

Blood Component Utilization, Return, and Expiration Patterns across Four Teaching Hospitals in South Khorasan, Iran: A Multicenter Cross-Sectional Study

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ABSTRACT

Background: Efficient utilization of blood components is a major goal in transfusion medicine, particularly in healthcare systems facing rising demand and limited donor resources. This study evaluated patterns of blood component utilization, return, and expiration in four teaching hospitals in Birjand, South Khorasan, Iran.

Materials and Methods: This multicenter cross-sectional study was conducted over six months (September 2024–March 2025) in hospitals affiliated with Birjand University of Medical Sciences. Data on requests, issuance, transfusion, and return of blood components were extracted from blood bank and hospital information systems. In total, 622 requests and 10,295 issued units were analyzed. Utilization rate, return rate, and crossmatch-to-transfusion (C:T) ratio were calculated. The Kruskal–Wallis test was used to compare return rates among hospitals.

Results: The overall utilization rate was 97.54%, with a return rate of 2.46% and a C:T ratio of 1.05. Significant inter-hospital variability was observed ($P < 0.0001$). Razi Hospital accounted for 71.3% of returned units (return rate: 6.10%), while Iranmehr Hospital achieved near-complete utilization (0.02%). ICUs and CCUs represented over 75% of returns, and leukocyte-reduced red blood cells were the most frequently returned component (64.5%). A total of 261 units were discarded, mainly due to expiration (74.3%), with B+ showing the highest expiration frequency (19.9%).

Conclusion: Although overall transfusion efficiency was high, substantial variability in return and expiration patterns suggests that targeted, data-driven interventions may further reduce wastage and improve patient safety.

Keywords: Blood component utilization; Blood return; Blood expiration; Transfusion efficiency

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INTRODUCTION

Blood transfusion and blood products constitute one of the most essential and widely utilized medical interventions worldwide, playing a critical role in saving the lives of critically ill patients, particularly in surgical wards, intensive care units, and in the management of thalassemia and cancer¹. Despite significant advances in medical science over recent decades, no effective substitute for human blood has yet been developed. Consequently, ensuring a safe and adequate blood supply remains a major challenge for healthcare systems worldwide². Blood and blood products are finite biological resources obtained exclusively from voluntary donors, and their processing requires complex, resource-intensive, and costly technologies³.

Globally, nearly 120 million blood donations are collected annually, highlighting the continuing importance of maintaining adequate and sustainable blood supplies⁴. In Iran, nearly 3 million units of blood and blood products are transfused to patients each year⁵. However, inappropriate ordering, non-utilization, and inefficient inventory practices remain important contributors to blood component wastage in hospital transfusion services^{6,7}. Excessive requisition and subsequent non-use of blood products not only waste financial and human resources but also limit timely access for patients with genuine needs and increase the risk of preventable outdating and discard⁸. Studies conducted in Iran have reported that a considerable proportion of requested blood products remain unused, a problem particularly prevalent in surgical wards and operating rooms⁹. A similar situation has been observed internationally, with high rates of unused requested blood products reported across different countries^{10,11}. These findings underscore that the discrepancy between blood product delivery and consumption is a pervasive global issue requiring focused attention and strategic interventions.

Another major challenge in blood transfusion systems is the wastage of blood components due to expiration, inappropriate ordering, improper storage, and other operational factors. Recent studies have highlighted the substantial contribution of inventory management and component-specific handling practices to blood wastage^{6,7}. Studies in Iran

have reported notable wastage rates of blood products^{12,13}. Internationally, the most common causes of expiration include outdating, positive screening test results for transfusion-transmissible infections, and product quality-related issues^{14,15}. Notably, targeted interventions such as staff training and supply chain optimization have been shown to substantially reduce wastage rates¹⁶.

Although blood product consumption patterns are generally expected to reflect the distribution of blood groups in the population, factors such as ward type, physician request patterns, and prevalent diseases may alter this relationship. Nevertheless, no study in Iran has simultaneously examined the three key indicators of blood product delivery, consumption, and return alongside the causes of expiration and blood group distribution. Given the high volume of blood product requests and consumption in the hospitals affiliated with Birjand University of Medical Sciences in eastern Iran, this study was conducted to evaluate consumption patterns, compare blood product delivery and consumption across different hospitals and wards, identify the main causes of expiration, and analyze consumption patterns by blood group.

