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Blood transfusion trends by disease category in the United States, 2000 to 2014

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ABSTRACT

Background: Better understanding of blood usage rates could identify trends in transfusion practices over time and inform more efficient management.

Methods: Inpatient admissions from the Healthcare Cost and Utilization Project National Inpatient Sample and State Inpatient Databases were analyzed for packed red blood cell (PRBC), plasma, platelet, and whole blood (WB) transfusions. The transfusion rates per admission and per prevalent case were calculated. Prevalence estimates were from the Global Burden of Disease 2017 study (GBD).

Results: From 2000 to 2014, blood usage rates for most causes peaked around 2010. Across all causes, PRBC were the most commonly transfused component, followed by plasma, platelets, and WB. However, the relative use of each type varied by cause. Nutritional deficiencies (1.75 blood product units across all components per admission; 95 % uncertainty interval (UI) 1.62–1.87), neoplasms (0.95; 0.87–1.04), and injuries (0.92; 0.86 – 0.98) had the greatest blood use per admission. Cardiovascular diseases (96.9 units per 1000 prevalent cases; 89.3–105.0) and neoplasms (92.7 units per 1000 prevalent cases; 84.3–101.5) had the greatest blood use per prevalent case. Across all admissions, over three million blood units were saved in 2014 compared to 2011 due to transfusing at a reduced rate.

Conclusions: Blood transfusion rates decreased from 2011 to 2014 in the United States. This decline occurred in most disease categories, which points towards broad strategies like patient blood management systems and disease specific improvements like changes in surgical techniques being effective.

1. Introduction

Blood transfusion is a vital resource used in many clinical services. The underlying diagnoses that lead to blood transfusions are not tracked by blood banks and data on transfusion trends by cause are unknown. In 2012, AABB (formerly known as the American Association of Blood Banks) released transfusion guidelines recommending a threshold hemoglobin level of 7–8 g/dL for stable patients among other recommendations for the safe use of blood components [1]. The recommendations came after evidence from multiple clinical trials supported improved outcomes and decreased cost [2–6]. It has been hypothesized that the adoption of these guidelines and improvements in surgical techniques have led to decreasing transfusion rates in the United States and other high-income countries [7–10]. In recent years, several studies have analyzed blood transfusion trends and specifically studied transfusions rates, amount of blood transfused, and predictors of poor outcomes [7,8,11–14]. In the United States, the U.S. Department of Health and Human Services and AABB conduct periodic surveys of overall blood collection and transfusion in the National Blood Collection and Utilization Survey (NBCUS) and Blood Collection, Utilization, and Patient Blood Management Survey, respectively [15–17]. To our knowledge, no prior study has quantified blood transfusions in the inpatient setting or by population prevalence by diagnostic group, which can improve our understanding of the driving factors behind transfusion practices. Analyzing transfusion rates by prevalent cases has the advantage that these are not affected by changes in admission practices, and can give insight into transfusion practices by diagnostic groups along with more general trends over time.

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2. Material and methods

2.1. Data sources

We used two databases from the Healthcare Cost and Utilization Project (HCUP) to estimate blood transfusion rates in the United States (US) – the National Inpatient Sample (NIS) and State Inpatient Databases (SID) [18,19]. NIS is the largest publicly available inpatient health care database in the US that can be used to make national estimates of adult and pediatric hospital inpatient stays from age zero onwards, and includes up to 15 diagnosis and procedures codes based on the International Classification of Diseases-9th edition (ICD9) per admission (eTable 1). NIS data from 2000 to 2014 were included. SID databases are state-specific datasets containing all inpatient care records in participating states. SID datasets contain both ICD9-coded diagnoses and procedures but also more in-depth service information records such as revenue codes used for billing. Included SID data were from 6 states and spanned five years, from 2003 to 2007 (Table 1). See eTable 2 for further SID metadata. HCUP SID and NIS databases are publicly accessible and anonymized, and institutional review board approval was not required.

2.2. ICD mapping to the Global Burden of Disease study cause list

To analyze blood product usage by disease prevalence at the national level, we used annual prevalence estimates from the Global Burden of Disease (GBD) 2017 study. The GBD is a comprehensive assessment of mortality and morbidity from 354 causes of disease and injury and 84 risk factors for 195 countries and territories from 1990 to 2017, by age and sex [20]. We mapped ICD9 diagnosis codes from NIS and SID to the GBD cause list, which is a hierarchical list of three levels. The primary diagnosis code for each admission was used for cause mapping. See eMethods for a more detailed description of the cause mapping process, and Supplementary Table 1 for the ICD to GBD cause map.

