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Chromatographic insights into hemoglobinopathies: Spectrum analysis by high-performance liquid chromatography in a western Indian tertiary care hospital

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Abstract

Background: Hemoglobinopathies are a group of inherited disorders characterized by abnormal hemoglobin structure or synthesis, primarily classified into thalassemia syndromes and structural hemoglobin variants. Recognized as a global health priority, these disorders necessitate accurate diagnostic approaches. High-performance liquid chromatography (HPLC) has emerged as a reliable method for their detection. This study aimed to analyze the spectrum of hemoglobinopathies using HPLC in a population from Western Maharashtra, India.

Methods: A cross-sectional study was conducted at Bharati Vidyapeeth (DTU) Medical College, Pune, over three years. A total of 1,455 specimens from individuals of both genders were analyzed using the VARIANT™ II β-Thalassemia Short Program based on ion-exchange chromatography. Hematological parameters were assessed for all subjects, and the prevalence of hemoglobinopathies, along with their subtypes, was documented.

Results: The mean age of the study population was 26.91 ± 7.06 years, with a female predominance. The overall incidence of hemoglobinopathies was 8.78%, with β-thalassemia minor being the most prevalent, followed by β-thalassemia major, Hb S trait, and Hb S disease. Rare variants included two cases of Hb D Punjab heterozygosity and one case of Hb E heterozygosity. The Mentzer index exhibited a positive correlation with Hb F and mean corpuscular hemoglobin (MCH) and a negative correlation with hemoglobin levels, Hb A, and red cell distribution width (RDW-C).

Conclusion: The study revealed an 8.78% prevalence of hemoglobinopathies in the region, with β-thalassemia trait (Heterozygous) being the most common. Notably, co-inheritance of Hb E with β-thalassemia exacerbated anemia severity. These findings underscore the importance of HPLC-based screening for early diagnosis and management of hemoglobinopathies in high-risk populations.

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Introduction

Hemoglobinopathies are a group of inherited disorders affecting hemoglobin (Hb) structure or synthesis, encompassing both qualitative (Structural variants) and quantitative (Thalassemias) defects in globin chain production (1). As the most prevalent monogenic diseases worldwide, they pose a significant public health burden, with an estimated 7% of the global population being carriers (2). Originally concentrated in the Mediterranean region, Africa, and Asia, hemoglobinopathies have now spread globally due to migration (2,3). In India, these disorders contribute substantially to morbidity and mortality, with regional variations in prevalence (4). Approximately 0.37 per 1,000 fetuses in India are affected by hemoglobin disorders (4).

The Indian subcontinent faces a high burden of β-thalassemia and hemoglobinopathies. Mohanty et al. reported a β-thalassemia trait prevalence ranging from 0 to 9.3% across 59 ethnic groups, with an overall prevalence of 2.78% (5). A critical concern in India is the interaction between thalassemia and structural Hb variants (e.g., Hb S, Hb E), which exacerbates disease severity (6).

Diagnosis relies on hematological indices, hemoglobin electrophoresis, and chromatography (2,7). In 1975, the International Committee for Standardization in Hematology established diagnostic guidelines, including complete blood count (CBC), alkaline hemoglobin electrophoresis, sickling tests, and quantification of Hb A_2 and Hb F (8). High-performance liquid chromatography (HPLC) has since emerged as a rapid, reproducible, and precise method for screening and confirmation (9,10).

Prevention through population screening and genetic counseling remains the most effective strategy. However, data on hemoglobinopathy prevalence in Western Maharashtra are scarce. The present study aimed to determine the incidence of hemoglobinopathies and the spectrum of different types of hemoglobinopathies in all patients referred for Hb HPLC because precise data on the prevalence of hemoglobinopathies in the Western region of Maharashtra have been lacking. Finding the prevalence of thalassemia and other hemoglobinopathies in ANC patients was one of the objectives.