MATERIALS AND METHODS

Study Design and Setting

This multicenter cross-sectional study was conducted over a six-month period (September 2024 –March 2025) at four hospitals affiliated with Birjand University of Medical Sciences, located in eastern Iran. The study sites included Valiasr, Razi, Imam Reza, and Iranmehr hospitals. These four hospitals were included because they were the teaching hospitals affiliated with Birjand University of Medical Sciences in Birjand and had accessible and sufficiently complete blood bank records for the study period. Other hospitals in South Khorasan Province were not included because they were outside the predefined study setting and/or did not meet the data accessibility criteria.

Hospital Characteristics

The participating hospitals differed in their clinical services and patient populations. Blood component requests originated from a range of clinical units,

including intensive care units, coronary care units, cardiac surgery, emergency departments, operating rooms, obstetric and gynecologic units, pediatric and neonatal units, chemotherapy, neurology, and general surgery. These differences in clinical services and patient case mix were considered when interpreting inter-hospital variations in blood component utilization and return patterns.

Study Population and Sampling

The study population comprised all patients for whom a request for any blood component was registered in the hospital blood banks during the study period. Because this study was designed as a retrospective census-based operational assessment, all eligible blood component requests recorded during the predefined six-month study period were included. Therefore, no sampling-based sample size calculation was performed. The final sample size was determined by the number of eligible records available during the study period.

Patients were considered eligible if a blood component request had been recorded during the study period and the corresponding data were available in the blood bank registries or the hospital information system. Records identified as duplicate entries, unverified cases, or those lacking essential information such as requesting ward, blood component type, or number of issued units were excluded from the analysis.

Data Collection

Data for this study were retrieved from three primary sources, including blood bank request and utilization logbooks, blood component request forms, and the hospital information system. Collected variables included hospital identification, requesting clinical ward, type of blood component (packed red blood cells, platelets, fresh frozen plasma, and cryoprecipitate), number of units issued to the ward, number of units transfused to patients, number of units returned to the blood bank, patient ABO/Rh blood group (recorded for red blood cell components only), and the number of expired or discarded units together with documented reasons for discard (expiration, thawed but unused, improper storage at the ward level, or non-

utilization). Data collection was performed by trained researchers using standardized pre-designed data extraction checklists to ensure uniformity of data acquisition.

Definitions and Study Indicators

In this study, the number of cross-matched units was considered equivalent to the number of units issued to clinical wards. The following indicators were calculated:

- Utilization Rate (%) = $(\text{Units Transfused} \div \text{Units Issued}) \times 100$
- Return Rate (%) = $(\text{Units Returned} \div \text{Units Issued}) \times 100$
- Crossmatch-to-Transfusion (C:T) Ratio = $\text{Units Issued} \div \text{Units Transfused}$

Statistical analysis

Prior to analysis, data integrity was ensured by cross-checking all entries and excluding duplicate or non-verified records. Statistical analyses were performed using IBM SPSS Statistics version 27 (IBM Corp., Armonk, NY, USA) and GraphPad Prism version 10 (GraphPad Software, San Diego, CA, USA). Categorical variables were summarized as frequencies and percentages. The normality of continuous and count variables was rigorously assessed using both the D'Agostino–Pearson and Shapiro–Wilk tests, which revealed significant deviations from normality for the distribution of returned units across all four hospitals (all $P < 0.0001$), thereby justifying the use of non-parametric approaches. Accordingly, differences in returned units among hospitals were evaluated using the Kruskal–Wallis test, followed by Dunn's post-hoc pairwise comparisons with Bonferroni correction to control for multiple testing; given that six pairwise comparisons were performed, the adjusted significance threshold was set at $P < 0.0083$. For the analysis of discarded/expired units, the chi-square test was used to compare observed versus expected frequencies across hospitals, with all expected cell frequencies exceeding 5, thereby satisfying the test assumptions. To further validate the robustness of our findings, sensitivity analyses, including permutation tests with 10,000 replications, were conducted and confirmed the primary results. A two-

sided P value < 0.05 was considered statistically significant for all primary analyses, unless otherwise specified for multiple comparisons. SPSS was used for all statistical computations, while GraphPad Prism was employed for data visualization and figure preparation.

RESULT

Study Population and Blood Component Utilization

During the six-month study period (September 2024–March 2025), a total of 622 blood component requests were recorded across the four hospitals affiliated with Birjand University of Medical Sciences. Overall, 10,295 units of blood components were issued to clinical wards, of which 10,004 units (97.54%) were transfused to patients, while 293 units (2.46%) were returned unused to the blood bank (Table 1).

