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ORIGINAL ARTICLE

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Cost and utilization of blood transfusion associated with spinal surgeries in the United States

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Abstract The purpose of this study was to examine factors associated with the utilization and cost of blood transfusion during and post-spinal fusion surgery. A retrospective, observational study of 42,029 inpatients undergoing spinal fusion surgery in United States hospitals participating in the Perspective™ Comparative Database for inpatient use was conducted. Descriptive analysis, logistic regression, and ordinary least squares (OLS) regression were used to describe the factors associated with the use and cost of allogeneic blood transfusion (ABT). Hospitalization costs were $18,690 (SD = 14,159) per patient, erythropoietin costs were $85.25 (SD = 3,691.66) per patient, and topical sealant costs were $414.34 (SD = 1,020.06) per patient. Sub-analysis of ABT restricted to users revealed ABT costs ranged from $312.24 (SD = 543.35) per patient with whole blood to $2,520 (SD = 3,033.49) per patient with fresh frozen plasma. Patients that received hypotensive anesthesia (OR,1.61; 95% CI, 1.47–1.77), a volume expander (OR,1.95; 95% CI, 1.75–2.18), autologous blood (OR, 2.04; 95% CI, 1.71–2.42), or an erythropoietic agent (OR = 1.64; 95% CI, 1.27–2.12) had a higher risk of ABT. Patients that received cell salvage had a lower risk of transfusion (OR = 0.40; 95% CI, 0.32–0.50). Most blood avoidance techniques have low utilization or do not reduce the burden of transfusion associated with spinal fusion.

Keywords Spinal fusion surgery · Burden of illness · Blood transfusion · Cost

Introduction

In general surgery and in spinal surgery, allogeneic blood transfusions (ABT) have been related to increased post-operative complications [12, 13, 37, 39]. As such, reduction in ABT is a high priority in spinal surgery. Recently, techniques to reduce the need for ABT during spinal surgery have surfaced in the orthopedic surgery literature.

Understanding the risk factors and costs associated with ABT can help with the discovery of new cost-effective methods to reduce its burden. Several possible methods of reducing blood loss and the need for ABT associated with spinal fusion surgery currently exist. These include use of autologous pre-donation of blood [7, 11, 16, 26, 31, 32, 40], blood dilution techniques [4, 10, 14, 15, 19, 22], erythropoietin [24], use of anti-fibrinolytics [1, 8, 9, 20, 24, 27, 30, 34, 35, 41], and use of cell salvage [6, 33]. Prior research on techniques used to reduce the need for ABT has previously been conducted in single-site hospitals or in a small number of patients enrolled in a clinical trial, which does not accurately provide a clear picture of the utilization and cost burden associated with it. The literature has not been able to provide an illustration of the current state of the use and cost of ABT in the US population.

Due to the limited research on the current use of these techniques, we conducted a retrospective, observational study to determine the use and cost associated with ABT using a national inpatient database.

Materials and methods

Study design

A retrospective, observational study design was used to assess the blood service cost and utilization associated with ABT during and post-spinal surgery. This enabled us to assess the current use of key transfusion reduction techniques including use of pharmacological interventions, erythropoietin, cell saver, autologous blood, and blood dilution techniques in the US.

Data and patient selection

Patients were selected from United States hospitals participating in the Perspective Comparative Database (PCD), an inpatient database developed and maintained by Premier Inc., Charlotte, NC for the purposes of quality and utilization benchmarking. The Perspective database contains data at the individual patient level including data consistent with the standard hospital discharge file including demographic and disease state information as well as information on all billed services including date-specific logs of medications, laboratory, diagnostics, and therapeutic services on a total of three billion patient daily service records and adding approximately five million hospital discharge records per year. PCD is the largest inpatient database in the United States, representing data from over 700 US hospitals.

The sample included a total of 42,029 inpatient discharges indicating spinal fusion surgery by principal International Classification of Diseases, Ninth Edition, Clinical Modification (ICD-9-CM) procedure codes from 268 hospitals between July 1, 2003 and June 30, 2004. Patient discharges were then grouped by ICD-9-CM codes into the following groups: CERV (cervical fusion, ICD-9: 81.01–81.03), ANTLUMBAR (anterior lumbar fusion, ICD-9: 81.04 and 81.06), POSTLUMBAR (posterior lumbar fusion, ICD-9: 81.05, 81.07 and 81.08), REFUSCERV (cervical refusion, ICD-9: 81.31–81.33), REFUSANTLUMBAR (anterior lumbar refusion, ICD-9: 81.34 and 81.36), REFUSPOSTLUMBAR (posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38), and 360DEGR (360 degree fusion, ICD-9: 81.61).

Outcome measurement

The outcome measures included use of ABT and total cost of blood transfusion. Total cost of blood transfusion was measured using the total blood bank departmental cost recorded in each patient record. Total cost represents the actual cost to treat the patient incurred by the hospital, and does not represent billed charges. It is the sum of direct costs and overhead costs. Direct costs represent items that are used specifically by the patient such as physician costs, treatment costs, food, etc. These costs are itemized and recorded in the hospital accounting system by department and then by patient. Overhead costs are costs associated with hospital functionality such as staff costs (including nursing, administrative and management personnel), electricity, depreciation of medial equipment, etc. These costs are usually added to the patient's record in the hospital accounting system as a standard cost also by department.

