

## Original Research

### Characterization of Hemoglobin Variants in the Çukurova Region of Turkey: Prevalence and Clinical Implications

Seyyede Touran Hosseini<sup>1</sup>, Mehmet Akif Çürük<sup>2</sup>, Sule Menziletoglu Yildiz<sup>3\*</sup>

1. Department of Biotechnology, Institute of National and Applied Sciences, Cukurova University, Adana, Turkey Orcid: 0000-0002-2438-9642

2. Department of Medical Biochemistry, Faculty of Medicine, Cukurova University, Adana, Turkey Orcid: 0000-0002-4668-0852

3. Balcalı Hospital Blood Center, University of Çukurova, Adana, Turkey. Orcid: 0000-0002-5144-3843

**\*Corresponding Author:** Sule Menziletoglu Yildiz. Balcalı Hospital Blood Center, University of Çukurova, Adana, Turkey. **Email:** suleyildiz01@yahoo.com

#### Abstract

**Background:** Hemoglobinopathies, the most prevalent single-gene disorders worldwide, are projected to see an increase in prevalence in the future. This study aims to identify abnormal hemoglobin variants in the Çukurova region.

**Methods:** Blood samples were collected at the Central Laboratory of Çukurova University Balcalı Hospital, and abnormal hemoglobin types were determined using hemoglobin electrophoresis, sickling, and ARMS methods.

**Results:** The study identified 115 cases of HbAS, 60 cases of HbSS, 3 cases of HbSC, 2 cases of HbAC, and 1 case of HbAE. The findings indicate that the carriage of sickle cell traits is highest in the Çukurova region. The objective is to reduce the number of affected births and mitigate the economic burden on the country by implementing screening programs in regions where hemoglobinopathy is endemic.

**Conclusion:** The Çukurova Region's high prevalence of HbS and the common practice of consanguineous marriages increase the likelihood of babies being born with HbSS. New screening methods are urgently needed to accurately distinguish carriers from patients and rule out common conditions like iron deficiency anemia. The success of screening programs depends on the population's acceptance, which can be improved through awareness creation and effective genetic counseling post-diagnosis.

**Keywords:** Hemoglobin Variants, Çukurova, Prevalence, Clinical Implications

Submitted: 20 Feb 2024,

Revised: 16 March 2024 ,

Accepted: 23 Apr 2024

## Introduction

Hemoglobinopathies, such as sickle cell disease and thalassemias, represent intricate red blood cell disorders that are prevalent globally and exhibit diverse clinical manifestations (1). Diagnosing these conditions often necessitates molecular DNA analysis due to the presence of copy number variants (CNVs), which can be difficult to identify without specific diagnostic techniques like multiplex ligation-dependent probe amplification (MLPA) (2).

Mutations in globin genes, which alter the oxygen affinity of hemoglobin variants, contribute to the range of hemoglobin disorders by affecting oxygen dissociation curves. Accurate recognition of clinical and laboratory findings is crucial for diagnosis (3). Comprehensive databases like IthaPhen have been developed to enhance the understanding and management of hemoglobinopathies. These databases integrate genotypic and phenotypic data, aiding in genotype-phenotype correlations and standardized variant classification, thus improving clinical care and genetic counseling. Hemoglobin variant analysis, typically conducted through methods such as high-performance liquid chromatography and capillary electrophoresis, helps in identifying specific variants like HbS, HbD, HbE, HbC, and HbH. The technique of DNA isolation and the use of electrophoresis methods have been common practices for analyzing hemoglobins. A thorough understanding of the molecular pathology, clinical manifestations, and treatment options for these disorders is essential for effective management and prevention strategies. For example, hemoglobin variants can impact diagnostic tests like HbA1c measurements, as observed with the North Manchester mutation affecting HbA1c levels (4). The prevalence of hemoglobin variants, including thalassemias and structural variants, varies geographically. Studies underscore the importance of screening in regions with high prevalence, such as Pakistan (5). Advanced techniques like nano LC-MALDI MS/MS have

been developed to improve the identification and analysis of Hb variants, highlighting the need for precise methods due to the high sequence homology between normal and variant chains. Accurate diagnosis and management of hemoglobinopathies rely on characterizing hemoglobin variants. Analytical methods such as capillary electrophoresis, gel electrophoresis, and high-performance liquid chromatography are commonly employed for phenotypic detection of hemoglobin variants (6). Molecular genetic analysis, including Sanger sequencing, plays a crucial role in identifying rare variants like Hb Olupona and Hb Liangqing, providing insights into their genetic basis and clinical significance (7). Advancements in sample processing methods, such as the use of trifluoroethanol (TFE) and LC-MALDI MS/MS, have improved sequence coverage and the accurate identification of single substitution mutations in hemoglobin variants. This offers a robust and reproducible approach for variant analysis. To differentiate HbS and HbD, a sickling test is performed. Hemoglobin S is identified by the sickle shape of erythrocytes in an oxygen-free environment or in the presence of sodium metabisulfite. For the separation of HbC and HbE, the ARMS (Amplification Refractory Mutation System) method is employed. Specific primers designed to amplify segments of DNA are used in PCR reactions to identify the mutations associated with HbC, and HbE. The resulting fragments are analyzed through agarose gel electrophoresis. Hemoglobin variants encompass a broad array of mutations with varying clinical implications. For example, the HbS trait with elevated HbS levels (8), Hemoglobin North Manchester causing false HbA1c readings (9), and Hb Dompierre leading to hemolysis and splenomegaly (10), all underscore the importance of accurate detection and characterization. Genetic studies have identified common variants associated with elevated fetal hemoglobin levels, impacting treatment response in conditions like Myeloproliferative Neoplasms and Myelodysplastic Syndromes (11). Moreover,

