Type and screen method and Coombs crossmatch method for pretransfusion testing: A prospective comparative study in a tertiary care hospital in Delhi

K. Devi Anu, Sangeeta Pahuja, Geetika Sharma

Abstract:

BACKGROUND: The aim of pretransfusion testing (PTT) is to prevent the immune-mediated hemolytic reaction by the transfusion of incompatible donor red cells. The methods of PTT have evolved over the years and a new method of type and screen (T and S) was introduced, in which only ABO grouping, Rh typing, and antibody screening would be carried out with omission of routine Coombs crossmatch. Although T and S is an accepted method for PTT in developed countries, only a few studies in literature have evaluated its efficacy in India.

AIM AND OBJECTIVE: The aim of the study was to compare T and S method with conventional Coombs crossmatch method for PTT.

MATERIALS AND METHODS: Two thousand and fifty samples were randomly selected from the samples received in blood bank for requisition of blood transfusion after taking informed consent. ABO blood grouping and Rh typing were performed for each recipient's sample. "T and S" and "Coombs crossmatch" were done simultaneously by two different persons without knowing the result of each test. A commercially available three cell panel was used for antibody screening, in which the recipient's plasma was reacted with red cells in the low ionic strength solution Coombs Gel card at 37°C by column agglutination technology.

RESULTS: Antibody screening was positive in 29 (1.41%) patients and negative in 2021 (98.59%) patients. Out of 29 patients, 27 had alloantibodies and 2 had autoantibody. Most common alloantibody found in our study was anti-D. Other antibodies found were anti-K, anti-C + D, anti-E, anti-C, anti-c, anti-Jk\(a\), and anti-Mi (a). Crossmatch on first attempt was compatible in 2028 (98.93%) patients and incompatible in 22 (1.07%) patients. Out of 29 patients who were positive for antibody screening, crossmatch was incompatible in nine patients. Crossmatch was compatible in twenty patients, who had positive antibody screen. However, crossmatch compatibility in these patients, reflect either absence of corresponding antigen or antigen present in low dose (heterozygous) in donor blood. On the other hand, out of 22 patients incompatible on first crossmatch, antibody screening was negative in 13 patients and was positive in only nine patients. Hence, 13 patients with antibody would have been missed by antibody screen alone. Kappa statistics was used to compare the efficacy of "type and screening" and "Coombs crossmatch." It showed \(\kappa = 0.445\) \((P < 0.001)\) implying moderate agreement between the two variables of "T and S" and "Coombs crossmatch."

CONCLUSION: T and S is a scientifically better method but needs to be implemented with caution. We need to develop our own cell panels having adequate representation of indigenous antigen (including In, Mi (a), etc.). Large-scale studies need to be done in India with indigenous screening cells to evaluate efficacy and safety of T and S method.

Keywords: Alloantibodies, crossmatch, type and screening

How to cite this article: Anu KD, Pahuja S, Sharma G. Type and screen method and Coombs crossmatch method for pretransfusion testing: A prospective comparative study in a tertiary care hospital in Delhi. Asian J Transfus Sci 2022;16:83-8.
Introduction

Pretransfusion testing (PTT) is done in order to prevent the immune-mediated hemolytic reaction by the transfusion of incompatible donor red cells. Since the introduction of pretransfusion compatibility testing for the first time by Ottenberg in 1907, it has undergone continuous revisions and modifications. Description of Coombs test by Coombs, Mourant, and Race to identify incomplete antibodies in 1945, added a new dimension to the safety of blood transfusion. According to the International Society of Blood Transfusion, 352 blood group antigens have been identified.

Purpose of crossmatch is to identify antibodies in the recipient’s serum against antigens on the donor’s red blood cells and to verify ABO compatibility. In traditional method of Coombs crossmatch, blood bags are held back for particular recipient who may not need it. This results in wastage of reagents, money, manpower, and blood products. Furthermore, routine Coombs crossmatch may result in delay in issue of blood. This led to the development of a newer method, i.e., type and screen (T and S), in which only ABO grouping, Rh typing, and antibody screening would be carried out with omission of Coombs crossmatch. This was invaluable in reducing the need for routine crossmatch in surgical procedures, wherein blood and blood products were infrequently transfused.

