Percentage change in hemoglobin level and morbidity in spine surgery patients

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OBJECTIVE The aim of this study was to characterize the association between percentage change in hemoglobin (Δ Hb)—i.e., the difference between preoperative Hb and in-hospital nadir Hb concentration—and perioperative adverse events among spine surgery patients.

METHODS Patients who underwent spine surgery at the authors' institution between December 4, 2008, and June 26, 2015, were eligible for this retrospective study. Patients who underwent the following procedures were included: atlanto-axial fusion, subaxial anterior cervical fusion, subaxial posterior cervical fusion, anterior lumbar fusion, posterior lumbar fusion, lateral lumbar fusion, excision of intervertebral disc, and excision of spinal cord lesion. Data on intraoperative transfusion were obtained from an automated, prospectively collected, anesthesia data management system. Data on postoperative hospital transfusions were obtained through an Internet-based intelligence portal. Percentage Δ Hb was defined as: $([\text{preoperative Hb} - \text{nadir Hb}]/\text{preoperative Hb}) \times 100$. Clinical outcomes included in-hospital morbidity and length of stay associated with percentage Δ Hb.

RESULTS A total of 3949 patients who underwent spine surgery were identified. Of these, 1204 patients (30.5%) received at least 1 unit of packed red blood cells. The median nadir Hb level was 10.6 g/dl (interquartile range 8.7–12.4 g/dl), yielding a mean percentage Δ Hb of 23.6% (SD 15.4%). Perioperative complications occurred in 234 patients (5.9%) and were more common in patients with a larger percentage Δ Hb ($p = 0.017$). Hospital-related infection, which occurred in 60 patients (1.5%), was also more common in patients with greater percentage Δ Hb ($p = 0.001$).

CONCLUSIONS Percentage Δ Hb is independently associated with a higher risk of developing any perioperative complication and hospital-related infection. The authors' results suggest that percentage Δ Hb may be a useful measure for identifying patients at risk for adverse perioperative events.

<https://thejns.org/doi/abs/10.3171/2017.7.SPINE17301>

KEY WORDS transfusion; surgery; blood loss; hemoglobin; morbidity; anemia; diagnostic technique

PERIOPERATIVE blood transfusion is associated with a number of risks, including allergic or febrile reactions, acute lung injury, impaired immunity, and infection.^{2–4,9,12,15,16,25,26,29,31,32,35} Given the potential risks associated with perioperative blood transfusions, nadir hemoglobin (Hb) thresholds have been proposed as a way to standardize transfusion protocols, prevent packed red blood cell (PRBC) overuse, and improve surgical outcomes.^{5,6,10,11,13,14,36} A number of prospective and randomized control trials in cardiac and hip surgery have demon-

strated that restrictive transfusion “triggers” are associated with similar or better outcomes in patients when compared with liberal triggers.^{6,7,17,20} We have previously shown that transfusion using a liberal trigger is associated with increased perioperative morbidity within spine surgery.³⁰ However, guidelines based on nadir Hb concentrations assume that the amount of acceptable blood loss does not vary by baseline Hb level and do not consider the range of potential Hb levels in the normal population.²³

Several studies in other specialties have demonstrated

ABBREVIATIONS ASA = American Society of Anesthesiologists; CCI = Charlson Comorbidity Index; EBL = estimated blood loss; Hb = hemoglobin; ICD-9 = *International Classification of Diseases, 9th revision*; IQR = interquartile range; LOS = length of stay; PRBC = packed red blood cell; Δ Hb = change in hemoglobin.

SUBMITTED March 12, 2017. **ACCEPTED** July 14, 2017.