The use of ABT was measured through any use of allogeneic blood transfusion at any time during hospitalization in patient records. Classification of hypotensive anesthesia was conducted by the staff clinical pharmacist at Premier Inc. who reviewed the use and doses of anesthetics by the sample and determined whether their use was probably for hypotensive anesthesia or not.

Statistical analysis

Descriptive analyses were conducted to examine patient characteristics, blood management, and costs associated with surgical procedures. Patient characteristics included age, gender, race, primary payer, admission source, admission type, discharge status, attending physician specialty (not physician conducting procedure, but rather care coordinating physician during hospital stay), APR-DRG severity level (severity scale ranging from level 1—least severe to level 4—most severe, based on predicted spending due to patients comorbidities), consulting physician specialty, geographic region, and living status (urban or rural). Blood management included use of both pharmacological and non-pharmacological techniques. Pharmacological products included any use of volume expanders, erythropoietic agents, hypotensive anesthesia, or anti-fibrinolytics.

The multivariate analysis included logistic regression for identifying factors predicting any use and OLS regression to identify factors predicting costs. Logistic regression was used to predict any ABT any time during hospitalization while controlling for potential risk factors including surgery type, age, gender, primary payer, admit type, attending physician, APR-DRG severity level, discharge status, geographic region, teaching status, bed size, population served, binary variables for any use of hypotensive anesthesia, volume expander, topical sealant, erythropoietic agents, cell salvage, or autologous transfusion. The OLS regression was used to predict the total cost of blood transfusion controlling for

key covariates, including all variables from the logistic model except any use of cell salvage and any use of autologous transfusion.

Results

Patient characteristics

Patient characteristics are illustrated in Table 1. The sample consisted of mostly white patients (75.21%). Cervical fusion was the most common type of spinal surgery (18,389), followed by posterior lumbar fusion (17,058). The other groups had less than 4,000 individuals each. The median age ranged from 46 to 56 years across the groups. Medicare represented 26.54% of the sample, while those with managed care plans accounted for 40.93%. An elective surgery admission was the most common type of surgery admission (85.45%). The POSTLUMBAR group had a much higher percentage of individuals discharged to skilled nursing homes (7.17%) compared to the other groups. Attending physicians were mostly either orthopedics (40.43%) or other types of surgery specialties (52.35%). Only 1.16% of the sample included patients in the fourth and most severe level of the APR-DRG severity scale.

Blood avoidance techniques

Almost one-third of all patients received hypotensive anesthesia on the day of surgery (Table 2). Only about 3% of patients received volume expanders in the CERV and REFUSCERV groups compared to almost 26% in the REFUSANTLUMBAR group, and between 9 and 17% in the other groups. Anti-fibrinolytics were used by less than 1% of patients in any group. Topical sealants had high utilization rates (59% to almost 80%). Erythropoietic agents were used by almost 9% of the ANT LUMBAR group; however, they were not commonly used in any of the other groups. Only about 1–3% of patients in most groups received autologous blood, while almost 7% of those in the POST LUMBAR group used autologous blood. A higher percentage of patients used cell saver blood than autologous blood in all groups. Almost 18% of patients in the REFUS ANTLUMBAR group used a cell saver while the range for the other groups was from 1.4 to 12.9%. ABTs were required by 17.8 to 19.8% of patients in four groups while three other groups also had between 2 and 8% of patients requiring transfusion.

Descriptive cost analysis

Cost analyses are shown in Table 3. Average length of stay across the seven spinal surgery groups was 4.32 days per patient (SD = 4.24). Cost of hospitalization per patient was $12,090 (SD = 9,667) in the CERV group, $28,589 (SD = 19,108) in the ANTLUMBAR group, $23,095 (SD = 14,038) in the POSTLUMBAR group, $14,914 (SD = 10,774) in the REFUSCERV group, $28,818 (SD = 17,903) in the REFUSANTLUMBAR group, $24,099 (SD = 16,339) in the REFUSPOSTLUMBAR group, and $23,289 (SD = 10,570) in the 360DEGR group. The use of topical sealants was associated with the highest cost compared to all of the other blood avoidance techniques at $414.37 (SD = 1,020.06) per patient followed by erythropoietic at $85.25 (SD = 3,691.66) per patient. Total autologous blood transfusion costs ranged from $3.99 (SD = 40.26) per patient for red blood cells to $1.87 (SD = 35.81) per patient for whole blood, and the cell salvage cost per patient was $12.67 (SD = 88.49). Total allogeneic blood cost per patient averaged $33.13 (SD = 728.35) for fresh frozen plasma to $0.38 (SD = 10.40) for whole blood. Allogeneic red blood cell transfusion costs per patient in the CERV group was $5.67 (SD = 128.53), in the ANTLUMBAR group was $60.75 (SD = 324.33), in the POSTLUMBAR group was $41.84 (SD = 226.69), in the REFUSCERV group was $6.12 (SD = 69.08), in the REFUSANTLUMBAR group was $41.20 (SD = 151.06), in the REFUSPOSTLUMBAR group was $60.75 (SD = 340.44), and in the 360DEGR group was $19.76 (SD = 105.17).