It was recommended that patients with negative antibody screen and negative history of red cell antibodies do not require a complete 20–60 min Coombs crossmatch. Thus, in 1984, American Association of Blood Bank recommended that the conventional crossmatch could be replaced by an abbreviated crossmatch in patients with negative antibody screening. The probability of missing clinically significant antibody with a negative antibody screen (false negative) was reported to be 1–4/10,000 cases.

Even though, T and S is an accepted method for PTT in developed countries, its use in India is still a matter of consideration. In India, for PTT, blood grouping followed by antibody screening and Coombs crossmatch is recommended. As per regulatory guidelines (Drug Controller General India (DCGI) and National AIDS Control Organisation (NACO) standards), Coombs crossmatch is mandatory before issue of blood/components for transfusion.

Efficacy of T and S method for PTT has not been extensively studied in India and in South Asia. Hence, a study was planned to compare the efficacy of “T and S” method versus “Coombs crossmatch” method for PTT.

Materials and Methods

The study was conducted in the Department of Immunohematology and Blood Transfusion, Lady Hardinge Medical College and Associated Hospitals, New Delhi. This was a descriptive, cross-sectional, hospital-based study, conducted from November 2016 to March 2018. Two thousand and fifty (2050) samples were randomly selected from the samples received in the department for requisition of blood transfusion. Informed consent was taken from the patient/guardian. Patients who refused to give consent and cases of emergency transfusion requisitions of blood were excluded. Patients of hemoglobinopathies (including thalassemia) were not included in the study. Ethics clearance was received from institutional Ethics committee for human research.

ABO blood grouping and Rh typing was performed for each recipient’s sample using both forward and reverse blood grouping method according to the standard operating procedures of the department. Plasma was separated into two parts after blood grouping. One part was used for antibody screening. Other half was used for coombs crossmatch with same blood group. Both “T and S” and “Coombs crossmatch” were done simultaneously by two different persons without knowing the results of each test.

A commercially available three cell panel (ID Diacell I-II-III Asia; BIORAD ID microtyping system, BIORAD, Asia) was used for antibody screening, in which the recipient’s plasma was reacted with red cells in the low ionic strength solution (LISS) Coombs Gel card at 37°C by column agglutination technology. In antibody-positive cases, 11 cell panel (ID-DiaPanel; BIORAD) was used for antibody identification and if required the ID Diacell extended panel (six cells, BIORAD, Asia) was used. After antibody identification, corresponding antigen was looked for in recipient’s red cells for confirmation. Crossmatching of the recipient’s plasma with the donor’s red blood cells was carried out in the LISS Coombs Gel card (ID-Card LISS/Coombs; BIORAD) at 37°C by column agglutination technology, to confirm donor-recipient compatibility. Results of antibody screening and identification were compared with Coombs crossmatch. Any discrepancy between “T and S” and “crossmatch” was sorted out, and the patient was given corresponding antigen negative, Coombs crossmatch compatible blood. Clerical and technical discrepancies were ruled out before issuing the blood.

The statistical analysis was done using the Statistical Package for the Social Sciences (SPSS) version 23.0 (IBM SPSS software, New York, USA). Agreement between two variables was tested using Kappa statistics. A “P < 0.05” was considered to be significant.
Results

A total of 2050 patients were enrolled in this study for whom “T and S” and “Coombs crossmatch” were done independently and results of both the tests were compared before issuing the blood.

Majority of the patients were in the age group of 19–60 years, who represented 50.58% of the study population. Hematological disorders, for example, aplastic anemias and leukemia (780/2050 [38.05%]) were the most common indication for blood transfusion. Other indications were obstetrics (638/2050 [31.12%]), medical disorders (212/2050 [10.34%]), surgical conditions (208/2050 [10.15%]), gynecological problems (85/2050 [4.15%]), orthopedics (75/2050 [3.66%]), nonhematological malignancies (35/2050 [1.71%]), and other diseases (17/2050 [0.83%]). Multitransfused thalassemia patients on regular blood transfusion were excluded in the study. Nearly 69.95% of patients had never received blood transfusion, whereas 13.51% had received blood transfusion once or twice and 16.54% of patients had received blood transfusion multiple times.