INCLUDE WHEN CITING Published online December 22, 2017; DOI: 10.3171/2017.7.SPINE17301.

the importance of considering the change in Hb (Δ Hb) in the formula for appropriate transfusions, where Δ Hb is the difference between a patient's preoperative Hb and nadir Hb concentration during a hospital stay.³⁴ Among patients undergoing gastrointestinal surgery, a percentage Δ Hb of 50% or more was associated with a higher risk of postoperative adverse events and, in particular, ischemic complications. This was true even in patients whose nadir Hb did not drop to a restrictive trigger concentration (Hb < 7 or 8 g/dl).³⁴ Similar results have been shown among cardiac surgery patients.^{21,23} One study found that, even in patients with a nadir Hb above the restrictive trigger concentration, cardiac surgery patients with Δ Hb of 50% or greater had increased risk of renal failure, cerebrovascular accident, myocardial infarction, and in-hospital mortality.²¹ To the best of our knowledge, no study has examined the association between percentage Δ Hb and perioperative morbidity in spine surgery patients. Thus, we aimed to determine the perioperative clinical outcomes associated with percentage Δ Hb as an independent factor among spine surgery patients.

Methods

Collected Data

Our institutional surgical billing database was queried for inpatients who were discharged following spinal surgery between 2008 and 2015, which yielded 33,043 patients. Patients were stratified into 8 groups according to the surgical procedure performed: atlantoaxial fusion, subaxial anterior cervical fusion, subaxial posterior cervical fusion, anterior lumbar fusion, posterior lumbar fusion, lateral lumbar fusion, excision of intervertebral discs, and excision of spinal cord lesion (Table 1). Following exclusion of patients who underwent surgeries other than these 8 major groupings, 3949 patients were included for analysis. This study was approved by the institutional review board of Johns Hopkins University School of Medicine.

The surgical database provided data on basic patient characteristics, including American Society of Anesthesiologists (ASA) status, the Charlson Comorbidity Index (CCI) score, and total PRBC units given during the hospitalization. Procedure codes and perioperative morbidity data were identified using *International Classification of Diseases, 9th edition* (ICD-9) codes at discharge. The primary outcome was composite morbidity, which consisted of 1) hospital-acquired infection (including sepsis, surgical site infection, *Clostridium difficile*, and drug-resistant infection), 2) clinically relevant thrombotic event (pulmonary embolus, deep venous thrombosis, or disseminated intravascular coagulation), 3) kidney injury, 4) respiratory event, and/or 5) ischemic event (transient ischemic attack, myocardial infarction, or cerebrovascular accident), as we have previously described.²² To avoid bias in patients with polycythemia or preoperative anemia, we only included female patients with preoperative Hb concentrations of 12.0–16.0 g/dl and male patients with Hb concentrations of 13.0–18.0 g/dl.²⁷

We considered only PRBC transfusion for the purposes of this study. Data on intraoperative transfusion were obtained from an automated, prospectively collected, anes-

TABLE 1. Surgical procedure groups and corresponding subgroups identified by ICD-9 codes

Group	Group Name	Procedure Name (ICD-9 Code)
1	Atlantoaxial fusion	Atlas–axis spinal fusion (81.01)
		Refusion of atlas–axis spine (81.31)
2	Subaxial anterior cervical fusion	Other cervical fusion, anterior technique (81.02)
		Refusion of other cervical spine, anterior technique (81.32)
3	Subaxial posterior cervical fusion	Other cervical fusion, posterior technique (81.03)
		Refusion of other cervical spine, posterior technique (81.33)
4	Anterior lumbar fusion	Dorsal & dorsolumbar fusion, anterior technique (81.04)
		Refusion of dorsal & dorsolumbar spine, anterior technique (81.34)
		Refusion of lumbar & lumbosacral spine, anterior technique (81.36)
5	Posterior lumbar fusion	Dorsal & dorsolumbar fusion, posterior technique (81.05)
		Lumbar & lumbosacral fusion, anterior technique (81.06)
		Lumbar & lumbosacral fusion, lateral transverse process technique (81.07)
		Refusion of dorsal & dorsolumbar spine, posterior technique (81.35)
		Refusion of lumbar & lumbosacral spine, posterior technique (81.38)
6	Lateral lumbar fusion	Refusion of lumbar & lumbosacral spine, lateral transverse process technique (81.37)
7	Disc excision	Excision, destruction, & other repair of intervertebral disc (80.5)
		Excision of intervertebral disc (80.51)
8	Excision of spinal cord lesion	Excision spinal cord lesion (03.4)

thesia data management system (Metavision, iMDsoft).¹⁴ Data on postoperative hospital transfusion were obtained through an Internet-based intelligence portal (IMPACT Online; Haemonetics Corp.).¹³ Percentage Δ Hb was calculated as previously defined:^{10,11,13} [(preoperative Hb – nadir Hb)/preoperative Hb] $\times$ 100. Nadir Hb was defined as the lowest Hb value measured during a patient's hospital stay. The nadir Hb “trigger” of 7 g/dl was chosen based on previous research in gastrointestinal and cardiac surgery and also previously published randomized trials.^{17,20,23}