2.3. Quantifying the number of transfusions

In the NIS and SID, transfusions are coded with ICD9 procedure codes, which are a binary indicator of whether or not a transfusion occurred. To calculate the number of blood transfusion units coded per procedure code, we created a scalar based on SID billing data consisting of UB-04 revenue codes. We used revenue codes 0381 (PRBC), 0382 (WB), 0383 (plasma), and 0384 (platelets) to indicate the number of units of blood products transfused during an admission. We winsorized all observations above the 99th percentile of units recorded by revenue code to the 99th percentile to remove outliers (see eMethods for details). We divided the total number of blood product units by the number of admissions with an ICD9 procedure code to get a cause- and component-specific scalar reflecting the units per ICD9 procedure code. We used 9903 (transfusion of WB), 9904 (transfusion of PRBC), 9905 (transfusion of platelets), and 9907 (transfusion of serum/plasma) ICD9 procedure codes. We multiplied this scalar by the number of admissions with a transfusion-related ICD9 procedure code to determine the total number of units transfused in the US for a given year and cause from 2000 to 2014, and divided this by the total number of cause-specific admissions and prevalent cases. To estimate the proportion of admissions where a transfusion was performed, we divided the number of admissions with a transfusion-related revenue code by the number of admissions with a transfusion-related ICD code in SID. We applied this scalar by the number of admissions with a transfusion-related ICD9 code in NIS. See eMethods for equations used to estimate transfusion rates.

Uncertainty was calculated at every step of the process. We bootstrapped SID data 1000 times after selecting admissions with transfusion revenue codes (N = 30,770 admissions across all states and years) to calculate a 95 % confidence interval around the scalar. We used the Survey package in R [21] to calculate standard errors around the number of ICD9 procedure codes for each cause in NIS, which were used to calculate 1000 draws from each cause-specific distribution (eMethods). Finally, we used 1000 draws from the GBD yearly prevalence estimates to calculate the blood usage per prevalent case. 95 % uncertainty estimates were the 2.5th and 97.5th percentile of these draws. All analyses were done using R statistical software [22].

Table 1
Data availability of SIDS revenue-coded data.

State	Years	Number of transfusions coded with revenue codes 0381, 0382, 0383, 0384
Arkansas	2005, 2006, 2007	3484
Massachusetts	2004, 2005, 2006	98
Maryland	2006, 2007	3058
North Carolina	2003, 2004, 2005, 2006, 2007	15,611
Nevada	2003, 2004, 2005, 2006, 2007	7804
Washington	2003, 2004, 2005, 2006, 2007	715

3. Results

3.1. Blood usage over time

We estimated that the number of blood product units transfused in the United States in the inpatient setting increased from 12,777,472 (95 % uncertainty interval (UI) 12,456,534 to 13,109,063) units in 2000 to 22,403,550 (95 % UI 21,871,242 to 22,971,561) units in 2014, with the maximum number of transfusions given in 2011, when 28,567,254 (95 % UI 27,882,294 to 29,273,379) were transfused (Fig. 1). Blood usage varied by component, with packed red blood cells (PRBC) being the most transfused component with 13,809,375 units (95 % UI 13,392,592 to 14,230,114) in 2014, followed by plasma (4,413,870; 95 % UI: 4,191,573 to 4,639,371), platelets (3,022,334; 95 % UI: 2,825,633 to 3,208,294) and whole blood (WB) (153,015; 95 % UI: 125,431 to 188,900).

Across all causes and components, the transfusion rate per admission was lowest in 2000 at 0.30 (95 % UI 0.29 to 0.30) units per admission and greatest in 2011 at 0.64 (95 % UI 0.62 to 0.66) units per admission. In 2014 the rate per admission was equal to 0.39 (95 % UI 0.38 to 0.40) for PRBCs, 0.13 (95 % UI 0.12 to 0.13) for plasma, 0.09 (95 % UI 0.08 to 0.09) for platelets, and 0.005 (95 % UI 0.004 to 0.006) for WB. The blood usage rate per prevalent case across all causes was also lowest in 2000 at 12.7 (95 % UI 12.3–13.1) units per 1000 prevalent cases, and highest in 2011 at 24.9 (95 % UI 24.1–25.6) units per 1000 prevalent cases. In 2014, the transfusion rates per prevalent case by component were equal to 12.7 (95 % UI 12.3–13.2) units PRBCs, 4.3 (95 % UI 4.1–4.5) units plasma, 3.0 (95 % UI 2.8–3.2) units platelets, and 0.19 (95 % UI 0.16 to 0.24) units of WB (Fig. 1).