“T and S” and “crossmatch” were done simultaneously in blood samples of 2050 patients. Antibody screening was positive in 29 (1.41%) patients and negative in 2021 (98.59%) patients [Table 1]. Out of 29 patients who had positive antibody screening, six patients gave a history of blood transfusion, 14 patients had a history of pregnancy, eight patients had both the histories of blood transfusion and pregnancy (in these eight patients, one patient had warm autoimmune hemolytic anemia), and one male patient had autoimmune hemolytic anemia with no past history of blood transfusion. Out of 29 patients, 27 had alloantibodies and 2 had autoantibody. The most common alloantibody found in our study was anti-D, which contributed to (9/29) 31.03% of total antibodies. Other antibodies found were anti-K (3/29 [10.34%]), anti-C + D (2/29 [6.90%]), anti-E (2/29 [6.90%]), anti-C (1/29 [3.45%]), anti-c (1/29 [3.45%]), anti-Jka (1/29 [3.45%]), and anti-Mi (a) (1/29 [3.45%]) [Table 2]. However, in six patients out of 27, alloantibody specificity could not be identified by either antibody identification panel or extended cell panel or on enzyme phase.

On the other hand, crossmatch on first attempt was compatible in 2028 (98.93%) patients and incompatible in 22 (1.07%) patients. Out of 29 patients who were positive for antibody screening, crossmatch was incompatible in nine patients. Crossmatch was compatible in twenty patients, who had positive antibody screen. However, this included 11 patients who were Rh (D) negative and had alloanti-D. In all these patients, crossmatch was put up with type specific packed red blood cells (i.e., Rh [D] negative blood according to the blood group), hence crossmatch would not pick up anti-D. This implies that nine patients with alloantibodies (anti E [1], anti K [2], anti JKa [1], and nonspecific antibodies [5]) were missed on crossmatch which were picked up by antibody screen [Table 3]. However, crossmatch compatibility in these patients, reflect either the absence of corresponding antigen or antigen present in low dose (heterozygous) in donor blood. In our study, the blood units put up for crossmatch were negative for corresponding antigen “E,” “K,” and heterozygous for JKa antigen.

On the other hand, out of 22 patients incompatible on first crossmatch, antibody screening was negative in 13 patients and was positive in only nine patients. Hence, 13 patients with antibody would have been missed by antibody screen alone. In incompatible crossmatch group, nine patients had a history of blood transfusion, eight patients had a history of pregnancy, four patients had both the past histories of blood transfusion and pregnancy, and one male patient had autoimmune hemolytic anemia with no history of blood transfusion.

In 13 cases with incompatible crossmatch and negative on antibody screen (and identification), incompatibility was mostly weak to 1+ with one case showing 3+ reaction strength. Serum of all the 13 patients was screened for In (a) antibody using 1% In (a) + red cell suspension. Single strength. Serum of all the 13 patients was screened for In (a) antibody using 1% In (a) + red cell suspension. Single case showing incompatibility of 3+ and negative antibody screening and identification showed a positive reaction with 1% In (a) + red cell suspension which decreased on treatment with papain, thus confirming the specificity as anti-In (a). However, the clinical significance of rest

| Crossmatch | Antibody screening | Total |
|------------|-------------------|-------|
|            | Negative | Positive |       |
| Compatible| 2008      | 20      | 2028   |
| Incompatible| 13       | 9       | 22     |
| Total      | 2021      | 29      | 2050   |

| Number (n=29), n (%) |
|----------------------|
| Anti D          | 9 (31.03) |
| Anti K          | 3 (10.34) |
| Anti C+D        | 2 (6.90)  |
| Anti E          | 2 (6.90)  |
| Anti C          | 1 (3.45)  |
| Anti c          | 1 (3.45)  |
| Anti Jka        | 1 (3.45)  |
| Anti D +c + k + C* | 1 (3.45)  |
| Anti Mi (a)     | 1 (3.45)  |
| Nonspecific antibodies | 6 (20.68) |
| Warm autoantibody | 2 (6.90)  |
Anu, et al.: Comparative study of pretransfusion testing methods

