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RARE BLOOD BANKS: CHALLENGES AND SOLUTIONS IN BRAZIL AND WORLD WIDE

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ABSTRACT

The growing demand for compatible blood for rare phenotypes highlights significant global and national challenges in transfusion medicine. Brazil, marked by extensive genetic diversity, faces difficulties in infrastructure, logistics, and donor identification. In contrast, countries like India, South Korea, and Austria have developed advanced genotyping techniques and robust regional registries, improving response times and transfusion safety. Despite advances such as the creation of Brazil's national rare donor panel, gaps remain in donor recruitment and rare blood management. Adopting international best practices and expanding donor registries are essential to optimize Brazil's rare blood supply system.

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INTRODUCTION

The development and management of blood banks with rare phenotypes is essential to guarantee safe transfusions, especially in regions with specific diversity, such as Brazil. The introduction of phenotyping and genotyping techniques has the possibility of identifying and registering rare donors, which is crucial for serving patients with safe blood phenotypes and minimizing complications related to alloimmunization (DUTRA *et al*., 2019; SETYA *et al*., 2020). In the Brazilian context, studies show that the genetic diversity of the population makes it difficult to achieve compatibility in transfusions, reinforcing the importance of strategies to expand donor banks with genotyped profiles (CALDAS *et al*., 2022). Internationally, countries such as India and South Korea have implemented rare donor registries to improve the management and distribution of rare blood. In India, for example, the creation of a regional registry significantly improved the response time for making rare blood available, demonstrating the effectiveness of a structured approach (POLAVARAPU; SHASTRY; CHENNA, 2023). In Korea, a donor registry specific to phenotypes such as D-- has guaranteed adequate supply for emergency situations (HAN; KWON; JEKARL, 2021). The use of modern genotyping techniques has proven to be an effective complementary solution to traditional serological methods. Genotyping makes it possible to predict phenotype with high accuracy from DNA, which is advantageous for polytransfused patients and those who develop rare antibodies (QUIRINO *et al*., 2019; BARBAGALLO *et al*., 2022). This advance is particularly useful in blood bank programs, where the need for phenotypically compatible blood is key to preventing transfusion reactions and improving the management of patients with alloimmunization (QUIRINO *et al*., 2019; DUTRA *et al*., 2019). Faced with these challenges, Brazil needs to expand its network of rare blood banks, adopting good practices from countries that have already faced and overcome similar barriers. The creation of a robust national registry, with collaboration between regional centers, can improve efficiency and agility in responding to specific demands, as well as contributing to safer and more comprehensive transfusion management. The aim of this study is to analyze rare blood bank programs, comparing infrastructure and practices in Brazil with other countries. The problem addressed is limited management and insufficient response to the demand for rare blood. The justification is the need to optimize practices to ensure safe and efficient transfusions, strengthening the Brazilian health network and increasing the availability of compatible donors.

METHODOLOGY

This study is characterized as exploratory-descriptive bibliographical research, with a qualitative approach, based on previously published

material on blood banks and rare donors. For data collection, a bibliographic survey was carried out in renowned databases, including Latin American and Caribbean Literature in Health Sciences (LILACS), Scientific Electronic Library Online (SciELO) and PubMed, covering publications from the last 10 years. We selected complete and relevant articles, available in Portuguese and English, which met the scope of the study. Articles unrelated to the topic, duplicated, incomplete or opinionated material, such as criticisms and debates, were excluded. The LILACS and BDENF databases were consulted using PubMed, the Virtual Health Library (VHL) and ScienceDirect. The searches were carried out using the Health Sciences Descriptors (DeCS) of the Regional Library of Medicine (Bireme), using the Boolean operators "AND" and "OR" to refine the results. The keywords used in the search included: "Blood banks", "Rare donor", "Blood" and "Blood donor". Based on these keywords and their alternative terms, tables were drawn up with the relevant articles, eliminating duplicates at each stage. Next, an initial screening was carried out based on the title and abstract, followed by a detailed reading of the articles that met the inclusion criteria. In the analysis of the data, three axes of discussion were defined, guided by the specific objectives of the study: (1) historical construction and structure of blood banks with rare donors, (2) methods and processes for identifying and managing rare donors in different contexts, and (3) solutions adopted for optimization and challenges faced in the management of rare blood. These axes guided the critical and in-depth reading of the articles, forming a conceptual basis for the results and investigation. The structured methodology resulted in a robust and well-founded investigation, guaranteeing the validity and depth of the results presented in the study.