The transfusion rates per admission and per prevalent case increased through the late-2000′s and then declined for all causes with the magnitude of the change over time varying by cause (eFigs. 1,2). Nutritional deficiencies, which primarily includes iron-deficiency anemia, required the greatest number of blood transfusions per admission, with a minimum rate of 1.7 (95 % UI 1.6–1.9) in 2000 and a maximum rate in 2013 of 2.8 (95 % UI 2.6–3.0) units per admission. Admissions for neoplasms, including hematologic malignancy, had the second highest transfusion rate at 0.95 (95 % UI 0.9–1.0) in 2000 and 1.9 (95 % UI 1.7–2.1) units per admission in 2009. Cardiovascular diseases had the greatest transfusion rate per 1000 prevalent cases, with a minimum rate of 96.9 (95 % UI 89.3–105.0) in 2000 and a maximum rate of 161.1 (95 % UI 148.6–174.3) in 2009. Neoplasms had the second highest transfusion rate per 1000 prevalent cases, with a minimum rate of 92.6 (95 % UI 84.3–101.5) in 2000 and a maximum rate of 143.5 (95 % UI 129.9–158.0) in 2007.

The composition of the type of blood unit transfused varied by cause

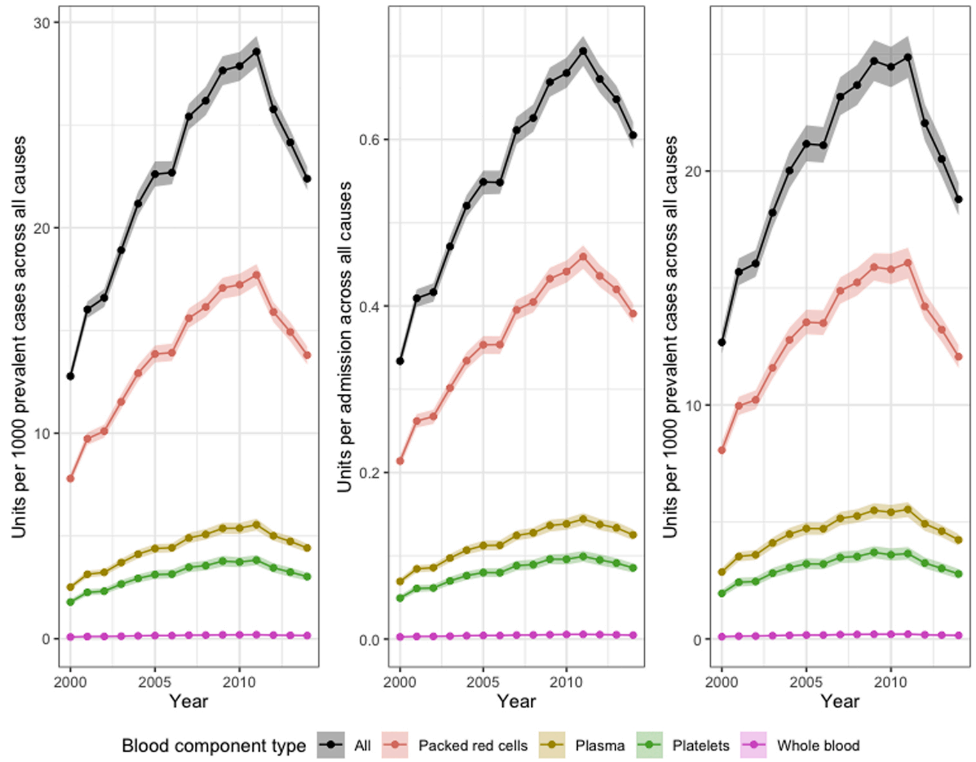

Fig. 1. Blood transfusion trends over time from 2000 to 2014 over all causes, stratified by blood component type.

