Mutation analysis of β-thalassemia in East-Western Indian population: a recent molecular approach

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Background: β-Thalassemia is the most prevalent genetic disorder in India. Its traits and coinheritance vary from mild to severe conditions, resulting in thalassemia minor, intermediate, and major, depending upon many factors.

Purpose: The objective of this study was to identify the incidence of β-thalassemia traits, their coinheritance, and mutations, as well as to support the patients already diagnosed with β-thalassemia in East-Western Indian population for better management.

Patients and methods: Seventy-five referral cases for β-thalassemia were analyzed for various β-thalassemia traits, heterozygosity, and homozygosity conditions. Blood phenotypic parameters using cell counter and capillary electrophoresis were investigated. Analyses of eight common mutations of thalassemia in India were carried out using polymerase chain reaction-amplification refractory mutation system, end point polymerase chain reaction, and DNA sequencing methods.

Results: Of these (75) referral cases from East-Western Indian region, 68 were positive for β-thalassemia (90.67%). The majority of case types were of β-thalassemia minor (49, 65.33%), followed by HbE traits (6, 8.0%) and β-thalassemia major, including heterozygous and homozygous (5, 6.66%; 4, 5.33%) types and then HbE homozygous (2, 2.66%), as well as one each of the HbE/β-thalassemia and HbD/β-thalassemia (1, 1.34%) combination. Mutation analysis also revealed that the highest frequency of mutation was c.92G>A (8, 11.76%) in our study group. Five cases (nos. 24, 27, 33, 58, and 71) exhibited coinheritance between β/β⁺ (2), β⁺/β⁺ (1), and c.124_127delTTCT/β⁺ or β⁺ (2) affecting the Rajasthani and Gujarati populations in our study of the Western region of India.

Conclusion: We strongly recommend these Western populations for genetic screening before adopting reproductive technologies and interracial marital relations.

Keywords: β-thalassemia traits, coinheritance, hematogram, capillary electrophoresis, PCR-ARMS, DNA sequencing, mutation analysis, East-Western India

Introduction

β-Thalassemia is one of the hemoglobinopathies belonging to a class of genetic disorders. It occurs due to mutation in β-gene of autosomal chromosome 11.¹ The incidence of β-thalassemia trait in India is 3.3% with 1%–7% of couples being affected annually.² Approximately 300 mutations would occur in this type, affecting β-chain globin synthesis. If the synthesis of two β-chains is absent (β⁻/β⁻), the person has β-thalassemia major (Cooley’s anemia). This condition follows severe microcytic and hyochromic anemia. The person requires lifelong transfusion. β-Thalassemia minor is asymptomatic and results in microcytosis and mild anemia and HbA2 level increases, designated as β⁺/β⁺ or β⁺/β⁻. Usually thalassemia intermedia is a condition between the major and minor forms depending on the severity of the anemic condition (β⁺/β⁻ or β⁺/β⁻) among other cases.³⁴

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Others are HbE trait, HbE homozygous, HbD/β-thalassemia, and HbE/β-thalassemia hemoglobinopathies. The latter one, HbE/β-thalassemia, is maximum in Thailand. The gene mutation takes place in another one of β-gene only in addition to β-thalassemia minor/allele (β/β or β'/β), leading to coinheritance. In India, such coexisting HbE/β-thalassemia and HbD/β-thalassemia are less debated and occur in some parts of India, Pakistan, and Iran. Recently, a report was published in Eastern Indian population about the status of thalassemia and hemoglobinopathies and suggested that more such studies are necessary in other regions of India. Prevalence of common hemoglobinopathies in Gujarati population was documented by Patel et al in screening programs, where β-thalassemia minor cases were maximum comparatively. Hence, we report β-thalassemia, HbE, HbD traits, and their coinheritance as well as the mutation analysis of β-thalassemia distribution in East-Western Indian population using electrophoresis, polymerase chain reaction-amplification refractory mutation system (PCR-ARMS), end point PCR, and gene sequencing technology in our study.

Patients and methods
Patient selection
Blood samples of 75 referral cases of both sexes varying in age from 6 months to 38 years were collected from Gujarat (17), Rajasthan (40), Maharashtra (7), Assam (3), and West Bengal (6) in India for β-thalassemia testing after duly filling the patient consent form in our Supratech Micropath Research Institute, Ahmedabad. These patients were referred at random. This project was approved by Human Ethical Committee (HEC) of Gujarat University, Ahmedabad (GU/HEC-001/15), in 2015 for investigation.