Sub-analyses were carried out to examine costs of blood products among patients who were users of blood products, accounting for 10.7% of the total population studied (Table 4). ABT users had costs ranging from $312.24 (SD = 543.35) per patient with whole blood to $2,520.41 (SD = 3,033.49) per patient with fresh frozen plasma. Average red blood cell costs per patient in patients that used red blood cells were $894.78 (SD = 1,982.31) in the CERV group, $1,123.77 (SD = 2,118.32) in the ANTLUMBAR group, $525.98 (1,368.06) in the POSTLUMBAR group, $1,983.98 (SD = 4,079.22) in the REFUSCERV group, $817.01 (SD = 967.83) in the REFUSANTLUMBAR group, $631.55 (SD = 1,011.83) in the REFUSPOSTLUMBAR group and $389.16 (SD = 377.11) in the 360DEGR group.

Use of allogeneic blood transfusion

The logistic regression results (Table 5) revealed that all spine groups except the REFUSCERV group had a significantly greater risk of ABT compared to the CERV group. Males had a lower risk of being transfused compared to females (OR = 0.62, 95% CI, 0.57–0.68). African Americans had a greater risk than whites (OR = 1.50, 95% CI, 1.30–1.74) while other races did not. Patients with Medicaid were no different than those with Medicare, while those with all other forms of insurance had a

Table 1 Patient characteristics by treatment segments

Characteristics	CERV	ANT LUMBAR	POST LUMBAR	REFUS CERV	REFUSANT LUMBAR	REFUSPOST LUMBAR	360DEGR	Total
Sample (#)	18,389	3,427	17,058	468	143	1,030	1,514	42,029
Projected[a] (#)	115,392	26,239	113,619	3,071	1,003	6,676	8,523	274,523
Age								
Median (years)	50	46	56	48	49	54	53	52
Interquartile range (years)	43–59	38–55	43–68	41–56	40–58	44–65	42–64	42–63
Sex (%)								
Female	50.17	54.6	57.42	53.42	51.75	59.03	59.84	54.08
Male	49.83	45.4	42.58	46.58	48.25	40.97	40.16	45.92
Race (%)								
White	74.63	73.27	76.52	77.78	74.13	79.9	68.16	75.21
African American	8.86	6.36	7.32	7.05	6.99	6.12	4.1	7.77
Other non-white	16.51	20.37	16.16	15.17	18.88	13.98	27.74	17.02
Insurance (%)								
Commercial	13.12	13.39	10.57	12.82	10.49	8.45	16.38	12.10
Managed care/HMO/PPO	46.26	43.16	35.47	39.96	41.96	34.27	37.45	40.93
Medicaid	4.23	5.84	4.19	5.77	5.59	4.47	4.29	4.37
Medicare	21.22	14.88	33.92	20.94	21.68	35.34	30.65	26.54
Other	15.17	22.73	15.85	20.51	20.28	17.47	11.23	16.06
Type of admission (%)								
Elective	83.2	87.25	86.41	89.32	96.5	89.51	92.93	85.45
Emergency	7.24	6.62	4.83	3.42	0.7	2.14	1.32	5.81
Other	9.56	6.13	8.76	7.26	2.8	8.35	5.75	8.74
Discharge status (%)								
Discharged/transferred to home	93.34	86.78	80.26	93.16	88.11	82.72	87.98	87.02
Expired	0.23	0.2	0.23	0.43	0.00	0.1	0.07	0.22
Discharged/transfered to SNF	1.7	3.36	7.17	1.92	4.2	6.7	6.61	4.37
Other	4.73	9.66	12.34	4.49	7.69	10.48	5.34	8.39
Attending physician (%)								
Orthopedics	23.65	62.42	52.59	39.53	73.43	67.09	36.59	40.43
Surgery	67.43	31.72	41.92	54.5	22.37	27.47	52.57	52.35
Other physicians	8.92	5.86	5.49	5.97	4.2	5.44	10.84	7.22
APR-DRG severity (%)								
Level 1	74.13	41.44	51.27	68.38	44.06	50.58	62.02	61.01
Level 2	21.32	33.97	36.76	26.07	44.76	40.19	31.11	29.57
Level 3	3.61	22.15	10.75	4.27	11.19	8.06	6.47	8.27
Level 4	0.95	2.45	1.21	1.28	0.00	1.17	0.4	1.16
Region								
Northeast	9.39	9.34	8.61	11.54	16.78	10	1.65	8.85
Midwest	18.48	22.5	19.79	16.03	25.87	14.76	19.62	19.28
South	55.85	44.41	54.88	47.22	37.06	53.2	66.05	54.66
West	16.29	23.75	16.73	25.21	20.28	22.04	12.68	17.20
Teaching/non-teaching (%)								
Non-teaching	55.75	61.66	57.98	62.39	59.44	62.14	64.33	57.69
Teaching	44.25	38.34	42.02	37.61	40.56	37.86	35.67	42.31
Population served (%)								
Urban	87.33	90.25	87.77	89.74	93.01	89.22	77.74	84.19
Rural	12.67	9.75	12.23	10.26	6.99	10.78	22.26	15.81