The overall crossmatch-to-transfusion (C:T) ratio was 1.05, indicating efficient alignment between issued and utilized blood components at the institutional level.

Considerable variation in utilization patterns was observed among hospitals. Valiasr Hospital accounted for the highest transfusion volume, with 3,596 units transfused during the study period. In contrast, Razi Hospital contributed the largest proportion of returned units ($n = 209$), representing 71.3% of all returned components. Hospital-specific utilization rates ranged from 93.90% at Razi Hospital to 99.98% at Iranmehr Hospital. Correspondingly, return rates varied between 0.02% and 6.10%, while hospital-level C:T ratios ranged from 1.00 to 1.18 (Table 1).

Blood product utilization varied notably across hospitals and ABO blood groups. Valiasr Hospital had the highest consumption (1,336 units, 38.1% of total consumption), followed by Imam Reza Hospital (986 units, 28.1%), Razi Hospital (888 units, 25.3%), and Iran Mehr Hospital (300 units, 8.5%). With respect to ABO blood groups, O+ was the most frequently transfused group (1,025 units, 29.2%), followed by A+ (927 units, 26.4%) and B+ (907 units, 25.8%). The lowest consumption was observed for the AB- blood group (23 units, 0.7%).

Patterns of Returned Blood Components Across Hospitals, Clinical Wards, and Product Types

During the study period, a total of 293 blood component units were returned to the blood bank. The breakdown of returned products across hospitals, clinical wards, and component types is summarized in Table 2 and Figure 1.

Normality testing showed that the distribution of return units was non-normal in all four hospitals. Specifically, the D'Agostino–Pearson and Shapiro–Wilk tests were significant for Emam Reza, Iran Mehr, Razi, and Valiasr hospitals (all $P < 0.0001$), indicating violation of the normality assumption. Therefore, non-parametric analyses were applied. The Kruskal–Wallis test indicated a statistically significant difference in return units across the four hospitals ($\chi^2=26.52$, $P < 0.0001$; $n = 622$). Post-hoc pairwise comparisons using Dunn's test revealed that Razi Hospital exhibited significantly higher return units compared to Emam Reza (adjusted $P = 0.0003$), Iran Mehr (adjusted $P < 0.0001$), and Valiasr (adjusted $P = 0.01$). No statistically significant differences were observed between Emam Reza and Iran Mehr (adjusted $P > 0.99$), Emam Reza and Valiasr (adjusted $P = 0.67$), or Iran Mehr and Valiasr (adjusted $P = 0.12$) (Figure 1A).

Regarding component type, Leukocyte-Reduced Red Blood Cells (LRBC) constituted the predominant category of returned products ($n = 189$, 64.5%), followed by Packed Red Blood Cells, Random Platelets, Cryoprecipitate, and Fresh Frozen Plasma (Figure 1B).

Analysis by clinical ward demonstrated that the Intensive Care Unit (ICU) contributed nearly half of all returned products ($n = 145$, 49.5%), followed by the Coronary Care Unit (CCU) ($n = 78$, 26.6%), whereas other wards accounted for substantially smaller proportions (Figure 1C).

To further elucidate the interaction between hospital and ward characteristics, we examined hospital-ward combinations with the highest return frequencies. The greatest number of returns was observed in the ICU of Razi Hospital (108 units), followed by the CCU of Razi Hospital (78 units) and the ICU of Valiasr Hospital (37 units). Notably, these three hospitals–ward combinations collectively accounted for more than 75% of all returned blood

products, highlighting critical hotspots for targeted intervention.

Table 1: Blood Component Requests, Issuance, Transfusion, and Return Rates across Four Study Hospitals (September 2024–March 2025)

Hospital	Requests (n)	Units Issued	Units Transfused	Units Returned	Utilization Rate (%) ¹	Return Rate (%) ²	C:T Ratio ³
Valiasr	262	3671	3596	77	98.20	1.86	1.02
Razi	149	2969	2760	209	93.90	6.10	1.18
Imam Reza	124	1579	1573	6	98.93	1.07	1.00
Iranmehr	87	2076	2075	1	99.98	0.02	1.00
Total	622	10,295	10,004	293	97.54	2.46	1.05

¹Utilization Rate = (Transfused ÷ Issued) × 100

²Return Rate = (Returned ÷ Issued) × 100

³C: T Ratio = Issued ÷ Transfused

*Data represent aggregate counts from hospital blood bank registries during the study period.

