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Hematocrit as a predictor of preoperative transfusion-associated complications in spine surgery: A NSQIP study

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ABSTRACT

Background context: Preoperative optimization of medical comorbidities prior to spinal surgery is becoming an increasingly important intervention in decreasing postoperative complications and ensuring a satisfactory postoperative course. The treatment of preoperative anemia is based on guidelines made by the American College of Cardiology (ACC), which recommends packed red blood cell transfusion when hematocrit is less than 21% in patients without cardiovascular disease and 24% in patients with cardiovascular disease. The literature has yet to quantify the risk profile associated with preoperative pRBC transfusion.
Purpose: To determine the incidence of complications following preoperative pRBC transfusion in a cohort of patients undergoing spine surgery.
Study design: Retrospective review of a national surgical database.
Patient sample: The national surgical quality improvement program database
Outcome neasures: Postoperative physiologic complications after a preoperative transfusion. Complications were defined as the occurrence of any DVT, PE, stroke, cardiac arrest, myocardial infarction, longer length of stay, need for mechanical ventilation greater than 48 h, surgical site infections, sepsis, urinary tract infections, pneumonia, or higher 30-day mortality.
Methods: The national surgical quality improvement program database was queried, and patients were included if they had any type of spine surgery and had a preoperative transfusion.
Results: Preoperative pRBC transfusion was found to be protective against complications when the hematocrit was less than 20% and associated with more complications when the hematocrit was higher than 20%. In patients with a hematocrit higher than 20%, pRBC transfusion was associated with longer lengths of stay, and higher rates of ventilator dependency greater than 48 h, pneumonia, and 30-day mortality.
Conclusion: This is the first study to identify an inflection point in determining when a preoperative pRBC transfusion may be protective or may contribute to complications. Further studies are needed to be conducted to stratify by the prevalence of cardiovascular disease.

1. Introduction

Preoperative optimization is an increasingly important component of ensuring intraoperative safety and postoperative success. In the spinal surgery population, optimizing preoperative nutritional status, bone density, blood glucose levels, and hematocrit are paramount to maximizing the safety profile of the surgery and minimizing postoperative complications. Hematocrit is particularly salient to spinal procedures in which patients can lose significant amounts of blood; indeed, up to one in six patients receive a blood transfusion while undergoing a posterior

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lumbar fusion [1]. The American College of Cardiology (ACC) recommends transfusion of packed red blood cells (pRBC) when hematocrit is less than 21% in patients without cardiovascular disease and less than 24% in patients with cardiovascular disease [2]. While optimizing HCT throughout the perioperative course is important, it is not without risks. Transfusion-related acute lung injury (TRALI), febrile reactions, infection, and impaired immune reaction have all been attributed to pRBC transfusion during and after spinal surgery [3]. Additionally, research has shown that patients who have received peri- and postoperative pRBC transfusions have higher rates of wound infections, deep vein thrombosis (DVT), pulmonary embolism (PE), myocardial infarction (MI), prolonged length of stay, and urinary tract infection [4–10].

One reason patients require a peri- or postoperative transfusion is preoperative anemia[4] which is also risk factor for postoperative complications, reoperation, and extended length of stay in patients undergoing spinal surgery [11–13]. As pRBC transfusions are associated with worse outcomes in spinal surgery, ways to mitigate anemia in patients are important for preoperative optimization [14]. For many patients, supplemental intravenous iron and erythropoiesis-stimulating agents are sufficient; however, for patients with more severe anemia, pRBC transfusion may be required [15,16]. While the effects of postoperative pRBC transfusions have been thoroughly documented, there is a paucity of literature examining the impact of preoperative pRBC transfusions in patients undergoing spinal surgery.

The purpose of this study is to examine the effects of preoperative pRBC transfusions on patient complications following spinal surgery. We hypothesize that patients who underwent preoperative pRBC transfusion prior to spine surgery will experience an increase in postoperative complications compared to those who did not undergo a preoperative pRBC transfusion.

