British Journal of Hospital Medicine

Br. J. Hosp. Med. (Lond) **2026**; 87(11): 52785
https://doi.org/10.31083/BJHM52785

Article

Retrospective Analysis of Simplified Compatibility Testing Process and Transfusion Adverse Reactions in Emergency Blood Transfusion

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Academic Editor: Jessie Welbourne
Submitted: 10 April 2026 Revised: 8 August 2026 Accepted: 27 August 2026 Published: 12 November 2026

Abstract

Aims/Background: Emergency transfusion is a critical life-saving intervention for patients with severe trauma, massive hemorrhage, or hemorrhagic shock. To balance timeliness and safety, simplified compatibility testing protocols are frequently employed in clinical practice; however, whether such approaches increase the risk of transfusion-related adverse reactions remains controversial. This study aimed to retrospectively evaluate the safety and timeliness of a simplified compatibility testing protocol in emergency red blood cell transfusion, with a focus on its association with the incidence of transfusion-related adverse reactions. **Methods:** Clinical data were collected from patients who received emergency blood transfusions at Haiyan People's Hospital between January 2023 and June 2025; patients with known irregular antibodies were excluded. Events were categorized into two groups based on the compatibility testing protocol used: the control group (conventional testing protocol, n = 1856) and the observation group (simplified testing protocol, n = 1348). The department of transfusion administration, testing time, blood transfusion initiation time, and incidence and severity of transfusion adverse reactions (monitored within 24 hours after transfusion) were compared between the two groups. Univariable logistic regression analysis was performed to identify variables associated with transfusion-related adverse reactions. **Results:** The testing time in the observation group was significantly shorter than that in the control group ($p < 0.001$), and the blood transfusion initiation time was significantly shorter in the observation group than in the control group ($p < 0.001$). A total of 41 cases (1.28%) of adverse reactions occurred in the two groups of patients. The distribution of each type of adverse reaction did not differ significantly between the two groups (all $p > 0.05$), and the severity distribution of adverse events was comparable ($p = 0.396$). Allergic reactions accounted for the largest proportion of adverse reaction events in both groups (48.39% and 36.36%, respectively). Univariate logistic regression analysis showed that there was no significant correlation between the variables and transfusion adverse reactions (all $p > 0.05$). **Conclusion:** In the context of excluding patients with known irregular antibodies, the simplified compatibility testing process—comprising ABO blood group system (ABO) forward and reverse grouping/Rhesus blood group system (Rh) typing, saline medium cross-matching, and polybrene cross-matching—can significantly shorten the testing time and blood transfusion initiation time. Additionally, our findings showed no evidence that the simplified process could increase the risk of transfusion-related adverse reactions.

Keywords: emergency blood transfusion; compatibility testing; transfusion adverse reactions; timeliness; safety assessment; simplified protocol

1. Introduction

Emergency blood transfusion is one of the core interventions in the management of critically ill patients [1,2,3]. It rapidly replenishes blood volume and oxygen-carrying red blood cells, restores effective circulating blood volume, increases blood pressure and tissue perfusion pressure, and prevents multiple organ ischemia-hypoxia necrosis induced by circulatory failure [4]. Blood transfusion support for patients with severe trauma is crucial during emergencies because a delay in transfusion exceeding 10 minutes significantly increases the patient's risk of mortality [5].

Transfusion compatibility testing is a critical procedure that ensures transfusion safety, aimed at avoiding hemolytic transfusion reactions caused by ABO blood group system (ABO) or Rhesus blood group system (Rh) incompatibility and reducing the risk of adverse reactions [6]. The routine transfusion compatibility testing process consists of five steps: forward and reverse typing of ABO/Rh blood group, saline medium cross-matching, irregular antibody screening, polybrene cross-matching, and antihuman globulin cross-matching, with the entire process taking approximately 30 minutes [7]. In emergency rescue scenarios, while this process can minimize the risk of blood group incompatibility, the excessively long testing time may delay transfusion and cause patients to miss the optimal treatment window. To address this contradiction, clinical practice has gradually explored the adoption of a simplified testing process that omits the irregular antibody screening step to facilitate immediate transfusion after rapid ABO/Rh typing, combined with saline medium cross-matching and polybrene cross-matching [8]. However, the safety of the simplified process remains controversial. Irregular antibody