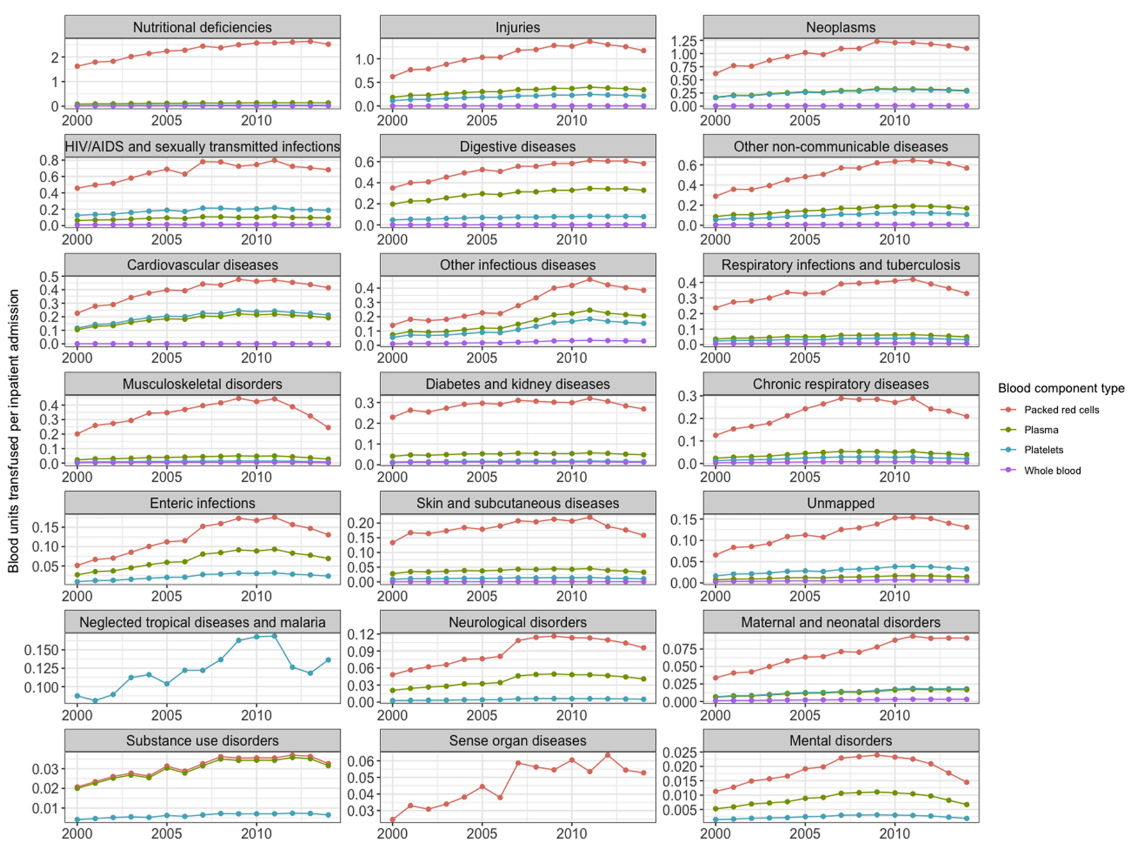

Fig. 2. Trends in blood units transfused per inpatient admission over time from 2000 to 2014 and stratified by blood component type and level 2 GBD cause. See eFig. 3 for 95 % uncertainty interval estimates. Causes are in descending order by transfusion rate per inpatient admission in the year with minimum blood usage, which is 2000 for every cause but "Neglected tropical diseases and malaria," which is 2001.