2. Methods

The National Surgical Quality Improvement Program (NSQIP) database is a multicenter database that is sponsored by the American College of Surgeons [17]. The NSQIP database was chosen because it tracks patients in both inpatient and outpatient settings for 30 days postoperatively which allows for thorough documentation of short term complications. Additionally, as a quality improvement database, it provides granularity in the coding of operative procedures, allowing for strict exclusion/criteria to be maintained. We retrospectively queried NSQIP for patients undergoing spinal surgery from 2005 to 2017. Inclusion criteria included patients who were over the age of 18, underwent spinal surgery and had preoperative pRBC transfusion data. Exclusion criteria included those who received a postoperative pRBC transfusion and those who underwent trauma surgery. Patients who received a preoperative pRBC transfusion (at least one unit of whole pRBC 72 h prior to surgery) were compared to those who did not receive a preoperative pRBC transfusion.

Demographic data including age, gender, race, body mass index (BMI), smoking status, preoperative platelet count, partial thromboplastin time (PTT), international normalized ratio (INR), hematocrit, preoperative comorbidities including dyspnea, sepsis, diabetes, hypertension, ventilator dependency, ascites, acute renal failure, and chronic obstructive pulmonary disease (COPD) were recorded for each group.

SAS software, Version 9.4 (SAS Institute, Cary, NC) was used for statistical analysis. Patient demographics and comorbidities were compared between those who received a preoperative pRBC transfusion and those who did not. Patients had postoperative complications if they experienced any of the following: DVT, PE, stroke, cardiac arrest, MI, longer length of stay, need for mechanical ventilation greater than 48 h, surgical site infections, sepsis, urinary tract infections, pneumonia, or higher 30-day mortality. The incidence of postoperative complications was compared between patients who received a preoperative pRBC transfusion and those who did not. Student *t*-test was performed for discrete variables, and chi-squared tests were performed for categorical variables. Preliminary analysis showed that patients who received a preoperative pRBC transfusion with a hematocrit greater than 20% were significantly more likely to have a postoperative complication than those transfused patients with hematocrit less than 20%. Therefore, a hematocrit of 20% was selected as it was an inflection point in terms of postoperative complications. The remaining analysis was conducted in a patient cohort with hematocrit greater than 20% to quantify postoperative complication profile. Univariate analysis was then performed, and variables that were found to be significant ($p \leq 0.05$) with chi-squared analysis and reasonable based on clinical judgment then underwent multivariable regression to assess more complicated associations in the presence of other variables. Statistical significance was assessed at $p \leq 0.05$. A propensity score two to one multivariate matching system was implemented to control for baseline differences found on univariate analysis.

3. Results

3.1. Transfusion complications by preoperative hematocrit level

The patient's preoperative hematocrit level was categorized into one-point increments (such as 24.0–24.99%, and 25.0–25.99% were characterized as anyone having a hematocrit of 24%, and 25%, respectively). Hematocrit levels were then graphed against the presence of any postoperative complication, as seen in Fig. 1. An inflection point was found in terms of the occurrence of postoperative complications. The occurrence of a preoperative pRBC transfusion was protective against complications when the preoperative hematocrit was 20.0% or lower. However, when a preoperative pRBC transfusion was performed with a preoperative hematocrit 20% or greater, there was a higher rate of postoperative complications. An area under the curve analysis was conducted to determine the incidence of one or more postoperative complications. A preoperative pRBC transfusion with a hematocrit of 20% or higher result in 5.01 times greater chance of having one or more postoperative complications when compared to those who received a pRBC transfusion with a hematocrit less than 20% (odds ratio 5.01, 95% confidence interval 3.67–6.84, $p < 0.0001$). Accordingly, the remaining analysis was adjusted to those patients with a hematocrit higher than 20% and comparing postoperative complications with and without the occurrence of a preoperative pRBC transfusion.

