Original Research Article

RHD GENOTYPING TO RESOLVE WEAK AND DISCREPANT RHD PHENOTYPES: THE "SERENISSIMA" EXPERIENCE

Abstract

Background: A considerable number of RHD alleles responsible for weak and partial D phenotypes have been identified. Serologic determination of these phenotypes is often doubtful and makes genetic analysis of RHD gene highly desirable in transfusion recipients and pregnant women.

Aim: We report the experience of Mestre Blood Bank in analysis of the RHD gene in six years from 2018 to 2023.

Methods: Subjects for RHD gene analysis were selected ~~for~~ based onpresence of a serological weak D phenotype, defined as reactivity of RBCs with an anti-D reagent giving no or weak (≤2+) score in initial testing but agglutinating moderately or strongly with antihuman globulin. These samples were selected for genotyping using the microarray-based method "Bead-Chip" supplied by Immucor.

Results: From 2018 to 2023, we selected, for RHD gene analysis, 547 subjects with D weak phenotype; 86 subjects (15.5%) were D positive, ~~and~~ 56 (10.1%) were D negative~~,~~ without variant, and ~~in~~ 413 subjects with a D weak or a D variant was observed.

Discussion: Many serological weak D phenotypes are associated with RHD gene mutations leading to one or more amino acids substitutions in the RhD protein wherepredicted to be within or below the RBC membrane causing decreased antigen expression on the red cell surface. Prevalence of serological weak D phenotypes varies by race and ethnicity. Serological weak D phenotypes are the most common D variants detected in Caucasians (0.2%-1.0%), the majority, as in our series, are associated with weak D type 1, 2 or 3. Our data confirmed a high prevalence of weak D type 1 and type 2, but we observed a high prevalence of type 11 and 15 and of the uncommon type 18, too. The most common partial D phenotypes in Europe are DNB, DVI, and DVII. Our data confirmed a high prevalence of D partial type VI. Studies indicate that transfusion recipients of D partial are at risk for forming alloanti-D when exposed to conventional RhD-

Comment [rZ1]: When gene name is meant should be in italic.

UNDER PEER REVIEW

positive blood units. As matter of fact the subject with D Partial DAR, a pregnant woman, developed and anti-D.

Comment [rZ2]: Abstract; discussion is too long and some parts are redundant. A conclusion should be included. Specially a clinical suggestion may be needed.

Key Words

D variant, D weak, Genotypes, RHD

Introduction

The Rh blood group system consists of 56 antigens carried on two proteins (RhD and RhCE) each consisting of 417 amino acids. Combinations (hybrids) between the two genes are not uncommon. The proteins consist of 12 membrane-spanning domains. The inheritance of Rh system antigens is determined by a complex of 2 closely associated genes located on chromosome 1: a *RHD* gene which encodes the D protein which confers D antigenic specificity; in D negative Caucasian individuals the *RHD* gene is usually deleted while in other populations the D negative phenotype is associated with an inactive, mutated or partially active *RHD* gene. ~~A~~ *RHCE* gene ~~which~~ codes for proteins that confer the antigenic specificities C,c,E,e: the alleles are *RHCe*, *RHCE*, *RHcE* and *RHce* [1-3]. The RHD antigen is the most important and immunogenic antigen of the Rh blood group system. Correct identification of RhDantigen is of great clinical significance to prevent allo-immunization leading to post transfusion haemolytic reactions and to foetal and neonatal haemolytic disease [4,5]. Usually, serotyping is the standard method to study of RhD antigen, and serological studies have distinguished three broad categories of D variants, namely, weak D, partial D and DEL, from wild-type or conventional D. A serological weak D phenotype is defined as reactivity of RBCs with an anti-D reagent giving no or weak (≤2+) reactivity in initial testing but agglutinating moderately or strongly with antihuman globulin. Partial D phenotypes are associated with amino acid substitutions in the RhD protein on the RBC surface and lack of D epitopes. DEL phenotypes present by conventional blood typing as RhD negative and are not detected serologically unless adsorption and elution studies are performed [6-8]. ~~So~~So, genotyping by molecular techniques is a complementary tool to overcome these limitations [9,10].