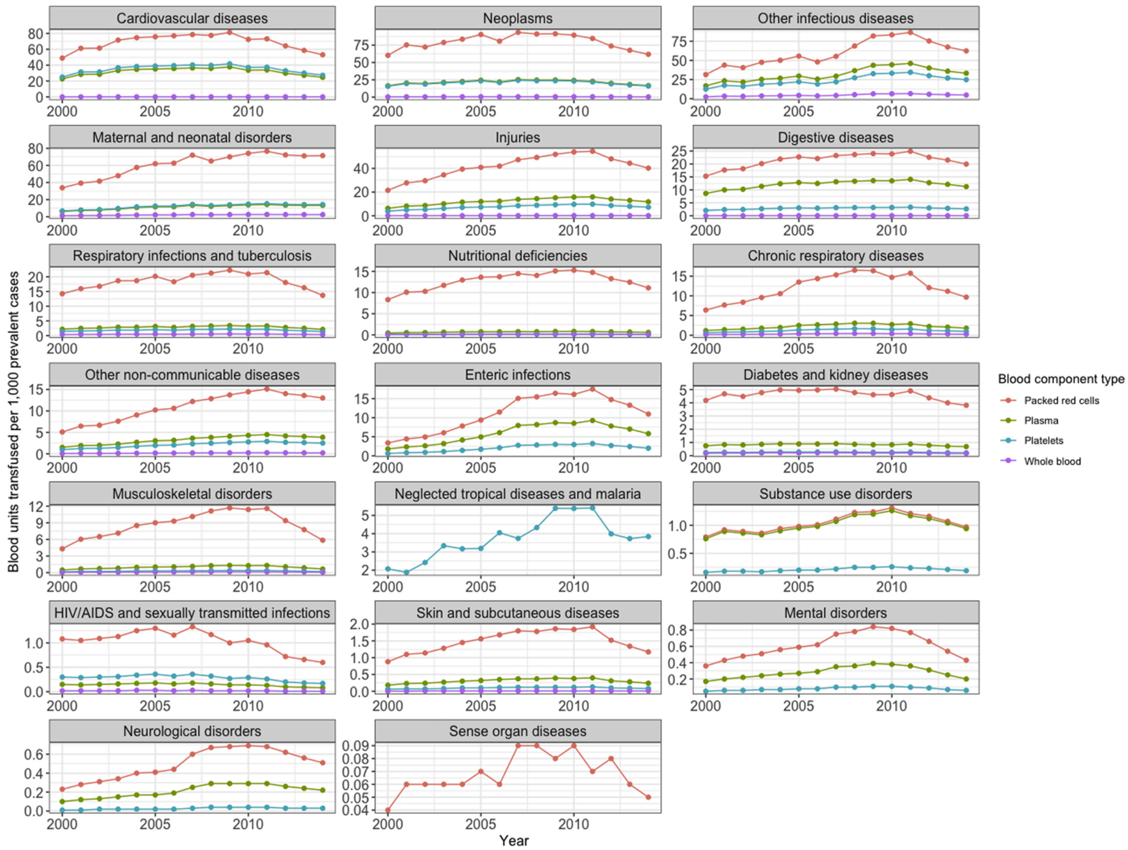

Fig. 3. Trends in blood units transfused per 1000 prevalent cases over time from 2000 to 2014 and stratified by blood component type and level 2 GBD cause. See eFig. 4 for 95 % unicertainty inverval estimates. Causes are in descending order by transfusion rate per prevalent case in the year with minimum blood usage, which is 2000 for every cause but "Neglected tropical diseases and malaria," which is 2001.

(Figs. 2,3). Nutritional deficiencies had the highest relative rates of PRBC transfusions, with 92.9 % (95 % UI 90.2%–95.6%) of the transfused units of blood coming from PRBC transfusions, followed by 4.9 % (95 % UI 2.6%–7.6%) coming from plasma, 1.4 % (95 % UI 0.5%–2.3%) coming from platelets, and 0.8 % (95 % UI 0.2%–1.6%) coming from WB transfusions. Of causes with transfusions for all four component types, digestive diseases had the greatest relative proportion of plasma transfusions, at 33.2 % (95 % UI 31.0–35.4) and cardiovascular diseases had the greatest relative proportion of platelet transfusions, at 25.9 % (95 % UI 23.2%–28.7%).

For each cause, the blood usage rate per admission dropped from their respective peak years to 2014 (Table 2). Across all causes, these savings were equivalent to 3,265,647 units of blood (95 % UI: 3,170,373 to 3,363,989) in 2014. The decrease in blood usage rates from peak year to 2014 and the relative savings across all admissions varied by cause with the most significant savings coming from decreased transfusion rates in the care for injuries and cardiovascular diseases (Table 2).

We analyzed blood transfusion rates at the more specific level three of the GBD hierarchy to understand the variability between more detailed causes. eFigure 5 and eFigure 6 show the 30 causes with the greatest blood usage per inpatient admission and per prevalent case, respectively. Of the 30 causes with the greatest use per inpatient admission, 16 were neoplasms, 5 were cardiovascular diseases, and 4 were digestive diseases, with the remaining causes being other non-communicable diseases, other infectious diseases (acute hepatitis), nutritional deficiency (iron deficiency), and HIV/AIDS. In 2014, ovarian cancer had the greatest inpatient blood use per admission. See Supplementary Table 2 for all level 3 cause usage rates.

4. Discussion

Transfusion rates in the United States have been decreasing since 2010 [23]. This has been attributed to multiple factors including an increased awareness of the safety of restrictive transfusion strategies and the potential harms of overtransfusion [2]. What is not well understood is if this trend differs by transfusion indication. A better understanding of transfusion practices by disease group can help determine the causes behind declining transfusion needs and predict future needs. We used administrative hospital databases to estimate the rate of blood product units used by cause of admission. We also used GBD estimates on disease prevalence for the United States to determine the trends in transfused blood product units per prevalent case. Using prevalent cases as the denominator in the analysis of transfusion rates eliminates the factor of changing admission practices as the reason behind changes in transfusion rates.

We have shown that between 2000 and 2014, blood product transfusions in the United States peaked in 2011 with 0.7 blood product units per inpatient admission and 26 blood product units per 1000 prevalent cases across all diseases. By 2014, the rates had decreased to 0.6 blood product units per admission and 20 blood product units per 1000 prevalent cases. Across the more than 35 million admissions in the United States in 2014, this represented a decrease of 3.3 million blood product units. Importantly, blood usage rates have differentially changed across patient diagnostic categories.