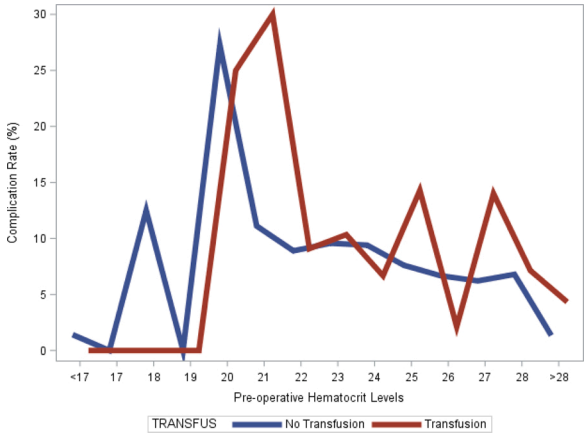

Fig. 1. Distribution of postoperative complication by hematocrit level and transfusion status. This graph shows the rate of complications following preoperative packed red blood cell transfusion as categorized by the preoperative hematocrit level. Preoperative transfusion at a hematocrit less than 20% was associated with fewer postoperative complications than patients that received no transfusions. Preoperative transfusions at a hematocrit higher than 20% were associated with more postoperative complications than patients who did not undergo transfusion. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

3.2. Demographics

Table 1 shows the baseline patient demographics. NSQIP database query resulted in 272,669 patients who did not receive a preoperative pRBC transfusion, and 651 patients who did receive a preoperative pRBC transfusion were found in the NSQIP database. On univariate analysis, the cohort who received preoperative pRBC transfusion was significantly more likely to be patients of older age, non-Caucasian race, higher preoperative INR and PTT, lower hematocrit, were dyspneic, sepsis within 48 h prior to surgery, diabetes, hypertension requiring medications, ventilator dependency, ascites, acute preoperative renal failure, and a history of COPD. The cohort who did not receive preoperative pRBC transfusion had significantly higher BMI and were more likely to be smokers. Additional analyses examining sociodemographic factors was also performed and is included in the Supplementary Material.

Table 1
Patient demographics in study.

	Preoperative transfusion		
	No transfusion $N = 272,669$	Transfusion $N = 651$	*P*-value
Age	57.51 ± 14.21	63.37 ± 13.52	<0.0001
Gender			0.31
Female	131,070 (48.08)	326 (50.08)	
Male	141,537 (51.92)	325 (49.92)	
Race			<0.0001
Other	30,073 (11.03)	114 (17.51)	
Unknown	25,465 (9.34)	56 (8.60)	
White	217,131 (79.63)	481 (73.89)	
BMI	30.36 ± 6.55	28.65 ± 6.94	<0.0001
Smoking status			0.0059
No	210,020 (77.02)	531 (81.57)	
Yes	62,649 (22.98)	120 (18.43)	
Preoperative platelet count	246.44 ± 69.68	240.76 ± 131.65	0.27
Preoperative INR	1.01 ± 0.22	1.16 ± 0.24	<0.0001
Preoperative PTT	29.07 ± 4.43	31.47 ± 6.95	<0.0001
Preoperative hematocrit	41.21 ± 4.35	30.88 ± 5.60	<0.0001
Dyspnea			0.0003
No	258,868 (94.94)	598 (91.86)	
Yes	13,799 (5.06)	53 (8.14)	
Sepsis within 48 h Prior to Surgery			<0.0001
No	269,553 (98.94)	509 (78.19)	
Yes	2881 (1.06)	142 (21.81)	
Diabetes			<0.0001
No	226,010 (82.89)	480 (73.73)	
Yes	46,659 (17.11)	171 (26.27)	
Hypertension requiring medication			<0.0001
No	134,370 (49.28)	250 (38.40)	
Yes	138,299 (50.72)	401 (61.60)	
Ventilator dependent			<0.0001
No	272,382 (99.90)	591 (90.78)	
Yes	393 (0.10)	60 (9.22)	
Ascites			<0.0001
No	272,609 (99.98)	647 (99.39)	
Yes	60 (0.02)	4 (0.61)	
Preoperative acute renal failure			<0.0001
No	272,481 (99.39)	634 (97.39)	
Yes	188 (0.07)	17 (2.61)	
History of COPD			<0.0001
No	261,080 (95.75)	584 (89.71)	
Yes	11,589 (4.25)	67 (10.29)	

BMI = body mass index, PT = prothrombin, PTT = partial thromboplastin time, COPD = chronic obstructive pulmonary disease.