Comment [rZ3]: RhD or RHD should be used uniformely across the manuscript

In this paper we report a six years experience~~about~~ onthe utility of a genotyping based approach to resolve weak and discrepant D serotyping in a large Urban Tertiary Care Hospital in North-East Italy.

Materials and Methods:

UNDER PEER REVIEW

Serological Assay: Routine RhD serotyping was performed, in EDTA whole blood, using a gel card assay: DG Gel 8 ABO/Rh (2D) supplied by Grifols Italy (MI). The principle of the test is based on the gel technique described by Yves Lapierre [11]. The DG Gel 8 cards are composed of eight microtubes. Each microtube is made of a chamber, also known as incubation chamber, at the top of a long and narrow microtube, referred to as the column. Buffered gel solution containing specific antibody (anti-A, anti-B, anti-AB, anti-DVI- or anti-DVI+) has been prefilled into the microtube of the plastic card. Figure 1 reported the gel card structure: Microtube A: monoclonal antibody anti-A. Mixture of IgM and IgG antibodies of murine origin, clones 16243G2 and 16247E6. Microtube B: monoclonal antibody anti-B. IgM antibody of murine origin, clone 9621A8. This reagent does not react with acquired B cells. Microtube AB: monoclonal antibodies anti-AB. Mixture of IgM antibodies of murine origin, anti-A(B) clone ES15, anti-A clone LA-2, and anti-B clone LB-2. Microtube DVI: monoclonal antibody anti-D. IgM antibody of human origin, clone P3x61. This reagent does not detect partial DVI. Microtube DVI+: monoclonal antibody anti-D. Mixture of IgM antibodies of human origin, clones P3x61 and ESD1M. This reagent detects partial DVI. Microtube Ctl.: buffered solution without antibodies (control microtube). Microtubes N: buffered solution without antibodies for the ABO reverse group test. Agglutination occurs when the red blood cell antigens react with the corresponding antibodies, present in the gel solution or in the serum or plasma sample (in the case of reverse grouping test). The gel column acts as a filter that traps agglutinated red blood cells as they pass through the gel column during the centrifugation of the card. The gel column separates agglutinated red blood cells from non-agglutinated red blood cells based on size. Any agglutinated red blood cells are captured at the top of or along the gel column, and non-agglutinated red blood cells reach the bottom of the microtube forming a pellet, Figure 2 reported the semi quantitative score system for agglutination interpretation [12,13]. Assays were performed following the manufacturer instructions using three Grifols ErytraEflexis fully automated analysers. Methods were CE and FDA approved and all methods were validated in house before being authorized for routine use.

Comment [rZ4]: Professional editing is mandatory.

Genotyping Assay: Routine genotyping was performed, in EDTA whole blood, using the ImmunorBioArray HEA BeadChip kit. This assay allow the molecular characterization of allelic variants that predict erythrocyte antigen phenotypes in the Rh (C [RH2], c [RH4], E [RH3], e [RH5], V [RH10], VS [RH20]), Kell (K [KEL1], k [KEL2], Kpa [KEL3], Kpb [KEL4], Jsa [KEL6], Jsb [KEL7]), Duffy (Fya [FY1], Fyb [FY2], GATA [FY-2], Fyx [FY2W]), Kidd (Jka [JK1], Jkb [JK2]), MNS (M [MNS1], N [MNS2], S [MNS3], s [MNS4], Uvar [MNS-3,5W],