Statistical Analysis

Linear regression was used to test the association between preoperative risk factors and percentage decrease in Hb concentrations while controlling for the following potential confounding factors: age, sex, ASA class, CCI score, surgical group, preoperative Hb level, nadir Hb level < 7 g/dL, PRBC transfusion, units of PRBC transfused,

estimated blood loss (EBL), crystalloid fluid volume, and length of stay (LOS). Logistic regression was used to test the effect of percentage Δ Hb on morbidity while controlling for age, ASA class, CCI score, surgical group, nadir Hb level < 7 g/dl, PRBC transfusion, units of PRBC transfused, EBL, crystalloid fluid volume, and LOS. Logistic regression was also used to test the effect of percentage Δ Hb on hospital-related infection while controlling for ASA class, CCI score, nadir Hb level < 7 g/dl, PRBC transfusion, units of PRBC transfused, and LOS. Variables with a p value < 0.1 in the univariate analyses were included in the multivariate logistic regression model. The results of logistic regression analysis are presented as odds ratios with 95% confidence intervals. All data were analyzed using SPSS (version 24, IBM Corp.). A p value < 0.05 was considered to be statistically significant.

Results

Study Population and Demographics

A total of 3949 patients met the inclusion criteria (Table 2). Between December 4, 2008, and June 26, 2015, these patients underwent atlantoaxial fusion (49 [1.2%]), subaxial anterior cervical fusion (788 [20.0%]), subaxial posterior cervical fusion (297 [7.5%]), anterior lumbar fusion (101 [2.6%]), posterior lumbar fusion (1733 [43.9%]), lateral lumbar fusion (107 [2.7%]), disc excision (553 [14.0%]),

and excision of spinal cord lesion (321 [8.1%]). In our sample, 1853 patients were men (46.9%) and the median age was 51 years (interquartile range [IQR] 28–63 years). The majority of patients self-identified as white (2965 [75.1%]). The median CCI score was 0 (IQR 0–1), and 1373 patients (42.5%) were classified as ASA class III or IV. The median EBL was 300 ml (IQR 100–850 ml). The median LOS was 4 days (IQR 3–6 days).

A total of 1204 patients received a PRBC transfusion (at least 1 unit of PRBCs), yielding an overall transfusion rate of 30.5%. In patients who received PRBC transfusions, the median number of PRBC units transfused was 3 (IQR 2–6 U). The median volume of crystalloid fluid infused was 3788 ml (IQR 2000–5000 ml). The median preoperative Hb level for all patients was 13.8 g/dl (IQR 13.1–14.6 g/dl), and the median nadir Hb level was 10.6 g/dl (IQR 8.7–12.4 g/dl), thereby yielding a mean $\pm$ SD percentage Δ Hb level of 23.6% $\pm$ 15.4%.

Factors Associated With Percentage Δ Hb

The impact of the preoperative patient characteristics on a larger magnitude decrease in Hb in patients undergoing spine surgery was also assessed (Table 3). Univariate analyses indicated that age, sex, ASA class, CCI score, surgical group, preoperative Hb level, nadir Hb level < 7 g/dl, PRBC transfusion, units of PRBC transfused, EBL, crystalloid fluids, and LOS were associated with an increased percentage Δ Hb (all p < 0.0001). After adjusting for competing preoperative factors on the multivariate analysis, age, sex, ASA class, surgical group, preoperative Hb level, nadir Hb level < 7 g/dl, PRBC transfusion, units of PRBC transfused, EBL, crystalloid fluids, and LOS remained independently associated with a larger percentage Δ Hb (p = 0.011 for ASA class; p < 0.0001 for all others).

