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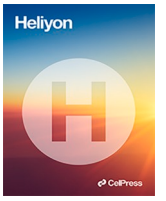

Research article

Incidence and risk factors of blood transfusion after total knee arthroplasty: A retrospective nationwide inpatient sample database study

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ABSTRACT

Introduction: Common postoperative complications of total knee arthroplasty (TKA) include blood transfusion. Although risk factors and incidence of blood transfusion have been studied through national databases, the relative impact of each risk factor needs to be synthesized over a longer time period into a new model need to be revised.

Material and methods: Patient data were extracted from the National Inpatient Sample (NIS), which is the largest hospital care database in the US, and analyse patient data retrospectively from 2010 through 2019. The final data included the patients undergoing TKA. The final analysis assessed the demographics of patients, type of insurance, type of hospital, length of stay (LOS), preoperative comorbidities, total charge, inpatient mortality, medical-surgical postoperative complications.

Results: After extracting data from the NIS database, a total of 1,250,533 patients with TKA were included in the analysis, and the rate of transfusion was 6.60 %. TKA patients who receive blood transfusion had longer LOS (from 2-3 days to 3–4 days), more preoperative comorbidities, higher inpatient mortality rate, and increased total charge ($P < 0.001$). Moreover, postoperative complications associated with inpatients included sepsis, acute myocardial infarction and shock. Elective admission and private insurance were also regarded as protective factors.

Conclusion: Blood transfusion could bring postoperative complications to patients, which were also linked to health costs and risks. It was also a common preoperative comorbidities for older patients who underwent TKA. Through better blood management strategies, we could reduce patient transfusion rates and improve clinical outcomes.

Level of Evidence: Diagnostic Level III.

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1. Introduction

Every year, more than 100,000 total knee arthroplasties (TKAs) were performed in the US [1]. What's more, experts predicted that the number of patients undergoing TKA surgery would continue to increase in the future [1]. TKA was identified as one of the ten procedures with the highest incidence of blood transfusion based on an investigation of NIS. TKA has increased the need for post-operative medical services and blood transfusions among patients. Therefore, effective perioperative management was becoming more important and gathered more attention and resource.

At the same time, some negative consequences were associated with blood transfusions, including allergic reactions, blood transfusion reactions, transfusion-related circulatory overload, and increased infection risk [1]. To solve these problems, various blood management protocols has been introduced such as strict transfusion-trigger guidelines, and blood product substitution programs [2]. Supplements and micronutrients during the perioperative period treated the patient's anemia and reduced the patients need for blood transfusion, thereby reducing the incidence of blood transfusion [3,4]. And a previous research found a marked decline in the proportion of TKA patients receiving transfusions in the perioperative period between 2010 and 2015 [5].

However, previous studies that extracted data on TKA patients from large databases and statistically analyzed the incidence of blood transfusion and risk factors have become obsolete, and previous studies have had fewer assessment metrics and did not fully characterize patients.

Consequently, the aim of this study was to evaluate the prevalence of blood transfusion and to identify risk factors for blood transfusion in patients undergoing TKA via analyzing the data from the NIS, therefore identifying patients who need optimal pre-operative management, reducing transfusion rates, and improving surgical outcome. We hypothesised that the incidence of blood transfusion in TKA patients has decreased over the last decade, but expanding the observed variables would produce more transfusion-related complications.

2. Material and Methods

2.1. Ethical approval and data availability statement

The data used in this study came from the Nationwide Inpatient Sample database, which was consistently recognized as the largest public database in the nation. This study used de-identified public data and was therefore considered exempt and did not require IRB approval or informed consent.

2.2. Data source

The retrospective database was compiled from the NIS, through analyzing a group of patients who underwent TKA from January 1, 2010, to December 31, 2019. Sizes of hospitals uploaded data to this system, which could almost cover all American citizens and geographic regions around the US. The International Classification of Diseases, Ninth and Tenth (ICD-9, ICD-10) was queried in order to retrieve the procedure and diagnosis codes (Supplemental data file). We also identified all cases of the knee arthroplasty and the targeted characteristics.

2.3. Cohort selection

Patients older than 18 years of age who underwent the unilateral or bilateral TKA were selected from hospital discharge data from 2010 to 2019 according to ICD-9 and ICD-10 procedure codes (Supplemental data file). There were data for a total of 1,371,400 patients. After removing patients with missing data of hospital characteristics and patient demographics, including age, death, elective admission, gender, LOS, type of insurance, race, total charge and bed size of hospital, about 1,250,533 patients were eventually extracted from the NIS (Fig. 1).