UNDER PEER REVIEW

Uneg [MNS-3,-4,-5]), Lutheran (Lua [LU1], Lub [LU2]), Dombrock (Doa [DO1], Dob [DO2], Hy [DO4], Joa [DO5]), Landsteiner-Wiener (LWa [LW5], LWb [LW7]), Diego (Dia [DI1], Dib [DI2]), Colton (Coa [CO1],Cob [CO2]), and Scianna (Sc1[SC1], Sc2 [SC2]) blood group systems in human genomic DNA. The procedure starts with extraction of DNA from ethylenediaminetetraacetic acid (EDTA)–collected whole blood, using the QIAcube (Qiagen, Inc). The DNA segments of interest (which contain the sequence variations that are the basis for the phenotypic variations) are amplified by a multiplexed polymerase chain reaction (PCR) using a Veriti thermal cycler supplied by applied Biosystem. The resulting PCR product is treated to remove residual primers and deoxynucleotide triphosphates and to generate single-stranded DNA. The amplified, single-stranded DNA then anneals with oligonucleotide allele-specific probes that are attached to microscopic beads (each approximately 3.2 microns in diameter). Those beads have been dispersed onto a chip containing approximately 4000 wells; each well is large enough to accommodate only 1 bead. The bead chips come in 96-chip formats. The beads have a characteristic fluorescent signature specific for each allele-specific probe. The location of the beads (with their attached allele-specific probes) on the chip is documented at the manufacturing site. When the amplified DNA is perfectly matched to the probe, it undergoes elongation and incorporates a fluorescently ~~labeled~~labelled nucleotide (a process called elongation mediated multiplexed analysis of polymorphisms). Only perfectly matched DNA segments will elongate and incorporate the fluorescent label. The bead fluorescence profile is captured by a Nikon AIS400C fluorescence microscope and analyzed by the BioArray Solutions Information System (BASIS; Immunocor, Inc.), which translates the fluorescent signal profile into genotype determination and phenotype prediction [14.15].

Assays were performed following the manufacturer instructions. Methods were CE and FDA approved and all methods were validated in house before being authorized for routine use.

Samples selection: Subjects for RHD gene analysis were selected for presence of a serological weak D phenotype, defined as reactivity of RBCs with an anti-D reagent giving no or weak (≤2+) score in initial testing but agglutinating moderately or strongly with antihuman globulin. Moreover, were selected samples showing discordant reactivity in anti-DVI- / anti-DVI+ microtube [16].

Results

Comment [rZ5]: PCR, menu, conditions, primer sequences, product size, detection of the products, validation of the product sequences

Comment [rZ6]: How treatment is done?

Comment [rZ7]: The authors should provide a validation method for their genotyping results as the gold standard for genotypying is DNA sequencing.

Comment [rZ8]: Editing needed.

Formatted: Highlight

From January 2018 to December 2023 considering samples with serological weak phenotype or with discordant DVI+/DVI- reactivity wereselected, 547 subject for RHD gene analysis,. As reported in table I: 86 subjects (15.5%) were D positive and 56 (10.1%) were D negative, without variant, in 16 subjects (2.9%) a rhG genotype was observed. In 362 subjects (65.2%) we observed a weak D and in 43 subjects (7.7%) a D variant was detected. As reported in table I, the D weak type observed with ~~grater~~greater frequency was the D weak type 1 (227, 40.8%) followed by D weak type 11 (47, 8.4%), type 2 (46, 8.3%) and Type (34, 6.1%). Of note is the discovery of 4 (0.7%) subjects carrying the D weak type 18 which is quite uncommon in the Caucasian population. Considering the D variants, the most frequently observed genotype, as expected, was DVI (27, 4.9%).

Comment [rZ9]: The sentence is jumbled.

Comment [rZ10]: Which type? Should be 15!

Discussion

This study was conducted in North-East Italy in a Caucasian population, this fact must be taken into consideration because prevalence of serological weak D phenotypes differs with race/ethnicity: in the Caucasian population, the prevalence of serological weak D phenotype~~s~~ is estimated to be relatively high, ranging from 0.2% to 1.0%; however, it is tenfolds lower in the Asian population. In addition, different RhD serotyping methods could result in substantially different estimates rates for the prevalence of serological weak D phenotypes [17,18].