Association of Percentage Δ Hb With Perioperative Morbidity

Overall, 5.9% of all patients (234 patients) experienced at least 1 perioperative complication (Table 4). The incidence of having any morbid event varied among the 8 groups of spinal procedures: atlantoaxial fusion (8.2%; 4 of 49 patients), subaxial anterior cervical fusion (2.2%; 17 of 788 patients), subaxial posterior cervical fusion (4.0%; 12 of 297 patients), anterior lumbar fusion (12.9%; 13 of 101 patients), posterior lumbar fusion (8.1%; 141 of 1733 patients), lateral lumbar fusion (7.5%; 8 of 107 patients), disc excision (4.9%; 27 of 553 patients), and excision of spinal cord lesion (3.7%; 12 of 321 patients). Most common among these were thrombotic events (87 patients [2.2% of all patients]) and kidney injury (62 patients [1.6% of all patients]). Hospital-related infection occurred in 60 patients (1.5% of all patients).

The impact of perioperative risk factors on developing at least 1 perioperative complication was evaluated (Table 5). On the univariate analysis, age, ASA class, CCI score, surgical group, nadir Hb level < 7 g/dl, PRBC transfusion, units of PRBC transfused, EBL, crystalloid fluid volume, LOS, and percentage Δ Hb were associated with the development of at least 1 complication (p = 0.016 for age; all others p < 0.0001). After adjusting for compet-

TABLE 2. Demographic characteristics and surgical groupings for all patients

Patient Characteristic	Value
No. of patients	3949
Median age (IQR), yrs	51 (28–63)
Male sex	1853 (46.9)
White	2965 (75.1)
Median ASA class (IQR)	2 (2–3)
Median CCI score (IQR)	0 (0–1)
Surgical group	
Atlantoaxial fusion	49 (1.2)
Subaxial anterior cervical fusion	788 (20.0)
Subaxial posterior cervical fusion	297 (7.5)
Anterior lumbar fusion	101 (2.6)
Posterior lumbar fusion	1733 (43.9)
Lateral lumbar fusion	107 (2.7)
Disc excision	553 (14.0)
Excision of spinal cord lesion	321 (8.1)
Median preop Hb level (IQR), g/dl	13.8 (13.1–14.6)
Nadir Hb level <7 g/dl	132 (3.3)
Mean $\pm$ SD percentage Δ Hb	23.6 $\pm$ 15.4
PRBC transfusion	1204 (30.5)
Median PRBCs transfused per patient (IQR), units	3 (2–6)
Median EBL (IQR), ml	300 (100–850)
Median crystalloid fluids (IQR), ml	3788 (2000–5000)
Median LOS (IQR), days	4 (3–6)

Values are shown as the number of patients (%) unless indicated otherwise.

TABLE 3. Preoperative factors associated with percentage decrease in Hb concentration

Factor	Univariate				Multivariate		
	p Value	B	95% CI	R ²	p Value	B	95% CI
Age	<0.0001	-0.098	-0.121 to -0.076	0.018	<0.0001	-0.056	-0.075 to -0.038
Male sex	<0.0001	3.370	2.413 to 4.326	0.012	<0.0001	6.025	5.184 to 6.867
White	0.873	0.090	-1.020 to 1.201	0.000006	NA	NA	NA
ASA class	<0.0001	4.974	4.147 to 5.802	0.041	0.011	0.829	0.187 to 1.471
CCI score	<0.0001	1.261	0.943 to 1.579	0.015	0.127	0.202	-0.058 to 0.461
Surgical group	<0.0001	1.280	1.029 to 1.531	0.025	<0.0001	0.527	0.330 to 0.724
Preop Hb level	<0.0001	1.398	0.977 to 1.819	0.011	<0.0001	3.403	3.038 to 3.769
Nadir Hb level <7 g/dl	<0.0001	30.541	28.044 to 33.037	0.127	<0.0001	13.999	11.826 to 16.173
PRBC transfusion	<0.0001	22.099	21.316 to 22.882	0.437	<0.0001	14.117	13.059 to 15.176
Units of PRBC transfused	<0.0001	2.385	2.250 to 2.521	0.231	<0.0001	-0.497	-0.678 to -0.316
EBL	<0.0001	0.009348	0.008848 to 0.10	0.310	<0.0001	0.004	0.003 to 0.005
Crystalloid fluids	<0.0001	0.001962	0.001770 to 0.002155	0.110	<0.0001	0.000338	0.000187 to 0.000489
LOS	<0.0001	1.253	1.172 to 1.333	0.192	<0.0001	0.439	0.361 to 0.518

NA = not applicable.