compound heterozygous sickle cell trait and Hb-Ferrara can complicate diabetes management, emphasizing the need for comprehensive hemoglobin evaluation and appropriate therapeutic adjustments (12). Understanding the prevalence and clinical implications of these hemoglobin variants is crucial for accurate diagnosis, effective management, and genetic counseling. Hemoglobin variants exhibit significant geographical diversity, impacting prevalence and clinical implications. Genetic variation in hemoglobin concentration is complex and influenced by factors like altitude, nutritional status, and genetic diversity, with malaria-endemic regions showing high frequencies of variants associated with anemia (14). Research on hemoglobin variants in Thailand identified 23 variants, underscoring the importance of DNA sequencing for accurate identification due to similar elution patterns (15). Additionally, studies in Sri Lanka highlighted the variable distribution of hemoglobin disorders over short distances, influenced by factors like malaria, altitude, and ethnic origin, emphasizing the need for precise heterozygote mapping for effective prevention and management (16). In Turkey, studies have identified 60 hemoglobin variants, including 15 alpha, 37 beta, 1 gamma, 2 delta, 2 hybrid hemoglobins, and variants with structural changes due to deletion/insertion, with 10 of these variants being first identified in the Turkish population. The frequency of HbS in Turkey ranges between 0.5-44.2%, Hb E between 0.16-2.4%, Hb D at 0.2%, and Hb C and Hb O-Arab at 3.9% (17, 18). Table 1 shows the distribution of abnormal hemoglobins in Turkey (17). Extensive studies in the Çukurova region of Türkiye have identified mutations such as Hb S IVS-I-110 (G > A) in  $\beta$ -thal and the 3.7 kb deletion in  $\alpha$ -thal (19). Additionally, prenatal diagnosis studies have revealed novel mutations like a homozygous 5 nt deletional mutation [ $\alpha$ 2 IVS-1 134.-138. nt (TGAGG)] and Hb Stanleyville II [ $\alpha$ 2 78 (EF 7) Asn → Lys (AAC → AAA)] (20). Molecular characterization in individuals with low Hb A2

levels has led to the identification of new  $\delta$ -globin variants like Hb A2-Canakkale (21). These findings underscore the importance of comprehensive genetic analyses in understanding and managing hemoglobinopathies in the Çukurova region of Türkiye.

### Methods

In this research, blood samples were collected from individuals who visited Çukurova University Balcalı Hospital. A total of 5 mL of blood was drawn into EDTA tubes and transported to the laboratory while maintaining the cold chain. Hemoglobin electrophoresis was performed on these samples to identify HbS, HbD, HbC, and HbE variants. DNA was then extracted for further analyses, and the genomic DNA samples were stored at +4°C for future use.

The blood samples were analyzed for hemoglobin (Hb), erythrocyte count, hematocrit (Hct), mean corpuscular hemoglobin (MCH), mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC) using a Beckman DxH 800 device. The samples were washed three times with physiological serum. Subsequently, 200  $\mu$ L of blood and 1000  $\mu$ L of physiological serum were placed in Eppendorf tubes and mixed using a vortex.

Plasma was separated by centrifugation at 3000 rpm for 1 minute to sediment the erythrocytes. After adding 1 mL of physiological serum to the sedimented cells, the mixture was centrifuged at 3000 rpm for 10 minutes, and the supernatant was discarded. This washing process was repeated, and after the final centrifugation, the washed erythrocytes remained at the bottom of the tube. Then, 200  $\mu$ L of hemolysis solution was added to an Eppendorf tube, followed by 50  $\mu$ L of washed erythrocytes, resulting in a 1/5 dilution of the erythrocytes. The hemolysate obtained from this process was used for Hb electrophoresis.

Hemoglobin electrophoresis was conducted to separate hemoglobin variants based on their migration rates in an electric field at an alkaline pH. The SAS-1 AlkHb Kit components included

agarose gels, acid blue stain, hemoglobin lysing agent, and washing solutions.

The procedure involved:

1. Adding 35  $\mu$ L of hemolysate to each well of the SAS-1 sample tray.
2. Preparing and placing the SAS-1 AlkHb Gel in the electrophoresis chamber.
3. Conducting electrophoresis at 250°C for 30 minutes at 200 volts.
4. Staining, washing, and drying the gel according to a specific protocol.
5. Analyzing the stained gel to determine the hemoglobin types and percentages.

To differentiate HbS and HbD, a sickling test was performed. Hemoglobin S was identified by the sickle shape of erythrocytes in an oxygen-free environment or in the presence of sodium metabisulfite. Reagents included 0.2 g Na<sub>2</sub>S<sub>2</sub>O<sub>5</sub> dissolved in 10 mL water. A sample of 20  $\mu$ L whole blood was placed on a slide and mixed with a drop of 2% sodium metabisulfite. This mixture was then covered with a coverslip, sealed with adhesive, and incubated for 5-30 minutes. Under a microscope, the presence of sickled erythrocytes indicated HbS, whereas the absence of sickling indicated HbD.

