across both cohorts. Therefore, we suggest that the reduction in hospital stay in the SpHb group is likely associated with more accurate transfusion triggers and a subsequent decrease in the total amount of blood transfused. Numerous studies in the literature support that avoiding unnecessary blood transfusions can shorten hospital stay by reducing transfusion-related risks.[10,12]

More than 90% of hip fractures occur in people over the age of 65 years, and the risk of hip fracture doubles every decade after the age of 50 years.[15] The mortality rate in the first year after hip surgery varies between 10% and 40%.[16] The mortality rates observed in our study are consistent with the existing literature. A 10-year retrospective study previously conducted at our clinic reported a 1-year mortality rate of 16.98% for hip surgery patients.[17] In our current cohort, although the numerical values varied slightly between the SpHb and conventional groups at the 1-month and 3-month intervals, no statistically significant differences were observed. This suggests that while SpHb monitoring optimizes perioperative management and reduces transfusion requirements, its direct impact on short-term mortality may be limited, or a larger sample size may be required to detect such a difference.

Several independent risk factors may affect mortality in patients undergoing hip surgery, including advanced age, male sex, anemia, clinical comorbidities, surgical scheduling, and surgical

Table 4. Comparison of secondary outcome measurements between groups

Variables	Group SpHb	Group CONV	p
RBC units transfused per patient	1 (1–4)	2 (1–5)	0.025[a]
Number of RBC units transfused			0.007[b]
1 unit, n (%)	17 (65.38)	6 (23.07)	
2 units, n (%)	8 (30.76)	16 (61.53)	
3 units, n (%)	1 (3.84)	4 (15.38)	
Length of stay, days	5 (2–19)	9 (2–60)	0.043[a]
Mortality, n (%)			
30-day mortality	3 (11.53)	2 (7.69)	0.266[b]
90-day mortality	3 (11.53)	5 (19.23)	0.184[b]

Values are presented as median (min–max) or number (%). [a]p-values were calculated using the Mann–Whitney U test. [b]p-values were calculated using the Fisher-Freeman-Halton test.

technique.[18] When we examined studies on the relationship between low hemoglobin (Hb) levels and mortality rates, we found some inconsistencies. For example, there is currently no global consensus regarding the Hb threshold for transfusion during hip surgery. The National Institute for Clinical Excellence (NICE) recommends blood transfusions for patients with Hb levels <7 g/dL or <8 g/dL in those with cardiac problems; however, the American Association of Blood Banks (AABB) recommends a transfusion threshold of 8 g/dL for surgical patients.[19,20] Therefore, the lack of a standard guideline makes the issue of whether the Hb value used for blood transfusion has a positive or negative impact on mortality debatable. In the present study, a hemoglobin threshold of 9 g/dL was selected as the trigger for blood transfusion. While some guidelines suggest more restrictive thresholds, our choice was informed by the specific clinical profile of our study population, which consisted of patients aged 60 years and older, with a mean age of approximately 75 years. Geriatric patients undergoing major orthopedic procedures often have a high prevalence of cardiovascular and pulmonary comorbidities that may limit their physiological compensatory mechanisms for anemia. Furthermore, hip surgeries are associated with significant perioperative blood loss and fluid shifts. By selecting a 9 g/dL threshold, we aimed to provide a safer margin for oxygen delivery and to prevent potential myocardial or cerebral ischemia in this vulnerable age group, consistent with clinical practices that prioritize perioperative stability in high-risk elderly patients. Second, the results of studies conducted on this subject are contradictory. For example, Engoren et al.[21] reported in a study involving 229 hip fractures that perioperative blood transfusion did not affect postoperative mortality on the 30th or 90th day; however, they showed that transfusion is a risk factor for death at least 90 days or more after hip surgery. Arshi et al.[22] found that the 30-day mortality rate in patients who underwent hip surgery and received blood transfusions was significantly higher than that in patients who did not receive transfusions. Smeets et al.[23] investigated the effect of blood transfusion on survival after hip surgery and found no significant differences in mortality at 30 days, 1 year, or 2 years. Consistent with these findings, we observed no statistically significant difference in 3-month mortality between our groups ($p>0.05$). However, it is important to note that the mortality rate in the conventional group (19.23%) was numerically nearly double that of the non-invasive hemoglobin (SpHb) group (11.53%). Because our sample size was calculated specifically to evaluate transfusion triggers rather than survival outcomes, this pilot-sized cohort is likely underpowered to detect a true statistical difference in mortality. Therefore, while SpHb monitoring shows a promising clinical trend toward reducing short-term mortality, these results should be interpreted cautiously and validated in larger, adequately powered multicenter studies.

Strengths and Limitations

The most significant aspect of this study is that, to our knowledge, no randomized controlled studies investigating the relationship between non-invasive hemoglobin (SpHb) monitoring and mortality have been reported. However, we found that mortality studies are typically conducted retrospectively with large sample sizes. In our study, we chose the sample size based on our main objective and included 52 patients with 95% power in the power analysis. The sample size calculation was based on the primary transfusion-related outcome structure and was not designed to ensure sufficient power for smaller event-based subgroup analyses or secondary outcomes, such as mortality. As a result, we consider the number of patients in our study insufficient for mortality analysis, which is a major limitation.

Another limitation in terms of mortality is related to the study methodology. Patients' families were contacted by phone to collect mortality data. Therefore, information such as survival status may be obscured, which may make the results debatable.

CONCLUSION

Our findings show that SpHb monitoring provides a reliable measure of critical bleeding thresholds during hip operations, which could assist with early transfusion treatments and reduce the total volume of blood required. This condition improved perioperative oxygenation and reduced hospital stay by increasing healing time. Therefore, it may be possible to improve postoperative clinical outcomes by monitoring SpHb levels during surgical procedures that represent a significant risk of blood loss.

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Informed Consent: Written informed consent was obtained from all patients before surgery.

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