3.3. Data analysis

Univariate analysis of postoperative complications in relationship to preoperative pRBC transfusion is shown in Table 2. Patients who received a preoperative pRBC transfusion had significantly higher rates of postoperative DVT, cardiac arrest requiring cardiopulmonary resuscitation (CPR), MI, longer length of stay, ventilator dependency for longer than 48 h, postoperative pneumonia, surgical site infection, postoperative sepsis, postoperative urinary tract infection, and 30-day mortality. Furthermore, a two to one matched cohort multivariate analysis was conducted, and results are shown in Table 3. This analysis

Table 2
Rates for primary and secondary outcomes.

	Preoperative transfusion		
	No transfusion $N = 271,718$	Transfusion $N = 485$	*P*-value
Vein thrombosis requiring therapy			<0.0001
No	270,938 (99.37)	625 (96.01)	
Yes	1731 (0.63)	26 (3.99)	
Pulmonary embolism			0.060
No Complication	271,522 (99.58)	654 (99.08)	
Pulmonary embolism	1147 (0.42)	6 (0.92)	
CVA/stroke with neurological deficit			0.055
No Complication	272,314 (99.87)	648 (99.54)	
Stroke/CVA	355 (0.13)	3 (0.46)	
Cardiac arrest requiring CPR			0.0001
Cardiac arrest requiring CPR	457 (0.17)	7 (1.08)	
No complication	272,212 (99.83)	644 (98.92)	
Myocardial infarction			0.0003
Myocardial infarction	680 (0.25)	8 (1.23)	
No complication	271,989 (99.75)	643 (98.77)	
Total length of hospital stay	3.02 ± 5.28	15.51 ± 20.17	<0.0001
Occurrence of on ventilator > 48 h occurrences			<0.0001
No complication	271,395 (99.53)	588 (90.32)	
On ventilator greater than 48 h	1274 (0.47)	63 (9.68)	
Postoperative pneumonia			<0.0001
No complication	270,519 (99.21)	595 (91.40)	
Pneumonia	2150 (0.79)	56 (8.60)	
Surgical site infections			<0.0001
No	267,916 (98.26)	610 (93.70)	
Yes	4753 (1.74)	41 (3.60)	
Postoperative sepsis			<0.0001
No complication	270,753 (99.30)	611 (93.86)	
Sepsis	1916 (0.70)	40 (6.14)	
Postoperative urinary tract infections			<0.0001
No complication	269,300 (98.76)	621 (95.39)	
Urinary tract infection	3369 (1.24)	30 (4.61)	
30 day mortality			<0.0001
No	271,833 (99.69)	608 (93.39)	
Yes	836 (0.31)	43 (6.61)	

CVA = cerebrovascular accident, CPR = cardiopulmonary resuscitation.

Table 3
Comparison based on matched cohort.

