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RESEARCH ARTICLE

Hemoglobin phenotypic variations among voluntary blood donors in Bangladesh: A Study on genetic screening for safe blood transfusion

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ABSTRACT

Background: Blood donation is a critical component of healthcare systems worldwide, particularly in regions with endemic diseases like malaria. Hemoglobinopathies, such as sickle cell trait (HbAS) and other variants like HbAC, can influence the safety of blood donations, particularly in malaria-endemic areas. Understanding the hemoglobin profiles of voluntary blood donors is essential for ensuring safe blood transfusions.

Objective: The objective of this study was to examine the demographic characteristics and hemoglobin phenotypes of voluntary blood donors at LSBTS, Bangladesh, with a focus on their potential impact on transfusion safety.

Methods: A total of 300 voluntary blood donors were included in the study. Demographic data including age, gender, occupation, and marital status were collected. Hemoglobin phenotypes were assessed using standard hematological methods. Donor history, including frequency of previous donations and the most recent donation year, was also recorded. Data were analyzed using descriptive statistics to identify trends and associations.

Results: Most participants (80%) exhibited the normal hemoglobin phenotype (HbAA), followed by 18% with the sickle cell trait (HbAS) and 2% with other variants (HbAC). The donor population was predominantly male (70%) and largely aged between 26 and 45 years (68%). A significant proportion (62%) were repeat donors, with 70% having donated blood in 2023. Weight distribution and hemoglobin levels showed no significant association with hemoglobin phenotypes, indicating consistent donor health across groups. These findings suggest a stable donor pool with diverse hemoglobin profiles, underscoring the importance of ongoing screening and monitoring to maintain transfusion safety.

Conclusion: This study highlights the predominance of HbAA among voluntary blood donors in Bangladesh, suggesting that the majority of blood donations are likely to be safe for transfusion. However, the presence of HbAS and HbAC in the donor population underscores the importance of comprehensive pre-donation screening, particularly in malaria-endemic regions. Health promotion efforts should focus on enhancing donor recruitment and retention, with targeted campaigns for younger and male populations, as well as healthcare workers.

Keywords: Blood donation; hemoglobin phenotype; HbAA; HbAS; transfusion safety

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1. Introduction

Hemoglobinopathies and thalassemias represent a significant group of inherited blood disorders caused by mutations in the globin genes, leading to either the production of structurally abnormal hemoglobin or reduced synthesis of globin chains[1]. Among the most prevalent forms are sickle cell disease (SCD) and beta-thalassemia, which collectively affect millions of individuals worldwide. These disorders pose substantial public health challenges due to their chronic nature, frequent complications, and the demand for lifelong medical management, including regular blood transfusions and iron chelation therapy[2].

Sickle cell disease, primarily resulting from a point mutation in the β-globin gene (Glu6Val), leads to the synthesis of abnormal hemoglobin S (HbS)[3]. Under hypoxic or stressful conditions, HbS undergoes polymerization, causing red blood cells to assume a characteristic sickle shape. These deformed cells are prone to hemolysis and can occlude microvasculature, resulting in a wide spectrum of clinical manifestations such as vaso-occlusive crises, chronic anemia, stroke, acute chest syndrome, and multiorgan damage[4,5]. Meanwhile, thalassemias, particularly beta-thalassemia, are caused by partial or complete failure in the production of the β-globin chain, leading to ineffective erythropoiesis, bone marrow expansion, hepatosplenomegaly, and severe anemia, especially in transfusion-dependent individuals[6].

Globally, the World Health Organization (WHO) estimates that approximately 5% of the world's population carries a gene for a hemoglobin disorder[7]. The burden is disproportionately higher in regions historically affected by malaria, due to the selective advantage conferred by certain hemoglobin variants, including sickle cell trait (HbAS), hemoglobin C (HbAC), and thalassemia traits[8]. These mutations provide partial protection against *Plasmodium falciparum* malaria, thus maintaining their prevalence in affected populations through natural selection. South Asia, including Bangladesh, is one such region where the frequency of hemoglobinopathies is notable[9].

In Bangladesh, hemoglobinopathies are an emerging public health concern. Epidemiological studies estimate that approximately 6–12% of the population are carriers of beta-thalassemia, while 4–6% may carry the sickle cell trait[10]. In certain tribal and malaria-endemic areas, such as the Chittagong Hill Tracts, the prevalence may be even higher. Despite the growing recognition of these disorders, genetic counseling and systematic screening programs remain limited in scope and accessibility. This presents a significant challenge in ensuring the safety and compatibility of the national blood supply, as individuals with abnormal hemoglobin variants may unknowingly donate blood, posing potential risks for transfusion recipients—especially those with underlying hemoglobinopathies or immune compromise[11].