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screening is an important component of routine testing; approximately 1%–3% of patients have irregular antibodies in the Rh, Kell, MNSs blood group system (MNSs), and other blood group systems. Failure to detect such antibodies may trigger delayed hemolytic transfusion reactions [9]. A study suggests that the simplified process may increase the risk of adverse reactions due to the omission of irregular antibody testing [10], while another study has confirmed that in emergency settings, the incidence of adverse reactions in the simplified process is not significantly different from that in the routine process [11].

This study retrospectively analyzed the clinical data of emergency transfusion patients who underwent different compatibility testing processes, comparing the testing time, blood transfusion initiation time, and incidence of adverse reactions between a control group receiving the routine process and an observation group receiving the simplified process to evaluate the safety of the simplified process and its impact on the promptness of blood transfusion. The research results aim to provide a reference for clinical decision-making during emergency transfusion, offer practical guidance for medical institutions to optimize emergency transfusion processes and balance treatment efficiency with transfusion safety.

2. Methods

2.1 Study Subjects

A total of 3204 emergency red blood cell transfusion events between January 2023 and June 2025 were retrospectively included. The inclusion criteria were: (1) patients requiring emergency blood transfusion due to severe trauma, massive hemorrhage, hemorrhagic shock, or other conditions; and (2) availability of complete clinical data. The exclusion criteria were: (1) patients undergoing elective surgical transfusion; and (2) patients with known irregular antibodies. Events were divided into a control group (1856 cases) and an observation group (1348 cases) based on the transfusion compatibility testing process.

2.2 Blood Compatibility Testing Process and Transfusion Protocols

2.2.1 Control Group (Routine Testing Process)

(1) ABO forward and reverse grouping and Rh(D) typing: The microcolumn gel method was used with ABO forward and reverse typing and Rh blood type detection cards (Aikang Company, Shenzhen, China). Testing was performed strictly in accordance with the manufacturer's instructions to determine the patient's ABO blood group and Rh(D) blood group.

(2) Irregular antibody screening: The microcolumn gel antiglobulin method was adopted using antibody screening cells (Shanghai Blood Biotechnology Co., Ltd., Shanghai, China) to detect the presence of irregular antibodies in the patient's serum. If antibody screening was positive, further antibody identification was conducted, and blood products without the corresponding antigens were selected for cross-matching.

(3) Antihuman globulin cross-matching: Major cross-matching was performed between the patient's serum and the donor's red blood cells, and minor cross-matching between the donor's serum and the patient's red blood cells using anti-human globulin test kit (Shanghai Blood Biotechnology Co., Ltd., Shanghai, China). Agglutination or hemolysis reactions were assessed, and transfusion was performed only if cross-matching results indicated compatibility.

(4) Polybrene cross-matching: For major cross-matching, the patient's serum is tested against the donor's red blood cells; for minor cross-matching, the donor's serum is tested against the patient's red blood cells. Polybrene reagent sourced from Beso Biotechnology Co., Ltd. (Zhuhai, China) was used. Agglutination or hemolysis reactions were assessed, and only blood units that demonstrated compatibility in cross-matching were transfused.

(5) Saline medium cross-matching: The patient's serum and the donor's red blood cells are subjected to cross-matching in a normal saline medium. Only samples showing no agglutination in saline medium proceeded to the subsequent cross-matching steps; transfusion was performed only after all compatibility tests indicated compatibility.