Table 3: Details of patients with positive antibody screening and compatible on first crossmatch

| Diagnosis                                      | Previous history of blood transfusion | Previous history of pregnancy | Blood Group | Compatible on first crossmatch | Antibody screening |
|------------------------------------------------|--------------------------------------|-------------------------------|-------------|---------------------------------|-------------------|
| G2P1L1 with anaemia in early labor             | No history of BT                     | G2P1L1                        | B positive  | Compatible                      | Anti E            |
| G2P1L1 with 34 + 5 with PROM                   | No history of BT                     | G2P1L1                        | AB negative | Compatible                      | Anti D            |
| G2A1 with 37 + 5 with fetal distress          | History of BT                        | G2A1                          | O negative  | Compatible                      | Anti D            |
| G3P1L1A1 with 38 + 2 in early labor           | History of BT                        | G3P1L1A1                      | AB negative | Compatible                      | Anti D            |
| G2P1L1 with postpartum haemorrhage            | No history of BT                     | G2P1L1                        | A negative  | Compatible                      | Anti D            |
| fracture right humerus                         | History of BT                        | None                          | A positive  | Compatible                      | Nonspecific antibodies |
| G2P1L1 with 29 + 2 with anaemia               | History of BT                        | G2P1L1                        | O negative  | Compatible                      | Anti D            |
| Thalassemia major                             | Multitransfused                      | Nullipara                      | O positive  | Compatible                      | Anti K            |
| G3P2L2 with 38 + 2 with early labor           | No history of BT                     | G3P2L2                        | O negative  | Compatible                      | Nonspecific antibodies |
| G2P1L1 with previous LSCS with moderate anemia| No history of BT                     | G2P1L1                        | O positive  | Compatible                      | Nonspecific antibodies |
| Abnormal uterine bleeding with fibroids       | History of BT                        | P3L3                          | AB negative | compatible                      | Anti D            |
| G2P1L1 with 34 + 5 with PROM                   | History of BT                        | G2P1L1                        | AB positive | Compatible                      | Nonspecific antibodies |
| G2A1 with 38 + 1 in early labor with Rh negative pregnancy | No history of BT | G2A1 | AB negative | Compatible | Anti D |
| G2P1L1 with anemia                            | No history of BT                     | G2P1L1                        | O negative  | Compatible                      | Anti D            |
| Thalassemia major                             | Multitransfused                      | None                          | B positive  | Compatible                      | Anti K            |
| G3P2L2 with 39 + 1 in early labor             | No history of BT                     | G3P2L2                        | B positive  | Compatible                      | Nonspecific antibodies |
| G2P1L1 with 37 + 4 with prev LSCS             | History of BT                        | G2P1L1                        | B negative  | Compatible                      | Anti D            |
| G2P1L1 with anemia                            | No history of BT                     | G2P1L1                        | B negative  | Compatible                      | Anti C+D          |
| P2L2 with severe anemia                       | History of BT                        | P2L2                          | B negative  | Compatible                      | Anti D            |
| G2P1L1 with 35 + 1 with PROM                   | No history of BT                     | G2P1L1                        | AB positive | Compatible                      | Anti Jka          |

Kappa statistics was used to compare the efficacy of “type and screening” and ‘coombs crossmatch’. It showed kappa value of 0.445 (P<0.001) implying moderate agreement between the two variables of “type and screen” and ‘coombs crossmatch’. BT=Blood transfusion, LSCS=Lower segment Cesarian section, PROM=Premature Rupture of Membranes

Discussion

Detection of alloantibody is one of the major objectives of PTT. The T and S method is routinely used in west for patients with negative antibody screening and the blood unit is issued by omitting the Coombs crossmatch. However, in India, efficacy and sensitivity of T and S method have not been adequately established. In the present study, an attempt was made to compare the efficacy of T and S method with conventional crossmatch method for PTT.