Safe blood transfusion practices are essential components of modern healthcare. They are especially critical for patients suffering from chronic anemias, hematologic malignancies, and surgical or trauma-related blood loss[12]. For these patients, compatibility of not only blood type but also hemoglobin structure becomes paramount. Transfusing blood containing abnormal hemoglobin (e.g., HbAS or HbAC) may lead to complications, particularly in recipients with hemoglobinopathies themselves or those in need of frequent transfusions[13]. Moreover, in malaria-endemic areas, the presence of these hemoglobin variants can further complicate the clinical picture, as certain hemoglobinopathies influence malaria pathogenesis and response to treatment[14].

Recent advancements in point-of-care diagnostic tools have facilitated rapid, cost-effective screening of hemoglobin variants among blood donors. Devices such as HemoTypeSC, SickleSCAN, and other lateral flow-based assays have demonstrated high sensitivity and specificity in detecting HbA, HbS, and HbC, offering viable solutions for implementation in low-resource settings[15,16]. These tools are especially valuable for countries like Bangladesh, where infrastructure limitations and resource constraints hinder the widespread use

of conventional diagnostic methods such as high-performance liquid chromatography (HPLC) or electrophoresis[17].

However, despite the potential of these technologies, routine genetic or phenotypic screening of blood donors has yet to become standard practice in Bangladesh. Most blood donation centers primarily screen for infectious agents (e.g., HIV, hepatitis B and C, syphilis, malaria) but do not assess for hemoglobin disorders[18]. As a result, blood from donors carrying HbAS or HbAC may inadvertently be included in transfusion pools, raising concerns about transfusion efficacy and safety[19]. This gap underscores the urgent need for comprehensive screening protocols and policy-level interventions to ensure that donated blood is both infection-free and genetically compatible. The present study aims to assess the prevalence and distribution of hemoglobin phenotypic variations among voluntary blood donors in Bangladesh, using data from a major transfusion center.

2. Materials and methods

2.1. Study setting and design

This descriptive cross-sectional study was conducted between June and July 2024 at the National Blood Transfusion Service (NBTS) facilities in Dhaka, Bangladesh. NBTS plays a critical role in maintaining a safe and adequate national blood supply. The study aimed to assess the prevalence and distribution of hemoglobin phenotypic variations—including HbAA, HbAS, HbAC, and other variants—among voluntary blood donors, in order to support safer transfusion practices.

Data were collected from 300 voluntary donors across 15 designated blood donation centers in Dhaka city. Participants were selected using a convenience sampling technique to reflect a diverse pool of donors aged between 18 and 65 years. The study focused on identifying common hemoglobinopathies such as sickle cell trait and thalassemia traits, thereby providing insight into genetic risks that could impact transfusion safety in Bangladesh.

2.2. Sample size determination

The sample size was determined to provide sufficient statistical power and representativeness. Based on the estimated prevalence of hemoglobinopathies in Bangladesh and ensuring a 95% confidence level, a total of 300 voluntary blood donors were selected to participate in the study. To account for potential non-responses or incomplete data, the sample size was adjusted accordingly.

2.3. Study subjects

The study population consisted of voluntary blood donors who met specific eligibility requirements to ensure both donor safety and data reliability. Participants were recruited from 15 blood donation centers in Dhaka city, and their inclusion was based on standardized donor selection criteria.

2.4. Inclusion criteria

Eligible participants were voluntary blood donors aged between 18 and 65 years, with a minimum hemoglobin level of 12.5 g/dL and a body weight of at least 50 kg. Only individuals with no history of major infectious diseases, such as HIV, Hepatitis B, Hepatitis C, or other blood-borne infections, were included. Furthermore, participants were required to provide written informed consent prior to enrollment in the study.

2.5. Exclusion criteria

Donors were excluded from the study if they had hemoglobin levels below 12.5 g/dL, weighed less than 50 kg, or had a known history of infectious diseases such as HIV, HBV, or HCV. Individuals previously diagnosed with hemoglobinopathies or identified as being at genetic risk were also excluded. Additionally, anyone unwilling to provide informed consent was not considered for participation.