Boldface type indicates statistical significance.

ing perioperative risk factors, CCI score ($p = 0.010$), LOS ($p < 0.0001$), and percentage Δ Hb ($p = 0.017$) remained independently associated with the development of a complication.

Finally, the impact of percentage Δ Hb and a nadir Hb level less than 7 g/dl on the development of a hospital-related infection were assessed (Table 6). On the multivariate analysis and after adjusting for competing risk factors, LOS ($p < 0.0001$) and percentage Δ Hb ($p = 0.001$) remained independently associated with the development of infection. In particular, percentage Δ Hb was found to be associated with infection, showing 1.057 times higher odds of infection (95% CI 1.023–1.093). PRBC transfusion was not independently associated with the odds of a morbid event (positively or negatively) in the multivariate model (Table 5).

Discussion

Our analysis revealed that percentage Δ Hb was independently associated with the development of at least 1 in-hospital complication. A larger percentage Δ Hb also resulted in higher odds of developing a hospital-related

infection, even after controlling for potential confounders. Our results suggest that additional consideration of relative anemia, rather than an absolute nadir Hb trigger alone, may be useful in informing transfusion practices during spine surgery. Because patient baseline Hb concentrations are variable, an absolute nadir Hb trigger of 7 g/dl may not be an ideal indicator of clinically important acute anemia for all patients.

Our findings of worse perioperative outcomes associated with an increased percentage Δ Hb are consistent with research in other surgical specialties. Karkouti et al.²³ were the first to demonstrate the effect of a Δ Hb of 50% or greater in patients undergoing cardiac surgery. The authors dichotomized percentage Δ Hb at 50% and found that percentage Hb loss greater than this threshold was independently associated with an adverse event, which was defined as death, stroke, and/or kidney failure (OR 1.53; 95% CI 1.12–2.08; $p = 0.007$). Of note, the authors did not find an independent association of nadir Hb level with increased risk of perioperative complications ($p = 0.4$). Hogervorst et al.²¹ also examined the relationships among intraoperative percentage Δ Hb of at least 50%, Hb nadir, and morbidity outcomes in cardiac surgery patients. Compared with a reference group of patients whose nadir Hb remained above the defined 7 g/dl trigger and whose Hb decline was less than 50%, patients with a nadir Hb above 7 g/dl but with an Hb decline greater than 50% had a higher risk of composite morbidity (adjusted OR 1.27; 95% CI 1.14–1.41). Finally, Spolverato et al.³⁴ found similar results in a population of patients who underwent major gastrointestinal surgery. Patients with a nadir Hb below 7 g/dl and with an Hb decline larger than 50% had a greater risk of composite postoperative morbidity compared with patients whose nadir Hb remained above 7 g/dl and whose Hb decline was less than 50% (OR 1.98; 95% CI 1.18–3.33; $p = 0.01$). Even in patients with a nadir Hb of 7 g/dl or higher, an Hb decline of 50% or more was associated with an increased risk of ischemic complications (OR

TABLE 4. Frequency of complications among all patients

Complication	Value
All complications*	234 (5.9)
Infection	60 (1.5)
Thrombotic event	87 (2.2)
Kidney injury	62 (1.6)
Respiratory event	44 (1.1)
Ischemic event	15 (0.4)
Death	6 (0.2)

Values are shown as the number of patients (%).

* Some patients had more than 1 complication.