RESULTS AND DISCUSSION

Structure of Rare Blood Banks: The identification and registration of blood donors with rare phenotypes is fundamental to guaranteeing the safety and efficacy of transfusions, especially in regions with high ethnic diversity. Recent studies highlight initiatives in different countries to address the challenges associated with collecting and maintaining rare blood. For example, the Czech Republic created a strategic frozen blood bank in 2006 to respond to national crises, storing units with rare antigens for civilian and military use (BOHONEK; SEGHATCHIAN, 2020). Similarly, programs such as South Korea's, which since 2013 has kept a register of donors with specific phenotypes such as D--, have ensured the rapid availability of compatible units for patients (HAN; KWON; JEKARL, 2020). In Asia, China has implemented serological and genetic screening programs to identify rare donors in recent years, with more than 1,300 donors catalogued by 2016 (ZHU *et al*., 2016). Another noteworthy example is Iran, where the national rare donor program was implemented in 2009 and is managed by the Immunohematology Reference Laboratory in Tehran, centralizing the identification and maintenance of the rare blood group database (GHEZELBASH; MOGHADDAM; AGHAZADEH, 2018). In Japan, the Red Cross has coordinated a rare donor program since 1987, categorizing types that occur in fewer than 1 in 10,000 people and those that are more common but still rare, found in 1 in 100 individuals (TANI, 2016). In Europe, France and Italy serve as examples of efficient structuring. France, a pioneer in the 1960s, formalized its national rare blood bank in the 1980s, managed by the National Reference Center for Blood Groups (CNRGS) and the National Blood Service (PEYRARD, 2016). Italy, although it does not have a consolidated national program, has initiated regional programs, such as that of Lombardy in 2005, which has received significant governmental and financial support to develop a robust bank of rare donors (PACCAPELO, 2016). In addition, Switzerland, in partnership with Germany and Austria, implemented the "DGTI Register of Rare Donors" in 2012, an international database that facilitates access to donors with rare phenotypes (HUSTINX, 2014). Other countries have also innovated in their approaches. In Spain, the creation of the rare donor program in 2005 was the result of the collaboration of regional centers and the support of the Spanish Society of Blood Transfusion, consolidating a national database for the cryopreservation of rare units (MUÑIZ-DIAZ, 2016). Singapore, for its part, has been using cryopreservation with glycerol since 2004 to store rare blood for up to 10 years, ensuring a rapid response to transfusion needs (ALCANTARA; CHAY; ANG, 2016). In North America, the American Rare Donor Program (ARDP), created in 1998, has a 93.8% transfusion rate, demonstrating its high efficiency and responsiveness (FLICKINGER, 2016). Latin America also has notable examples of progress. In Brazil, a national panel of rare donors was developed in 2012, with the Ministry of Health collaborating with the Albert Einstein Hospital to develop frozen stocks and carry out regional screening (CASTILHO, 2016). This effort aims to fill a gap in a national system and meet local demands for rare blood. In New Zealand, since 1986, the country has maintained an up-to-date national inventory to record expanded phenotypes, ensuring that units of rare blood are available for local use (GOUNDER, 2016). The implementation and expansion of rare donor programs in different countries show that, although there are variations in the approaches and technologies adopted, the common goal is to guarantee the safety and efficacy of transfusions for patients with specific needs. By following international examples and adapting strategies according to its population characteristics and logistical challenges, Brazil can strengthen its initiatives and create an infrastructure that supports the identification, maintenance and distribution of rare blood effectively. This demonstrates the importance of public policies and partnerships between health centers to promote a more inclusive and efficient transfusion system.