For the separation of HbC and HbE using the ARMS (Amplification Refractory Mutation System) method, DNA was first isolated from blood samples. Using a kit from Roche (Cat No: 11796828001, USA), reagents were prepared accordingly: Proteinase K dissolved in 4.5 ml distilled water, Inhibitor Removal Buffer with 20 ml absolute ethanol, and Wash Buffer with 80 ml absolute ethanol.

The DNA isolation procedure involved:

1. Mixing 200  $\mu$ L Binding buffer, 40  $\mu$ L Proteinase K, and 200  $\mu$ L whole blood, followed by incubation at 70°C for 10 minutes.
2. Adding 100  $\mu$ L isopropanol, vortexing, filtering, and centrifuging at 8000 rpm for 1 minute.
3. Discarding the solution under the filter, adding 500  $\mu$ L Inhibitor Removal Buffer, and centrifuging.

4. Repeating wash steps with 500  $\mu$ L Wash Buffer twice, followed by centrifugation.

5. Adding 200  $\mu$ L of 70°C Elution Buffer and centrifuging to collect the genomic DNA, which was stored at +4°C until use.

In the research, specific primers were crucial for the molecular analysis of hemoglobin variants. These primers were short, synthetic sequences of nucleotides designed to bind to complementary sequences in the DNA. They were selected based on their ability to flank the regions of the genes encoding for hemoglobin, ensuring precise annealing to the target DNA sequences.

The primers used in this study were carefully designed to amplify segments of DNA that included the common hemoglobin variants HbC, and HbE. This process involved:

### 1. Primer Design and Selection:

- The primers were designed to be specific to the regions of the  $\beta$ -globin gene where mutations associated with HbC, and HbE occur. This specificity was essential to differentiate these variants accurately.

- The sequences of the primers were chosen to ensure high specificity and efficiency. This involved selecting sequences that would not bind non-specifically to other regions of the genome.

- The common primers used were:

Common primer 1: 5' ACC TCA CCC TGT GGA GCC AC 3'

Common primer 2: 5' CCC CTT CCT ATG ACA TGA ACT TAA 3'

- The constant primers used were:

- 5' Constant primer: 5' CAA TGT ATC ATG CCT CTT TGC ACC 3'

- 3' Constant primer: 5' GAG TCA AGG CTG AGA GAT GCA GGA 3'

### 2. ARMS Primers:

- For the identification of HbE, the ARMS (Amplification Refractory Mutation System) method was used, employing specific primers:

- Hb E (T→C)1 (Mutant primer): 5' TAA CCT TGA TAC CAA CCT GCC CAG GGC GTT 3'

- Hb E (T→C)2 (Normal primer): 5' TAA CCT TGA TAC CAA CCT GCC CAG GGC GTC 3'

These carefully designed primers ensured the precise amplification of the target DNA sequences, allowing for accurate differentiation and analysis of the hemoglobin variants present in the samples.

## 2. PCR Amplification:

The designed primers were used in a Polymerase Chain Reaction (PCR) to amplify the target DNA regions. Each PCR reaction included the genomic DNA extracted from the blood samples, the designed primers, nucleotides, DNA polymerase, and other necessary reagents.

During the PCR cycles, the primers annealed to their complementary sequences on the DNA template, allowing the DNA polymerase to extend from the primer and replicate the target DNA region.

## 3. Detection and Analysis:

- The amplified DNA fragments were then subjected to further analysis, such as gel electrophoresis, to confirm the presence and size of the amplified products.

- Sequencing or restriction enzyme digestion might have been used to identify the specific hemoglobin variants present in each sample, based on the known mutations.

## 4. Storage and Subsequent Use:

- The PCR products and remaining genomic DNA samples were stored appropriately, often at +4°C, for any subsequent analyses or validations needed.

By using these primers, the study successfully identified and characterized the prevalence of different hemoglobin variants in the Çukurova region, providing insights into the genetic diversity and clinical implications of these hemoglobinopathies in the local population.

The ARMS method identifies point mutations or small deletions by using mutation-specific primers. For this process, various reagents and primers are used to prepare a PCR mix, which is then placed in a thermal cycler device. The thermal cycler follows a programmed cycle to amplify the DNA, producing a 585 bp fragment,

which is analyzed through agarose gel electrophoresis.

The agarose gel electrophoresis process involves preparing a 1% agarose gel, loading the DNA samples mixed with loading buffer, and applying an electric current. After electrophoresis, the gel is stained with Ethidium Bromide, washed, and the DNA fragments are visualized and photographed under UV light. The resulting bands help detect mutations in HbC and HbE, as illustrated in Figure 15 showing agarose gel images for HbAC and HbAE mutations detected using the ARMS method.

## Results

This study involved patients with severe anemia whose blood counts were conducted at the Central Laboratory of Çukurova University Balcalı Hospital. The study included blood samples from 181 individuals without iron deficiency. Hemoglobin analysis was carried out using hemoglobin electrophoresis, and abnormal hemoglobins were differentiated using the sickling test and the Amplification Refractory Mutation System (ARMS) method in patients suspected to have HbAS, HbSS, HbAE, HbAC, or HbAD. In our study, hemoglobin electrophoresis, ARMS, and sickling tests identified 115 cases of HbAS, 60 cases of HbSS, 3 cases of HbSC, 2 cases of HbAC, and 1 case of HbAE (Table 2 and Table 3).