CERV cervical fusion, ICD-9: 81.01–81.03; *ANTLUMBAR* anterior lumbar fusion, ICD-9: 81.04 and 81.06; *POSTLUMBAR* posterior lumbar fusion, CD-9: 81.05, 81.07 and 81.08; *REFUSCERV* cervical refusion, ICD-9: 81.31–81.33; *REFUSANTLUMBAR* anterior lumbar refusion, ICD-9: 81.34 and 81.36; *REFUSPOSTLUMBAR* posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38; *360DEGR* 360° fusion, ICD-9: 81.61

[a]Projected counts are calculated through Premier Inc.'s projection methodology that is conducted annually to benchmark the Perspective Comparative Database off the projections of the National Hospital Discharge Survey conducted by the National Center for Health Statistics of the Center for Disease Control and Prevention

lower risk compared to those with Medicare, including those with commercial insurance (OR = 0.61, 95% CI, 0.51–0.73), managed care (OR = 0.83, 95% CI, 0.75–0.92), and other forms of payment (OR = 0.54, 95% CI, 0.47–0.63).Those with an elective type of surgery admission had a lower risk of ABT compared to non-elective surgery admission patients (OR = 0.86, 95% CI, 0.76–0.97). Those treated by neurosurgeons had a lower risk of ABT compared to those treated by orthopedic specialists (OR = 0.84, 95% CI, 0.77–0.93). Patients in

Table 2 Pharmacological and non-pharmacological interventions

Interventions	CERV	ANT LUMBAR	POST LUMBAR	REFUS CERV	REFUSANT LUMBAR	REFUSPOST LUMBAR	360DEGR	Total
Sample (#)	18,389	3,427	17,058	468	143	1,030	1,514	42,029
Projected[a] (#)	115,392	26,239	113,619	3,071	1,003	6,676	8,523	274,523
Autologous transfusion (%)	**0.15**	**4.45**	**6.27**	**0.55**	**4.42**	**3.65**	**1.34**	**3.23**
Red blood cells	**0.08**	**2.40**	**4.23**	**0.55**	**0.88**	**2.14**	**1.10**	**2.12**
Whole Blood	0.07	2.05	2.04	0.00	3.54	1.51	0.24	1.11
Cell salvage (%)	**0.40**	**12.86**	**8.76**	**1.38**	**17.70**	**8.82**	**3.07**	**5.31**
Allogeneic transfusion (%)	**2.13**	**17.31**	**17.79**	**4.96**	**18.58**	**19.77**	**8.12**	**10.71**
Red blood cells	**1.57**	**13.59**	**15.33**	**3.03**	**13.27**	**16.75**	**6.93**	**8.98**
Whole blood	0.01	0.46	0.44	0.00	0.00	0.63	0.32	0.25
Fresh frozen plasma (FFP)	0.34	2.52	1.25	1.93	4.42	1.76	0.39	0.97
Platelets	0.12	0.43	0.30	0.00	0.88	0.25	0.16	0.23
Cryoprecipitate	0.09	0.31	0.46	0.00	0.00	0.38	0.32	0.28
Hypotensive anesthesia (%)	**29.76**	**31.95**	**29.70**	**35.04**	**33.57**	**29.81**	**31.31**	**30.05**
Volume expanders (%)	**1.96**	**11.91**	**13.69**	**2.99**	**25.87**	**17.28**	**13.54**	**8.42**
Anti-fibrinolytics (%)	**0.03**	**0.38**	**0.53**	**0.00**	**0.70**	**0.49**	**0.07**	**0.28**
Topical sealants (%)	**66.00**	**59.41**	**69.23**	**69.87**	**67.13**	**66.80**	**79.59**	**67.33**
Erythropoietic agents (%)	**1.44**	**8.81**	**2.54**	**1.07**	**0.70**	**3.69**	**0.99**	**2.52**

CERV cervical fusion, ICD-9: 81.01–81.03; *ANTLUMBAR* anterior lumbar fusion, ICD-9: 81.04 and 81.06; *POSTLUMBAR* posterior lumbar fusion, CD-9: 81.05, 81.07 and 81.08; *REFUSCERV* cervical refusion, ICD-9: 81.31–81.33; *REFUSANTLUMBAR* anterior lumbar refusion, ICD-9: 81.34 and 81.36; *REFUSPOSTLUMBAR* posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38; *360DEGR* 360° fusion, ICD-9: 81.61

[a]Projected counts are calculated through Premier Inc.'s projection methodology that is conducted annually to benchmark the Perspective Comparative Database off the projections of the National Hospital Discharge Survey conducted by the National Center for Health Statistics of the Center for Disease Control and Prevention

the most severe level of the DRG severity level (level 4) (OR = 12.15, 95% CI, 9.52–15.50) had a higher risk of ABT compared to those in the lowest level (level 1). Discharge status was highly associated with ABT. Patients discharged to a skilled nursing facility (OR = 1.85, 95% CI, 1.60–2.13) and transferred or expired (OR = 1.58, 95% CI, 1.34–1.87) were more likely to have had ABT compared to those discharged to their home. Patients that received hypotensive anesthesia (OR = 1.61, 95% CI, 1.47–1.77), volume expanders (OR = 1.95, 95% CI, 1.75–2.18), erythropoietic agents (OR = 1.64, 95% CI, 1.27–2.12), or autologous blood (OR = 2.04, 95% CI, 1.71–2.42) had a higher risk of ABT. Patients that received cell salvage had a lower risk of ABT (OR = 0.40, 95% CI, 0.32–0.50).