Structure and Processes for Identifying and Managing Rare Bloods: Blood bank programs focusing on rare donors have evolved significantly around the world, reflecting the need for specialized approaches to ensure transfusion safety. In China, the urea hemolysis test was developed for the initial screening of rare phenotypes such as Jk(a-b-), with confirmation by classical serological methods and sequencing of exons of the SLC14A1 gene (ZHANG; GAO, 2023). These practices enrich the understanding of the genetic diversity of rare blood types. In Iran, rare donor management is centralized in Tehran, where specific manufacturing practices and operational protocols ensure the availability of rare blood for emergencies. This structure, coupled with donor registries, allows for a rapid and effective response in critical situations (GHEZELBASH; MOGHADDAM; AGHAZADEH, 2018). In Europe, countries such as Italy and Germany stand out for their innovation in techniques for identifying and managing rare donors. In Italy, the LORD-P program uses modern methods, such as DNA microarray and Luminex technology, for molecular typing and polymorphism analysis in various blood systems (PACCAPELO, 2016). Germany, for its part, maintains an online database, the DGTI Register, where donors with rare antigens such as k- and Yt(a-) are registered, making it easier to find compatible donors (HUSTINX, 2014). These examples illustrate the importance of advanced technological solutions for the efficient management of rare blood banks. The approach in Singapore and South Africa shows the flexibility and regional collaboration in maintaining rare blood stocks. In Singapore, targeted screening and the use of cryopreservation with 40% glycerol ensure the availability of rare units for up to 10 years (ALCANTARA; CHAY; ANG, 2016). In South Africa, the regional program stores units in Durban and manages liquid and frozen donations, meeting both local and international demands, including shipments to Ireland and Canada (SOEKER, 2016). These practices reveal how cooperation and technology are crucial for the effective management of rare blood. In Latin America, Brazil has made progress in identifying rare donors with regional initiatives. Strategic centers in cities such as São Paulo and Manaus carry out serological screening and genotyping, creating a support network that can be integrated to form a national panel of rare donors (CASTILHO, 2016). These practices are complemented by the development of databases and the use of digital platforms to facilitate donor tracking and stock management. In contrast, programs in the US, such as ARDP, centralize the identification and maintenance of donors in reference laboratories, which ensures a high response rate to rare blood communications (FLICKINGER, 2016). The application of advanced methods, such as multiplex PCR and next-generation sequencing, has been key in countries such as Canada, where around 2,000 rare donors are part of a national

database managed by the Canadian Blood Service (CBS), which includes frozen inventories ready for use in any region of the country (GOLDMAN; ST CROIX, 2016). These strategies reflect a significant advance in transfusion support for patients with specific needs, highlighting the importance of a well-personalized and collaborative infrastructure. However, a comparative analysis of the challenges and solutions adopted by high- and low-income countries for the identification and management of rare blood types is essential in order to understand global best practices. The following table presents a detailed comparison of the challenges faced and the strategies implemented.

Table 1. Comparative Analysis of Challenges and Solutions Related to Rare Bloods

Aspect	High-Income Countries	Low- and Middle-Income Countries
Infrastructure	High technology and advanced cryopreservation	Limited infrastructure, focus on local solutions
Technologies	Multiplex PCR, sequencing, Luminex	Basic serology, local screening
Donor Retention	Continuous campaigns with technology use	Logistical and engagement challenges
Government Support	Sustained by public policies	Limited, relies on regional initiatives
International Collaboration	Common (e.g., DGTI, ARDP)	Rarely explored
Additional Challenges	Logistics coordination and high costs	Financial and regional limitations

In high-income countries, as the challenges are more linked to advanced genotyping technologies and high costs, solutions such as the use of regional programs and international partnerships have been effective in improving identification and distribution. In low-income countries, on the other hand, the lack of infrastructure and donor recruitment programs is a significant obstacle, being solved through partnerships and community initiatives that expand the donor network and improve access to rare blood.