Along with general transfusion practice reforms, there have been specialty-specific guidelines on transfusion decision making. For example, trauma resuscitation practices have changed over the last decade with an emphasis on optimizing massive transfusion protocols [24]. During admission for musculoskeletal disorders, transfusions were likely given in the perioperative setting. The decrease in transfusion

Table 2
Differences in blood product management between 2014 and the year of maximum blood usage and the resulting savings in blood product units.

GBD cause	2014 inpatient admissions	Maximum year	Maximum year units per admission	2014 units per admission	Absolute difference in transfusion rate (95 % UI)	Percentage difference in transfusion rate (95 % UI)	Units saved transfusing at 2014 rate (95 % UI)
Cardiovascular diseases	4,558,012	2009	0.94 (0.88–1.02)	0.82 (0.77–0.89)	0.123 (0.114–0.133)	13.03 (12.64–13.42)	560,841 (519,525–607,043)
Chronic respiratory diseases	1,536,826	2011	0.38 (0.34–0.43)	0.28 (0.25–0.31)	0.105 (0.094–0.118)	27.62 (26.98–28.45)	161,338 (145,040–181,031)
Diabetes and kidney diseases	772,985	2011	0.41 (0.37–0.46)	0.34 (0.31–0.38)	0.066 (0.058–0.075)	16.09 (15.07–17.02)	51,068 (45,026–57,743)
Digestive diseases	3,007,321	2011	1.04 (1–1.08)	0.99 (0.95–1.03)	0.051 (0.047–0.056)	4.93 (4.6–5.28)	154,275 (142,152–167,474)
Enteric infections	214,250	2011	0.3 (0.23–0.39)	0.22 (0.17–0.29)	0.078 (0.059–0.102)	25.8 (24.08–27.7)	16,648 (12,572–21,846)
HIV/AIDS and sexually transmitted infections	60,495	2011	1.14 (0.89–1.45)	0.97 (0.76–1.24)	0.164 (0.119–0.217)	14.39 (11.78–16.82)	9899 (7,222–13,143)
ICDs not mapped to GBD level 2 cause	5,516,850	2011	0.22 (0.2–0.24)	0.18 (0.17–0.2)	0.033 (0.03–0.0370)	15.19 (14.54–15.84)	181,510 (163,674–201,932)
Injuries	2,929,786	2011	2.01 (1.88–2.16)	1.73 (1.61–1.85)	0.289 (0.268–0.310)	14.34 (14.01–14.69)	845,925 (785,146-908,297)
Maternal and neonatal disorders	4,293,890	2011	0.13 (0.12–0.15)	0.13 (0.12–0.14)	0.004 (0.003–0.005)	2.92 (1.97–3.85)	16,606 (11,101–22,383)
Mental disorders	1,566,553	2009	0.04 (0.02–0.06)	0.02 (0.01–0.04)	0.015 (0.009–0.024)	39.55 (37.48–41.65)	23,131 (13,669–38,060)
Musculoskeletal disorders	2,078,592	2009	0.52 (0.47–0.56)	0.28 (0.26–0.31)	0.233 (0.213–0.255)	45.17 (44.82–45.54)	485,001 (441,740–529,941)
Neglected tropical diseases and malaria	10,560	2011	0.19 (0.12–0.32)	0.15 (0.09–0.25)	0.036 (0.016–0.07)	19.13 (12.03–28.56)	376 (172–741)
Neoplasms	1,206,076	2009	1.89 (1.72–2.08)	1.69 (1.54–1.86)	0.201 (0.181–0.224)	10.61 (10.16–11.07)	242,038 (218,488–269,680)
Neurological disorders	818,795	2009	0.17 (0.13–0.23)	0.14 (0.1–0.19)	0.03 (0.021–0.043)	17.61 (15.99–19.27)	24,834 (17,563–35,028)
Nutritional deficiencies	86,040	2013	2.83 (2.65–3.04)	2.71 (2.53–2.91)	0.121 (0.1–0.143)	4.28 (3.63–4.93)	10,423 (8,636–12,298)
Other infectious diseases	191,050	2011	0.93 (0.68–1.26)	0.77 (0.57–1.05)	0.153 (0.111–0.211)	16.57 (15.12–18.02)	29,305 (21,205–40,379)
Other non-communicable diseases	3,881,972	2011	0.97 (0.92–1.02)	0.86 (0.81–0.9)	0.115 (0.108–0.122)	11.86 (11.56–12.16)	446,747 (420,037–472,456)
Respiratory infections and tuberculosis	1,433,245	2011	0.54 (0.46–0.62)	0.42 (0.36–0.48)	0.116 (0.099–0.135)	21.66 (20.97–22.37)	166,706 (142,513–193,596)
Sense organ diseases	60,715	2012	0.08 (0.02–0.18)	0.06 (0.02–0.15)	0.013 (0.003–0.03)	16.85 (9.36–25.24)	778 (167–1,835)
Skin and subcutaneous diseases	698,275	2011	0.28 (0.24–0.33)	0.2 (0.17–0.24)	0.078 (0.066–0.094)	28.05 (26.98–29.18)	54,810 (46,039–65,810)
Substance use disorders	436,530	2012	0.08 (0.06–0.11)	0.07 (0.05–0.09)	0.009 (0.006–0.014)	11.63 (9.14–14.69)	4001 (2,805–5,995)