2.2.2 Observation Group (Simplified Testing Process)

(1) Rapid ABO forward and reverse grouping and Rh(D) typing: ABO blood type and Rh (D) blood type identification were completed using the test tube method for forward and reverse typing. Antisera (e.g., anti-A, anti-B), reagent red blood cells (e.g., A1, B, O), and anti-D antibody reagent (immunoglobulin M [IgM]; Beso Biotechnology Co., Ltd., Zhuhai, China) were used for blood group identification. Except for the anti-D, other reagents were acquired from Shanghai Blood Biomedical Co., Ltd. (Shanghai, China).

(2) Saline medium cross-matching: Same as above.

(3) Polybrene cross-matching: Same as above.

Patients' conditions were dynamically assessed. All patients received appropriate sedation and analgesia, with continuous monitoring of electrocardiogram, blood pressure, and blood oxygen saturation as routine. Before blood group confirmation, patients requiring urgent transfusion were administered O-type RhD-negative leukoreduced suspended red blood cells. After blood group confirmation by respective methods, the patient should receive ABO/RhD-compatible red blood cell units as soon as possible. The transfusion rate was adjusted according to the patient's condition. Vital signs were closely monitored during transfusion and within 24 hours post-transfusion, and transfusion adverse reactions (such as fever, rash, dyspnea, and hemoglobinuria) were recorded. Delayed reactions beyond this observation window were not systematically evaluated.

2.3 Collection of Indicators

Clinical data were collected through the medical record system and the blood transfusion management system.

(1) Baseline indicators: Sex, age, comorbidities (hypertension, diabetes mellitus, cardiovascular diseases, and other), department of transfusion administration, and total blood transfusion volume (the number of red blood cell units transfused in a single blood transfusion event).

(2) Testing time: The duration from blood sample receipt to completion of compatibility testing and issuance of the cross-matching report.

(3) Blood transfusion initiation time: The duration from the time when the physician issues a prescription for routine or simplified blood transfusion compatibility testing to the time when the patient actually begins the transfusion of ABO/RhD-compatible red blood cells. The time of emergency O-type blood transfusion administered prior to blood group confirmation was not included in this calculation.

(4) Transfusion adverse reactions: Allergic reactions (skin itching, urticaria, anaphylactic shock), nonhemolytic fever reactions (increased body temperature, chills), transfusion-related circulatory overload (chest tightness, accelerated heart rate, dyspnea, orthopnea), and others. Severity of transfusion-related adverse events was classified according to the grading standards established by the China Society of Blood Transfusion: Grade IV refers to an adverse event that leads to patient death; Grade III refers to an adverse event causing fatal harm to the patient; Grade II refers to an adverse event that causes severe damage, resulting in permanent or significant disability or loss of working ability for the patient; Grade I refers to an adverse event that causes no harm or only minor harm and from which the patient can fully recover without any treatment [12,13]. The number of transfusion-related adverse reactions in both groups was recorded, and the distribution of their severity was compared between groups.

2.4 Statistical Analysis

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Normality of continuous variables was assessed using the Shapiro–Wilk test. Normally distributed data are presented as mean ± standard deviation (SD). For data with homogeneous variances (determined with the Levene test), an independent-samples *t*-test was used for comparison between groups; for data with heterogeneous variances, the Welch *t*-test was employed. Categorical variables are expressed as numbers (percentages) [n (%)], and intergroup comparisons were performed using the chi-square (χ^2) test or Fisher's exact test when expected cell frequencies were less than 5. The standardized mean difference (SMD) was used to evaluate the balance of covariates. An SMD value <0.1 indicates good balance. A univariate logistic regression model was used to identify variables associated with transfusion-related adverse reactions. The inclusion criteria for the variables were determined based on clinical rationality and previous literature, including age, sex, comorbidities, blood transfusion volume, detection time, start time of blood transfusion, and type of detection protocol. A two-sided $p < 0.05$ was considered statistically significant.