Interpretation of D type in blood donors can be complex, because some variants of the D antigen with low antigenic density can be undetectable by methodologies with relatively low sensitivity. Consequently, blood components can be mislabelled as RhD-negative, exposing RhD-negative patients to the risk of anti-D alloimmunisation. In serological investigations, the main difficulties occur inpatients with sickle cell disease who are of African descent and with great miscegenation, which makes the presence of non-detectable RhD and RhCE variants common. The same occurs in patients with oncological ~~diseases~~ and other haematological diseases who receive periodic transfusions because of chemotherapy. In general, the *RH* variant is suspected only after alloimmunisation. In this study, among the considered population, we found weak D reactivity in 547 samples, in one or both clones tested, and reactivity discrepancy between the two clones in the same sample. Routine serological techniques are not able to differentiate between weak D and partial D, but they detect the weak expression of the D antigen, suggesting the presence of *RHD* and *RHCE* variant alleles. Subjects, blood donors and/or patients~~,~~ with this condition should be studied molecularly [19,20].

UNDER PEER REVIEW

The first consideration that emerges when examining the results obtained in our study is that the selection criterion adopted to identify the samples to be subjected to RHD genotyping on the basis of the phenotyping for the D antigen does not appear to be completely adequate. In fact, out of 547 samples sent for genotyping, 86 (15.5%) were D positive and 40 (7.2%) were D negative, without RHD genotyping allowing the highlighting of D weak or D variant. As regards the 86 D positive subjects, who were genotyped, without evidence of Dweak or D variant, this observation is not surprising as the literature has well reported the possibility of observing a weakly expressed D in serology, as a consequence of a gene interaction between the RHC and RHCE alleles [21-23]. As regards the 40 D negative subjects, who were genotyped, without evidence of Dweak or D variant, this is a consequence of our sample selection policy. In fact, in the case of observing a D negative subject, in our laboratory the search for D weak is carried out using the Coombs serum method and at the same time a direct antiglobulin test is carried out. If the test for D weak is uninterpretable due to a positive direct antiglobulin test, the sample is sent for RHD genotyping [24].

Comment [rZ11]: The sentence is vague and incomprehensive.

Studies conducted in Europe analysed the frequency of *RHD* alleles and found that 95% ofCaucasian individuals with weak D antigen expression are RHDweak D type 1 to 3 [25-27]. In other studies, in the Brazilian population, *RHD*weak D type 1* was the most frequently found variant [28]. Results obtained in this study are partially in agreement with the data reported in the literature, in fact of the 547 subjects examined, 362 (66%) showed a weak D after RHD genotyping. In the considered series, the most frequently observed D weak was D weak type 1 (227 cases, 40.8%), as expected in the Caucasian population. D weak type 11 (47 cases, 8.4%) and D weak type 2 (46 cases, 8.3%) followed in frequency, followed by D weak type 15 (36 cases, 6.1%). However, no case of D weak type 3 was observed. Of note were 4 cases (0.7%) of D weak type 18 which is considered rather rare in the reference population.As expected, none of the subjects with weak D developed antibodies with anti-D specificity. As matter of facts in 2015, the American Association of Blood Banks (AABB) College of American Pathologists (CAP) Working Group recommended that *RHD* genotyping be performed in patients with a serological weak D phenotype, as patients carrying any of the three most prevalent alleles in Caucasians with a serological weak D phenotype (RHD*01W.1, RHD*01W.2, and RHD*01W.3) can be safely managed as D-positive. This practice allows optimal allocation of scarce D-negative RBCs and prevents unnecessary administration of Rh immune globulin (RhIG). More recently, members of the AABB-CAP Working Group have updated their recommendations

UNDER PEER REVIEW

that patients with the RHD*09.03.01 (weak D type 4.0) or RHD*09.04 (weak D type 4.1) allele also be managed as D-positive [29-31].