	Preoperative transfusion		
	No transfusion $N = 1233$	Transfusion $N = 626$	*P*-value
Vein thrombosis requiring therapy			0.34
No	1196 (97.00)	602 (96.17)	
Yes	37 (3.00)	24 (3.83)	
Pulmonary embolism			0.73
No complication	1219 (98.86)	620 (99.04)	
Pulmonary embolism	14 (1.14)	6 (0.96)	
CVA/stroke with neurological deficit			0.72
No complication	1227 (99.51)	624 (99.68)	
Stroke/CVA	6 (0.49)	2 (0.32)	
Cardiac arrest requiring CPR			0.19
Cardiac arrest requiring CPR	24 (1.95)	7 (1.12)	
No complication	1209 (98.05)	619 (98.88)	
Myocardial infarction			0.64
Myocardial infarction	11 (0.89)	7 (1.12)	
No complication	1222 (99.11)	619 (98.88)	
Total length of hospital stay	10.06 ± 12.80	15.40 ± 20.33	<0.0001
Occurrence of on ventilator > 48 h Occurrences			0.026
No complication	1154 (93.59)	568 (90.73)	
On Ventilator greater than 48 h	79 (6.41)	58 (9.27)	
Postoperative pneumonia			0.025
No complication	1164 (94.40)	574 (91.69)	
Pneumonia	69 (5.60)	52 (8.31)	
Surgical site infections			0.74
No	1159 (94.00)	586 (93.61)	
Yes	74 (6.00)	40 (6.39)	
Postoperative sepsis			0.93
No complication	1153 (93.51)	586 (93.61)	
Sepsis	80 (6.49)	40 (6.39)	
Postoperative urinary tract infections			0.39
No complication	1188 (96.35)	598 (95.53)	
Urinary tract infection	45 (3.65)	28 (4.47)	
30 Day mortality			0.028
No	1184 (96.03)	586 (93.61)	
Yes	49 (3.97)	40 (6.39)	

CVA = cerebrovascular accident, CPR = cardiopulmonary resuscitation.

showed that those who received preoperative pRBC transfusions had significantly higher rates of longer length of stay, ventilator-dependent for longer than 48 h, postoperative pneumonia, and 30-day mortality.

4. Discussion

While the risks of postoperative transfusions in spine surgery have been well documented in the literature, the data on risks of preoperative pRBC transfusion are sparse. This is the first study to examine the relationship between preoperative pRBC transfusion and postoperative complications in the spine surgery population. These data suggest that preoperative pRBC transfusion is more common in patients with multiple preexisting comorbidities. This study also independently corroborates the guidelines made by the American College of Cardiology, via demonstration of an inflection point (preoperative hematocrit is less than 20%, which corresponds to a hemoglobin of 6.7 g/dl) where the rate of postoperative complications is lower with preoperative pRBC transfusion's. When the preoperative hematocrit is higher than 20% or 6.7 g/dl, preoperative pRBC transfusion is associated with an increased frequency of postoperative complications. The association may be mediated by reduced cardiac strain and improved end-organ perfusion. In contrast, the deleterious effects may be mediated by the activation of the coagulation and inflammatory cascades as well as deposition of immune complexes in organs causing injury. Along with these known coagulation and inflammatory risks, our patient population also showed higher rates of pulmonary complications including ventilator dependency and pneumonia which could be associated with pulmonary edema due to an increase in intravascular fluid status and pulmonary capillary bed injury secondary to immune complex deposition.

The risk of postoperative complications associated with pRBC transfusion after spine surgery has been well established. A retrospective study by Fisahn et al. comparing deformity correction patients showed that postoperative transfusion was associated with a 26% increase in overall infections ($p = 0.03$) [6]. A further stratification showed that smoking may further modify and increase the risk of infection when a postoperative transfusion occurs. A similar study by Aoude et al. utilized the NSQIP database to show that patients undergoing cervical spine fusion who received postoperative pRBC transfusions had significantly higher rates of DVT, PE, MI, wound infection, and mortality when compared to those who did not receive transfusions [13]. Given these risks, the authors recommended that cervical spinal fusions that require a transfusion be conducted in an inpatient environment rather than an ambulatory setting. A propensity score matching study by Kato et al. in 2016 showed that those patients who received a transfusion after a spinal surgery had a significantly increased risk of not only surgical site infections but also urinary tract infections [9].

Risks from blood transfusions are not limited to physical complications; they have also been associated with increases in postoperative neurocognitive disorders. Specifically, Elsamadicy et al in showed that the rate of postoperative delirium was 46.7% in those who received allogenic pRBC postoperative versus 11.5% in those who did not receive pRBC after spinal surgery ($p = 0.0002$) [18]. Further analysis showed that allogenic pRBC specifically increased postoperative delirium when compared to autologous (46.7% versus 17.4%, $p = 0.0335$).[15] In an additional study, Elsamadicy et al. found that perioperative RBC transfusions were associated with an increase in 30-day readmission rate (16.67% versus 5%, $p = 0.01$) [19].