3. Results

3.1 Baseline Characteristics

There were no statistically significant differences between the control and observation groups in terms of sex, age, comorbidities, department of transfusion administration, or transfusion volume ($p > 0.05$ for all), and all SMD values were <0.1, indicating good baseline comparability (Table 1).

3.2 Testing Time and Blood Transfusion Initiation Time

The testing time and blood transfusion initiation time in the observation group were significantly shorter than those in the control group (both $p < 0.001$) (Table 2).

3.3 Incidence of Transfusion Adverse Reactions

Within the 24-hour observation window, the total incidence of adverse reactions to blood transfusion among the patients was 1.28% (41/3204). The distribution of each type of transfusion-related adverse reaction did not differ significantly between the two groups (all $p > 0.05$), and the severity of adverse events was also comparable ($p = 0.396$; see Tables 3,4). Allergic reactions accounted for the largest proportion of adverse reaction events in both groups.

3.4 Univariate Logistic Regression Analysis of Transfusion-Related Adverse Reactions

Taking the occurrence of transfusion-related adverse reactions as the dependent variable, the variables that might be related to the occurrence of adverse reactions (based on relevant literature, clinical practice and a limited number of events) were included in the univariate logistic regression model. The results showed that none of these factors were significantly associated with transfusion-related adverse reactions (Table 5).

4. Discussion

4.1 Reduced Testing and Transfusion Initiation Time With the Simplified Testing Process

In emergency blood transfusion scenarios, promptness in delivering treatment is critical for successful rescue. The golden rescue window for patients with massive hemorrhage is 1 hour after injury, and delayed transfusion significantly increases the risk of circulatory failure [14,15]. In this study, both the testing time and blood transfusion initiation time in the observation group subject to the simplified process were significantly shorter than those in the control group receiving the routine testing process. The simplified process enables rapid restoration of circulating blood vol-

Table 1. Comparison of baseline characteristics between the two groups.

	Control group (n = 1856)	Observation group (n = 1348)	χ^2/t	p-value	SMD
Sex			1.823	0.177	0.048
Male, n (%)	1025 (55.23)	712 (52.82)			
Female, n (%)	831 (44.77)	636 (47.18)			
Age (years), mean ± SD	60.50 ± 11.70	61.20 ± 12.50	1.607	0.108	0.058
Comorbidities, n (%)			8.533	0.074	0.076
Hypertension	328 (17.67)	212 (15.73)			
Diabetes	280 (15.09)	242 (17.95)			
Cardiovascular diseases	209 (11.26)	173 (12.83)			
Others	315 (16.97)	228 (16.91)			
No comorbidities	724 (39.01)	493 (36.57)			
Department of transfusion administration, n (%)			7.041	0.218	0.064
Intensive care unit	682 (36.75)	476 (35.31)			
Emergency department	494 (26.62)	397 (29.45)			
Trauma surgery	326 (17.56)	235 (17.43)			
Gastroenterology department	138 (7.44)	112 (8.31)			
Obstetrics and gynecology	72 (3.88)	46 (3.41)			
Other departments	144 (7.76)	82 (6.08)			
Total blood transfusion volume (U), mean ± SD	3.12 ± 1.41	3.22 ± 1.60	1.835	0.066	0.067

Note: Comorbidities were classified according to the main recorded comorbidity. SMD, standardized mean difference.

Table 2. Comparison of testing time and blood transfusion initiation time between the two groups (mean ± SD, min).

	Control group (n = 1856)	Observation group (n = 1348)	t-value	p-value
Testing time	38.45 ± 5.62	29.18 ± 3.05	59.940	<0.001
Blood transfusion initiation time	51.89 ± 8.76	45.12 ± 6.18	25.647	<0.001

Table 3. Comparison of transfusion-related adverse reactions between the two groups [n (%)].