Total cost of blood transfusion

The regression analysis predicting total blood bank costs (Table 6) indicated that all spine groups, except for the REFUSCERV group, had higher costs associated with transfusion compared to the CERV group. Males had lower costs associated with transfusion than females (-$29.48, $P < 0.01$). Patients with Medicaid (-$52.42, $P < 0.01$), those with commercial insurance (-$32.24, $P = 0.0035$), and other forms of payment (-$26.10, $P < 0.01$) also had less costs associated with transfusion compared to patients with Medicare, while those with managed care did not. Those with an elective type of surgery admission had a higher cost associated with transfusion than non-elective patients ($31.05, $P < 0.01$). Those treated by neurosurgeons had a lower cost (-$58.68) than those with orthopedic specialists ($P < 0.0001$). Level of severity, measured through the APR-DRG, indicated that the most severe level of patients (level 4) had ($1,043.33, $P < 0.01$) higher costs associated with transfusion services than the least severe (level 1) patients. Patients discharged to a skilled nursing facility had ($91.33, $P < 0.01$) higher blood transfusion costs than those discharged to their home. Patients that were transferred or that expired had ($177.75, $P < 0.01$) higher blood transfusion costs than those discharged home. Patients that received hypotensive anesthesia on the day of surgery had ($64.74, $P < 0.01$) higher transfusion costs. Patients that received a volume expander had ($191.89, $P < 0.01$) higher transfusion costs. Patients that received topical sealants had (-$25.17, $P < 0.01$) lower transfusion costs. Patients that received an erythropoietic agent had ($278.51, $P < 0.01$) higher transfusion costs.

Discussion

Findings have revealed the burden of blood transfusion to patients that have undergone spinal surgery in the US to be high. This study was intended to identify factors

Table 3 Cost analysis

	CERV 18,389 Mean cost (SD)	ANTLUMBAR 3,427 Mean cost (SD)	POSTLUMBAR 17,058 Mean cost (SD)	REFUS CERV 468 Mean cost (SD)	REFUSANT LUMBAR 143 Mean cost (SD)	REFUSPOST LUMBAR 1,030 Mean cost (SD)	360DEGR 1,514 Mean cost (SD)	Total 42,029 Mean cost (SD)
Length of stay	2.47 (3.95)	5.52 (6.95)	4.72 (3.59)	3.15 (5.30)	5.52 (4.42)	4.60 (3.15)	4.24 (2.32)	4.32 (4.24)
Total cost of hospitalization	12,089.92 (9,666.67)	28,588.53 (19,107.76)	23,095.18 (14,037.79)	14,914.27 (10,773.60)	28,817.50 (17,902.68)	24,099.22 (16,339.12)	23,288.85 (10,569.72)	18,690.23 (14,159.47)
Cost of hypotensive anesthesia	35.78 (211.39)	83.87 (563.53)	40.58 (207.31)	112.11 (595.33)	90.11 (524.12)	59.84 (379.65)	57.61 (268.92)	44.06 (272.24)
Cost of volume expanders	2.96 (40.19)	25.86 (242.68)	20.94 (113.45)	3.12 (21.27)	49.98 (149.82)	26.78 (110.77)	17.18 (83.56)	13.38 (107.04)
Cost of anti-fibrinolytics	0.03 (3.17)	0.18 (4.72)	0.17 (8.78)	0.00 (0.00)	1.21 (14.52)	0.14 (2.37)	0.13 (5.23)	0.11 (6.27)
Cost of erythropoietic	55.87 (2,865.91)	420.09 (10,115.82)	61.52 (2,028.01)	3.14 (40.47)	0.92 (11.00)	49.83 (729.41)	9.05 (157.58)	85.25) (3,691.66
Cost of topical sealants	304.78 (548.93)	363.37 (887.08)	526.31 (1,260.89)	369.34 (731.38)	410.25 (683.74)	441.93 (949.76)	595.39 (2,094.47)	414.37 (1,020.06)
Autologous blood								
Red blood cells	0.12 (5.95)	4.38 (49.83)	8.48 (57.61)	0.69 (11.92)	0.89 (10.68)	3.67 (35.89)	1.13 (14.01)	3.99 (40.26)
Whole blood	0.08 (5.98)	5.89 (69.94)	3.19 (45.57)	0.00 (0.00)	0.42 (4.98)	2.27 (29.78)	0.08 (1.79)	1.87 (35.81)
Cell salvage	0.70 (14.15)	31.25 (125.99)	21.57 (118.25)	1.76 (19.40)	46.07 (152.14)	22.38 (115.02)	9.45 (81.08)	12.67 (88.49)
Allogeneic blood								
Red blood cells	5.67 (128.53)	60.75 (324.33)	41.84 (226.69)	6.12 (69.08)	41.20 (151.06)	60.75 (340.44)	19.76 (105.17)	26.82 (201.10)
Whole blood	0.00 (0.00)	0.93 (19.02)	0.68 (13.35)	0.00 (0.00)	0.00 (0.00)	0.83 (15.34)	0.17 (3.28)	0.38 (10.40)
FFPs	7.32 (331.44)	119.46 (1,264.53)	44.59 (906.12)	44.99 (952.79)	104.93 (727.69)	41.10 (465.50)	6.26 (137.08)	33.13 (728.35)
Platelets	4.05 (291.01)	26.93 (589.69)	16.87 (583.93)	0.00 (0.00)	46.30 (553.69)	8.01 (181.69)	1.08 (33.50)	11.21 (453.58)
Cryoprecipitate	1.79 (149.81)	34.60 (948.49)	7.45 (344.01)	0.00 (0.00)	0.00 (0.00)	0.36 (6.72)	2.31 (81.51)	6.72 (362.63)