Along with increased risk of infection, thrombosis, and delirium, the activation of coagulation, inflammatory, and immune system cascades caused by pRBC transfusions has been linked to organ specific complications in patients undergoing spine surgery [20–22]. Deposition of immune system complexes in the lungs and kidney can result in TRALI [23] and acute renal injury or failure respectively [24]. While there is not much literature studying renal complications after transfusion in spine surgery populations, they have been extensively studied in the field of cardiac surgery. A study by Khan et al. showed that patients receiving two or more pRBC transfusions had 2.3 times increased risk of doubling their baseline serum creatinine when compared to patients who did not receive a pRBC transfusion ($p = 0.01$) [25]. Khan et al. concluded that pRBC transfusion was an independent risk factor for renal injury.

As our population ages, there will be an increasing need for spinal surgery along with an increasing burden of complicating comorbidities [26]. Surgeons must determine ways to optimize patient outcomes and reduce the associated risks of spine surgery. Preoperative optimization is a collaborative effort by the surgeon, anesthesiologist, and any additional specialists to ensure patients can safely survive surgery and have an acceptable outcomes [27–30]. Preoperative anemia has been associated with worse outcomes after spine surgery [10,11,31]. Therefore, it is critical to implement strategies to minimize these complications. The current recommendations by the American College of Cardiology is that patients without cardiovascular disease with a hematocrit less than 21% and patients with cardiovascular disease with a hematocrit less than 24% [2] should receive a pRBC transfusion. The rationale behind transfusing at these thresholds is to ensure sufficient oxygen delivery to end organs along with reduction of cardiac oxygen requirements and risk of cardiac ischemia. However, given the complications that can result from transfusion, it is important to note that anemia in many patients can be managed with alternative interventions including intravenous iron supplementation and erythropoietin stimulating agents [15,16]. This is relevant to our study as we identified a population of

patients slightly beyond the inflection point who had both low hematocrits and an increased risk of postoperative complications after preoperative transfusion. Identification of this inflection point for increased postoperative complications secondary to low hematocrit and preoperative transfusion further emphasizes that long-term hematocrit optimization strategies that occur over the course of weeks to months prior to operation are likely preferable to acute corrections. These long-term strategies such as iron supplementation are not only safer but also allow for maximization of improvement prior to relying on pRBC transfusions.

4.1. Limitations

There are several limitations to this multicenter retrospective study based upon the NSQIP database. The NSQIP database represents only specifically selected larger hospitals throughout the nation. In addition, NSQIP is both an inpatient and outpatient surgical database which could lead to some heterogeneity within our sample. Specifically, outpatient surgeries may have additional time for preoperative optimization whereas inpatient/transfer surgeries may be more urgent and without time for optimization. For this reason, implementation of additional strategies to mitigate anemia is more challenging in the inpatient sample. Further analysis can stratify and compare outcomes in inpatient surgery versus outpatient surgery.

Additionally, our study is limited by the variables that are and are not collected by NSQIP. Specifically, NSQIP also does not provide information on some important preoperative comorbidities including atelectasis and the prevalence of cardiovascular disease, which is important when deciding to perform a pRBC transfusion. Certain preoperative medical considerations that could impact hematocrit and postoperative complications including whether patients received chemotherapy were not collected consistently by NSQIP throughout the study period, so we could not incorporate these factors into our analysis. Additionally, the preoperative comorbidities noted in this database simply indicate the presence of disease not the severity, which limited out ability to stratify at risk patients with more granularity. Furthermore, we acknowledge that while excluding patients who received postoperative transfusions mitigated the confounding effect of postoperative transfusions, it did exclude the subset of patients who receive both pre and postoperative transfusions from our analysis. Thus, our conclusions may not apply to this patient population. Finally, NSQIP does not report more than one preoperative hematocrit nor the post-transfusion "new baseline hematocrit," both of which may have helped elucidate if the observed inflection point is caused by more aggressive preoperative transfusion versus more limited preoperative transfusion (i.e., "new baseline" hematocrit).