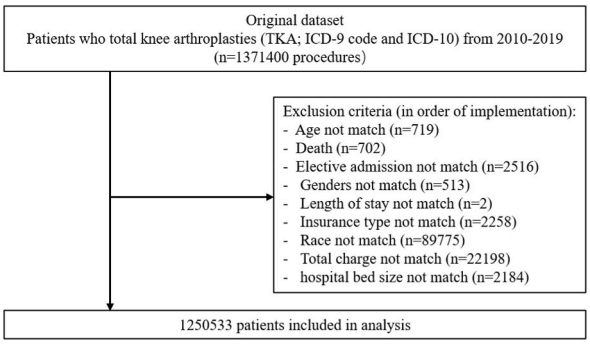

Fig. 1. This picture shows analysis plan.

2.4. Statistical analysis

We chose chi-square tests to perform univariate and descriptive analyses as the method of statistical analysis (Tables 2 and 3). The purpose was to compare blood transfusion rates base on different demographic variables. We used logistic regression analysis to perform multivariate analysis as the method of risk factor analysis. The purpose was to screen risk factors and the correlation between blood transfusion and undergoing TKA. Gender, number of comorbidity (0, 1, 2, and 3), procedure year (2010–2019), age (18–44 years, 45–64 years, 65–74years and ≥75 years), insurance type (Medicaid, Medicare, Self-pay, Private Insurance, No charge and Others), and race (White, Hispanic, Black, Native American, Asian or Pacific Islander and Other), elective admission, LOS, total charge, hospital bed size (Large, Medium and Small), hospital location, hospital teach, hospital region (Midwest or North Central, Northeast, West and South), died and complications. 95 % confidence intervals (CIs) and Odds ratios (ORs) were obtained after statistically analyzing (Table 1). Whole analytical calculations were used by IBM SPSS Statistics 25 to perform analysis. It was statistically significant if the *P*-value reached 0.001.

3. Results

3.1. Incidence of blood transfusions in patients undergoing total knee arthroplasty

From 2010 to 2019, 1,250,533 patients were estimated to have performed TKA in the United States, which could be identified in the NIS. Overall, a total number of 82,552 patients who underwent blood transfusion after TKA was observed during their hospitalization and the incidence of blood transfusion was estimated to about 6.60 % (Table 2). This showed a downward trend in blood transfusion rates from 21.11 % in 2010 to 1.98 % in 2019 (Fig. 2). However, the transfusion rate did not decline uniformly; there was a sharp phase of decline in the transfusion rate during this decade, from 2012 (17.98 %) to 2015 (5.55 %).

3.2. Patient demographics between the two groups

Comparing the patients' age between two group, patients receiving transfusion were 3 years older (69 years vs. 66 years) and more likely to be female (71.83 % vs. 61.23 %) than those who did not receive transfusion ($P < 0.001$). Meanwhile, there were also differences in the age distribution between these two groups of patients, the incidence of blood transfusion was 11.56 % higher in patients over 75 years old who underwent TKA (31.79 % vs. 20.23 %; $P < 0.001$) (Table 2 and Supplement Fig. 1 A&B). Compared to no blood transfusions patients, white (77.42 % vs 82.54 %) and native American (0.44 % vs 0,47 %) had a lower rate of blood transfusions ($P < 0.001$) (Table 2 and Supplement Fig. 1 C&D).

3.3. Hospital characteristics between the two groups

As expected, patients receiving blood transfusion after TKA were 2.67 % less likely to elect admission compared to patients not receiving blood transfusion (92.88 % vs. 95.55 %; $P < 0.001$) (Table 2). Additionally, blood transfusion tended to occur in hospitals with large-size beds (51.60 % vs. 45.56 %; $P < 0.001$) (Table 2 and Supplement Fig. 1 E&F). Blood transfusion also had lower likelihood of occurring in urban hospital (86.46 % vs. 89.64 %) and teaching hospital (44.33 % vs. 54.61 %) compared to no blood transfusion ($P < 0.001$) (Table 2). What's more, there were also significant differences in the region of hospitals. Hospitals in the northeast (23.42 % vs. 18.61 %) and west (15.76 % vs. 18.27 %) had higher incidence of blood transfusion ($P < 0.001$) (Table 2 and Supplement Fig. 1 G&H).

3.4. Adverse outcomes of blood transfusion after total knee arthroplasty

After statistical analysis, TKA patients receiving blood transfusions had more 3≥ comorbidities than those without blood transfusion (87.84 % vs. 81.72 %; $P < 0.001$) (Table 2). And mortality rate for TKA patients who received blood transfusions was more than

Table 1
Variables used in binary logistic regression analysis.

Variables Categories	Specific Variables
Patient demographics	Age (≥65 years and ≤64 years), race (White, Black, Native American Asian or Pacific Islander, Hispanic, and Other), sex (male and female)
Hospital characteristics	Type of insurance (Medicaid, Medicare, Self-pay, Private Insurance, No Charge, Other), type of admission (non-elective, elective), location of the hospital (South, Midwest or North Central, Northeast, West), bed size of hospital (Large, Medium, Small), location of hospital (Rural, Urban), teaching status of hospital (Nonteaching, Teaching)
Comorbidities	AIDS, deficiency anemia, chronic blood loss anemia, rheumatoid diseases, diabetes (with chronic complications), alcohol abuse, congestive heart failure, coagulopathy, chronic pulmonary disease, hypothyroidism, depression, diabetes (uncomplicated), lymphoma, metastatic cancer, paralysis, fluid and electrolyte disorders, obesity, neurological disorders, psychoses, renal failure, valvular disease, peripheral vascular disorders, hypertension, pulmonary circulation disorders, drug abuse, weight loss, liver disease, peptic ulcer disease and solid tumor without metastasis

AIDS: Acquired immunodeficiency syndrome.