Types of adverse reactions	Control group	Observation group	χ^2	p-value
Allergic reaction (yes)	15 (48.39)	8 (36.36)	0.757	0.384
Non-hemolytic febrile reactions (yes)	6 (19.35)	7 (31.82)	1.080	0.299
Circulatory overload (yes)	9 (29.03)	5 (22.73)	0.263	0.608
Others (yes)	1 (3.23)	2 (9.09)		0.563
Total	31 (100)	22 (100)		

Note: "n" represents the number of occurrences of adverse reaction events, and a single patient may experience multiple types of adverse reactions. Percentages represent the composition of adverse reaction events within each group (denominator = total number of events), not the incidence rate.

Table 4. Comparison of severity of transfusion-related adverse events between the two groups [n (%)].

Levels of adverse reactions	Control group	Observation group	p-value
Grade I	19 (90.48)	15 (75.00)	
Grade II	1 (4.76)	3 (15.00)	
Grade III	1 (4.76)	2 (10.00)	
Total	21 (100)	20 (100)	0.396

Note: "n" represents the number of patients who experienced adverse events.

ume and maintenance of hemodynamic stability, as well as ensuring that there is ample time for subsequent surgical hemostasis or etiological treatment. Additionally, the simplified process is more straightforward to operate, does not require complex equipment or highly specialized technical personnel, and can be quickly implemented in primary hospitals or emergency on-site settings, demonstrating stronger clinical applicability.

4.2 Safety of the Simplified Testing Process

The key finding of this study was that no significant difference was observed in the distribution of each type of adverse reaction between the two groups, providing no evidence of an increased risk of adverse reactions attributable to the simplified compatibility testing process. The underlying reasons for this result may include the follow-

Table 5. Univariate logistic regression analysis of transfusion-related adverse reactions.

Variable	With transfusion-related adverse reactions (n = 41)	Without transfusion-related adverse reactions (n = 3163)	β	SE	p-value	OR	95% CI
Sex (male), n (%)	23 (56.10)	1714 (54.20)	0.075	0.316	0.813	1.078	0.580–2.002
Age, mean ± SD	60.70 ± 10.10	60.80 ± 12.20	−0.008	0.016	0.599	0.992	0.961–1.023
Comorbidities (yes) n (%)	26 (63.41)	1961 (62.00)	0.061	0.326	0.852	1.063	0.561–2.015
Blood transfusion volume, mean ± SD	2.91 ± 1.04	3.16 ± 0.74	−0.320	0.206	0.121	0.726	0.485–1.087
Testing time, mean ± SD	34.80 ± 5.90	34.55 ± 5.30	0.047	0.038	0.216	1.048	0.973–1.130
Blood transfusion initiation time, mean ± SD	49.54 ± 8.95	49.04 ± 9.47	0.053	0.029	0.068	1.054	0.996–1.117
Type of testing process (simplified process), n (%)	20 (48.78)	1328 (41.98)	0.275	0.314	0.381	1.316	0.711–2.436

ing: First, ABO blood group incompatibility is the primary cause of acute hemolytic transfusion reactions [16]. The simplified process strictly implements rapid ABO forward and reverse grouping and Rh(D) typing, ensuring the accuracy of blood group identification and reducing the risk of the most dangerous ABO-incompatible transfusions. Second, saline medium cross-matching can quickly detect agglutination reactions caused by IgM blood group antibodies, which are mostly natural antibodies and the main antibodies leading to immediate hemolytic reactions [17]. Finally, polybrene cross-matching was used to supplement the detection of delayed hemolytic transfusion reactions that may be caused by incomplete antibodies [18]. The combination of these three compatibility testing procedures addresses the majority of transfusion incompatibility risks. Therefore, the safety of the simplified process may depend on the patient population, and caution should be exercised when applying it to patients with a history of multiple transfusions or pregnancies.