In our series only 47 subjects (7.8%) had a D variant after RHD genotyping. As expected, DVI was the most frequently observed D variant (27cases,4.9%). DVI is considered a clinically significant variant since DV+ subjects can also produce antibodies with anti-D specificity following immunotherapy following transfusion or during pregnancy. In our laboratory we actively search for the DVI variant with serological methods using gel card tests with two anti-D microtube, one of which is capable of specifically recognizing the DVI variant [32]. This screening method has proven to be extremely sensitive (1.00) and specific (1.00). In fact, genotyping for RHD confirmed the presence of a DVI variant in all 27 samples identified by the serological method. While in none of the samples not identified by serology screening did, we identify a DVI variant by RHD genotyping. In our series of ~~patients~~patients, we found the formation of a specific anti-D allo antibody in a woman in her second pregnancy carrying a D variant type DAR [33].

This study has some limitations: it is in fact a single-center retrospective study; where the selection of samples to be subjected to RHD genotyping was carried out based on the results of serological tests. Both donors and patients were therefore selected. It was therefore not possible to establish a prevalence data of the forms of weak D / variant D in the reference population but only an analysis of the frequencies of the different forms of D variants / weak D observed.

Comment [rZ12]: Difficult sentence!

Comment [rZ13]: Is this percent or proportion??!!!

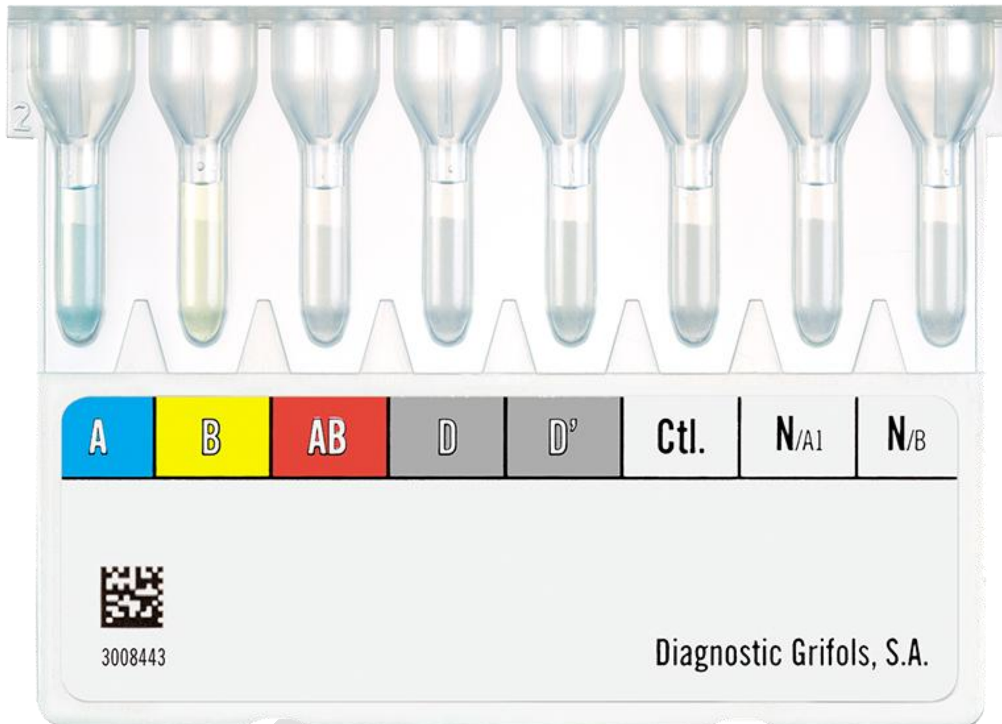
Table I: RHD genotyping results

RHD Genotype	Case N° (%)	RHD Genotype	Case N° (%)
D weak type 1	227 (40.8%)	D partial type III	3 (0.5%)
D weak type 2	46 (8.3%)	D partial type IV	1 (0.2%)
D weak type 4	4 (0.7%)	D partial type V	4 (0.7%)
D weak type 11	47 (8.4%)	D partial type VI	27 (4.9%)
D weak type 15	34 (6.1%)	DAR	1 (0.2%)
D weak type 18	4 (0.7%)	DFR2	3 (0.5%)
D positive (non variant)	86 (15.5%)	DAU4	1 (0.2%)
D negative (no variant)	40 (7.2%)	DNB	3 (0.5%)
D negative rG	16 (2.9%)		

Comment [rZ14]: Possibly non variant!!??