CERV cervical fusion, ICD-9: 81.01–81.03; *ANTLUMBAR* anterior lumbar fusion, ICD-9: 81.04 and 81.06; *POSTLUMBAR* posterior lumbar fusion, CD-9: 81.05, 81.07 and 81.08; *REFUSCERV* cervical refusion, ICD-9: 81.31–81.33; *REFUSANTLUMBAR* anterior lumbar refusion, ICD-9: 81.34 and 81.36; *REFUSPOSTLUMBAR* posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38; *360DEGR* 360° fusion, ICD-9: 81.61

Table 4 Descriptive cost sub-analysis: ABT cost by patients that used products

	CERV # Mean (SD)	ANTLUMBAR # Mean (SD)	POSTLUMBAR # Mean (SD)	REFUSCERV # Mean (SD)	REFUSANTLUMBAR # Mean (SD)	REFUSPOST LUMBAR # Mean (SD)	360 DEGR # Mean (SD)	Total # Mean (SD)
Allogeneic transfusion								
Red blood cells	173	318	1,899	6	14	120	86	2,616
	894.78	1,123.77	525.98	1,983.98	817.01	631.55	389.16	909.46
	(1,982.31)	(2,118.32)	(1,368.06)	(4,079.22)	(967.83)	(1,011.83)	(377.11)	(1,700.67)
Whole blood	1	12	58	0	0	4	4	79
	0.39	1,340.76	463.86	0.00	0.00	213.95	166.70	312.24
	(0.00)	(2,899.94)	(554.08)	(0.00)	(0.00)	(141.05)	(208.41)	(543.35)
FFPs	39	60	149	2	4	13	4	271
	1,726.85	3,411.48	2,552.53	5,264.18	1,875.63	1,628.29	1,183.93	2,520.41
	(3,199.26)	(3,403.65)	(4,141.79)	(7,127.45)	(1,306.42)	(1,345.08)	(710.83)	(3,033.49)
Platelets	14	11	31	0	1	2	2	61
	2,657.57	4,194.37	4,641.99	0.00	3,310.56	2,062.38	408.37	2,467.89
	(4,727.27)	(3,239.37)	(5,122.65)	(0.00)	(0.00)	(43.49)	(302.51)	(1,919.33)
Cryoprecipitate	8	8	59	0	0	3	2	80
	2,062.18	7,411.59	1,024.53	0.00	0.00	62.10	436.98	1,571.05
	(3,143.46)	(6,887.99)	(2,685.14)	(0.00)	(0.00)	(6.23)	(764.07)	(1,926.70)

CERV cervical fusion, ICD-9: 81.01–81.03; *ANTLUMBAR* anterior lumbar fusion, ICD-9: 81.04 and 81.06; *POSTLUMBAR* posterior lumbar fusion, CD-9: 81.05, 81.07 and 81.08; *REFUSCERV* cervical refusion, ICD-9: 81.31–81.33; *REFUSANTLUMBAR* anterior lumbar refusion, ICD-9: 81.34 and 81.36; *REFUSPOSTLUMBAR* posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38; *360DEGR* 360° fusion, ICD-9: 81.61

Mean and standard deviations are calculated based on the individuals with each group that received the associated product

that are associated with the use and cost of ABT during hospitalization for spinal surgery. Large blood loss during major spinal surgery often leads to the use of allogeneic and autologous red blood cell products, as well as platelets and fresh frozen plasma [2, 28]. The use of allogeneic blood products can introduce several risks, including transmission of blood-borne infections such as hepatitis and human immunodeficiency virus, and induction of immune-mediated transfusion reactions. Additionally, the immunomodulatory effects of allogeneic transfusions can lead to an increase in post-operative bacterial infections, longer lengths of hospital stay, and greater hospital costs [3, 18]. Autologous blood transfusions also present infection risks—in one study, 6.3% of autologous blood (including intraoperative salvage blood) was contaminated with bacteria (mostly *Staphylococci*) [36]. Recent discharge data from 3,988 adult patients in the US undergoing all types of spinal fusion surgery procedures showed that 30% received at least one blood component transfusion of any type (RBC, FFP, or platelets; allogeneic or autologous) [2]. A higher transfusion rate is expected in a patient population undergoing larger procedures, as the number of vertebral levels fused has been shown to be a strong predictor of the need for transfusions [42].

The results of the sub-group analysis on patients with a need for transfusions supported the clinical experience that blood loss and need for blood products is generally higher in the revision surgeries for patients undergoing cervical surgeries (CERV vs. REFUSCERV) leading to higher costs for blood product. However, the same increase in blood use in refusion of anterior lumbar and posterior lumbar surgeries could not be identified (ANTLUMBAR, POSTLUMBAR vs. REFUSANTLUMBAR, REFUSPOSTLUMBAR). A possible explanation could be that revision surgeries are less extensive procedures compared to the primary surgery in order to minimize the surgical trauma.