2.6. Materials and equipment

Blood samples were collected using sterile procedures into EDTA tubes to prevent clotting. The samples were immediately transported to the laboratory for analysis. Hemoglobin phenotyping was performed using cellulose acetate electrophoresis, which allows the separation of hemoglobin variants based on their different electrical charges. In addition, a hemoglobin electrophoresis system was used to detect and classify various hemoglobin types, including HbA, HbS, and HbC, among others. The electrophoresis was carried out at a pH of 8.6, which is optimal for distinguishing between common hemoglobin variants.

2.7. Sample collection and analysis

Approximately 2 mL of venous blood was collected from each participant using sterile EDTA tubes to prevent clotting. The samples were transported to the laboratory under appropriate conditions and analyzed using hemoglobin electrophoresis at an alkaline pH of 8.6. This method allowed for the separation and identification of various hemoglobin phenotypes based on their electrical charge and mobility. The resulting electrophoretic banding patterns were compared against established reference standards to classify the hemoglobin types, including normal hemoglobin (HbAA), sickle cell trait (HbAS), sickle cell disease (HbSS), and thalassemia-associated variants such as HbA2 or HbF. All findings were recorded systematically and entered into a database for subsequent statistical analysis.

2.8. Statistical analysis

Data analysis was performed using SPSS version 25. Descriptive statistics were used to summarize the demographic characteristics of the participants, such as age, gender, and hemoglobin levels. Chi-square tests were used to determine associations between hemoglobin phenotype variations and other demographic factors, such as age and sex. A p-value of <0.05 was considered statistically significant. The prevalence of hemoglobinopathies in the voluntary donor population was calculated, and the findings were compared across different demographic groups.

3. Results

The **Table 1** presents detailed demographic and behavioral data for a total of 300 participants. It includes information on age, gender, occupation, marital status, and previous blood donation experience, offering a holistic view of the study population. In terms of age distribution, the largest group of participants falls within the 26–35-year range, accounting for 36% of the total. This is followed closely by those aged 36–45, representing 32%. Participants aged 18–25 make up 19% of the sample, while the smallest age group is 46–65 years, comprising only 13%. This indicates that the majority of participants are in their most active professional and social years, which may influence both their health status and availability for donation. Regarding gender, the sample is predominantly male, with 70% (210 individuals) identifying as male, while only 30% (90 individuals) are female. This significant gender imbalance may reflect trends in volunteer participation or cultural factors affecting willingness or ability to donate blood. When looking at occupation, students form the largest occupational group, making up 45% of the participants. Private sector workers follow at 30%, while medical professionals account for 15%. The remaining 10% are categorized as "Other," which could include a variety of roles such as homemakers, freelancers, or unemployed individuals. The high proportion of students

aligns with the younger age groups represented and may suggest that outreach efforts have been effective among educational institutions. In terms of marital status, the distribution is relatively balanced, with 52% of participants being single and 48% married. This near-equal split provides a diverse perspective on how relationship status might correlate with blood donation behavior or motivations. Finally, the data on previous blood donations reveals that 40% of participants have donated between one and five times, indicating a moderate level of experience. Notably, 22% have donated six times or more, suggesting a committed group of regular donors. Meanwhile, 38% are first-time donors, highlighting a significant portion of the sample that is new to blood donation. This group represents an important target for future retention and education campaigns.

Table 1. Demographic and donation profile of participants (N = 300)

Category	Subcategory	Number of Participants	Percentage (%)
Age Group (Years)	18–25	57	19%
	26–35	108	36%
	36–45	96	32%
	46–65	39	13%
Gender	Male	210	70%
	Female	90	30%
Occupation	Student	135	45%
	Private Sector Worker	90	30%
	Medical Professional	45	15%
	Other	30	10%
Marital Status	Married	144	48%
	Single	156	52%
Previous Blood Donations	1–5 Donations	120	40%
	6+ Donations	66	22%
	First-time Donors	114	38%

The majority of participants (70%) had donated blood in 2023, indicating that recent donation activity is relatively high. The remaining participants had donated in 2022 or earlier. This suggests a steady engagement in blood donation in recent years (Table 2).

Table 2. Most recent blood donation year

Year of Donation	Number of Participants	Percentage (%)
2023	210	70
2022	45	15
2021 or earlier	45	15
Total	**300**	**100**

This **Table 3** presents the distribution of hemoglobin phenotypes among the participants. Most participants had the normal hemoglobin phenotype (HbAA) at 80%, while 18% had the sickle cell trait (HbAS) and 2% had other variants like HbAC. The prevalence of these hemoglobin phenotypes is crucial for ensuring the safety and compatibility of blood transfusions.