UNDER PEER REVIEW

Figure 1: Description of the Grifols DG Gel 8 ABO/Rh (2D) gel card



Each microtube of the DG Gel 8 ABO/Rh (2D) card contains a gel in buffered medium with preservative. The five first microtubes also contains antibody reagents and the last three microtubes have only the buffered medium. The different microtubes are identified on the front label of the card. Microtube A: monoclonal antibody anti-A. Mixture of IgM and IgG antibodies of murine origin, clones 16243G2 and 16247E6. Microtube B: monoclonal antibody anti-B. IgM antibody of murine origin, clone 9621A8. This reagent does not react with acquired B cells. Microtube AB: monoclonal antibodies anti-AB. Mixture of IgM antibodies of murine origin, anti-A(B) clone ES15, anti-A clone LA-2, and anti-B clone LB-2. Microtube DVI- : monoclonal antibody anti-D. IgM antibody of human origin, clone P3x61. This reagent does not detect partial DVI. Microtube DVI+: monoclonal antibody anti-D. Mixture of IgM antibodies of human origin, clones P3x61 and ESD1M. This reagent detects partial DVI. Microtube Ctl.: buffered solution without antibodies (control microtube). Microtubes N: buffered solution without antibodies for the ABO reverse group test

Figure 2: Semiquantitative scoring system for agglutination interpretation

0 Negative: well-defined pellet of non-agglutinated red blood cells at the bottom of the gel column and no visible agglutinated cells in the rest of the gel column. Weak reactvity: w+ Barely visible small-sized clumps of agglutinated cells in the lower part of the gel column and a pellet of unagglutinated cells at the bottom. Reactivity 1+ Some small-sized clumps of agglutinated cells most frequently in the lower half of the gel column. A small pellet may also be observed at the bottom of the gel column. 2+ Reactivity Small or medium-sized clumps of agglutinated cells throughout the gel column. A few unagglutinated cells may be visible at the bottom of the gel column. 3+ Reactivity Medium-sized clumps of agglutinated cells in the upper half of the gel column. 4+ Reactivity A well-defined band of agglutinated red blood cells in the top part gel column. A few agglutinated cells may be visible below the band. mf Mixed-field. A band of red blood cells at the top part of the gel or dispersed throughout the gel column, and a pellet in the bottom as a negative result. H Hemolysis in the microtube with very few or no red blood cells in the gel column. ff hemolysis is present in the microtube but not in the sample the reaction must be considered positive (4+).

Conclusions

Approximately 0.2% to 1% of routine RhD blood typings result in a “serological weak D phenotype.” In the era of “phenotyping only” assays, serological weak D phenotypes have been managed by policies to protect RhD-negative women of child-bearing potential, as well as patients who will be candidates for chronic transfusion therapy (hemoglobinopathies, leukemias, etc.) from exposure to weak D antigens. Typically, blood

donors with a serological weak D phenotype have been managed as RhD-positive, in contrast to transfusion recipients and pregnant women, who have been managed as RhD-negative. RHD genotyping allows a simple identification of D weak / D variant. Most serological weak D phenotypes in Caucasians express molecularly defined weak D types 1, 2 or 3 and can be managed safely as RhD-positive, eliminating unnecessary administrations of Rh immune globulin and conserving limited supplies of RhD-negative RBCs.

CONSENT

It is not applicable

ETHICAL APPROVAL

It is not applicable.