TABLE 5. Risk factors for at least 1 perioperative complication among all patients

Patient Characteristic	Univariate		Multivariate	
	OR (95% CI)	p Value	OR (95% CI)	p Value
Age	1.008 (1.001–1.015)	0.016	1.009 (1.000–1.019)	0.056
Male sex	0.933 (0.715–1.216)	0.608	NA	NA
White	1.203 (0.875–1.656)	0.255	NA	NA
ASA class	2.422 (1.867–3.143)	<0.0001	1.214 (0.882–1.669)	0.234
CCI score	1.269 (1.192–1.350)	<0.0001	1.131 (1.030–1.241)	0.010
Surgical group	NA	<0.0001	NA	0.220
Atlantoaxial fusion	Reference	NA	Reference	NA
Subaxial anterior cervical fusion	0.248 (0.08–0.768)	0.016	2.772 (0.390–19.697)	NA
Subaxial posterior cervical fusion	0.474 (0.146–1.533)	0.212	2.388 (0.336–16.988)	NA
Anterior lumbar fusion	1.662 (0.512–5.391)	0.398	4.724 (0.631–35.355)	NA
Posterior lumbar fusion	0.996 (0.353–2.811)	0.995	2.812 (0.421–18.800)	NA
Lateral lumbar fusion	0.909 (0.260–3.176)	0.881	2.416 (0.305–19.158)	NA
Disc excision	0.577 (0.194–1.723)	0.325	4.325 (0.622–30.091)	NA
Excision of spinal cord lesion	0.437 (0.135–1.413)	0.167	1.349 (0.183–9.975)	NA
Preop Hb level	0.940 (0.835–1.058)	0.304	NA	NA
Nadir Hb level <7	4.484 (2.872–7.002)	<0.0001	1.108 (0.493–2.491)	0.804
PRBC transfusion	4.249 (3.229–5.591)	<0.0001	0.920 (0.545–1.555)	0.756
Units of PRBC transfused	1.196 (1.160–1.233)	<0.0001	1.036 (0.986–1.089)	0.160
EBL	1.000322 (1.000204–1.000441)	<0.0001	0.999818 (0.999599–1.000038)	0.105
Crystalloid fluids	1.000157 (1.000107–1.000208)	<0.0001	1.000053 (0.999989–1.000117)	0.107
LOS	1.173 (1.150–1.198)	<0.0001	1.141 (1.109–1.174)	<0.0001
Percentage Δ Hb	1.053 (1.043–1.063)	<0.0001	1.024 (1.004–1.045)	0.017

Boldface type indicates statistical significance.

5.68; 95% CI 1.44–22.39; $p = 0.01$). While our study did not consider dichotomous groupings of percentage Δ Hb, our results similarly supported the association between percentage Δ Hb and adverse postoperative events.

Our results also demonstrated an association between percentage Δ Hb and the risk of developing a hospital-related infection. In this study, hospital-related infection was defined as sepsis, surgical-site infection, *C. difficile*, or drug-resistant infection. An acute percentage decrease in Hb has been shown to negatively impact end-organ function, most notably in oxygen-dependent organs such as the brain, kidney, and heart.^{19,21} Impaired kidney function has been associated with higher rates of hospital-related infections.⁸ Moreover, if a larger percentage Δ Hb decrease is suggestive of greater overall blood loss intraoperatively, and by proxy case complexity, it is possible that these patients were less mobile following surgery. Impaired mobility and longer hospital stays have been associated with increased rates of pressure ulcers, respiratory infections, and *C. difficile* infection.^{1,24,28,33} Pressure ulcers in particular demonstrate high rates of colonization by methicillin-resistant *Staphylococcus aureus*, which is included in our definition of a hospital-related infection.²⁸ It is conceivable that the patients in our study who experienced larger percentage Δ Hb had greater neurological deficits that resulted in impaired mobility or required longer postoperative immobilization, thereby placing them at a higher risk for infection.¹⁸