4.2. Conclusion

This is the first study to analyze the effect of preoperative pRBC transfusion and its postoperative complications in the spine surgery population. In this data set, we identified an inflection point where preoperative pRBC transfusion is protective against postoperative complications when a patient's preoperative hematocrit is less than 20% and increases postoperative complications when the preoperative hematocrit is higher than 20%. Our results show that preoperative pRBC transfusions in those with a hematocrit higher than 20% results in an increased in length of stay, ventilator dependency greater than 48 h, pneumonia, and 30-day mortality. Preoperative pRBC transfusions may result in a similar increase in postoperative complications as postoperative pRBC transfusions, as described previously in the literature. This study found that preoperative pRBC transfusion in patients with a hematocrit of 20% or higher had a 5.01 times risk of one or more postoperative complications as compared to those who received a pRBC transfusion with hematocrit less than 20%. Further granular institutional and randomized controlled trial studies need to be conducted to determine the appropriate preoperative hematocrit level in order to optimize spinal surgery outcomes and minimize postoperative complications, especially in those with cardiovascular disease and preoperative anemia.

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CRediT authorship contribution statement

Vikram A. Mehta: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Project administration. **Florence Van Belleghem:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Meghan Price:** Data curation, Writing - review & editing, Visualization. **Matthew Jaykel:** Writing - review & editing. **Luis Ramirez:** Data curation, Formal analysis. **Jessica Goodwin:** Data curation, Visualization. **Timothy Y. Wang:** Writing - review & editing. **Melissa M. Erickson:** Writing - review & editing. **Khoi D. Than:** Writing - review & editing. **Dhanesh K. Gupta:** Writing - review & editing. **Muhammad M. Abd-El-Barr:** Writing - review & editing, Supervision, Project administration. **Isaac O. Karikari:** Writing - review & editing, Supervision, Project administration. **Christopher I. Shaffrey:** Writing - review & editing, Supervision. **C. Rory Goodwin:** Writing - review & editing, Supervision, Project administration.

Declaration of Competing Interest

The authors report no declarations of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.clineuro.2020.106322.

References

[1] B.A. Basques, et al., Risk factors for blood transfusion with primary posterior lumbar fusion, Spine 40 (22) (2015) 1792–1797.

[2] J.L. Carson, et al., Clinical practice guidelines from the AABB: red blood cell transfusion thresholds and storage, JAMA 316 (19) (2016) 2025–2035.