References

1. Reid ME, Lomas-Francis C, Olsson ML. The blood group antigen facts book. Third edition, Elsevier, London 2012.
2. Schenkel-Brunner H. Human blood groups, chemical and biochemical basis of antigen specificity. Third Edition, Spinger, Wien 2012.
3. Gessoni G. Immunohematology. In Clinical and Laboratory medicine textbook, Ciaccio M editor. First edition, Spinger London 2024.
4. Vege S, Sprogøe U, Lomas-Francis C, et al. Impact of RHD genotyping on transfusion practice in Denmark and the United States and identification of novel RHD alleles. Transfusion. 2021; 61: 256-265. doi: 10.1111/trf.16100.
5. Londero D, Merluzzi S, Dreossi C, Barillari G. Prenatal screening service for fetal RHD genotyping to guide prophylaxis: the two-year experience of the Friuli Venezia Giulia region in Italy. Blood Transfus 2023; 21:93-99. doi: 10.2450/2022.0004-22.
6. Barriteau CM, Lindholm PF, Hartman K, et al. RHD genotyping to resolve weak and discrepant RhD patient phenotypes. Transfusion. 2022; 62: 2194-2199. doi: 10.1111/trf.17145.
7. Sandler SG, Chen LN, Flegel WA. Serological weak D phenotypes: a review and guidance for interpreting the RhD blood type using the RHD genotype. Br J Haematol. 2017; 179: 10-19. doi: 10.1111/bjh.14757.
8. Perez-Alvarez I, Hayes C, Hailemariam T, Shin E, et al. RHD genotyping of serologic RhD-negative blood donors in a hospital-based blood donor center. Transfusion. 2019; 59: 2422-2428. doi: 10.1111/trf.15325.
9. Oodi A, Daneshvar Z, Goudarzi S, Amirizadeh N. RHD genotyping of serological weak D phenotypes in the Iranian blood donors and patients. TransfusApher Sci. 2020; 59: 102870. doi: 10.1016/j.transci.2020.102870.
10. Ying Y, Zhang J, Hong X, et al. The Significance of <i>RHD</i> Genotyping and Characteristic Analysis in Chinese RhD Variant Individuals. Front Immunol. 2021; 12: 755661. doi: 10.3389/fimmu.2021.755661.