Table 3. Distribution of hemoglobin phenotypes among participants

Hemoglobin Phenotype	Number of Participants	Percentage (%)
HbAA (Normal)	240	80
HbAS (Sickle Cell Trait)	54	18
HbAC (Other Variants)	6	2
Total	**300**	**100**

This **Table 4** examines the distribution of weight ranges across different hemoglobin phenotypes. It shows that most participants with the HbAA phenotype were in the 61-70 kg weight range, while the HbAS phenotype was distributed more evenly across several weight ranges. However, there were no significant associations found between weight and hemoglobin variants, suggesting that weight does not influence hemoglobin phenotypes in this population.

Table 4. Relationship between weight and hemoglobin variants

Hemoglobin Phenotype	Weight Range (kg)	Number of Participants	Percentage (%)
HbAA	50-60	50	20
	61-70	90	37.5
	71-80	60	25
	81-90	30	12.5
	91+	10	5
HbAS	50-60	12	22.2
	61-70	25	46.3
	71-80	13	24.1
	81-90	3	5.6
HbAC	50-60	1	16.7
	61-70	3	50
	71-80	2	33.3
Total	**300**	**300**	**100**

The **Table 5** provides an analysis of hemoglobin levels among participants based on their hemoglobin phenotypes. It focuses on three different phenotypes: HbAA, HbAS, and HbAC, and categorizes participants by their hemoglobin concentration in grams per deciliter (g/dL), which is an indicator of overall blood health. For participants with the HbAA phenotype, which is the most common and considered normal, the distribution shows a relatively even spread across the three hemoglobin level ranges. About 35.4% of individuals with HbAA have hemoglobin levels between 13–14 g/dL. The largest proportion, 41.7%, falls within the 15–16 g/dL range, indicating a healthy hemoglobin concentration. Additionally, 22.9% of HbAA individuals have hemoglobin levels above 17 g/dL, which is typically considered very healthy or slightly elevated. This pattern suggests that the majority of HbAA individuals maintain hemoglobin levels within or above normal limits. In the case of the HbAS phenotype, which is associated with the sickle cell trait, the majority of participants—55.6%—have hemoglobin levels between 15–16 g/dL. About 37% fall into the 13–14 g/dL range, and a smaller proportion, 7.4%, have hemoglobin levels of 17 g/dL or higher. This indicates that while most individuals with HbAS maintain decent hemoglobin levels, fewer reach the higher levels seen more commonly in the HbAA group. This could reflect the physiological impact of carrying the sickle cell trait. For the HbAC phenotype,

which is less common, the distribution is spread across all three hemoglobin level ranges, though the numbers are small. Only 1 participant (16.7%) has a hemoglobin level between 13–14 g/dL, while 3 participants (50%) fall in the 15–16 g/dL category. Two participants (33.3%) have hemoglobin levels above 17 g/dL. While the sample size for this group is very small, it still demonstrates that individuals with HbAC can maintain healthy to high hemoglobin concentrations.

Table 5. Hemoglobin level distribution across hemoglobin phenotypes

Hemoglobin Phenotype	Hemoglobin Level (g/dL)	Number of Participants	Percentage (%)
HbAA	13–14	85	35.4
	15–16	100	41.7
	17+	55	22.9
HbAS	13–14	20	37.0
	15–16	30	55.6
	17+	4	7.4
HbAC	13–14	1	16.7
	15–16	3	50.0
	17+	2	33.3
Total	**300**	**300**	**100**

4. Discussion

This study provides a comprehensive analysis of the demographic and hemoglobin characteristics of voluntary blood donors at LSBTS in Bangladesh. A key finding of this research is the high prevalence of HbAA, which is present in 80% of the participants. This is consistent with findings from other studies in African and South Asian populations, where HbAA is the dominant phenotype[20,21]. The predominance of HbAA in the donor pool suggests that the majority of the blood supply is likely to be safe for transfusion. However, the study also identifies the presence of hemoglobin variants such as HbAS (18%) and HbAC (2%), which could pose specific challenges for transfusion safety, particularly in malaria-endemic regions like Bangladesh[22].

Research has shown that while individuals with the sickle cell trait (HbAS) may experience a level of protection against malaria, HbAA carriers are at higher risk for asymptomatic malaria parasitemia (AMP), which could complicate blood safety[23]. As malaria remains endemic in many parts of Bangladesh, this finding emphasizes the importance of stringent pre-donation screening procedures to identify carriers of HbAS and other hemoglobinopathies, reducing the risk of transfusion-transmitted malaria (TTM) and other complications related to malaria. Furthermore, as transfusion-transmitted malaria remains a major concern in countries like Bangladesh, it is essential for blood banks to be vigilant about the genetic traits in the donor population that could potentially impact the safety of transfusions[24].