4.3 Clinical Application Recommendations

Several recommendations are proposed for the clinical application of the simplified blood transfusion compatibility testing procedure:

(1) Strictly adhere to the indications: The simplified process is only applicable to life-threatening emergency scenarios, such as hemorrhagic shock caused by severe trauma or massive hemorrhage, in which patients cannot wait for completion of routine testing. For patients undergoing elective surgery, those in clinically stable condition, or those with a history of multiple transfusions or pregnancies, the routine transfusion compatibility testing process should still be adopted. (2) Improve the "transfusion while tracing" mechanism: When the simplified process is adopted, antibody screening and antiglobulin cross-matching should be performed after the first unit of blood has been issued to the clinical department. If irregular antibodies are detected, the clinical team should be immediately notified to avoid the reuse of incompatible blood products in subsequent transfusions. (3) Strengthen monitoring of adverse reactions: Close monitoring of patients' vital signs is required during transfusion, especially within 30 minutes after the start of transfusion. If symptoms such as fever, rash, or dyspnea occur, transfusion should be immediately suspended and emergency protocols initiated. For patients with underlying diseases, anti-allergic medications may be administered in advance to prevent adverse reactions.

4.4 Limitation

Firstly, this study is a single-center retrospective study, and patients with known irregular antibodies were excluded from the research. Although the sample size is relatively large, selection bias cannot be excluded, and the generalizability of the findings requires further validation in multicenter and prospective studies. Secondly, this study only focused on adverse reactions of red blood cell transfusion and did not analyze other blood products, such as platelets and plasma, thereby limiting the applicability of the findings to these products. Additionally, the follow-up period was short, with adverse reactions monitored only within 24 hours after blood transfusion; delayed hemolytic reactions may occur beyond this observation window and could therefore have been missed. Fourthly, the lack of multivariate logistic regression or subgroup analysis may have biased the results. For example, the lack of analysis of patients who received type O blood before completing blood group confirmation may lead to differences in the actual transfusion strategy between the two groups, thus affecting the assessment of the safety of the simplified transfusion compatibility test. Finally, the present study evaluated only a limited number of variables, without investigating the effects of history of transfusion, pregnancy and transfusion rate on adverse reactions. In the future, prospective studies should further expand their scope and extend the follow-up period to enhance the universality of the research.

5. Conclusion

In the context of excluding patients with known irregular antibodies, the adoption of the simplified compatibility testing process for emergency blood transfusion, com-

prising ABO forward and reverse grouping and Rh(D) typing, saline medium cross-matching, and polybrene cross-matching, can significantly shorten the testing and blood transfusion initiation time. Additionally, our findings showed that the simplified process was not associated with a significant increase in the risk of transfusion-related adverse reactions. Taken together, the simplified compatibility testing process offers a faster approach to ensuring compatibility prior to blood transfusion during emergencies, without compounding risks of transfusion-related adverse reactions. This study provides potential support for future exploration of bedside rapid blood type testing and the standardization of emergency large-volume blood transfusion protocols.

Key Points

• For life-threatening emergency transfusion scenarios, a simplified compatibility testing process consisting of ABO forward and reverse grouping and Rh(D) typing, saline cross-matching, and polybrene cross-matching was implemented before blood transfusion in this study.

• Compared with the traditional compatibility testing, the simplified compatibility testing process reduces testing time and enables earlier initiation of blood transfusion.

• Compared with the traditional compatibility testing, the simplified compatibility testing process does not significantly increase the incidence of adverse reactions within the 24-hour observation window.

Availability of Data and Materials

The data analyzed are available upon request to the corresponding author.

Author Contributions

YQP had the original conception of the work. YQP, PTZ, YL and YMH collected the clinical data. YQP, YMH, RCW and DC performed the research. YQP, PTZ and YL drafted the manuscript. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was approved by the ethics review board of Haiyan People's Hospital (Approval No: 2025-21) and conducted in strict compliance with the principles outlined in the Declaration of Helsinki. All participants or their families provided written informed consent.

Acknowledgment

The authors would like to acknowledge the support and assistance of Haiyan People's Hospital, Affiliated Haiyan Hospital of Jiaxing University.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflicts of interest.

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