Methods

This cross-sectional study was conducted in the Department of Pathology of a tertiary care teaching hospital in Pune, Maharashtra, from April 2019 to March 2022. Participants included patients with abnormal hemograms suggestive of hemolytic anemia and patients who voluntarily came in for a premarital checkup. Transfusion-dependent children and adults were also included. The study was approved by the Institutional Ethics Committee (BVDUMC/IEC/131). After the inclusion of patients in the study, written informed consent was signed. This study was carried out by the Declaration of Helsinki for experiments involving humans.

The whole blood specimens were collected in a vacuum collection tube containing ethylenediaminetetraacetic acid (EDTA), and complete blood count, RBC indices, and reticulocyte count were estimated using the DxH-800 fully automated hematology analyzer (Beckman Coulter, Inc., USA). The EDTA blood specimens were also used for Hb variant analysis, for various hemoglobinopathies and variants. The tests were performed on VARIANT™ II β-thalassemia short program (Bio-Rad Laboratories, California, USA). The VARIANT™ II β-thalassemia short program utilizes principles of ion-exchange HPLC.

The positively charged Hb fractions were separated by HPLC using ionic interactions with a negatively charged stationary phase in a chromatography column and then eluted by a mobile phase with phosphate buffers varying in pH and ionic strength. The positively charged Hb molecules that had been adsorbed were eluted from the column into the liquid phase according to their affinity for the stationary phase. The retention time of the hemoglobins was used to identify them, and the area under the peak in the elution profile was used to calculate their concentration (4,11). Priming and calibration were performed before every run.

Results

A total of 1,455 samples were collected from participants of both genders, comprising 111 (7.60%) males and 1,344 (92.40%) females (Table 1). The mean age of the study population was 26.91 ± 7.06 years. All samples were analyzed using HPLC. The hematological parameters of the study population are summarized in Table 2.

Table 1. Distribution of demographic parameters in the study population (n=1,455)

Demographic parameters		Mean ± SD, n (%)
Age (Years)		26.91 ± 7.06
Gender	Male	111 (7.60%)
	Female	1344 (92.40%)

Table 2. Distribution of hematological parameters in the study population (n=1,455)

Hematological parameters	Mean	SD
Mentzer index (MCV/RBCs)	19.41	7.43
Hemoglobin (g/dL)	11.10	2.06
RBC count	4.25	0.72
PCV	33.57	5.70
MCV	79.83	10.82
MCH	26.36	4.52
MCHC	32.91	1.72
RDW-CV	16.57	4.35
Hb A	85.01	8.05
Hb F	1.16	6.67
Hb A2	2.87	0.70

Abbreviations: Hb: Hemoglobin; MCH: Mean Corpuscular Hemoglobin; MCHC: Mean Corpuscular Hemoglobin Concentration; MCV: Mean Corpuscular Volume; PCV: Packed Cell Volume; RBC: Red Blood Cell; RDW-CV: Red Cell Distribution Width-Coefficient of Variation.

The most common indication for HPLC testing was antenatal care (719 cases, 49.42%). Other indications included suspected thalassemia trait, anemia (After ruling out iron deficiency), and low vitamin B12 levels.

Over the three-year study period, 128 (8.78%) cases were diagnosed with various hemoglobinopathies (Table 3). Among these, β-thalassemia was identified in 11 (0.76%) homozygous and 85 (5.84%) heterozygous cases. Borderline Hb A2 levels were detected in 18 patients, leading to inconclusive diagnoses. Additionally, sickle cell hemoglobin (HbS) was found in 9 (0.62%) heterozygous and 2 (0.14%) homozygous cases. Heterozygous Hb D Punjab was observed in 2 (0.14%) cases, while Hb E heterozygous was detected in only 1 (0.07%) case. A low Hb A2 level was noted in 2 (0.14%) cases.