Tiwari et al.[13] (2017) have commented on safety of T and S method and found that immediate spinCross-match (CM) after negative antibody screen had sensitivity of 99.9% and specificity of 80%. They reported missing out on anti-P antibody in one patient, which was picked up on antihuman globulin (AHG) crossmatch (but missed on antibody screen). The study emphasized that, in antibody screen negative patients, immediate spin (IS) crossmatch is as safe as conventional AHG crossmatch as it improves patient care with quicker availability of many blood units. A prospective comparison was done by Aggarwal et al.[13] (2018) between T and S with AHG crossmatch and T and S with IS crossmatch and they found several advantages with IS crossmatch including significant improvement in crossmatch-to-transfusion ratio (C/T ratio), decreased turnaround time for issue of blood units, reduced number of expired blood units, man-hours consumption, and monetary benefits. Agrawal[14] carried out a study on antibody screening simultaneously with routine crossmatch in 354 high-risk patients. In their study, not a single case was found where antibody screen was negative and AHG crossmatch was incompatible. The study suggested that T and S policy can be implemented in Indian settings with no compromise on blood safety provided sufficient technical and infrastructural support is available at the center. Similar results were seen by Pathak et al.[8] (2011) in a study on antibody screening and Coombs crossmatch in 45,373 hospitalized patients and not a single case was found where antibody screen was negative and AHG crossmatch was incompatible. However, they have not commented upon multitransfused or parity status of the patients included in the study. Chaudhary and Agarwal[14] performed both antibody screening and indirect AHG
crossmatch for 2026 hospitalized patients. In their study, 15/2026 samples (0.75%) showed a positive antibody screening result which would have been missed if only conventional crossmatch was done. They reported one case where AHG crossmatch was incompatible, but antibody screen was negative. This study highlighted that T and S method reduces the number of unnecessary crossmatch tests and allows the optimal use of blood as donor blood is not held back by crossmatch for particular recipient and there is less chance of expiry of donor blood. Heddle et al. examined 9128 patients and found 0.3% (35 out of 10,899) transfused blood were serologically incompatible. They concluded that antiglobulin crossmatch can be omitted from PTT with a risk of 0.3% patients receiving incompatible blood. Boral and Henry (New York, 1977) conducted study on 12,848 blood samples. In their study, 11/283 (3.89%) antibodies were not detected by antibody screening which was 0.086% of 12,848 samples. Out of 11 antibodies which were missed by antibody screening, anti-Wr was the only antibody shown to cause hemolytic reaction.

T and S is a scientifically accepted method and permits recognition and identification of clinically significant antibodies which is essential in PTT to search for corresponding antigen-negative blood unit. This methodology is extremely useful where chances of transfusion are low as blood banks are not overburdened by doing unnecessary crossmatch. Blood can be issued within 10–15 min by T and S method (for routine issue of blood using AHG crossmatch, approximately 90 min is required).

In a study done by Aggarwal et al., T and S with IS crossmatch proved to be more economical than and T and S with AHG crossmatch 33%. While Kuriyan and Fox found that the use of IS crossmatch instead of AHG crossmatch resulted in up to 30% reduction in cost.

However, there are a few drawbacks of this methodology as highlighted in our study. First, missing out clinically significant antibodies to which antigens are not expressed on the screening cell panel. We found incompatible crossmatch in 0.6% of patients, even when antibody screen was negative. One of the reasons for this is weak/heterogeneous/nonexpression of corresponding antigen on the screening cells. Most of the commercially available cell panels are not indigenous and reflect Caucasian population, which might be the reason for negative screen result with antibodies in our hospital patient population. We could not assess the clinical significance of antibody in all the cases where crossmatch was incompatible as specificity could not be identified. Although 12/13 cases were weak to 1+ incompatible, one case showed 3+ incompatibility, which cannot be overlooked. This particular case was later found to have In (a) antibody. Another observation from our study was detection of one case of Mi (a) antibody which was possible only with the use of Asia screening panel and would have been missed if Mi (a) positive cells had not been included. Thus, it is imperative that antibody detection system used by each laboratory should be sufficiently sensitive and all antigens for clinically significant antibodies should be sufficiently represented.

This fact was also reported by Chaudhary and Agarwal that the reagent cell panels are not indigenous and may, therefore, miss some of the clinically significant antibodies. Second, in Indian blood bank, T and S method needs to be used with caution as the essential infrastructure and technical expertise may not be available in all the centers.

Although Coombs crossmatch is followed in India, it is not very effective method for PTT as it leads to overburdening of blood banks by performing unnecessary crossmatch (approximately 2–3 times more than blood being transfused). Furthermore, the crossmatched blood is not available for transfusion for 24–48 h. Surgeons are usually overzealous in ordering crossmatch for elective surgery due to fear of delay in supply of blood in emergency. However, this leads to unnecessary increase in work load and creates blood shortages and leads to inventory issues. Furthermore, some antigens get missed in heterozygous state by conventional Coombs crossmatch as seen in our study in case of one patient with anti-Jka but compatible crossmatch. Although Coombs crossmatch has its own drawbacks, it is a simple test, requiring minimal infrastructure and can be done at low cost even in remote areas. Moreover, if corresponding antigen is present on donor cells, it can get picked up unless antigen is in low dose/heterozygous state.