Table 2
Characteristics and outcomes of patients after total knee arthroplasty (2010–2019).

Characteristics	Transfusion	No Transfusion	P
Total (n = count)	82,552	1,167,981	
Total incidence (%)	6.60		
Age (median, years)	69 (62–77)	66 (60–73)	<0.001
Age group (%)			
18-44	1.17	1.45	<0.001
45-64	31.41	40.74	
65-74	35.63	37.58	
≥75	31.79	20.23	
Gender (%)			
Male	28.17	38.77	<0.001
Female	71.83	61.23	
Race (%)			
White	77.42	82.54	<0.001
Black	11.29	7.86	
Hispanic	6.48	5.62	
Asian or Pacific Islander	1.58	1.31	
Native American	0.44	0.47	
Other	4.37	2.20	
Number of Comorbidity (%)			
0	0.30	0.35	<0.001
1	2.01	3.14	
2	9.86	14.79	
≥3	87.84	81.72	
LOS (median, d)	3 (3–4)	3 (2–3)	<0.001
TOTCHG (median, $)	56,621 (40,494–81,952)	50,045 (36,597–70,559)	<0.001
Bed size of hospital (%)			
Small	22.01	26.98	<0.001
Medium	26.39	27.46	
Large	51.60	45.56	
Elective admission (%)	95.55	92.88	<0.001
Type of insure (%)			
Medicare	65.29	55.43	<0.001
Medicaid	3.52	3.86	
Private insurance	28.12	36.86	
Self-pay	0.43	0.47	
No charge	0.08	0.06	
Other	2.57	3.32	
Type of hospital (teaching %)	44.33	54.61	<0.001
Location of hospital (urban, %)	**86.46**	**89.64**	**<0.001**
Region of hospital (%)			
Northeast	23.42	18.61	<0.001
Midwest or North Central	18.00	24.68	
South	42.81	38.44	
West	15.76	18.27	
Died (%)	0.21	0.04	<0.001

TOTCHE: Total charge, LOS: Length of stay.

five times that of non-transfused patients (0.21 % vs. 0.04 %; $P < 0.001$) (Table 2). Although both groups had the same median LOS, having blood transfusion had extended LOS in compare to those without (3–4 days vs. 2–3 days; $P < 0.001$) (Table 2). In line with the prolonged hospital stay, the occurrence of blood transfusion would increase the total hospital charges by $6576 ($56,621 vs. $50,045; $P < 0.001$) (Table 2). Meanwhile, blood transfusion patients Medicare as insurance was 9.86 % higher than those not receiving blood transfusion (65.29 % vs. 55.43 %). But private insurance took an 8.74 % less proportion (28.12 % vs. 36.86 %; $P < 0.001$) (Table 2 and Supplement Fig. 1 I&J).

3.5. Relationship between other preoperative comorbidities and blood transfusion

The elderly patients with preoperative comorbidities, such as alcohol abuse (1.10 %), deficiency anemias (20.18 %), paralysis (0.38 %), chronic blood loss anemia (2.90 %), rheumatoid arthritis/collagen vascular diseases (5.60 %), coagulopathy (4.91 %), chronic pulmonary disease (16.71 %), depression (14.85 %), solid tumor without metastasis (0.62 %), diabetes uncomplicated (21.86 %), hypertension (73.14 %), hypothyroidism (18.93 %), liver disease (1.51 %), lymphoma (0.40 %), metastatic cancer (0.19 %), weight loss (0.82 %), pulmonary circulation disorders (2.11 %), other neurological disorders (5.06 %), valvular disease (5.36 %), obesity (21.42 %), psychoses (2.74 %), peripheral vascular disorders (3.19 %), congestive heart failure (5.04 %), renal failure (9.33 %),

Table 3
Relationship between preoperative comorbidities and blood transfusion.