Table 2: Breakdown of Returned Blood Products by Hospital, Clinical Ward, and Component Type

Category	Subcategory	Returned Units (n)	Percentage (%)
Hospital	Razi	209	71.3
	Valiasr	77	26.3
	Imam Reza	6	2.0
	Iran Mehr	1	0.3
Clinical Ward	ICU	145	49.5
	CCU	78	26.6
	Cardiac Surgery	20	6.8
	Operating Room	19	6.5
	Emergency	14	4.8
	Other wards*	17	5.8
Component Type	LRBC	189	64.5
	Packed RBC	43	14.7
	Random Platelets	26	8.9
	Cryoprecipitate	20	6.8
	FFP	15	5.1
Total		293	100.0

Other wards include Maternity (4), Gynecologic (4), Gynecologic Surgery (3), NICU/PICU (1), Pediatric (1), Chemotherapy (1), Neurology (1), and General Surgery (1).

CCU = Coronary Care Unit; FFP = Fresh Frozen Plasma; ICU = Intensive Care Unit; LRBC = Leukocyte-Reduced Red Blood Cells; RBC = Red Blood Cells

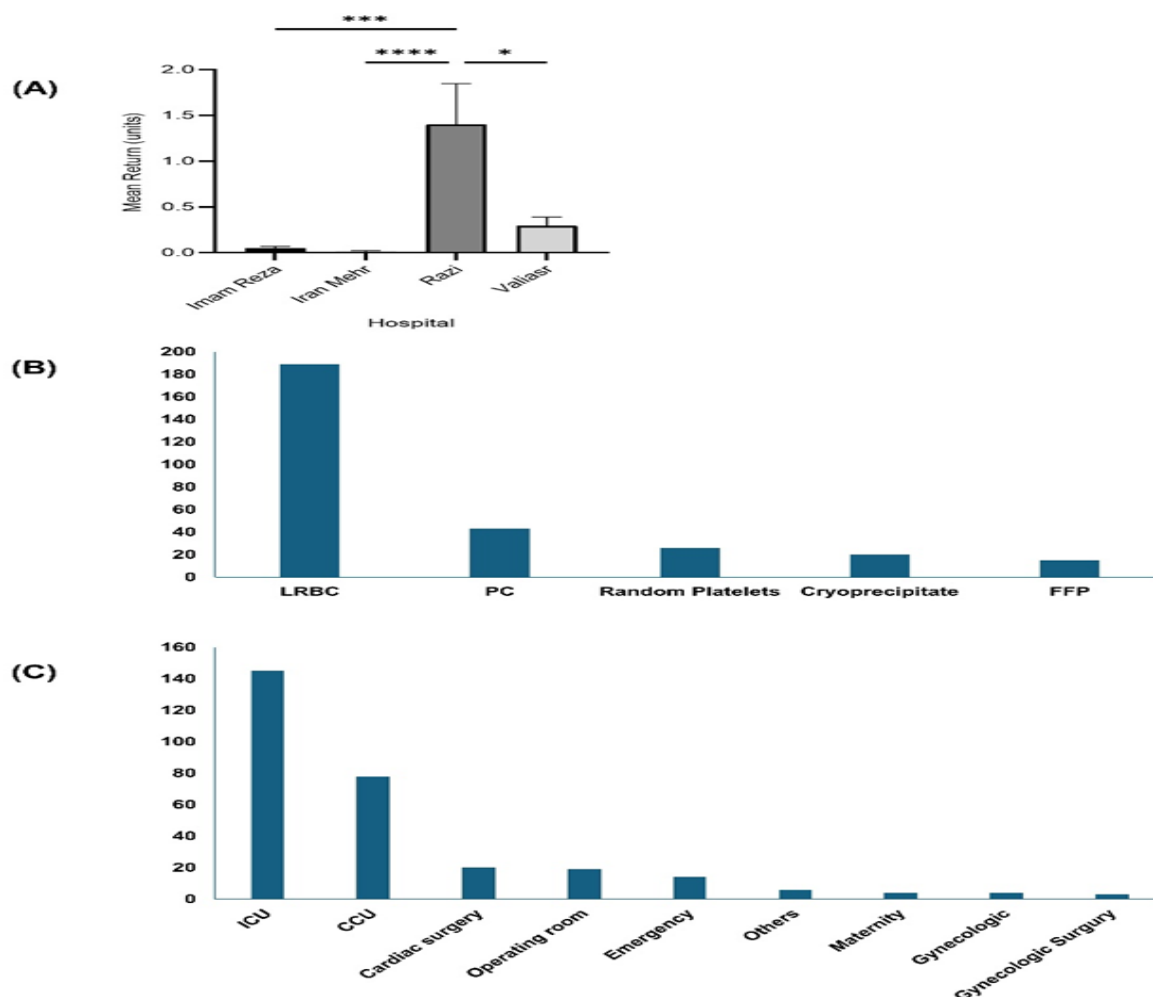


Figure 1. Distribution and statistical comparison of returned blood components across hospitals, product types, and clinical wards **(A)** Mean return units by hospital, displayed with error bars and pairwise significance markers (* $P < 0.05$, *** $P < 0.001$, **** $P < 0.0001$) based on Dunn's post-hoc test with Bonferroni correction. **(B)** Total number of returned units categorized by blood component type. **(C)** Total number of returned units by requesting clinical ward; only wards contributing ≥ 10 returned units are shown individually, while remaining wards are grouped as "Others". CCU, Coronary Care Unit; FFP, Fresh Frozen Plasma; ICU, Intensive Care Unit; LRBC, Leukocyte-Reduced Red Blood Cells; PC, Packed Red Blood Cells.

Expired and Discarded Blood Products: Frequency, Causes, and Patterns

During the study period, a total of 261 blood component units were discarded due to expiration or other documented disposal-related reasons. The breakdown of discarded products across hospitals, component types, disposal reasons, and ABO blood groups is summarized in Table 3. Valiasr Hospital recorded the highest number of discarded units (93 cases, 35.6%), followed by Imam Reza (67 cases, 25.7%), Iran Mehr (57 cases, 21.8%), and Razi Hospital (44 cases, 16.9%).

Regarding component type, platelets (PLT) accounted for the largest proportion of discarded blood products (n = 135, 51.7%), followed by fresh frozen plasma (FFP; n = 83, 31.8%), leukocyte-reduced red blood cells (LRBC; n = 26, 10.0%), and packed cells (PC; n = 17, 6.5%).