Efficiency in the Collection and Distribution of rare Blood: The identification and management of rare blood donors remains a significant challenge in various parts of the world due to the low frequency of certain phenotypes and the complexities associated with screening and maintaining stocks. In China, for example, the Jk(a-b-) phenotype was found in only 0.0031% of donors, highlighting the importance of molecular identification to improve accuracy and facilitate the screening of rare donors (ZHANG; GAO, 2023). In addition, the use of methods such as multiplex PCR has helped to identify some rare donors and increase transfusion safety, but the expansion of genetic typing to less common systems is still a necessity (JIAO *et al*., 2015). Creating adequate infrastructures for storing blood components is another challenge. In Italy, the LORD-P programme faced a shortage of donors and seasonal demand, but overcame these obstacles by developing specialized blood banks that store frozen red blood cells, ensuring availability even in critical periods (PACCAPELO, 2016). Similarly, Spain, prior to the implementation of its programme in 2005, faced a lack of centralized organization. The solution was the formation of the "Working Party on Rare Donors" and the creation of a national database, which increased efficiency in responding to emergencies (MUÑIZ-DIAZ, 2016). The development of screening and storage strategies is also crucial to address the extreme rarity of certain phenotypes, such as Rhnull. In South Africa's donor program, an approach of freezing for international use and sending liquid units to hospitals ensured that urgent needs were met efficiently (SOEKER, 2016). In Belgium, the limited antigenic diversity in some regions led to the development of strategies to recruit donors from more diverse ethnic backgrounds. Massive screening, using automated molecular methods, aims to expand the stock of rare blood and improve efficiency in collection and distribution, strengthening the blood bank (Vanhonsebrouck; Najdovski, 2016). The use of advanced technologies, such as KASP genotyping, has proven to be a highly efficient solution, reducing costs compared to traditional serology methods and increasing accuracy in donor screening. Studies conducted in European countries indicate that genotyping accuracy has reached 99.9%, providing a significant improvement in the identification of rare phenotypes and the expansion of specialized blood banks (KROG *et al*., 2019). In Brazil, the lack of storage capacity for frozen units has been addressed by centers such as the Sírio-Libanês Hospital, which has implemented screening and thawing processes to send units as needed (WENDEL *et al*., 2016). International collaboration and government support are necessary for rare donor programs to meet growing demands and maintain service efficiency (CASTILHO, 2016). Other challenges include donor retention, as observed in New Zealand, where the lack of donors among Maori and Polynesian communities has prompted proposals for recruitment programs focused on community responsibility (GOUNDER, 2016). In the United States, the ARDP faced difficulties in finding units with rare antigens, often resorting to importing from other countries to meet demand (MENY; FLICKINGER; MARCUCCI, 2013). The introduction of molecular testing in 2008 at the ARDP allowed for greater precision and an expansion in the number of identified donors, improving the response to patient needs (FLICKINGER, 2016).

Table 2. Rare Blood Donor Recruitment and Retention Strategies by Country

Country	Recruitment Strategies	Retention Strategies
United States	National campaigns with ARDP and advanced genotyping	Donor rewards, regular communication, and technological integration
France	Integration with CNRGS, public awareness campaigns	Long-term tracking of donors with incentives
Germany	Collaborative programs like DGTI Register	Database management and international collaborations
Japan	Targeting rare phenotypes via regional networks	Regular follow-ups and cultural awareness
Brazil	Regional triaging supported by public-private partnerships	Collaboration with research centers for donor engagement
South Africa	Regional storage centers and focused outreach in diverse areas	Integration of storage and outreach to maintain interest
China	Large-scale genetic and serological screenings	Periodic recognition programs for rare donors
Iran	Centralized donor identification through Tehran Lab	Dedicated support for frequent donors in emergencies
New Zealand	Community-based programs targeting underrepresented groups	Cultural sensitivity and retention campaigns
Czech Republic	Public donor banks integrated with emergency plans	Incentives tied to emergency response systems
South Korea	Phenotype-specific targeting and continuous donor engagement	Continuous updates and engagement via digital platforms
Canada	Nationwide donor networks with cryopreservation	Support networks and recognition for dedicated donors

The table summarizes the most common and effective strategies implemented in different national contexts. While high-income countries such as the United States benefit from advanced technologies such as molecular genotyping to optimize the screening and identification of rare donors, countries with fewer resources such as New Zealand and others in Africa resort to approaches based on community programs and international partnerships to overcome infrastructure and donor engagement barriers. These combined strategies have proven effective in improving efficiency in the collection and distribution of rare blood, showing that solutions adapted to local realities can be key to the success of these programs.

CONCLUSION

The analysis of rare blood bank programs revealed both common challenges and effective solutions adopted to address them. In high-

income countries, cutting-edge technologies such as molecular genotyping have been key to ensuring accuracy in the identification of rare blood types. However, the implementation of these technologies requires high investments, which limits the accessibility of these solutions in regions with fewer resources. Analyzing the data makes it possible not only to observe the distribution of rare phenotypes, but also to identify the difficulties faced in managing rare blood, taking into account the specific characteristics of each country. On the other hand, in low-income countries, structural challenges stand out, such as the lack of adequate infrastructure and the difficulty in recruiting rare donors. However, international collaboration programs and strategies based on community initiatives have shown that it is possible to overcome these barriers. The exchange of knowledge and resources between countries has been essential for strengthening health systems and expanding access to rare blood, especially in under-resourced regions. In the Brazilian context, progress in creating programs for rare blood is evident, but adapting international solutions, such as expanding the diversity of donors and using more effective technologies, will be decisive in optimizing rare blood management in the country. The adoption of best practices from other countries, combined with an adapted national strategy, could be the difference for Brazil to overcome structural and operational challenges, guaranteeing a more efficient and safer response to the needs of the population.

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