Comorbidities	Univariate Analysis			Multivariate Logistic Regression		
	No transfusion	Transfusion	P	OR	95 % CI	P
Preoperative comorbidities						
Acquired immune deficiency syndrome	854 (0.07 %)	40 (0.05 %)	0.01	0.67	0.48–0.92	0.014
Alcohol abuse	10,098 (0.86 %)	909 (1.10 %)	< 0.001	1.05	0.98–1.13	0.198
Deficiency anemia	67,080 (5.74 %)	16,658 (20.18 %)	< 0.001	3.62	3.55–3.69	< 0.001
Rheumatoid arthritis/collagen vascular diseases	45,999 (3.94 %)	4621 (5.60 %)	< 0.001	1.30	1.26–1.34	< 0.001
Chronic blood loss anemia	9226 (0.79 %)	2394 (2.90 %)	< 0.001	3.78	3.61–3.96	< 0.001
Congestive heart failure	29,667 (2.54 %)	4163 (5.04 %)	< 0.001	1.40	1.35–1.45	< 0.001
Chronic pulmonary disease	178,121 (15.25 %)	13,792 (16.71 %)	< 0.001	1.02	1.00–1.04	0.045
Coagulopathy	18,837 (1.61 %)	4057 (4.91 %)	< 0.001	2.30	2.22–2.39	< 0.001
Depression	161,320 (13.81 %)	12,262 (14.85 %)	< 0.001	1.03	1.01–1.05	0.004
Diabetes, uncomplicated	211,428 (18.10 %)	18,046 (21.86 %)	< 0.001	1.21	1.19–1.23	< 0.001
Drug abuse	6916 (0.59 %)	552 (0.63 %)	0.006	1.03	0.94–1.12	0.546
Hypertension	789,637 (67.61 %)	60,382 (73.14 %)	< 0.001	1.14	1.12–1.16	< 0.001
Hypothyroidism	193,039 (16.53 %)	15,630 (18.93 %)	< 0.001	1.10	1.08–1.12	< 0.001
Liver disease	15,935 (1.36 %)	1248 (1.51 %)	< 0.001	0.91	0.86–0.97	0.003
Lymphoma	2267 (0.19 %)	334 (0.40 %)	< 0.001	1.71	1.52–1.93	< 0.001
Fluid and electrolyte disorders	76,244 (6.53 %)	13,012 (15.76 %)	< 0.001	2.05	2.01–2.10	< 0.001
Metastatic cancer	775 (0.06 %)	155 (0.19 %)	< 0.001	2.10	1.75–2.53	< 0.001
Other neurological disorders	28,342 (2.43 %)	4176 (5.06 %)	< 0.001	1.68	1.62–1.74	< 0.001
Obesity	318,162 (27.24 %)	17,683 (21.42 %)	< 0.001	0.67	0.66–0.68	< 0.001
Paralysis	2072 (0.18 %)	316 (0.38 %)	< 0.001	1.60	1.41–1.81	< 0.001
Peripheral vascular disorders	23,357 (2.00 %)	2634 (3.19 %)	< 0.001	1.29	1.23–1.34	< 0.001
Psychoses	22,857 (2.00 %)	2259 (2.74 %)	< 0.001	1.25	1.19–1.31	< 0.001
Pulmonary circulation disorders	9358 (0.80 %)	1745 (2.11 %)	< 0.001	1.74	1.65–1.84	< 0.001
Renal failure	58,558 (5.01 %)	7699 (9.33 %)	< 0.001	1.39	1.36–1.43	< 0.001
Solid tumor without metastasis	5317 (0.46 %)	512 (0.62 %)	< 0.001	1.16	1.05–1.27	0.002
Valvular disease	37,120 (3.18 %)	4422 (5.36 %)	< 0.001	1.34	1.30–1.39	< 0.001
Weight loss	2368 (0.20 %)	674 (0.82 %)	< 0.001	2.41	2.19–2.64	< 0.001

CI: Confidence interval, OR: Odds ratio.

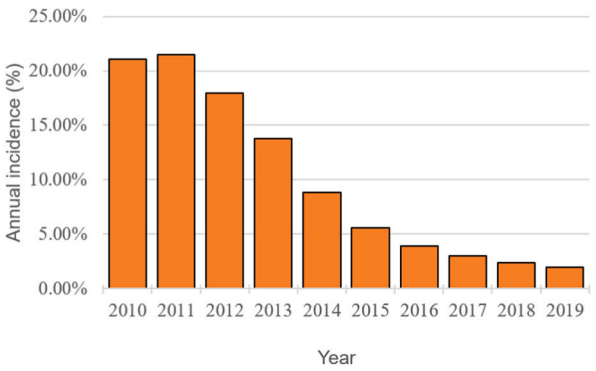

Fig. 2. This picture shows annual blood transfusion rates after total knee arthroplasty.

and fluid and electrolyte disorders (15.76 %) were more likely to receive blood transfusion ($P < 0.001$) (Table 3 and Supplement Fig. 2).