Regarding the causes of disposal, outdating was the predominant reason (194 cases, 74.3%), followed by thawed but unused products (38 cases, 14.6%) and unused products (25 cases, 9.6%). Other causes accounted for 4 cases (1.5%), including rupture of an FFP bag (n = 2), improper storage in the unit (n = 1), and discrepancy (n = 1).

The chi-square test revealed a statistically significant difference in the distribution of discarded units

among hospitals ($\chi^2 = 19.812$, $df = 3$, $P < 0.001$), indicating that the observed distribution was not uniform across the four hospitals. Compared with the expected frequencies, Valiasr Hospital had a higher number of discarded units than expected, whereas Razi Hospital had fewer than expected. Iran Mehr also had fewer discarded units than expected, while Imam Reza was relatively close to the expected frequency. All expected cell frequencies were above 5, satisfying the assumptions of the chi-square test.

Analysis of ABO blood groups showed that B-positive (B+) accounted for the highest number of discarded units (n = 52, 19.9%), followed by O-negative (O-) and A-positive (A+) (each n = 48, 18.4%). The AB-negative (AB-) group had the lowest frequency (n = 2, 0.8%) (Table 3).

Monthly analysis was available for Valiasr and Razi hospitals. The highest number of discarded units was observed in Mehr (October; n = 38), followed by Azar (December; n = 28) and Aban (November; n = 23). However, given the limited six-month observation period and incomplete monthly data for some hospitals, these findings should not be interpreted as definitive evidence of seasonal variation.

Table 3: Comprehensive breakdown of discarded blood products by hospital, component type, disposal reason, and ABO blood group (N = 261).

Variable	Category	Count (n)	Percentage (%)
Hospital	Valiasr	93	35.6
	Imam Reza	67	25.7
	Iran Mehr	57	21.8
	Razi	44	16.9
Disposal Reason	Expired (Outdating)	194	74.3
	Thawed / Not Used	38	14.6
	Not Used	25	9.6
	Other*	4	1.5
Component Type	PLT	135	51.7
	FFP	83	31.8
	LRBC	26	10.0
	PC	17	6.5
ABO Blood Group	O+	36	13.8
	O-	48	18.4
	A+	48	18.4
	A-	35	13.4
	B+	52	19.9
	B-	23	8.8
	AB+	17	6.5
	AB-	2	0.8
	Total	261	100

*Other includes: Rupture of FFP bag (n=2), Improper storage (n=1), and Discrepancy (n=1).