During hemoglobin electrophoresis, Hemoglobin S and D migrate to the same position. They were differentiated using the sickling test. Some patients also exhibit Hemoglobin F, as its levels are naturally high from birth until about 2 years of age. As the individual matures, Hemoglobin F is gradually replaced by Hemoglobin A.

The data of 60 hemoglobin patients as a result of hemoglobin electrophoresis and sickling test are shown in Table 4.

Tables 5 and 6 display the data for three hemoglobin cases resulting from hemoglobin electrophoresis and ARMS-PCR.

In our study, 115 HbAS, 60 HbSS, 3 HbSC, 2 HbAC, 1 HbAE hemoglobin types were



determined as a result of hemoglobin electrophoresis, ARMS and sickling tests. It is shown as a percentage in Table 7.

### Discussion

Hemoglobinopathies are among the most prevalent genetic abnormalities globally, with the World Health Organization estimating a 5% worldwide prevalence of hemoglobin disorders. These disorders are categorized into two main types: thalassemias and abnormal hemoglobins, the latter resulting from amino acid changes in the globin chains of the hemoglobin molecule (22).

Genetic research, bolstered by the widespread use of recombinant DNA technologies, has greatly advanced the identification of gene clusters and the genetic regulation of hemoglobin synthesis. In Turkey, thalassemia is notably common in the Çukurova, Mediterranean coastline, Aegean, and Marmara regions. Data from the Turkish Ministry of Health and the National Hemoglobinopathy Council indicate that 2.1% of the healthy Turkish population are beta thalassemia carriers, translating to approximately 1,300,000 carriers and 4,000 patients nationwide. Specifically, Adana reports a 3.7% beta thalassemia carrier frequency, with an Hb S frequency of 10% (23).

Geographic and racial variations significantly influence the distribution of abnormal hemoglobins. Besides Hb S, which is the most prevalent abnormal hemoglobin in Turkey and globally, other variants such as Hb D, Hb E, and Hb C are also present (24). For instance, a study by Yüregir et al. (1995) identified an Hb S carriage rate of 8.2% in the Çukurova region (25). Additionally, Arpacı (1991) reported an Hb S frequency of 22.1% and a  $\beta$  thalassemia frequency of 5.1% in Samandağ (26).

Attila et al. (1999) found an Hb S rate of 10%, a  $\beta$  thalassemia rate of 3.7%, and an  $\alpha$  thalassemia rate of 3.3% in Çukurova (27). Furthermore, Güler et al. (2007) observed a beta thalassemia carrier rate of 2% and an Hb S carrier rate of 0.05% in premarital screening studies in Konya (29).

In our study conducted in the Çukurova region, we found the following frequencies: HbAS at

63.53%, HbSS at 33.15%, HbSC at 1.65%, HbAC at 1.12%, and HbAE at 0.55%. No HbH patients were identified. Due to the instability of hemoglobin H, blood must be analyzed promptly after collection.

Reviewing these studies reveals significant regional variations in the distribution of mutant alleles within Turkey.

### Conclusion

In this study, the distribution of abnormal hemoglobins in the Çukurova Region was as follows: HbAS at 63.53%, HbSS at 33.15%, HbSC at 1.65%, HbAC at 1.12%, and HbAE at 0.55%. The high prevalence of HbS, coupled with the common practice of consanguineous marriages, increases the likelihood of babies being born with HbSS.

To address this issue, it is crucial to develop new screening methods that can effectively differentiate carriers from patients and exclude common conditions like iron deficiency anemia. The success of these screening programs relies heavily on the target population's acceptance, which can be enhanced by raising awareness and providing comprehensive genetic counseling post-diagnosis. Effective counseling can foster positive attitudes and dispel misconceptions, leading to better understanding and outcomes.

Micromapping studies have indicated a greater diversity in the mutation spectrum among populations in smaller geographic areas, suggesting that the current known prevalence rates of hemoglobinopathies may be underestimated. Gathering more micromapping data will aid in the better planning of future population screening programs.

Advancements in technology and biology are expected to make non-invasive prenatal diagnosis using fetal cells from maternal blood more common in the next decade. Incorporating and validating these new technologies within hemoglobinopathy testing guidelines will streamline future population screening efforts.

Given the significant global prevalence of hemoglobinopathies, various national or regional

programs have been implemented to control the disease burden. The success of these programs is often measured by the reduction in the incidence of affected births. Ensuring the continuous development and application of effective screening and diagnostic methods is vital for the ongoing management and reduction of hemoglobinopathy cases.

#### Acknowledgment:

We are grateful to the Central Laboratory of Balcali Hospital at Çukurova Medical School for providing essential facilities and resources that made this study possible. Furthermore, we are deeply grateful to the Çukurova University, BAP organization for their financial support of this project (code FYL-2022-14516). Their participation has been instrumental in the successful completion of this work.