Findings of the logistic regression analysis of comorbidities were presented as follows: alcohol abuse (odds ratio [OR] = 1.05; 95 % confidence interval [CI] = 0.98–1.13), deficiency anemias (OR = 3.62; CI = 3.55–3.69), liver disease (OR = 0.91; CI = 0.86–0.97), rheumatoid arthritis/collagen vascular diseases (OR = 1.30; CI = 1.26–1.34), chronic blood loss anemia (OR = 3.78; CI = 3.61–3.96), congestive heart failure (OR = 1.40; CI = 1.35–1.45), diabetes uncomplicated (OR = 1.21; CI = 1.19–1.23), hypertension (OR = 1.14; CI = 1.12–1.16), chronic pulmonary disease (OR = 1.02; CI = 1.00–1.04), hypothyroidism (OR = 1.10; CI = 1.08–1.12), depression (OR = 1.03; CI = 1.01–1.05), lymphoma (OR = 1.71; CI = 1.52–1.93), other neurological disorders (OR = 1.68; CI = 1.62–1.74), obesity (OR = 0.67; CI = 0.66–0.68), peripheral vascular disorders (OR = 1.29; CI = 1.23–1.34), psychoses (OR = 1.25; CI = 1.19–1.31), paralysis (OR = 1.60; CI = 1.41–1.81), pulmonary circulation disorders (OR = 1.74; CI = 1.65–1.84), metastatic cancer (OR = 2.10; CI = 1.75–2.53), weight loss (OR = 2.41; CI = 2.19–2.64), coagulopathy (OR = 2.30; CI = 2.22–2.39), solid tumor without

Table 4
Relationship between postoperative complications and blood transfusion.

Complications	Univariate Analysis			Multivariate Logistic Regression		
	No transfusion	Transfusion	P	OR	95 % CI	P
Medical complications						
Sepsis	1108 (0.09 %)	484 (0.59 %)	< 0.001	3.17	2.81–3.58	< 0.001
Acute myocardial infarction	3302 (0.28 %)	1067 (1.29 %)	< 0.001	3.69	3.43–3.97	< 0.001
Deep vein thrombosis	3033 (0.26 %)	735 (0.89 %)	< 0.001	2.81	2.58–3.06	< 0.001
Gastrointestinal hemorrhage	514 (0.04 %)	294 (0.36 %)	< 0.001	5.98	5.14–6.97	< 0.001
Cardiac arrest	478 (0.04 %)	142 (0.17 %)	< 0.001	1.76	1.42–2.17	< 0.001
Shock	145 (0.01 %)	85 (0.10 %)	< 0.001	4.20	3.11–5.66	< 0.001
Pneumonia	2928 (0.25 %)	941 (1.14 %)	< 0.001	3.33	3.08–3.61	< 0.001
Stroke	5224 (0.45 %)	784 (0.95 %)	< 0.001	1.99	1.84–2.14	< 0.001
Surgical complications						
Periprosthetic joint infection	816 (0.07 %)	309 (0.37 %)	< 0.001	3.63	3.15–4.18	< 0.001
Dislocation of prosthetic joint	126 (0.01 %)	40 (0.05 %)	< 0.001	3.98	2.75–5.75	< 0.001
Hemolysis	5 (0.00 %)	7 (0.01 %)	< 0.001	16.03	4.83–53.16	< 0.001
Lower limb nerve injury	170 (0.01 %)	31 (0.04 %)	0.01	2.48	1.68–3.65	< 0.001
Hemorrhage	2005 (0.17 %)	1131 (1.37 %)	< 0.001	7.21	6.69–7.77	< 0.001

CI: Confidence interval, OR: Odds ratio.

metastasis (OR = 1.16; CI = 1.05–1.27), fluid and electrolyte disorders (OR = 2.05; CI = 2.01–2.10), valvular disease (OR = 1.34; CI = 1.30–1.39), and renal failure (OR = 1.39; CI = 1.36–1.43) (Table 3 and Supplement Fig. 2).

3.6. Other postoperative complications in relation to blood transfusion

Patients, who received blood transfusion after TKA, had a higher incidence of developing many postoperative complications, including acute myocardial infarction (1.29 %), pneumonia (1.14 %), stroke (0.95 %), deep vein thrombosis (0.89 %), sepsis (0.59 %), gastrointestinal hemorrhage (0.36 %), cardiac arrest (0.17 %) and shock (0.10 %), in contrast to those who had not undergone blood transfusion ($P < 0.001$) (Table 5 and Supplement Fig. 3). Multiple regression analysis revealed that blood transfusion was associated with sepsis (OR = 3.17; CI = 2.81–3.58), acute myocardial infarction (OR = 3.69; CI = 3.43–3.97), deep vein thrombosis (OR = 2.81; CI = 2.58–3.06), gastrointestinal hemorrhage (OR = 5.98; CI = 5.14–6.97), cardiac arrest (OR = 1.76; CI = 1.42–2.17), shock (OR = 4.20; CI = 3.11–5.66), pneumonia (OR = 3.33; CI = 3.08–3.61) and stroke (OR = 1.99; CI = 1.84–2.14), (Table 5 and Supplement Fig. 3). Furthermore, the result of multiple analyses showed an association between blood transfusion and surgical complications, including periprosthetic joint infection (OR = 3.63; CI = 3.15–4.18) dislocation of the prosthetic joint (OR = 3.98; CI = 2.75–5.75) hemolysis (OR = 16.03; CI = 4.83–53.16) hemorrhage (OR = 7.21; CI = 6.69–7.77) (Table 4 and Supplement Fig. 3).