DISCUSSION

In this multicenter study evaluating 622 blood component requests across four teaching hospitals in South Khorasan, Iran, overall transfusion efficiency was high, with a crossmatch-to-transfusion (C:T) ratio of 1.05 and an overall blood return rate of only 2.46%. Nevertheless, considerable inter-hospital variation was observed. Razi Hospital accounted for 71.3% of all returned blood units, whereas Iranmehr Hospital achieved near-complete utilization with a return rate of only 0.02%. Intensive Care Units (ICUs) and Coronary Care Units (CCUs) together contributed to more than 75% of all returned blood products, and leukoreduced red blood cells (LRBCs) represented the predominant returned component (64.5%). Notably, the ICU and CCU of Razi Hospital and the ICU of Vali-e-Asr Hospital alone accounted for more than three-quarters of all returned blood products, identifying these units as critical hotspots for targeted intervention.

Regarding blood product expiration, 261 blood units were discarded during the study period. Vali-e-Asr Hospital had the highest number of expired units (93 cases; 35.6%), while Razi Hospital had the lowest (44 cases; 16.9%). Expiration due to shelf-life completion was the most common cause (194 cases; 74.3%), followed by thawed but unused products (14.6%) and unused products (9.6%). Among blood groups, B-positive had the highest frequency of expiration (52 cases; 19.9%), whereas AB-negative had the lowest (2 cases; 0.8%). Monthly analysis showed that the highest number of discarded units was recorded in Mehr (October; $n = 38$). However, the limited six-month observation period and incomplete monthly data for some hospitals preclude firm conclusions regarding seasonal patterns.

The observed C:T ratio of 1.05 compares favorably with international standards and reflects highly efficient blood utilization practices. Whitaker et al. (2016) reported C:T ratios ranging from 1.2 to 2.5 in hospitals across the United States¹⁷, while substantially higher ratios have been documented in resource-limited settings, such as 2.1 in Ethiopia¹⁰. Compared with previous Iranian studies, our findings also indicate progressive improvement over time. Anabi Sarab et al. reported a C:T ratio of 1.5 in Vali-e-Asr Hospital¹⁸, and Najafzadeh et al. reported a

ratio of 1.35 in the same center¹⁹. In contrast, the present study demonstrated a C:T ratio of 1.02 for Vali-e-Asr Hospital, suggesting gradual enhancement in transfusion practices and blood utilization policies over time.

Similarly, the overall blood return rate of 2.46% was substantially lower than the 32% reported in four hospitals in Tehran by Chegini et al.²⁰, as well as the 6–16% wastage rates reported in other Iranian centers²¹. These comparisons indicate that the studied hospitals generally exhibit acceptable transfusion management performance; however, the persistent variability among institutions suggests that further optimization remains achievable.

The clinical significance of these findings becomes particularly evident when considering patient safety and targeted resource allocation. The observation that only three hospital-ward combinations accounted for more than 75% of all returned blood products suggests that focused interventions in these specific units may be substantially more effective than generalized hospital-wide strategies. In the ICU and CCU of Razi Hospital, revising blood ordering practices, including reassessment of the necessity of all crossmatched units and substitution of full crossmatching with Type and Screen protocols for stable patients could potentially reduce return rates by more than 70%. Since unnecessary transfusions have been associated with approximately a 1.5% increase in mortality risk per unit transfused²², minimizing excessive blood ordering may directly improve patient outcomes.

An important finding of this study is the inverse relationship between blood return and blood expiration rates, indicating two distinct operational and clinical problems. In Razi Hospital, the coexistence of a high return rate (6.10%) with a relatively low expiration rate (16.9%) suggests excessive precautionary ordering and over-crossmatching of blood products. Such practices may waste laboratory resources and delay blood availability for patients in genuine need. Kiekkas et al. demonstrated that delays in blood transfusion among critically ill patients are associated with increased mortality²³. Conversely, in Vali-e-Asr Hospital, the low return rate (1.86%) combined with the highest expiration rate (35.6%) indicates more