In line with findings from other studies in South Asia, this study identifies a significant male dominance in blood donation, with 70% of participants being male. This is a consistent trend observed globally, where men tend to donate blood at higher rates than women[25]. Several factors may contribute to this trend, including greater awareness of health among men, fewer deferral rates, and eligibility criteria that tend to favor male donors. The high male participation in blood donation programs is crucial for understanding donor patterns and designing effective health promotion programs targeted at this group. Furthermore, the data shows a

predominant age group of participants between 26 and 45 years (68%), which aligns with the observation that individuals in this age group are typically more health-conscious and willing to engage in blood donation[26].

The occupational distribution of participants is also noteworthy. The largest group of blood donors were students (45%), followed by private sector workers (30%), medical professionals (15%), and others (10%). The fact that such a large percentage of donors are students may indicate that blood donation is being promoted as a social responsibility among the younger, more active population, and could be a result of university or school-based campaigns. In contrast, the relatively smaller representation of medical professionals (15%) suggests that there may be barriers to blood donation even among healthcare workers[27]. This could be a result of time constraints, concerns about personal health, or other occupational factors. Targeting healthcare workers for blood donation campaigns could help reduce this gap and increase participation from this vital professional group[28].

With regard to the ethnic background of participants, the majority were from the predominant ethnic group in Bangladesh, which helps contextualize the results within the regional demographic[29]. The study observed that while the majority of participants were of a single ethnic group, hemoglobin variants did not show a significant correlation with ethnicity, indicating that hemoglobinopathies are genetically determined and not influenced by ethnic background. This is important when considering the broader genetic diversity of the donor population, and it highlights that the observed hemoglobin phenotypes are a product of genetic inheritance rather than external factors such as ethnicity[30].

Another important finding from this study is the distribution of hemoglobin levels among different hemoglobin phenotypes. The majority of participants with HbAA had hemoglobin levels in the range of 13–16 g/dL (77.1%), with only a small percentage (22.9%) having hemoglobin levels higher than 17 g/dL. In contrast, participants with HbAS showed a slightly lower average hemoglobin level, with the majority of participants (55.6%) falling in the 15–16 g/dL range. These differences in hemoglobin levels highlight the genetic influence on blood characteristics and underline the importance of individualized screening to ensure donor suitability[31].

The findings also suggest that the weight distribution of participants does not significantly correlate with hemoglobin phenotype[32]. For example, the majority of participants with the HbAA phenotype were in the 61–70 kg weight range (37.5%), while those with HbAS were more evenly distributed across the weight ranges. The lack of significant associations between weight and hemoglobin variants suggests that blood donor screening should focus more on genetic factors and hemoglobin levels, rather than relying heavily on demographic characteristics like weight[33].

In terms of donation history, a significant proportion of participants (62%) were repeat donors, with 40% having donated 1–5 times and 22% having donated more than six times. This indicates a strong base of repeat blood donors at LSBTS, which is critical for ensuring a sustainable and reliable blood supply. The remaining 38% were first-time donors, highlighting the ongoing need for strategies to recruit new donors and maintain donor engagement[34].

The data also reveals that the majority of participants (70%) had donated blood in 2023, suggesting a high level of recent engagement in blood donation activities. This is promising for the overall health of the blood supply, as it indicates that there is sustained interest and participation in blood donation programs. However, it is essential to continue to encourage regular donations to meet the growing demand for blood products.

5. Conclusion

The findings from this study suggest that the blood donor population in Bangladesh is predominantly safe for transfusions, given the high prevalence of HbAA. However, the presence of HbAS and HbAC among donors highlights the need for stringent pre-donation screening processes to mitigate the risks of transfusion-transmitted malaria (TTM) and other complications associated with hemoglobinopathies. These findings emphasize the importance of genetic counseling, improved screening protocols, and continued public health initiatives to ensure the safety and sustainability of the blood supply. Additionally, targeted recruitment strategies for younger donors and healthcare professionals should be prioritized to maintain an adequate and diverse donor pool.

Conflict of interest

The authors declare no conflict of interest.

Author contributions

All authors contributed equally to the conception, design, data collection, analysis, and writing of this manuscript. All authors have read and approved the final version.

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