3.7. Risk factors associated with blood transfusion after total knee arthroplasty

Risk factors of blood transfusion were investigated by using multivariate logistic regression analysis (Table 3): advanced age (≥65 years, OR = 1.22; 95 % CI = 1.18–1.25; $P < 0.001$), female (OR = 1.56; CI = 1.53–1.58), race (White: refence; Hispanic: OR = 1.26; CI = 1.22–1,30; Black: OR = 1.47; CI = 1.44–1.51; Asian or Pacific Islander: OR = 1.28; CI = 1.20–1.35; Other: OR = 1.33; CI = 1.27–1,39; $P < 0.001$), bed size of hospital (Small: refence; Large: OR = 1.26; CI = 1.24–1.29; Medium: OR = 1.09; CI = 1.06–1.11; $P < 0.001$). A number of protective factors were also identified: type of insurance (Medicare: refence; Private Insurance: OR = 0.84; CI = 0.83–0.86; Medicaid: OR = 0.86; CI = 0.82–0.89; Other: OR = 0.84; CI = 0.80–0.88; $P < 0.001$)elective admission (OR = 0.72; CI = 0.70–0.74), teaching hospital (OR = 0.68; CI = 0.66–0.69; $P < 0.001$), urban hospital (OR = 0.88; CI = 0.86–0.90; $P < 0.001$), region of hospital (Northeast: refence; West: OR = 0.60; CI = 0.59–0.62; South: OR = 0.74; CI = 0.73–0.76; Midwest or North Central: OR = 0.51; CI = 0.50–0.52; $P < 0.001$). (Detailed data could be found in Table 5).

4. Discussion

Over the past decade, the incidence of blood transfusions in TKA patients has decreased, but more transfusion-related complications were available with additional study years and risk factor indicators. According to a large health economic analysis, the result indicated that the number of patients undergoing TKA was between 110,000 and 150,000 annually and had a fluctuating upward trend between 2010 and 2019. However, the rate of patients receiving blood transfusions in the perioperative or postoperative period had decreased annually (Fig. 2). Comparing the decline of the 1990s (from 85 % to 65 %) [6] and the first decade of the twenty-first century (from 25.6 % to 19.2 %) [1], the rate of blood transfusions declined from 21.11 % in 2010 to 1.98 % in 2019 (Fig. 2). As a previous study reported, blood transfusion rate slowly decreasing; this conclusion was similar to the past papers [5]. From 2012 to 2015, the incidence of blood transfusion dropped precipitously, from 18.00 % to 5.60 %. This abnormal phenomenon attracted our attention. While the definition of blood transfusion and TKA did not change over ten years, their diagnosis according to the ICD-9-CM was updated to ICD-10[7]. It led to data entry changes when medical staff uploaded data because of the diagnostic codes changing. Another possible explanation was that stricter blood management policies and transfusion guidelines, enhanced surgical techniques, clinical

Table 5
Risk factors associated with blood transfusion after total knee arthroplasty.

Variable	Multivariate Logistic Regression		
	OR	95 % CI	P
Age ≥ 65 years old	1.22	1.18–1.25	< 0.001
Female	1.56	1.53–1.58	< 0.001
Race			
White	Ref	–	–
Black	1.47	1.44–1.51	< 0.001
Hispanic	1.26	1.22–1.30	< 0.001
Asian or Pacific Islander	1.28	1.20–1.35	< 0.001
Native American	0.99	0.89–1.10	0.85
Other	1.33	1.27–1.39	< 0.001
Number of Comorbidity			
1	Ref	–	–
2	1.03	0.97–1.08	0.371
≥3	0.99	0.94–1.05	0.808
Type of insurance			
Medicare	Ref	–	–
Medicaid	0.86	0.82–0.89	< 0.001
Private insurance	0.84	0.83–0.86	< 0.001
Self-pay	0.89	0.79–0.99	0.031
No charge	1.12	0.86–1.46	0.409
Other	0.84	0.80–0.88	< 0.001
Bed size of hospital			
Small	Ref	–	–
Medium	1.09	1.06–1.11	< 0.001
Large	1.26	1.24–1.29	< 0.001
Elective admission	0.72	0.70–0.74	< 0.001
Teaching hospital	0.68	0.66–0.69	< 0.001
Urban hospital	0.88	0.86–0.90	< 0.001
Region of hospital			
Northeast	Ref	–	–
Midwest or North Central	0.51	0.50–0.52	< 0.001
South	0.74	0.73–0.76	< 0.001
West	0.60	0.59–0.62	< 0.001

protocols to maintain minimum preoperative haemoglobin levels, and the implementation of new medications, haemostatic agents and haemostatic devices had resulted in the sharp reduction in the transfusion rate [2]. Thus, hospitals around the world took initiatives to reduce perioperative transfusions. A previous study reported that the Patient Blood Management (PBM) program decreased half of red blood cell usage in perioperative period [8].