appropriate clinical ordering but inefficient inventory management, leading to product expiration before utilization. This observation aligns with findings by Ramirez et al., who reported that excessive reserve stock increases expiration rates²⁴. Also This pattern is consistent with the broader challenge of balancing adequate blood availability against wastage in hospital blood-bank inventory management. Recent modeling and operational studies have emphasized the importance of demand forecasting, inventory optimization, and redistribution policies in reducing expiration-related losses^{25,26}. Taken together, these findings suggest that different hospitals may require different approaches to reducing blood wastage, although the specific underlying causes cannot be established from the available data. The concentration of more than 75% of returned blood products within ICU and CCU settings reflects a well-recognized clinical challenge. Critically ill patients often experience unpredictable clinical deterioration, prompting physicians to order blood products preemptively to avoid delays during emergencies. Sadana et al. reported that 68% of blood requests in ICUs were outside standard transfusion protocols²⁷. Although such behavior is understandable from a clinical perspective, it inevitably increases blood wastage. Similarly, Alsughayyir et al. reported that ICUs accounted for a substantial proportion of blood returns²⁸, consistent with our findings.

Recent evidence has similarly identified intensive and high-dependency care settings as important contributors to returned blood components, highlighting the role of clinical status assessment and ordering practices in preventable returns²⁹.

From a managerial perspective, these findings emphasize that ICU and CCU wards should represent the primary targets for blood utilization interventions. Strategies such as daily review of pending crossmatched units, implementation of electronic alerts for units approaching expiration, and revision of transfusion protocols for clinically stable patients may significantly reduce wastage and improve blood bank efficiency.

The predominance of LRBCs among returned blood products (64.5%) appears largely attributable to prevailing clinical ordering patterns. Packed red

blood cells are the most frequently requested blood component and are often ordered prophylactically for surgical procedures, despite many patients ultimately not requiring transfusion. Nikpour et al. (2013) demonstrated that cardiac surgery wards generated the highest volume of blood requests (22%)³⁰, and approximately 35% of prophylactically ordered red cell units were never transfused. Recent large-scale hospital data have also demonstrated substantial variation in wastage according to blood component type, emphasizing the importance of component-specific inventory and utilization strategies⁷. These findings suggest that a substantial proportion of returned LRBCs results not from unexpected clinical changes but rather from precautionary over-ordering. Consequently, surgical and critical care teams should increasingly rely on evidence-based transfusion thresholds such as hemoglobin levels below 7–8 g/dL rather than empirical ordering practices. Previous studies have shown that implementation of restrictive transfusion protocols can reduce unnecessary transfusions by 30–50% without adversely affecting patient outcomes.

The predominance of expiration-related wastage (74.3%) further indicates that inefficient inventory management, rather than inappropriate clinical ordering alone, constitutes a major contributor to blood wastage. Vali-e-Asr Hospital, despite having the lowest return rate, exhibited the highest expiration rate, suggesting maintenance of excessive precautionary inventory to ensure blood availability. This reflects the classical challenge of balancing blood availability against wastage in transfusion medicine. The consequences of blood expiration are clinically and economically substantial, particularly during periods of reduced blood donation such as the COVID-19 pandemic¹⁰. Accordingly, Vali-e-Asr Hospital would likely benefit from improved demand forecasting and inter-hospital redistribution systems, whereas Razi Hospital requires interventions focused on physician education and optimization of blood ordering behavior.

Another clinically noteworthy observation was that B-positive blood group demonstrated the highest expiration frequency (19.9%), whereas O-positive—the most frequently transfused blood group (29.2%

of all transfusions)—ranked only fourth in expiration frequency (13.8%). This finding suggests that inventory management for highly demanded blood groups may be more efficient than for moderately prevalent groups. Our findings differ from those of Ravikanth et al., who identified O-positive blood as the leading contributor to wastage in India³¹, likely reflecting regional differences in blood demand and inventory practices. This observation may have practical implications for blood bank management, particularly during periods of high demand when shortages of B-positive blood products may occur. Yadala et al. (2025) similarly reported that platelets (50%) and O-positive blood (34%) accounted for the majority of blood wastage in their study¹³.

The observed increase in blood product expiration during October has important implications for seasonal blood inventory planning. Blood bank managers should anticipate these temporal fluctuations and adapt ordering and redistribution strategies accordingly to minimize seasonal wastage. Overall, our findings suggest that blood management policies should move beyond generalized institutional strategies toward targeted, data-driven interventions. The World Health Organization estimates the production cost of each blood unit at approximately 40 USD; therefore, the combined 293 returned units and 261 expired units identified in this study represent direct losses exceeding 22,000 USD. Beyond economic considerations, patient safety implications are equally important. Previous studies have linked returned blood products with bacterial contamination and bacteremia in critically ill patients, while every expired blood unit represents a lost opportunity to save a patient's life³².