There are limitations to this study that should be considered when interpreting our results. First, we purposely excluded patients with preexisting anemia or polycythemia and men and women whose preoperative Hb levels fell outside of 13.0–18.0 g/dl or 12.0–16.0 g/dl, respectively. This was done to allow comparison with previous studies on percentage Δ Hb^{21,23} and to avoid potential bias,³⁴ but it may limit generalizability to patients with preoperative anemia or polycythemia. Second, the databases used relied on correct and consistent coding of procedures, preoperative diagnoses, and clinical outcomes across patients. Third, the present study design is observational, which identifies associations rather than causal relationships, and does not determine if transfusion effectively prevents or reduces anemia-related morbidity. Given the apparent risks from Δ Hb and the recognized risks of allogeneic transfusion, perhaps the ultimate risk minimization strategy is derived from methods used to reduce or prevent bleeding (e.g., hemostatic agents, antifibrinolytics). In other words, prevention is better than the condition (anemia) or the treatment (transfusion). Finally, although our study benefited from a large sample size, we were limited to a convenience sample of patients who presented to an isolated tertiary care center, which may reduce the applicability of our results to other patient populations. Despite these limitations, the present study is the first to describe the effect of percentage Δ Hb on clinical outcomes in spine surgery patients.

TABLE 6. Risk factors for hospital-related infection events among all patients

Patient Characteristic	Univariate		Multivariate	
	OR (95% CI)	p Value	OR (95% CI)	p Value
Age	0.993 (0.981–1.005)	0.241	NA	NA
Male sex	0.805 (0.480–1.351)	0.412	NA	NA
White	0.837 (0.475–1.475)	0.538	NA	NA
ASA class	2.295 (1.421–3.708)	0.001	1.209 (0.680–2.149)	0.518
CCI score	1.217 (1.085–1.365)	0.001	1.130 (0.962–1.326)	0.136
Surgical group	NA	0.066	NA	NA
Atlantoaxial fusion	Reference	NA	Reference	NA
Subaxial anterior cervical fusion	NA	NA	NA	NA
Subaxial posterior cervical fusion	0.990 (0.117–8.403)	0.992	NA	NA
Anterior lumbar fusion	1.979 (0.215–18.196)	0.546	NA	NA
Posterior lumbar fusion	0.731 (0.097–5.499)	0.761	NA	NA
Lateral lumbar fusion	1.385 (0.140–13.658)	0.781	NA	NA
Disc excision	1.708 (0.224–13.036)	0.606	NA	NA
Excision of spinal cord lesion	0.150 (0.009–2.438)	0.182	NA	NA
Preop Hb level	0.910 (0.722–1.147)	0.424	NA	NA
Nadir Hb level <7 g/dl	7.852 (4.066–15.164)	<0.001	1.508 (0.497–4.580)	0.468
PRBC transfusion	3.494 (2.075–5.884)	<0.001	0.506 (0.204–1.257)	0.142
Units of PRBC transfused	1.114 (1.070–1.161)	<0.001	0.927 (0.843–1.109)	0.114
EBL	1.000136 (0.999881–1.000391)	0.297	NA	NA
Crystalloid fluids	1.000072 (0.999971–1.000172)	0.163	NA	NA
LOS	1.149 (1.121–1.177)	<0.001	1.132 (1.097–1.167)	<0.0001
Percentage ΔHb	1.072 (1.052–1.093)	<0.001	1.057 (1.023–1.093)	0.001

Boldface type indicates statistical significance.

Conclusions

In conclusion, little data exist that assess whether a relative change in Hb level during spine surgery predicts adverse postoperative events. Among patients undergoing spine surgery, percentage ΔHb was independently associated with a higher risk of developing perioperative complications. Percentage ΔHb was also independently associated with the development of hospital-related infection. These results suggest that percentage ΔHb, along with absolute nadir Hb levels, may be a helpful measure in developing transfusion guidelines. Moreover, consideration of percentage ΔHb is appropriate to identify patients at risk for perioperative complications.

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Disclosures

Dr. Frank: consultant for Haemonetics and Medtronic. Dr. Goodwin: a United Negro College Fund Merck postdoctoral fellow and received an award from the Burroughs Wellcome Fund and the Johns Hopkins Neurosurgery Pain Research Institute. Dr. Molina: consultant for Augmedics. Dr. Sciubba: consultant for DePuy-Synthes, Medtronic, Stryker, K2M, Globus, and Orthofix.

Author Contributions

Conception and design: Sciubba, Purvis, Frank. Acquisition of data: Frank. Analysis and interpretation of data: Purvis. Drafting the article: Purvis. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Statistical analysis: Purvis. Study supervision: Sciubba, Goodwin, Frank.

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