UNDER PEER REVIEW

11. Lapierre Y, Rigal D, Adam J,et al.The gel test: a new way to detect red cell antigen-antibody reactions. Transfusion. 1990; 30: 109-13. doi: 10.1046/j.1537-2995.1990.30290162894.x.
12. Cohn C, Delaney M, DO, Johnson TS, et al. Technical Manual. 21th edition, AABB Bethesda 2023.
13. Wen J, Jia S, Wang Z, et al. Molecular and serological analysis of the D variant in the Chinese population and identification of seven novel RHD alleles. Transfusion. 2023; 63: 402-414. doi: 10.1111/trf.17186.
14. Londero D, Monge J, Hellberg A. A multi-centre study on the performance of the molecular genotyping platform ID RHD XT for resolving serological weak RhD phenotype in routine clinical practice. Vox Sang. 2020;115: 241-248. doi:10.1111/vox.12886.
15. Aburto A, Zapata D, Retamales E, et al. Genotype analysis to clarify RhD variants in discrepant samples of Chilean population. Front Immunol. 2023;14: 1299639. doi: 10.3389/fimmu.2023.1299639.
16. Owaidah A, Aljuhani K, Albasri J, et al. Cases of RhD variants RhD*DAU2/DAU6 and RhD*weak D type 4.1 in pregnant women in Saudi Arabia. Acta Biomed. 2023; 94(S1): e2023080. doi: 10.23750/abm.v94iS1.14120.
17. Leiva-Torres GA, Chevrier MC, Constanzo-Yanez J, et al. High prevalence of weak Dtype 42 in a large-scale RHD genotyping program in the province of Quebec (Canada). Transfusion. 2021; 61: 2727-2735. doi: 10.1111/trf.16518.
18. Thongbut J, Laengsri V, Raud L, et. al. Nation-wide investigation of RHD variants in Thai blood donors: Impact for molecular diagnostics. Transfusion. 2021; 61: 931-938. doi:10.1111/trf.16242.
19. Denomme G, Dake LR, Vilensky D, et al. Rh discrepancies caused by variable reactivity of partial and weak D types with different serologic techniques. Transfusion. 2008; 48: 473-8. doi: 10.1111/j.1537-2995.2007.01551.x.
20. Choi S, Chun S, Lee HT, et al. Weak D Testing is not Required for D- Patients With C-E- Phenotype. Ann Lab Med. 2018; 38: 585-590. doi:10.3343/alm.2018.38.6.585.
21. Souza Silva TC, Cruz BR, Costa SS, et al. RHD and RHCE molecular analysis in weak D blood donors and in patients with Rh antibodies against their own corresponding Rh antigen. Blood Transfus. 2020; 18: 295-303. doi: 10.2450/2020.0026-20.
22. El Housse H, El Wafi M, Ouabdelmoumene Z, et al. Comprehensive phenotypic and molecular investigation of RhD and RhCE variants in Moroccan blood donors. Blood Transfus. 2019; 17: 151-156. doi: 10.2450/2018.0153-18.
23. Yin Q, Ouchari M. Transfusion management of Africans with RHD variants in China. Transfus Clin Biol. 2023; 30: 287-293. doi:10.1016/j.tracli.2023.01.003.
24. Van Sandt VS, Gassner C, Emonds MP, wt al. RHD variants in Flanders, Belgium. Transfusion. 2015; 55: 1411-7. doi:10.1111/trf.12947.
25. Flegel WA, Denomme GA, Queenan JT, et al. It's time to phase out "serologic weak D phenotype" and resolve D types with RHD genotyping including weak D type 4. Transfusion. 2020 Apr;60(4):855-859. doi: 10.1111/trf.15741.
26. SaficStanic H, Dogic V, Herceg I, et al. D variants in the population of D-negative blood donors in the north-eastern region of Croatia. Transfus Med. 2021; 31: 43-47. doi: 10.1111/tme.12726.

UNDER PEER REVIEW

27. Miranda MR, Dos Santos TD, Castilho L. Systematic RHD genotyping in Brazilians reveals a high frequency of partial D in transfused patients serologically typed as weak D. TransfusApher Sci. 2021; 60: 103235. doi: 10.1016/j.transci.2021.103235.
28. Sandler SG, Flegel WA, Westhoff CM, et al. It's time to phase in RHD genotyping for patients with a serologic weak D phenotype. College of American Pathologists Transfusion Medicine Resource Committee Work Group Transfusion. 2015; 55:680-9. doi: 10.1111/trf.12941.
29. Westhoff CM, Nance S, Lomas-Francis C, et al. Experience with RHD*weak D type 4.0 in the USA. Blood Transfus. 2019; 17: 91-93. doi: 10.2450/2018.0114-18.
30. Stensrud M, Bævre MS, Alm IM, et al. Terminating Routine Cord Blood RhD Typing of the Newborns to Guide Postnatal Anti-D Immunoglobulin Prophylaxis Based on the Results of Fetal RHD Genotyping. Fetal Diagn Ther. 2023; 50: 276-281. doi: 10.1159/000531694.
31. Fichou Y, Le Maréchal C, Scotet V, et al. Insights into RHCE Molecular Analysis in Samples with Partial D Variants: the Experience of Western France. Transfus Med Hemother. 2015 Nov;42(6):372-7. doi: 10.1159/000382086.
32. Pedini P, Filosa L, Bichel N, et al. Five-Years Review of <i>RHCE</i> Alleles Detected after Weak and/or Discrepant C Results in Southern France. Genes (Basel). 2022;13: 1058. doi: 10.3390/genes13061058.
33. Laget L, Izard C, Durieux-Roussel E, et al. Relevance and costs of RHD genotyping in women with a weak D phenotype. Transfus Clin Biol. 2019; 26: 27-31. Doi: 10.1016/j.tracli.2018.05.001.

UNDER PEER REVIEW