Based on these findings, several practical recommendations can be proposed. For Razi Hospital, implementation of Maximum Surgical Blood Ordering Schedule (MSBOS) protocols in ICU and CCU wards, provision of monthly physician feedback regarding blood return rates, and use of Type and Screen protocols instead of full crossmatching for clinically stable patients may help improve transfusion efficiency and reduce unnecessary crossmatching^{33,34}. For Vali-e-Asr Hospital, adoption of first-in-first-out (FIFO) inventory systems, enhanced demand forecasting

using historical data, and establishment of inter-hospital redistribution agreements for near-expiry blood units are recommended. For both hospitals, daily review of pending crossmatched units in ICUs, immediate cancellation of unnecessary requests, and continuous physician education regarding evidence-based transfusion thresholds could substantially reduce unnecessary blood requests and wastage.

Strengths and Limitations

The present study possesses several important strengths. Its multicenter design provides a realistic assessment of transfusion practices across different clinical environments. Simultaneous evaluation of returned blood products, expiration patterns, and ward-level performance offers a comprehensive systems-based perspective and enables identification of specific operational weaknesses that may serve as targets for quality improvement initiatives.

Nevertheless, several limitations should be acknowledged. First, the retrospective nature of the study limited evaluation of physician decision-making processes and detailed clinical indications for transfusion requests. Second, the study was conducted over a six-month period and included only four teaching hospitals affiliated with Birjand University of Medical Sciences; therefore, the findings may not fully capture longer-term or seasonal variations in blood component demand, utilization, and expiration. Third, limited clinical data prevented comprehensive assessment of transfusion appropriateness. In addition, the participating hospitals did not necessarily serve identical patient populations, and differences in clinical case mix may have contributed to the observed inter-hospital variation in blood component utilization and return rates. Furthermore, expiration data from Imam Reza and Iranmehr hospitals were available only as aggregated six-month totals, restricting monthly trend analysis in these centers. Finally, differences in data recording systems among hospitals may have affected data completeness and consistency. Accordingly, the findings should primarily be interpreted as an operational assessment of the participating hospitals in Birjand, South Khorasan, rather than as representative of all hospitals in the

province or of eastern Iran as a whole. Longer-term studies involving a broader range of hospitals and more comprehensive clinical data are warranted to provide more representative regional estimates.

CONCLUSION

In conclusion, although overall blood utilization efficiency across the studied hospitals was high, significant variability persisted in both return and expiration patterns. Blood wastage was primarily concentrated within specific hospital-ward interfaces rather than distributed uniformly across institutions. These findings support a shift toward targeted, data-driven transfusion stewardship strategies emphasizing hotspot-focused interventions and adaptive inventory management. Adoption of such approaches may further optimize blood component utilization, reduce preventable wastage, and strengthen sustainability of transfusion services within modern healthcare systems.

CONFLICT OF INTERESTS

The authors declare that they have no competing interests

Ethical Considerations

This study was approved by the Research Ethics Committee of Birjand University of Medical Sciences (ethics code: IR.BUMS.REC.1403.268). All patient information was kept confidential, and identification codes were used instead of patient names. Due to the retrospective nature of the study and the use of routine blood bank data, informed consent was waived by the Ethics Committee.

Consent for publication

Not applicable.

Data availability

All data generated or analyzed during this study are included in this published article. Additional data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Abbreviations

Abbreviation	Full Term
ABO	ABO blood group system
CCU	Coronary Care Unit
C:T Ratio	Crossmatch-to-Transfusion Ratio
FFP	Fresh Frozen Plasma
HDFN	Hemolytic disease of the fetus and newborn
IAT	Indirect antiglobulin test
ICU	Intensive Care Unit
LRBC	Leukocyte-Reduced Red Blood Cells
NICU	Neonatal Intensive Care Unit
PICU	Pediatric Intensive Care Unit
PLT	Platelets
PRBC / PC	Packed Red Blood Cells
RBC	Red Blood Cells
RFLP	Restriction fragment length polymorphism
RHD Ψ	Pseudogenized RHD alleles
Rh	Rhesus blood group system

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