rates as observed in our study is possibly related to the multimodal approaches aimed to reduce the need for blood transfusions in the perioperative setting like the use of tranexamic acid, treatment of preoperative anemia, optimization of hydration, or minimally invasive surgical techniques [25,26]. Our findings are in line with other analyses that have shown decreased blood product use for orthopedic surgeries [27].

Decreased blood product use for neoplasms may be explained by a platelet transfusion threshold of 10 K becoming more standardized practice . The increased use of less intense treatment approaches and the shift from chemotherapy to targeted agents also could have resulted ina decrease in chemotherapy induced cytopenias [28,29]. While using blood transfusion for the treatment of neoplasms decreased from 2009 to 2014, there was heterogeneity among the different neoplasms at the level 3 GBD cause level.

Improvements in the transfusion practice in cardiovascular diseases between 2011 and 2014 represented the second-greatest decrease in units transfused at 560,841 units saved (Table 2), which could be attributed to increasing evidence of improved outcomes after more restrictive transfusion practices [30]. Subsequent RCTs have supported that restrictive RBC strategies do not produce inferior outcomes compared to liberal transfusion strategies [31,32]. As of 2016, the AABB recommends a restrictive RBC transfusion threshold of 7 g/dL for hemodynamically stable hospitalized patients and 8 g/dL for patients undergoing orthopedic or cardiac surgery and those with preexisting cardiovascular disease and who are not at risk of acute coronary syndrome. For maternal and neonatal disorders, the transfusion trends per admission and per prevalent case increased between 2000 and 2014, which could be attributed to increasing cesarean section rates during this time [33]. Future studies should explore possible drivers of this trend.

When comparing changing trends over time between inpatient admissions and prevalent cases, causes where trends differ are nutritional deficiencies, neoplasms, HIV/AIDS and STIs, digestive diseases, and substance use disorders. For these causes, transfusions by prevalent case decreased more rapidly over recent years than transfusions by inpatient admission, indicating that the prevalent population required less transfusions over time but treatment practices for the admitted population had not changed to the same degree. In HIV/AIDS, the decrease in transfusion requirements for the general population is likely due to improved treatment with anti-retroviral therapy and better viral suppression, leading to fewer cytopenias [34,35]. Conversely, the treatment of nutritional deficiencies increased from 2000 to 2014, which is likely due to only the most severe anemia patients who will require a transfusion being admitted to the hospital. Future studies should investigate possible hypotheses for increasing transfusion rates in anemic patients, such as confounding rates of comorbidities like cirrhosis, diabetes, or kidney diseases in these patients.

This research extends on previous works conducted using HCUP NIS, and found similar transfusion trends over time as Goel et al. and West et al., with relative peaks of transfusion rates for every component in 2011 and a nearly twofold increase from 2000 to 2011 [7,8]. However, in their analyses no adjustment was made to estimate the actual number of units transfused since only procedure codes, rather than revenue codes, were included in the analysis. We were able to use SID to correct for this ascertainment bias, which is why our estimates show a higher proportion of admissions with transfusions. West et al. listed the top 15 conditions that necessitated a red blood cell transfusion in 2013, which we expanded on by looking across GBD causes and leveraging GBD yearly prevalence estimates to estimate blood usage per prevalent case.