The incidence of patients receiving blood transfusion was 6.60 % in the perioperative or postoperative period. This was far lower than previous findings of a fluctuating incidence of between 15 % and 25 % [1,5,9–11]. Whereas, a previous study found that only 3 % of TKA patients received perioperative transfusions, which was partly consistent with our study [12]. This might be due to different databases, and the data from previous studies was obtained from the National Surgical Quality Improvement Project (NSQIP) Database and only studied adult patients who underwent TKA in 2015 [12].

In the analysis of the demographic characteristics, the mean age of TKA patients who received transfusions was three years older than that of non-transfused patients. This result indicated a higher incidence of blood transfusion in older patients receiving TKA [13]. Furthermore, as identified by the logistics regression analysis, the advanced age was one of the independent risk factors for blood transfusion [14]. Similar to previous studies, females were risk factors for blood transfusion [13].

The likelihood of TKA patients receiving blood transfusion was additionally affected by their healthcare payment options. In our finding, transfused patients were more likely to use Medicare, while those without transfusion were more likelihood to use private insurance as their payment method (Table 2). However, according to the findings of the logistic regression analysis, the protective factor for TKA patients was private insurance, rather than Medicare [15](Table 2). One explanation was that private insurance often meant more affluent financial conditions. This could bring better perioperative care, more standardized surgery to TKA patients. These could lead to a better prognosis for patients [16].

Additionally, we found that the logistic regression analyses indicated elective admission was a protective factor (Table 2). When admitted electively, patients had a reduced probability of receiving blood transfusion [17]. Consequently, this indicated that elective admission had a considerable advantage in decreasing the incidence of transfusion for TKA patients during the perioperative or postoperative period [18](Table 2).

Besides, transfusion patients had more comorbidities, and transfused patients with 3 or more comorbidities were 6.12 % more likely to be transfused than non-transfused patients. This was because the more comorbidities had been correlated with inferior preoperative health, which led to a higher incidence of blood transfusion, more postoperative complications and ultimately a higher mortality rate in the transfusion group [9,10,17]. The results of statistical analysis obtained the same conclusion (Table 2). Additionally, blood transfusion increased the duration of stay and total cost by 6576 dollars respectively. In our study, the median LOS was

identical, but the majority of transfusion patients were hospitalized for three to four days, while patients without transfusions were being hospitalized for two to three days [3,11,17]. In accordance with the reported in previous studies, transfusion played a significant role in LOS and total charge [4,19,20]. Previous study reported that reducing blood transfusions could notably decrease the LOS and total charge [20]. A reasonable explanation for this was that blood transfusion was related to more perioperative comorbidities, which eventually had an adverse impact on the length of hospitalization and the total charge [21].

Summarizing the above, blood transfusion after TKA was related with more total hospital charge, longer LOS and higher hospitalization death rate. Reflecting hospital size by bed size, large hospitals were found to have higher transfusion rates than small hospitals. These might be related to the higher complexity and number of procedures undertaken on patients in larger hospitals. (Table 2). Associated complications after TKA, blood transfusion, preoperative anemia, iron and erythropoietin use, ambulatory ability and family support all could prolonged LOS [3]. At the same time, prolonged hospitalization and blood transfusion both resulted in additional total charge [3]. Meanwhile, previous study reported that blood transfusion caused increased hospital mortality [9].

Then, a total of 29 comorbidities were analyzed in logistic regression analysis, including drug abuse, obesity and hypertension (Table 3 and Supplement Fig. 2). Among the causes of the occurrence of blood transfusions, weight loss, chronic blood loss anemia, deficiency anemias was recognized as risk factor [22]. Under study, these risk factors could cause an increase in transfusion rates. Low hemoglobin were often associated with malnutrition, and anaemic patients undergoing TKA were more likely to require blood transfusions [23]. Meanwhile, depression, alcohol abuse were also risk factors of blood transfusion after TKA. As previous studied, these risk factors cause post-TKA patients to be prone revision and periprosthetic joint infection. Fluid and electrolyte disorders were also risk factors. We hypothesised that fluid and electrolyte disorders were caused by inpatients with comorbid chronic diseases such as liver disease, or consumptive comorbidities such as tumours. And preoperative corrective measures could not completely eliminate the symptoms. The above risk factors were also more likely to result more surgical complications, poorer functional outcomes and even higher mortality rates [24]. Hypothyroidism was also a risk factor associated with blood transfusion and we hypothesised that hypothyroidism could cause anemia [25].

Additionally, the analyses showed that some comorbidities such as renal failure, peripheral vascular disorders, congestive heart failure, obesity, valvular disease, coagulopathy, hypertension, psychoses, neurological disorders and pulmonary circulation disorders were regarded as risk factors, which were line with the previous reports [5,10,26–28]. The reason for this possibility was that the surgical procedure put a greater vascular burden on patients with pre-existing cardiovascular or circulatory disease. This ultimately leaded to a worsening of the original disease and an increased incidence of blood transfusions.