Table 3. Profile of hemoglobinopathies (Total number of patients evaluated 1,455, total number of patients detected to have hemoglobinopathies 128 (8.78%))

Profile of hemoglobinopathies	Frequency (n)	Percentage (%)
Normal	1,325	91.07
Heterozygous for β-thalassemia	85	5.84
Borderline HbA2 Value	18	1.24
Homozygous for β-thalassemia	11	0.76
Heterozygous for Hb S	9	0.62
Homozygous for Hb sickle cell	2	0.14
Heterozygous for Hb D Punjab	2	0.14
Low Hb A2	2	0.14
Heterozygous for Hb E	1	0.07
Total	1,455	100.00

Comparative analysis of hematological indices revealed distinct patterns among different hemoglobinopathy groups (Table 4). Homozygous β-thalassemia patients exhibited severe microcytic hypochromic anemia, with markedly reduced hemoglobin (5.04 ± 2.27 g/dL), RBC count (2.16 ± 0.88 ×10⁶/µL), and PCV (15.34 ± 6.24%), alongside elevated RDW-CV (38.14 ± 4.75%) and Hb F levels (89.85 ± 1.32%). Heterozygous β-thalassemia cases showed microcytosis (MCV: 64.93 ± 6.47 fL) and elevated Hb A2 (5.23 ± 2.36%). In contrast, heterozygous Hb Sickle patients had near-normal RBC indices but significantly reduced Hb A (58.67 ± 1.76%). Borderline Hb A2 cases demonstrated intermediate MCV (89.04 ± 14.11 fL) and marginally elevated Hb A2 (3.46 ± 0.09%).

The Mentzer index (MI) effectively discriminated between thalassemic and non-thalassemic microcytosis (Table 5). All homozygous β-thalassemia cases (n=11) and borderline Hb A2 cases (n=18) had an MI >13, while 48/85 (56.5%) heterozygous β-thalassemia cases had an MI <13. Notably, 57 normal subjects were misclassified with MI <13, but the majority (1,268/1,325) had MI >13, supporting its specificity.

Among antenatal care (ANC) patients, 38 hemoglobinopathy cases were detected (5.15% incidence), including 25 β-thalassemia traits, 4 heterozygous Hb S cases, 1 Hb D Punjab case, and 8 borderline Hb A2 cases. Representative chromatograms of hemoglobin variants are presented in Figure 1.

Table 4. Assessment of hematological parameters in different groups of patients and normal subjects

Hematological parameters	Normal (n=1,325)	Borderline HbA2 (n=18)	Homozygous for β-thalassemia (n=11)	Heterozygous for β-thalassemia (n=85)	Heterozygous for Hb sickle (n=9)	Others (n=7)
Mentzer index	19.41 ± 4.75	36.36 ± 42.10	41.07 ± 24.19	14.72 ± 8.90	12.93 ± 2.29	19.76 ± 5.18
Hemoglobin	11.24 ± 2.00	10.17 ± 2.91	5.04 ± 2.27	9.95 ± 2.08	10.50 ± 1.88	9.59 ± 2.98
RBC Count	4.25 ± 0.59	3.57 ± 1.14	2.16 ± 0.88	4.91 ± 1.10	5.11 ± 0.56	3.89 ± 0.82
PCV	34.00 ± 5.33	30.45 ± 8.52	15.34 ± 6.24	31.53 ± 6.67	33.30 ± 5.15	28.92 ± 8.44
M.C.V	80.29 ± 9.86	89.04 ± 14.11	70.98 ± 3.20	64.93 ± 6.47	65.30 ± 8.43	74.10 ± 11.24
M.C.H.	26.54 ± 4.15	29.69 ± 4.70	22.70 ± 3.45	20.50 ± 2.09	20.61 ± 3.38	24.59 ± 4.48
M.C.H.C	32.92 ± 1.63	33.36 ± 0.89	31.94 ± 4.28	31.57 ± 0.80	31.46 ± 1.39	33.03 ± 1.33
RDW-CV	16.16 ± 3.72	17.75 ± 6.60	38.14 ± 4.75	18.34 ± 4.49	18.04 ± 3.36	20.29 ± 7.57
Hb A	86.23 ± 2.51	86.36 ± 1.39	6.48 ± 2.71	82.51 ± 4.45	58.67 ± 1.76	34.25 ± 30.55
Hb F	0.48 ± 2.53	0.36 ± 0.26	89.85 ± 1.32	1.77 ± 2.46	1.10 ± 0.77	9.72 ± 9.71
HB A2	2.69 ± 0.29	3.46 ± 0.09	3.66 ± 1.37	5.23 ± 2.36	2.51 ± 0.19	9.01 ± 17.93