**Conclusion**

India is a very diverse country with very extensive phenotypic variation in blood group. It is time that we shift to T and S method, but at the same time, we need to develop our own red cell panels having adequate representation of indigenous antigens. In our study, anti-In (a) and Mi (a) would have got missed if only Caucasian antibody screening and identification panels had been used. Moreover, large-scale studies need to be done with indigenous screening cells to evaluate efficacy and safety of T and S method.

**Acknowledgment**

We would like to thank Ms. Manisha and Mr. Ramvilash, Medical Lab Technicians for the technical support in this study.
References

1. Harm SK, Dunbar NM. Transfusion-service-related activities: Pretransfusion testing and storage, monitoring, processing, distribution, and inventory management of blood components. In: Spitalnik SL, Westhoff CM, Fung MK, Eder A, editors. AABB Technical Manual. 19th ed. Maryland: AABB; 2017. p. 476-84.
2. Ottenberg R. II. Transfusion and arterial anastomosis: Some experiments in arterial anastomosis and a study of transfusion with presentation of two clinical cases. Ann Surg 1908;47:486-505.
3. Coombs RR, Mourant AE, Race RR. A new test for the detection of weak and incomplete Rh agglutinins. Br J Exp Pathol 1945;26:255‑66.
4. Chaudhary R, Agarwal N. Safety of type and screen method compared to conventional antiglobulin crossmatch procedures for compatibility testing in Indian setting. Asian J Transfus Sci 2011;5:157‑9.
5. Masouredis SP. Pretransfusion tests and compatibility: Questions of safety and efficacy. Blood 1982;59:873‑5.
6. Oberman HA, Barnes BA, Friedman BA. The risk of abbreviating the major crossmatch in urgent or massive transfusion. Transfusion 1978;18:137-41.
7. Mintz PD, Haines AL, Sullivan MF. Incompatible crossmatch following nonreactive antibody detection test. Frequency and cause. Transfusion 1982;22:107-10.
8. Pathak S, Chandrashekhar M, Wankhede GR. Type and screen policy in the blood bank: Is AHG cross-match still required? A study at a multispeciality corporate hospital in India. Asian J Transfus Sci 2011;5:153‑6.
9. Saran R. Pretransfusion (Compatibility) testing In: Saran RK, editor. Transfusion Medicine Technical Manual. 2nd ed. New Delhi: Directorate General of Health Services; 2003. p. 117-26.
10. Requirements for the functioning and operation of a blood bank and/or for preparation of blood components. Schedule F, Part XII B; The Drugs and Cosmetics Act, 1940 and Rules, 1945, amended till Dec 2016; Ministry of Health and Family Welfare; Government of India.
11. Bharucha ZS. Compatibility testing. In: Standards for Blood Banks and Blood Transfusion Services. 1st ed. New Delhi: NACO; 2007. p. 59-62.
12. Tiwari AK, Aggarwal G, Dara RC, Arora D, Gupta GK, Raina V. First Indian study to establish safety of immediate-spin crossmatch for red blood cell transfusion in antibody screen-negative recipients. Asian J Transfus Sci 2017;11:40-4.
13. Aggarwal G, Tiwari AK, Arora D, Dara RC, Acharya DP, Bhardwaj G, et al. Advantages of type and screen policy: Perspective from a developing country! Asian J Transfus Sci 2018;12:42-5.
14. Agrawal A. Type and screen policy: Is there any compromise on blood safety? Transfus Apher Sci 2014;50:271‑3.
15. Heddle NM, O’Hoski P, Singer J, McBride JA, Ali MA, Kelton JG. A prospective study to determine the safety of omitting the antiglobulin crossmatch from pretransfusion testing. Br J Haematol 1992;81:579-84.
16. Boral LI, Henry JB. The type and screen: A safe alternative and supplement in selected surgical procedures. Transfusion 1977;17:163-8.
17. Kuriyan M, Fox E. Pretransfusion testing without serologic crossmatch: Approaches to ensure patient safety. Vox Sang 2000;78:113-8.
18. Leger RM, Novotny AK. Blood group terminology and common blood groups: The Lewis, P, J, MNS, Kell, Duffy, Kidd and Lutheran. In Harmening DM, editor. Modern Blood Banking and Transfusion Practices. 7th ed. Chicago: Davis Plus; 2017. p. 173-211.