#### Funding:

Central Laboratory of Balcali Hospital at Çukurova Medical School

#### Authors Contributions:

All authors contributed toward data analysis, Drafting and revising the paper and agreed to be Responsible for all the aspects of this work

#### Ethical Consideration:

FYL-2022-14516

#### References

1. Jia., Wangwei, Irena, Tsui., Mariko, Morimoto., Deepak, Vishwakarma. (2023). IthaPhen: An Interactive Database of Genotype-Phenotype Data for Hemoglobinopathies. HemaSphere, doi: 10.1097/hs9.0000000000000922
2. Minaidou., Anna, Stella, Tamana., Coralea, Stephanou., Maria, Xenophontos., Cornelis, L., Harteveld., Celeste, Bento., Marina, Kleanthous., Petros, Kountouris. (2022). A Novel Tool for the Analysis and Detection of Copy Number Variants Associated with Haemoglobinopathies. International Journal of Molecular Sciences, doi: 10.3390/ijms232415920
3. Yudin., Jovana, Madeleine, Verhovsek. (2019). How we diagnose and manage altered oxygen affinity hemoglobin variants.. American Journal of Hematology, doi: 10.1002/AJH.25425.
4. Oğuz., Esra, Firat, Funda, Eren. (2022). The evaluation of tertiary care center hemoglobin variant data for three years period. Kırıkkale Üniversitesi Tıp Fakültesi Dergisi, doi: 10.24938/kutfd.1128242
5. Dasauni., Pushpanjali, Nirpendra, Pratap, Singh., Varun, Chhabra., Manoranjan, Mahapatra., Renu, Saxena., S, Kundu. (2022). Optimization and Identification of Single Mutation in Hemoglobin Variants with 2,2,2 Trifluoroethanol Modified Digestion Method and Nano-LC Coupled MALDI MS/MS. Molecules, doi: 10.3390/molecules27196357
6. Higgins., Victoria, Lauren, MacNeil., Iveta, Sosova., Ross, Ridsdale., Aisha, Bruce., Davor, Brinc., Wilkinson, David., Pierre, Bordeleau., Mathew, P., Estey., Michelle, L., Parker., Tabi, Agbor. (2023). Hemoglobin Variant in Disguise.. Clinical biochemistry, doi: 10.1016/j.clinbiochem.2023.110589
7. Zheng., Yu, Zi, Cassandra, Kovacic., Julie, Potz., Mitchell, McCale., Sarah, L., Ondrejka., Jessica, M, Colón-Franco. (2023). Characterization of Samples with Minor P3 Peak Elevations in a High Pressure Liquid Chromatography System for HbA1c: Contributions of Hemoglobin Variants and Storage Conditions.. The journal of applied laboratory medicine, doi: 10.1093/jalm/jfac090
8. Arishi, Wjdan A., Hani A. Alhadrami, and Mohammed Zourob. 2021. Techniques for the Detection of Sick Cell Disease: A Review. Micromachines 12, no. 5: 519. <https://doi.org/10.3390/mi12050519>
9. Mondesert., Etienne, Muriel, Giansily, Blaizot., Olivier, Tournilhac., Anne, François, Serre, Sapin., Bernard, Aubin., Jean-Luc, Pellequer., P., Martinez. (2020). The Importance of Characterizing the