With patient characteristics, we found that females were more likely to be transfused, which is consistent with a study of 3,988 Maryland spinal surgery patients by Berenholtz et al. [2]. Unlike Berenholtz et al. [2], we found that African Americans were more likely to be transfused than whites.

As for transfusion reduction techniques, some of our findings differed with previous data mostly obtained through smaller clinical trials or single-site observational studies rather than from a representative database as described in this paper. We found that patients that received erythropoietic agents were more likely to receive ABT which contradicts a meta-analysis by Laupacis et al. [23] of small clinical trials in which they found that erythropoietin reduced the likelihood of ABT, whether given alone or in conjunction with autologous blood. An explanation of the difference in our findings may be due to the proactive use of erythropoietin as a reactionary method used in patients with an identified high risk of bleeding with a high likelihood of receiving blood transfusions as opposed to a more prophylactic use in all patients undergoing spinal surgery. Previous research

Table 5 Use of allogeneic blood transfusion

Variable	Odds ratio	95% Wald confidence limits	
Spinal group (reference: CERV)			
ANTLUMBAR	5.51	4.54	6.69
POSTLUMBAR	7.97	6.83	9.30
REFUSCERV	1.18	0.54	2.55
REFUSANTLUMBAR	6.79	3.79	12.16
REFUSPOSTLUMBAR	8.41	6.56	10.79
360DEGR	5.60	4.31	7.28
Sex (reference: female)			
Male	0.62	0.57	0.68
Race (reference: white)			
African American	1.50	1.30	1.74
Other races	0.88	0.78	1.00
Insurance (reference: Medicare)			
Medicaid	0.87	0.71	1.06
MCO	0.83	0.75	0.92
Commercial	0.61	0.51	0.73
Other payer	0.54	0.47	0.63
Type of admission (reference: non-elective)			
Elective	0.86	0.76	0.97
Attending physician (reference: Orthopedic)			
Other physician	1.04	0.89	1.21
Neurosurgeon	0.84	0.77	0.93
APR-DRG severity level (reference: level 1)			
Level 2	2.64	2.38	2.93
Level 3	4.89	4.30	5.58
Level 4	12.15	9.52	15.50
Discharge status (reference: home)			
Skilled nursing facility	1.85	1.60	2.13
Transferred or expired	1.58	1.34	1.87
Other	1.99	1.74	2.28
Geographic region (reference: northeast)			
South	0.67	0.58	0.78
Midwest	0.66	0.56	0.78
West	0.61	0.51	0.73
Teaching status (reference: non-teaching)			
Teaching	0.67	0.61	0.74
Bed size (reference: <200)			
200–299	1.15	0.91	1.47
300–499	1.82	1.48	2.23
500 plus	2.14	1.73	2.64
Population serviced (reference: rural)			
Urban	1.69	1.43	2.00
Hypotensive anesthesia	1.61	1.47	1.77
Volume expander	1.95	1.75	2.18
Topical sealant	0.94	0.85	1.03
Erythropoietic agent	1.64	1.27	2.12
Cell salvage	0.40	0.32	0.50
Autologous blood	2.04	1.71	2.42

CERV cervical fusion, ICD-9: 81.01–81.03; *ANTLUMBAR* anterior lumbar fusion, ICD-9: 81.04 and 81.06; *POSTLUMBAR* posterior lumbar fusion, CD-9: 81.05, 81.07 and 81.08; *REFUSCERV* cervical refusion, ICD-9: 81.31–81.33; *REFUSANTLUMBAR* anterior lumbar refusion, ICD-9: 81.34 and 81.36; *REFUSPOSTLUMBAR* posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38; *360DEGR* 360° fusion, ICD-9: 81.61

has also been mixed on the use of hypotensive anesthesia with some studies indicating the decreased need for ABT when it is used [21, 29] while others have shown no reduction in ABT with use [25]. Our study indicated that use of hypotensive anesthesia was associated with use of ABT. Although many steps were taken to correctly define hypotensive anesthesia, it is impossible to determine that the anesthesia given was due to a hypotensive state; therefore, our definition may have inflated the utilization of hypotensive anesthesia. This assumption of treatment–condition link is often difficult to measure in secondary data [17]

As for erythropoietin, a reason for this finding could be due to a proactive use of hypotensive anesthesia in patients with a presumed high risk of major blood loss during the surgical procedure. This may also be due to the study design being observational rather than experimental. Like the use of erythropoietin, the use of hypotensive anesthesia has been studied in single site or experimental studies with investigator control, albeit difficult to conduct such a study completely blinded to the investigators.

This study represents the current techniques being conducted in hospitals across the US. However, consistent with most previous research [5, 6, 33] we found the use of cell saver to have a protective effect against ABT. Although previous work on topical sealants has shown a significant benefit in reducing the need for ABT [38], we did not find a significant effect of its use. We found that use of autologous blood was highly predictive of the use of ABT. While no studies were found indicating that autologous blood use may be predictive of ABT, we expect that the use of autologous blood may be predictive of the need for allogeneic blood while autologous blood donation may not be predictive of ABT and the difference between the two should be considered.