[3] T.E. Purvis, et al., Effect of liberal blood transfusion on clinical outcomes and cost in spine surgery patients, Spine J. 17 (9) (2017) 1255–1263.
[4] A. Aoude, et al., Incidence, predictors, and postoperative complications of blood transfusion in thoracic and lumbar fusion surgery: an analysis of 13,695 patients from the american college of surgeons national surgical quality improvement program database, Global Spine J. 6 (8) (2016) 756–764.
[5] C.W. Blackburn, et al., Clinical outcomes associated with allogeneic red blood cell transfusions in spinal surgery: a systematic review, Global Spine J. 9 (4) (2019) 434–445.
[6] C. Fisahn, et al., Association between allogeneic blood transfusion and postoperative infection in major spine surgery, Clin. Spine Surg. 30 (7) (2017) E988–e992.
[7] Y.K. He, H.Z. Li, H.D. Lu, Is blood transfusion associated with an increased risk of infection among spine surgery patients?: a meta-analysis, Medicine (Baltimore) 98 (28) (2019) e16287.
[8] S.J. Janssen, et al., Allogeneic blood transfusions and postoperative infections after lumbar spine surgery, Spine J. 15 (5) (2015) 901–909.
[9] S. Kato, et al., Risk of infectious complications associated with blood transfusion in elective spinal surgery-a propensity score matched analysis, Spine J. 16 (1) (2016) 55–60.
[10] A. Seicean, et al., The effect of blood transfusion on short-term, perioperative outcomes in elective spine surgery, J. Clin. Neurosci. 21 (9) (2014) 1579–1585.
[11] K. Phan, et al., Effect of preoperative Anemia on the outcomes of anterior cervical discectomy and fusion, Global Spine J. 7 (5) (2017) 441–447.
[12] R. Khanna, et al., Impact of Anemia and transfusion on readmission and length of stay after spinal surgery: a single-center study of 1187 operations, Clin. Spine Surg. 30 (10) (2017) E1338–e1342.
[13] A. Aoude, et al., Prevalence and complications of postoperative transfusion for cervical fusion procedures in spine surgery: an analysis of 11,588 patients from the american college of surgeons national surgical quality improvement program database, Asian Spine J. 11 (6) (2017) 880–891.
[14] N.R. Guinn, et al., How do we develop and implement a preoperative anemia clinic designed to improve perioperative outcomes and reduce cost? Transfusion 56 (2) (2016) 297–303.
[15] H. Gombotz, Patient blood management: a patient-orientated approach to blood replacement with the goal of reducing Anemia, blood loss and the need for blood transfusion in elective surgery, Transfus. Med. Hemother. 39 (2) (2012) 67–72.
[16] D. Enko, et al., The impact of an algorithm-guided management of preoperative anemia in perioperative hemoglobin level and transfusion of major orthopedic surgery patients, Anemia 2013 (2013) 641876.
[17] C, K, ACS NSQIP conference and semiannular report overview, ACS NSQIP National Conference (2009).
[18] A.A. Elsamadicy, et al., Independent association between type of intra-operative blood transfusion and post-operative delirium after complex spinal fusion for adult deformity correction, Spine (2019).
[19] A.A. Elsamadicy, et al., Association of intraoperative blood transfusions on postoperative complications, 30-Day readmission rates, and 1-Year patient-reported outcomes, Spine 42 (8) (2017) 610–615.
[20] N. Blumberg, J.M. Heal, Transfusion and recipient immune function, Arch. Pathol. Lab. Med. 113 (3) (1989) 246–253.
[21] E.A. Hod, et al., Transfusion of red blood cells after prolonged storage produces harmful effects that are mediated by iron and inflammation, Blood 115 (21) (2010) 4284–4292.
[22] R. Goel, et al., Association of perioperative red blood cell transfusions with venous thromboembolism in a north american registry, JAMA Surg. 153 (9) (2018) 826–833.
[23] A. Kotera, et al., [A case of transfusion-related acute lung injury following platelet transfusion during the cervical supine surgery], Masui 62 (10) (2013) 1245–1249.
[24] K. Van Avondt, E. Nur, S. Zeerleder, Mechanisms of haemolysis-induced kidney injury, Nat. Rev. Nephrol. 15 (11) (2019) 671–692.
[25] U.A. Khan, et al., Blood transfusions are associated with urinary biomarkers of kidney injury in cardiac surgery, J. Thorac. Cardiovasc. Surg. 148 (2) (2014) 726–732.
[26] C.P. Ames, et al., Adult spinal deformity: epidemiology, health impact, evaluation, and management, Spine Deform. 4 (4) (2016) 310–322.
[27] I.O. Karikari, L.N. Metz, Preventing pseudoarthrosis and proximal junctional kyphosis: how to deal with the osteoporotic spine, Neurosurg. Clin. N. Am. 29 (3) (2018) 365–374.
[28] J.W. Brallier, S. Deiner, The elderly spine surgery patient: pre- and intraoperative management of drug therapy, Drugs Aging 32 (8) (2015) 601–609.
[29] T.K. Kuprys, et al., Preoperative assessment of bone quality in spine deformity surgery: correlation with clinical practice and published recommendations, Spine 44 (12) (2019) E735–e741.
[30] G.E. Stoker, et al., Preoperative vitamin D status of adults undergoing surgical spinal fusion, Spine 38 (6) (2013) 507–515.
[31] K. Phan, et al., Impact of preoperative Anemia on outcomes in adults undergoing elective posterior cervical fusion, Global Spine J. 7 (8) (2017) 787–793.