- Hemoglobin Instability of New Variants: The Case of Hb Dompierre [ $\beta 29(\text{B11})\text{Gly}\rightarrow\text{Arg}$ , HBB: c.88G>C].. Hemoglobin, doi: 10.1080/03630269.2020.1721021
10. Ne., Igbneweka, Pilarski, A., R., H., Breton, A., Hall, H., J., D., Meeks, D., Chevassut, Tj., Thein, Sl., Menzel, S. (2022). Common Genetic Variants of Fetal Hemoglobin Modify Hematological Phenotypes in MDS/MPN/Myeloma Patients Receiving Cytotoxic Drugs. *Annals of hematology & oncology*, doi: 10.26420/annhematoloncol.2022.1403
  11. Karimi., Saman, S., Ming, Jin., Carlos, Murga-Zamalloa. (2023). Analytical and Clinical Significance of Rare Hemoglobin Variants during HbA1c Monitoring in Patients with Diabetes Mellitus: Two Cases of Hemoglobin G-Ferrara and Hemoglobin G-Copenhagen in Diabetic Patients with Sick Cell Trait.. *The journal of applied laboratory medicine*, doi: 10.1093/jalm/jfac135
  12. Xu., Anping, Weidong, Chen., Weijie, Xie., Yajun, Wang., Ling, Ji. (2021). Hemoglobin variants in southern China: results obtained during the measurement of glycated hemoglobin in a large population. *Clinical Chemistry and Laboratory Medicine*, doi: 10.1515/CCLM-2020-0767
  13. Barrera-Reyes., Paloma, K, M, Elizabeth, Tejero. (2019). Genetic variation influencing hemoglobin levels and risk for anemia across populations.. *Annals of the New York Academy of Sciences*, doi: 10.1111/NYAS.14200
  14. Khorchai., Areerat, Siripakorn, Sangkitporn., Sawitree, Duangrueng., Chonlada, Yodtup., Acharaporn, Dambua., Apichat, Chotchusri., Patcharaporn, Boonchoo., Somchai, Sangkitporn. (2017). Characteristic Properties of Hemoglobin Variants by Hemoglobin Separation and Quantitation Analysis - *Journal of Health Science*,
  15. Alkilani., Sima, Tuba, Sevimoğlu. (2023). In silico analysis of substitution mutations in the  $\beta$ -globin gene in Turkish population of  $\beta$ -thalassemia.. *Journal of Biomolecular Structure & Dynamics*, doi: 10.1080/07391102.2023.2176924
  16. Karakaya., Taner, Fatma, Silan., Oztuerk, Ozdemir. (2022). A New Mutation, Hb A2-Canakkale [ $\delta 10(\text{A7})\text{Ala}\rightarrow\text{Val}$ ; HBD: c.32C>T], and Other Well-Known  $\delta$  Variants Identified in a Selected Cohort with Low Hb A2 Levels. *Hemoglobin*, doi: 10.1080/03630269.2022.2083968
  17. Yıldız, i., Oral. D, Tekeş S, Çürük, M.A., (2019). ‘First Observation of Hemoglobin Hamilton [ $\beta 11(\text{A8})\text{Val}\rightarrow\text{Ile}$ ] in Turkey. *Balkan Clinical Laboratory Biochemical Society TBS 2019*.
  18. Dönbak, L., 2005. İnsan Hemoglobin (Hb) Varyantları KSU. *Journal of Science and Engine* 13:8 (2).
  19. Ariyurek., Sedefgul, Yuzbasioglu, Sule, Menziletoglu, Yildiz., Ali, Erdinc, Yalin., Figen, Güzelgül., Kıymet, Aksoy. (2016). Hemoglobinopathies in the Çukurova Region and Neighboring Provinces.. *Hemoglobin*, doi: 10.3109/03630269.2016.1155156
  20. Guzelgul., Figen, G.Şeyda, Seydel., Kıymet, Aksoy. (2020).  $\beta$ -Globin Gene Mutations in Pediatric Patients with  $\beta$ -Thalassemia in the Region of Çukurova, Turkey.. *Hemoglobin*, 44(4):249-253. doi: 10.1080/03630269.2020.1792489
  21. Guzelgul. Figen, (2014). The first observation of two alpha globin mutations in Turkey: Hb Stanleyville II and a homozygous 5nt deletion. *Turkish Journal of Biochemistry-turk Biyokimya Dergisi*, doi: 10.5505/TJB.2014.31967
  22. Flint J, Harding RM, Boyce AJ, Cleg JB. The population genetics of the haemoglobinopathies. *Br Clin Haematol*, 1998; 11: 1-51.



23. Canatan D. Dünyada ve Türkiye’de talasemi ve anormal hemoglobinler. Canatan D, Aydınok Y. Talasemi ve Hemoglobinopatiler, Retma, 2007: 11-19.
24. Lukens JN, Lee GR. The Abnormal Hemoglobins. In: Wintrobe's Clinical Hematology, Eds Lee GR, Bithell CT, Foester J, Athens JW, Lukens JN. Lee and Febiger Com, Pennsylvania 1993.
25. Yüregir GT, Arpacı A, Aksoy K, Tuli A, Dikmen N, Özgünen T, Kılınç Y. Population at risk for hemoglobinopathies in Çukurova. Türkiye: Need for prenatal diagnosis. Ann Med Sci, 1995; 4:61-60.
26. Arpacı A. Antakya yöresinde  $\beta$  talasemik gen sıklığı ve mutasyonların gen amplifikasyon yöntemi ile saptanması. Uzmanlık Tezi, ÇÜ Tıp Fakültesi, 1991.
27. Attila G, Çürük MA, Arpacı A, Özgünen FT, Kılınç Y, Aksoy K, Yüregir GT. Prenatal diagnosis of hemoglobinopathies in southern Turkey. Ann Med Sci, 1999; 8(2): 93-97.
28. Gürgey A, Altay Ç, Beksaç MS, Bhattacharya R, Kutlar F, Huisman THJ., (1989). Hydrops fetalis due to homozygosity for  $\alpha$  thalassemia-1,  $-(\alpha)20,5$  kb: The first observation in a Turkish family. Acta Haematol, 1989; 81: 169-171.
29. Güler E, Karacan M., (2007). Prevalans of beta-thalassemia and sickle cell anemia trait in premarital screening in Konya urban area, Turkey. J Ped Hem Onco, 2007; 29(11): 783-785.

## Tables&amp; Figures

Table 1. Distribution of abnormal hemoglobins in Turkey (Yıldız, 2019).