Estimates of the National Blood Collection and Utilization Surveys (NBCUS) are available to quantify the units of blood product collected and transfused overall in the US and by broad categories using hospital services as a surrogate for indication [15,16,23]. However, over 50 % of red cells are being used by general surgery and internal medicine services, which does not allow a detailed analysis into the underlying patient diagnosis and likely reason for transfusion [36]. Categorizing transfusions by the reason for admission as we have done in our analysis provides more granular information. Given the known adverse effects of transfusions as well as limited resources, future studies should focus on analyzing the factors determining transfusions as well as the primary reason of admission, like pre-transfusion hemoglobin/hematocrit values and bleeding status. Results should be used to identify areas with further potential to reduce transfusions and to provide insight into future needs.

4.1. Limitations

Our research had a few limitations. In order to estimate the number of units transfused in NIS, we used a correction factor derived from SID. Using the greater amount of depth present in SID datasets to make national estimates with NIS has been done previously [37], but compositional bias is possible if the states or years used from SID do not represent transfusion practices across the rest of the country or time period.

Revenue code usage varied at the hospital level, for example, the 038X codes that describes the specific blood product transfused is not used by hospitals who only report blood processing charges [38]. Despite the sparsity of revenue coded admissions available in certain states, there were a total of 30,770 admissions that included an ICD9 scalar and 038X revenue code, which were enough to create robust correction factors to scale up the mean number of blood units transfused per ICD9 procedure code by disease category. The uncertainty of this scalar adjustment was propagated throughout the analysis and is included in our final transfusion rate estimates. Estimates of blood usage for diseases where there were fewer revenue coded admissions had less precision than diseases where there were a greater number of revenue coded admissions and a more precise scalar. This can be seen in eFig. 1, where disease categories that more commonly require transfusions, such as cardiovascular diseases and neoplasms, have less uncertainty than disease categories that less frequently require transfusions, such as sense organ diseases, which include hearing and vision problems.

Due to insufficient data, we did not attempt to make estimates at the state level, and instead captured the average blood product usage for each disease at the national level. Our results could potentially be biased if hospitals that report blood processing charges only have different transfusion practices than hospitals that also report blood unit usage, however, no evidence supports a systematic difference in clinical practice.

The limited number of years we had access to for SID datasets does not completely overlap with the years of NIS data that we applied the scalar to. This likely led to an overestimation of the blood use scalar at the national level since blood usage was higher in the years of SID data available (2003–2007). However, our estimates of total units of blood products transfused in the United States are similar to estimates from the NBCUS. Our results also only include inpatient administrative records, however, over 90 % of transfusions are given in the inpatient setting and our results should capture most transfusions given in the United States [38].

Using administrative discharge databases like HCUP also has potential limitations, such as a lack of sensitivity in ICD9 coding [39–41]. We only evaluated blood transfusion practices until 2014, because in 2015 the US adopted the ICD10 coding system, and we did not want to introduce any biases due to differences in diagnosis or procedure coding. All of the SID data was ICD9-coded and minimizing the number of differences between the two sets of data was desirable. According to the most recent NBCUS 2017 report, overall blood transfusion trends have declined, but the rate of decline slowed between 2015 and 2017 [15]. Going forwards from 2020, the COVID-19 pandemic may create major disruptions in blood product management in the United States and globally, and changes in blood transfusion rates could be a useful metric to assess the disruption of the pandemic on health service delivery at different levels of the health system [42].

Another limitation was that we could not account for changing patterns in hospitalization over this time, and could not know if changes in blood transfusion were due to changes in the acuity of disease of admitted patients or actual blood transfusion behaviors. Our findings that blood product usage decreased over time across every diagnostic category supports that evolving blood transfusion practices across all causes took place, and our results are not simply due to changing admission patterns. In general, sensitivity and specificity of using administrative claims data for transfusions is high [43,44]. However, there were some outliers with over 100 blood units indicated as transfused in a single admission for which we capped the number of units transfused to the 99th percentile of transfusions of a given component.

5. Conclusion

Blood transfusions rates over the last years have decreased in the United States as in many other high income countries. Our analysis shows that this decline is seen across most disease categories, which points towards broad strategies like patient blood management systems being effective alongside disease specific improvements like changes in surgical techniques. Future research should consider how disease-specific transfusion rates can be used for benchmarking optimal blood transfusion clinical practices. Suggestions from the *Choosing Wisely* campaign and ongoing RCTs emphasizing more restrictive transfusion practices should continue to be implemented in everyday practice [45].

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CRediT authorship contribution statement

Nicholas Roberts: Methodology, Software, Validation, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Spencer L James:** Methodology, Validation, Writing - review & editing. **Meghan Delaney:** Conceptualization, Validation, Writing - review & editing. **Christina Fitzmaurice:** Conceptualization, Validation, Writing - review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare no conflict of interest concerning the materials or methods used in this study.

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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.transci.2020.103012.

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