Table 5. Distribution of patients based on the Mentzer index cut-off value of 13 among different hemoglobinopathies cases

Impression	Mentzer index category		
	< 13	> 13	Total
Borderline Hb A2 value	0	18	18
Heterozygous β-thalassemia	48	37	85
Heterozygous for Hb D Punjab	0	2	2
Heterozygous for Hb E	0	1	1
Heterozygous for Hb S	5	4	9
Homozygous for β-thalassemia	0	11	11
Homozygous for Hb sickle	0	2	2
Low Hb A2	0	2	2
Normal	57	1,268	1,325
Total	**110**	**1,345**	**1,455**

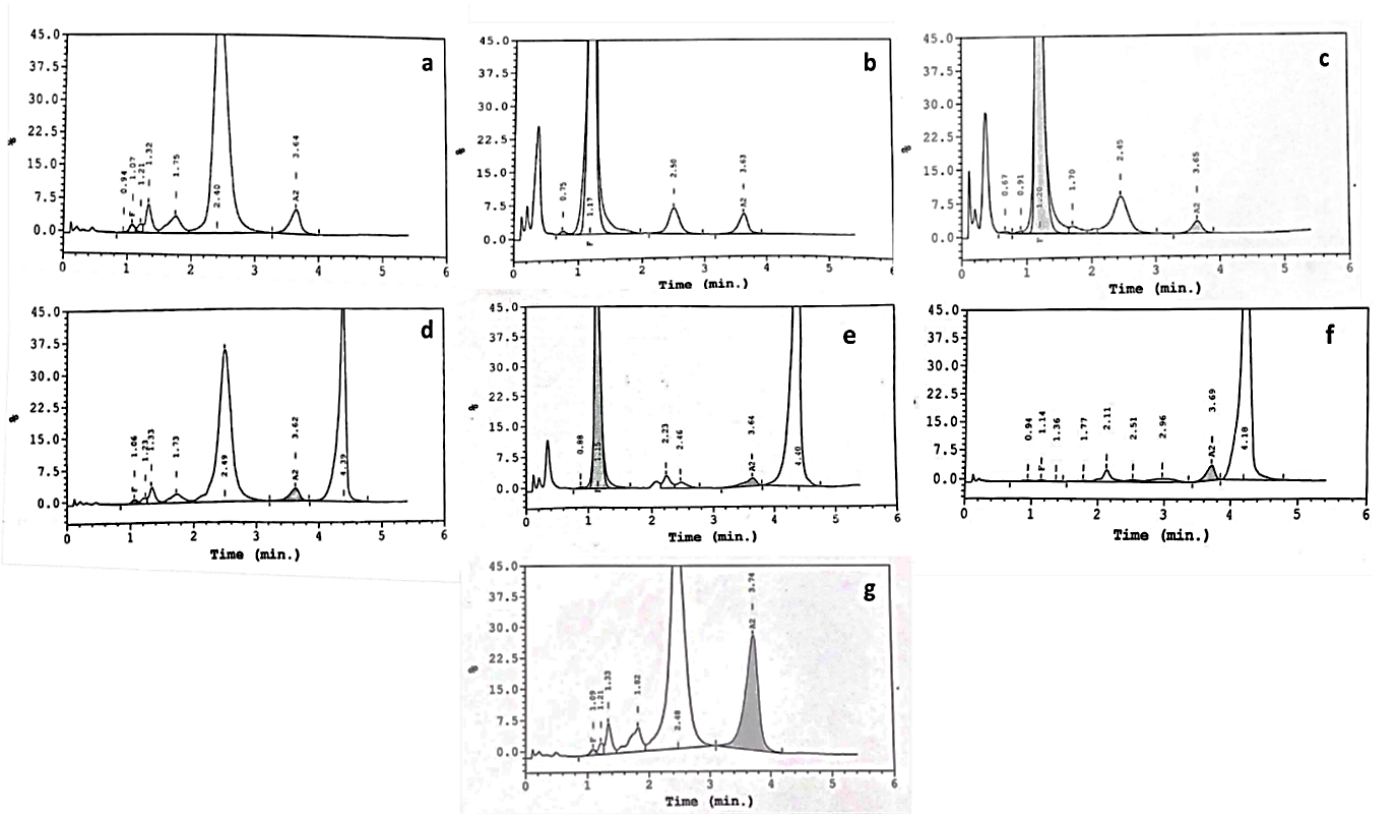

Figure 1. Electrophoretograms showing various hemoglobinopathies: a) Heterozygous β-thalassemia; b) Compound heterozygous with β-thalassemia; c) Homozygous β-thalassemia; d) Heterozygous Hb S; e) Hb S disease (homozygous); f) Homozygous for Hb D Punjab; and g) Heterozygous Hb E.

Discussion

HPLC is a sensitive, specific, and reproducible alternative to electrophoresis. It appeared to be an appropriate candidate for direct provisional identification and sensitive quantification of major and minor, normal and abnormal hemoglobin fractions with a high degree of precision. On the other hand, the technical performance of electrophoresis depends on various factors like hemoglobin concentration, amperage, running temperature, and length of electrophoresis run. These variables can affect the quality of separation and the relative positioning of the bands (10,12). The present prospective study conducted in Pune, i.e. western region of Maharashtra state, included 1,455 cases for analysis of blood samples by HPLC, which gave the incidence of hemoglobinopathies to be 8.78% (128/1,455). The mean age of the patients included in the present study was 26.91 ± 7.06 years, of which most belonged to their 20s and 30s, with a predominance of females. Among these patients with hemoglobinopathies, 77 patients had a MI of >13, which is indicative of iron deficiency anemia.