No	Name	Chain/Mutation	No	Name	Chain/Mutation
1	Adana*	$\alpha 59$ Gly>Asp	31	J-Antakya*	$\beta 65$ Lys>Met
2	Ankara*	$\beta 10$ Ala>Asp	32	J-Iran	$\beta 77$ His>Asp
3	A2 Yialousa	$\delta 82$ Ala>Ser	33	J-Meerut	$\alpha 120$ Ala>Glu
4	Antalya*	Deletion/insertion	34	Knosos	$\beta 27$ Ala>Ser
5	Başkent*	$\gamma 128$ Ala>Thr	35	Köln	$\beta 98$ Val>Met
6	Beograd	$\beta 121$ Glu>Val	26	Lepore-Boston	Hybrid
7	Brocton	$\beta 138$ Ala>Pro	37	M-Iwate	$\alpha 87$ His>Tyr
8	Bronova	$\alpha 103$ His>Leu	38	Moabit	$\alpha 86$ Leu>Arg
9	C	$\beta 6$ Glu>Lys	39	Monthgomery	$\alpha 48$ Leu>Arg
10	City of Hope	$\beta 69$ Gly>Ser	40	M-Saskatoon	$\beta 63$ His>Tyr
11	Costant Spring	Prolonged $\alpha$ chain	41	N-Baltimore	$\beta 95$ Lys>Glu
12	Crete	$\beta 129$ Ala>Pro	42	Noah	$\delta 143$ His>Tyr
13	Çapa*	$\alpha 94$ Asp>Gly	43	O-Arab	$\beta 121$ Glu>Lys
14	D-Iran	$\beta 22$ Glu>Gln	44	O-Podova	$\alpha 30$ Glu>Lys
15	D-Punjab	$\beta 121$ Glu>Gln	45	P-Nilotic	Hybrid
16	D-Ouled Rabah	$\beta 19$ Asn>Lys	46	Pyrgos	$\beta 83$ Gly>Asp
17	E	$\beta 26$ Glu>Lys	47	Q-Iran	$\alpha 75$ Asp>His
18	Ernz	$\beta 123$ Thr>Asn	48	S	$\beta 6$ Glu>Val
19	E-Saskatoon	$\beta 22$ Glu>Lys	49	Sarrebourg	$\beta 131$ Gln>Arg
20	G-Copenhagen	$\beta 47$ Asp>Asn	50	Setif	$\alpha 94$ Asp>His
21	G-Cousatta	$\beta 22$ Glu>Ala	51	Siirt*	$\beta 27$ Ala>Gly
22	G-Georgia	$\alpha 95$ Pro>Leu	52	South Florida	$\beta 1$ Val>Met
23	G-Szuhu	$\beta 80$ Asn>Lys	53	Strumica	$\alpha 112$ His>Arg
24	Hakkari*	$\beta 31$ Leu>Arg	54	Summer Hill	$\beta 52$ Asp>His

25	Hamadan	β56 Gly>Arg	55	Tunis	β124 Pro>Ser
26	Hamilton	β11 Val>Ile	56	Tyne	β5 Pro>Ser
27	Hasharon	α47 Asp>His	57	Ube-2	α68 Asn>Asp
28	Istanbul*	β92 His>Gln	58	Volga	β27 Ala>Asp
29	Izmir*	β86 Ala>Val	59	Yauzi	β79 Asp>Asn
30	J-Anatolia	α61 Lys>Thr	60	Westeinde	α125 Leu>Gln

\*First discovered in Turkish patients

Table 2. Hemoglobin types in percentage groups of all participants

Percentage/patient	0-25%	25-50%	50-75%	75-100%
HbA%	22	24	55	9
HbF%	76	24	1	1
HbS%	11	53	43	36
HbA2%	160	0	0	0
HbC%	-	5	-	-
HbE%	-	1	-	-

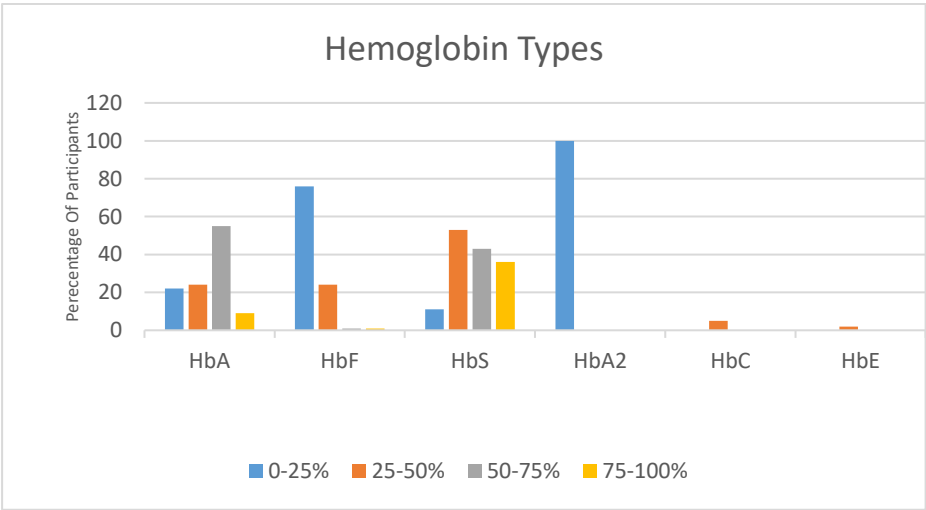


Diagram 1. Hemoglobin types in percentage groups of all participants

Table 3. Hemoglobin types in sickle cell carriers

Percentage/patient	0-25%	25-50%	50-75%	75-100%
HbA%	25	47	5	0
HbF%	22	4	2	3
HbS%	50	0	32	84
HbA2%	31	0	27	21