This study is consistent with previous findings that diabetes, rheumatoid arthritis and lymphoma are also risk factors for blood transfusion [29,30]. Besides, statistical analyses also found that chronic pulmonary disease, collagen vascular diseases, liver disease, metastatic cancer, paralysis, solid tumor without metastasis were all risk factors for blood transfusion, just the causes were unknown, but can be used as a basis for the patients' pre-admission health assessment.

As previous studies on transfusion risk factors in patients with TKA were outdated and fewer risk factors were included in the studies. After extending the study years and adding risk factor indicators to the analysis. The results showed that TKA patients who received blood transfusions had more medical and surgical complications compared to previous studies, mainly including pneumonia, acute myocardial infarction, gastrointestinal, cardiac arrest, shock, stroke, hemolysis and hemorrhage [5,10,26,27]. These postoperative complications might occur because of the increase in circulating blood volume and overloading of the cardiovascular system by blood transfusion. Infectious complications related to blood transfusion included pneumonia and sepsis/septicaemia; whereas complications associated with blood transfusion in TKA patients included deep vein thrombosis and periprosthetic joint infection. The above complications might be due to microbial infections caused by the weakened body immunity in TKA patients after surgery. At the same time, infection activated the immune coagulation system or triggered a decrease in blood volume. Therefore, infection and blood transfusion were related.

This study had inherent limitations because the retrospective analyses suffered from the restriction of large administrative databases. Firstly, the vast majority of hospitals only recorded information about patients prior to their discharge. This situation also meant that any data on complications, which occurred after the patients were discharged from the hospital, was not included in the NIS database, and led to a low incidence of blood transfusion. Moreover, the NIS database did not contain specific surgical details and personal information such as blood loss, number of units transfused, use of tourniquets or haemostatic agents, method of anaesthesia and specific personal information (BMI). This similarly resulted in a lack of discussion of certain recognized risk factors, such as duration of the procedure, sedation during recovery from anaesthesia, etc. Finally, there were coding and reporting biases existed when we entered information into the database, which may have resulted in low transfusion rates. In conclusion, it can only be informative when interpreting the results, but this study is still clinically relevant for screening risk factors for TKA patients receiving postoperative blood transfusions.

5. Conclusion

Blood transfusion was associated with comorbidities, including: coagulopathy, deficiency anemias, weight loss, rheumatoid arthritis/collagen vascular diseases, valvular disease, congestive heart failure, chronic blood loss anemia, peripheral vascular disorders, metastatic cancer, diabetes uncomplicated, hypertension, lymphoma, other neurological disorders, hypothyroidism, paralysis, psychoses, renal failure, pulmonary circulation disorders, fluid and electrolyte disorders, obesity, which were also linked to health cost and risk, and simultaneously were common complications after the old underwent TKA. From 2010 to 2019, 6.6 % of TKA patients received blood transfusions. And the annual transfusion rate for TKA patients decreased from 21.11 % in 2010 to 1.98 % in 2019. The previous studies could not give a specific explanation, so our study sought to find out risk factors associated with blood transfusion,

including advanced age (≥65 years), gander, race, type of insurance, elective admission, bed size of hospital, urban hospital, region of hospital, teaching hospital. Transfusion rates were also associated with perioperative complications (sepsis) and surgical complications (hemorrhage). We needed to guarantee appropriate perioperative blood management and decrease the transfusion rate to avoid adverse outcome. For older patients with more comorbidities and the necessity of blood transfusions, we needed to fully explain the situation and provide information about the risks of total knee surgery before surgery. Interventions and blood management in the perioperative period have been validated in clinical studies. We could determine the best blood management strategy for each patient, which purposed to decrease transfusion rate and deliver better clinical results.

Availability of data and materials

The data used in this study came from the National Inpatient Sample (NIS) database. The database is part of a project on health care costs and utilisation established by the Agency for Healthcare Research and Quality. The NIS database contains large inpatient care data. The data is freely available to the public. The database can be accessed by following this link: https://www.ahrq.gov/data/hcup/index.html. This study used de-identified public dataand was therefore considered exempt and did not require IRB approval or informed consent.

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Ethics declarations

Review and/or approval by an ethics committee was not needed for this study because the data used in this study came from the Nationwide Inpatient Sample database, which was consistently recognized as the largest public database in the nation. This study used de-identified public data and was therefore considered exempt and did not require IRB approval or informed consent.

CRediT authorship contribution statement

Yuanyuan Huang: Writing – original draft, Formal analysis, Data curation. **Zhennan Wang:** Writing – original draft, Formal analysis, Data curation. **Qinfeng Yang:** Project administration, Methodology, Conceptualization. **Hao Xie:** Writing – review & editing, Conceptualization. **Jingyi Wu:** Project administration, Methodology, Conceptualization. **Keyuan Chen:** Project administration, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e34406.

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