In a similar study, Bhokare et al. proved the role of Hb A2 by HPLC, giving the prevalence of abnormal hemoglobin to be 37.4% out of 500 suspected anemia patients (13). In the HPLC study by Mukhopadhyay et al., among the total of 10,407 subjects, 8,898 (85.5%) were diagnosed as normal, 579 (5.6%) were identified as β-thalassemia trait, and 522 (5.0%) were found to be detected as Hb E carriers. Ray et al. detected hemoglobinopathies in 50.2% of the 21,371 anemic patients, with β-thalassemia and sickle cell hemoglobinopathies being the major types observed, among others, including the Hb S gene in 52.48% cases, β-thalassemia in 54.06% and Hb E hemoglobinopathies in 9.19% cases (12,14). Out of 128 (8.78%) patients diagnosed with different hemoglobinopathies, 85 (5.84%) were confirmed to be heterozygous for β-thalassemia (Figure 1a). Among these patients, one patient had an increased level of Hb F, and one of the patients was compound heterozygous for Hb S (Figure 1a-b). Also, 18 (1.24%) of patients had borderline values for Hb A2, followed by 11 (0.76%) patients with β-thalassemia homozygous (Figure 1c). Among these 11 patients, one patient had Hb E, 9 (0.62%) cases were reported to have heterozygous Hb S (Figure 1d), and eight patients were suggestive of the presence of alpha (α)-thalassemia. Two of the patients had Hb S disease (Homozygous) (Figure 1e), and there were two cases of Hb D Punjab (Figure 1f), and both were reported to be heterozygous. Two patients had low levels of Hb A2, which were suggestive of α-thalassemia, and one case of heterozygous Hb E (Figure 1g).