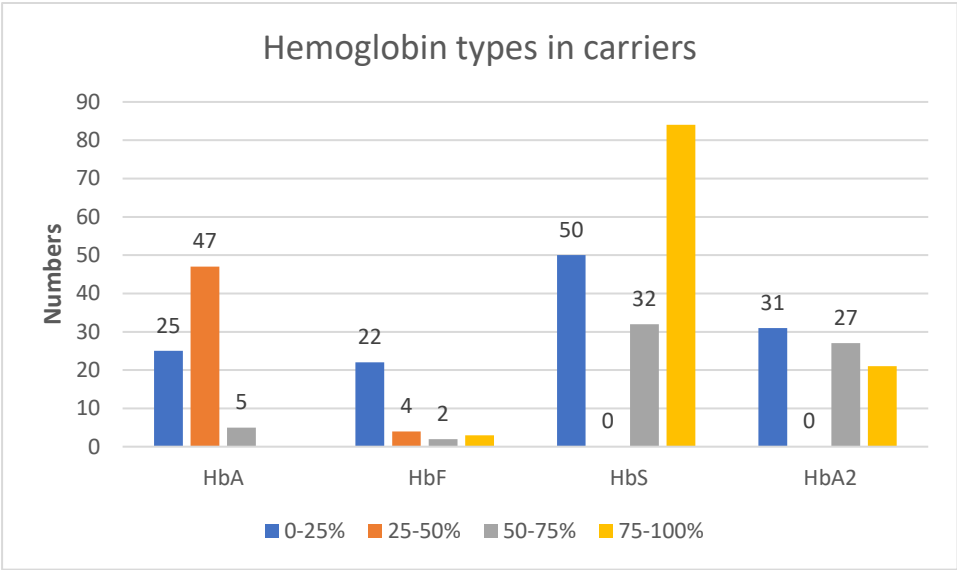


Diagram 2. Hemoglobin types in sickle cell carrier patients

Table 4. Hemoglobin types in percentage groups in sickle cell patients

Percentage/patient	0-25%	25-50%	50-75%	75-100%
HbF%	32	25	1	1
HbS%	1	2	29	28
HbA2%	60	0	0	0

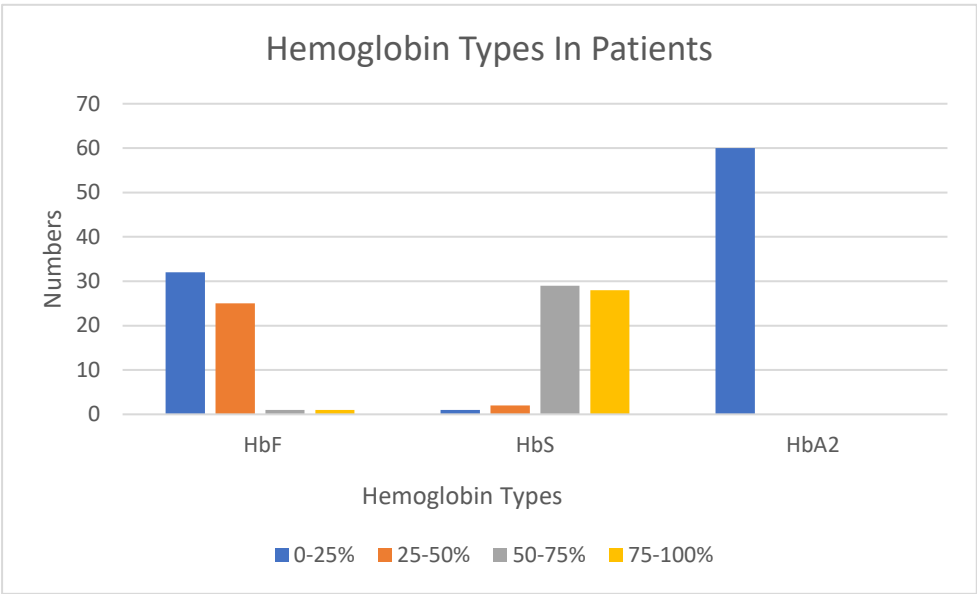


Diagram 3. Hemoglobin types in percentage groups in sickle cell patients

Table 5: Carriers with hemoglobin C

Carriers	HbA %	HbC %	Hb types
86	62.27	35.73	AC
109	67.10	32.90	AC

Table 6. Carriers with hemoglobin E

Carriers	HbA%	HbE%	Hb types
19	65.55	34.45	AE



Table7. Percentage of hemoglobin variants

Hemoglobin Variants	Percentage (%)
HbAS	63.53
HbSS	33.15
HbSC	1.65
HbAC	1.12
HbAE	0.55

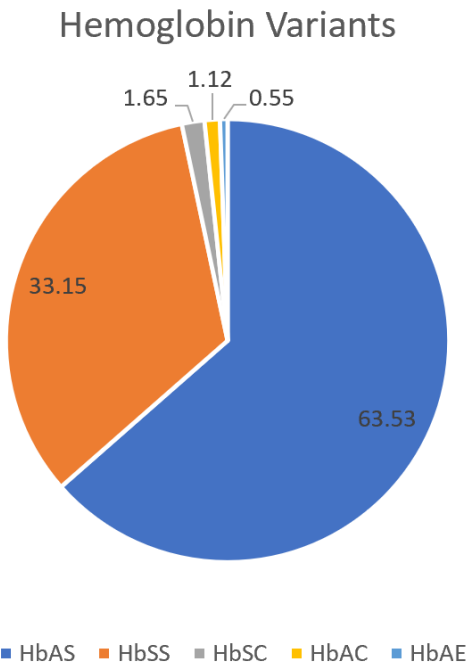


Diagram 4. Percentage of hemoglobin variants