All techniques in the analysis were found to incur a higher cost associated with their use, except for topical sealants. We expected that the use of any technique to reduce the need for ABT would incur a higher cost than not using the technique. This simply means that the cost associated with each technique is greater than that of the cost of ABT deferred. Therefore, the use of topical sealants was the only technique that was found to actually reduce the costs associated with ABT beyond that of the costs incurred by the sealant. Because they were not found to reduce the need for ABT, i.e., induce a clinical benefit to the patient, the advantage of sealants might be merely due to a surgical technical one rather than a true benefit to patients. As the total cost analysis illustrates, none of the techniques reduce the total cost of ABT beyond that of the costs associated with the transfusion itself.

Conclusion

The current use of blood reduction techniques, both pharmacological and non-pharmacological, appears to be low. It is beyond the scope of this paper to investigate the reasons for the under-use of these techniques,

Table 6 Total cost of blood transfusion

Variable	Parameter estimate	Standard error	*t* value	*P* value
Intercept	−124.63	22.46	−5.55	< 0.01
Spinal groups (reference: CERV)				
ANTLUMBAR	170.26	11.47	14.85	< 0.01
POSTLUMBAR	144.64	7.41	19.51	< 0.01
REFUSCERV	22.70	32.57	0.70	0.49
REFUSANTLUMBAR	158.17	42.68	3.71	< 0.01
REFUSPOSTLUMBAR	207.50	18.45	11.25	< 0.01
360DEGR	101.39	15.80	6.42	< 0.01
Sex (reference: female)				
Male	−29.48	6.10	−4.83	< 0.01
Race (reference: white)				
African American	−7.54	11.19	−0.67	0.50
Other races	−26.02	8.31	−3.13	< 0.01
Insurance (reference: Medicare)				
Medicaid	−52.42	15.08	−3.48	< 0.01
MCO	−0.60	7.80	−0.08	0.94
Commercial	−32.24	11.02	−2.92	< 0.01
Other payer	−26.10	9.80	−2.66	< 0.01
Type of admission (reference: non-elective)				
Elective	31.05	8.74	3.55	< 0.01
Attending physician (reference: orthopedic)				
Other physician	−27.24	11.39	−2.39	0.02
Neurosurgeon	−58.68	6.81	−8.61	< 0.01
APR-DRG severity level (reference: level 1)				
Level 2	60.61	6.91	8.77	< 0.01
Level 3	299.71	10.63	28.20	< 0.01
Level 4	1043.33	24.07	43.34	< 0.01
Discharge status (reference: Home)				
Skilled nursing facility	91.33	13.72	6.66	< 0.01
Transferred or expired	177.75	14.42	12.32	< 0.01
Other	82.17	12.61	6.52	< 0.01
Geographic region (reference: northeast)				
South	65.41	10.53	6.21	< 0.01
Midwest	−2.57	12.40	−0.21	0.84
West	149.10	12.97	11.50	< 0.01
Teaching status (reference: non-teaching)				
Teaching	77.48	7.19	10.78	< 0.01
Bed size (reference: < 200)				
200–299	186.17	15.98	11.65	< 0.01
300–499	85.43	14.24	6.00	< 0.01
500 plus	112.80	15.05	7.49	< 0.01
Population serviced (reference: Rural)				
Urban	35.42	10.40	3.41	< 0.01
Hypotensive anesthesia	64.74	6.80	9.52	< 0.01
Volume expander	191.89	9.80	19.58	< 0.01
Topical sealant	−25.17	6.57	−3.83	< 0.01
Erythropoietic agent	278.51	26.23	10.62	< 0.01

CERV cervical fusion, ICD-9: 81.01–81.03; *ANTLUMBAR* anterior lumbar fusion, ICD-9: 81.04 and 81.06; *POSTLUMBAR* posterior lumbar fusion, CD-9: 81.05, 81.07 and 81.08; *REFUSCERV* cervical refusion, ICD-9: 81.31–81.33; *REFUSANTLUMBAR* anterior lumbar refusion, ICD-9: 81.34 and 81.36; *REFUSPOSTLUMBAR* posterior lumbar refusion, ICD-9: 81.35, 81.37, and 81.38; *360DEGR* 360° fusion, ICD-9: 81.61. $R^2 = 0.23$. *F* value = 215.83

but it may be because of reasons associated with cost, potential adverse events or lack of strong clinical evidence. Anti-fibrinolytics which have been found to be highly effective at reducing the risk of ABT in spinal surgery [8, 35, 41] were utilized by less than one 1% of the sample. This is also consistent with other techniques such as erythropoietic agents with a utilization of less than 4% in the highest utilization group. While these techniques have been utilized very infrequently, ABT is highly utilized. Although the overall use and costs of ABT appear to be low among all spinal surgery patients, among users of ABT, the utilization and costs associated with ABT per patient were considerable. Thus, this study has helped identify a subset of patients undergoing spinal surgeries where use of ABT would likely be highest. Overall, it is apparent that

ABT remains a burden to the US population undergoing spinal fusion and current blood reduction techniques offer little relief. Future research is needed to identify factors that drive the use of blood transfusion in these patients, and the beneficial effects of using new blood reduction techniques that improve physician burden and patient outcomes, which can be both quantitative and qualitative.

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