The most common hemoglobinopathy reported by Bhokare et al. was sickle cell trait, followed by β-thalassemia trait, Hb S^{+}β-thalassemia trait, and β-thalassemia major, and similar to the present study, 1 case of Hb E, but in conjunction with thalassemia trait (13). Ankur et al., among a total of 2,789 patients, exhibited abnormalities in 30.8% of the cases (15). The most prevalent abnormality detected was β-thalassemia heterozygous, followed by thalassemia homozygous, Hb E heterozygous, and Sickle cell trait. Other variants identified included Eβ-thalassemia, Hb D Punjab trait, Hb E disease, sickle cell disease, Hb Lepore, hereditary persistence of fetal hemoglobin (HPFH), sickle-β-thalassemia, and double heterozygosity for β-thalassemia and Hb D Punjab, along with various other combinations. Additionally, a rare case of Hb Burke was detected, accounting for only 0.04% of the cases.

Singh J et al. found that among the 100 cases, 51 (51%) displayed abnormal hemoglobin fractions as detected by HPLC (16). Specifically, 42 (42%) cases were diagnosed as thalassemia trait, 4 (4%) cases as β-thalassemia major (With Hb F levels exceeding 75%), 2 (2%) cases as Hb E, and 3 (3%) cases as HPFH. Conversely, 49 cases demonstrated a normal HPLC pattern. In patients with hemoglobinopathies, the mean level of Hb A2 was 5.01 ± 1.67%, ranging from 1.1 to 56.7%. The highest values, i.e., 26.3 and 56.7% of Hb A2, were reported in a patient heterozygote for Hb E and in another patient diagnosed with homozygous β-thalassemia along with Hb E disease, respectively. This indicates the severity of the condition if thalassemia and Hb E are present in combination in a patient. Sickle cell anemia is one of the most common genetic pathologies worldwide. It is characterized by homozygous Hb S or Hb S associated with other Hb variants (17,18).

There is great clinical variation in the clinical manifestations between sickle cell disease patients; several factors are associated with the different presentations. Some determinants are already well established, such as genetic, clinical, and laboratory factors, while others, such as psycho-social and nutritional factors, have been less well studied (17,19-22). Among the patients with the presence of heterozygous and homozygous Hb S, the mean percentage of Hb S was 43.73 ± 19.24%. Among the 11 β-thalassemia homozygous patients, they had Hb S disease with only 5.8% and 5.7% of Hb A, 79.8% and 68.7% of Hb S, 10.0% and 20.6% of Hb F, and 4.4 and 5% of Hb A2 values. The hemoglobin levels in these two patients were also low, i.e., 7.4 and 8.4 g/dl, with a MI of >13. The 8 out of 9 patients who were heterozygous for Hb S had mean Hb A, Hb F, and Hb A2 values of 58.03 ± 5.97, 1.1 ± 1.09, and 2.57 ± 0.17%, respectively, which was suggestive of the presence of α-thalassemia in these patients. Further, among the patients diagnosed with hemoglobinopathies, we found a positive association of MI with the levels of Hb F (p=0.0010), MCH (p <0.0001), and a negative association with levels of hemoglobin (p <0.0001), Hb A (p=0.0187), RDWC (p <0.0001). One of the limitations of our study is that eight patients for whom we suspected α-thalassemia were not ruled out, as the present study was limited to HPLC.

Conclusion

This tertiary care study in Pune identified hemoglobinopathies in 8.78% of 1,455 patients, with β-thalassemia (6.6%) as the most prevalent. The heterozygous trait was predominant, though homozygous cases and Hb E co-inheritance were associated with severe anemia. These findings highlight the need for early HPLC-based screening, particularly in antenatal and high-risk populations, to guide clinical management and genetic counseling.

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Ethical statement

The study was approved by the Institutional Ethics Committee, Bharati Vidyapeeth (DTU) Medical College, Pune, Maharashtra, India (BVDUMC/IEC/131) and conducted according to the Declaration of Helsinki.

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Author contributions

Written informed consent was obtained from all participants after explaining the research objectives.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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