Hematological analysis and DNA extraction
Hematogram report was carried out on CELL DYN RUBY automated cell counter. Hemoglobin (Hb) levels were estimated by Sebia Capillary 2 Flex piercing electrophoresis. The DNA was extracted from 2 mL of EDTA blood using PerkinElmer Prepito DNA Blood 250 Kit automatic machine. The kit was used according to the manufacturer’s instructions. The extracted genomic DNA was used as a template and was kept at 4°C until further use after routine DNA check.

Amplification, purification, and cycle sequencing
The primers were synthesized from the Eurofins, India. The amplification reaction was performed in Verití Thermal Cycler. The PCR products were loaded on a 2.5% agarose gel, and the amplicons were visualized under ultraviolet transillumination after staining with ethidium bromide. PCR product cleanup using USB ExoSAP-IT kit (Affymetrix, Santa Clara, CA, USA) and cycle sequencing using BigDye Terminator V3.1 cycle sequencing kit (Applied Biosystems, Foster City, CA, USA) were used for further mutation identification.

Mutation analysis
The β-globin gene mutations were first characterized using two sets of allele-specific PCR-ARMS to detect eight common mutations in India including c.92+5G>C, deletion 619 bp, c.79G>A (p.E27K), c.47G>A (p.Trp16Ter), c.364G>C (p.E122Q), c.27_28insG, c.51delC, and c.124_127delTTCT. Unknown β-thalassemia genes were further characterized by direct DNA sequencing using 3500 Genetic Analyzer Applied Biosystems (ABI) for all coding regions and exon–intron boundaries to detect uncommon point mutations and small rearrangements in the β-globin gene. The c.92+5G>C mutation was detected by Sanger sequencing and PCR-ARMS, and deletion 619 bp was done by end point PCR (gel electrophoresis). Other mutations were analyzed only by Sanger sequencer. The data were analyzed using CodonCode Aligner v5.0.2 (CodonCode Corporation, Centerville, MA, USA) and Mutation Surveyor v5.0 (Softgenetics, State College, PA, USA). Mean and percentage were calculated wherever necessary.

Results
β-Thalassemia and other traits
Referral cases of 75 at our Supratech Micropath Research Institute, Ahmedabad, from 2015 to 2016 were analyzed for β-thalassemia and other traits based on Hb levels blood indices and mutation analysis from different parts of India. The affected (68) contributed 90.67% of the referral cases. High percentage (65.33%) had β-thalassemia followed by HbE trait (8%) and β-thalassemia major (heterozygous 6.66%; homozygous 5.33%). Others were HbE homozygous (2.66%), HbE/β-thalassemia, and HbD/β-thalassemia contributed only 1.34% each. Thus, 49 cases (65.33%) had β-thalassemia minor followed by HbE trait (8%) and β-thalassemia major (compound heterozygous 6.66% and homozygous 5.33%). Two were HbE homozygous (2.66%) and HbE/β-thalassemia and HbD/β-thalassemia contributed only 1.34% each. These hemoglobinopathies are well supported by increased levels of mean HbA2 (08.66%) with decreased mean corpuscular hemoglobin (MCH), mean corpuscular volume values, and altered mean HbD (1.25%), HbF (7.21%), and HbE (2.73%) levels, measured by capillary electrophoresis (Tables 1 and 2 and Figure 1).
Table 1  Classification of thalassemia traits in our study

| Nos | Types of thalassemia traits | Characteristics | Cases | Percentage |
|-----|-----------------------------|-----------------|-------|------------|
| 1   | β-thalassemia minor          | Increased HbA2 with ↓ MCV and ↑ RDW | 49    | 65.33      |
| 2   | HbE trait                   | ↑ HbA2/E, HbF, and ↓ HbA and ↑ RDW | 6     | 8.00       |
| 3   | β-thalassemia major (compound heterozygous) | ↑ HbA2 with ↓ MCV, ↑ HbF, and ↑ RDW | 5     | 6.66       |
| 4   | β-thalassemia major (homozygous) | ↑ HbA2 with ↓ MCV, ↑ HbF, and ↑ RDW | 4     | 5.33       |
| 5   | HbE homozygous              | ↑ HbA2/E, HbF, and ↓ HbA and ↑ RDW | 2     | 2.66       |
| 6   | Combination of HbE/β-thalassemia | ↑ HbA2/E, HbF, and ↓ HbA and ↑ RDW | 1     | 1.34       |
| 7   | Combination of HbD-β-thalassemia | ↑ HbAD, HbA2, and HbF ↑ (sometimes) and ↑ RDW | 1     | 1.34       |

Notes: Total cases 75; affected cases 68 (90.67%).
Abbreviations: ↑, increase; ↓, decrease; Hb, hemoglobin; HbF, fetal hemoglobin; MCV, mean corpuscular volume; RDW, red blood cell distribution width.

Table 2  Sex wise distribution of Hb variants and mutations in our study

| Nos | Age (years) | Sex | HbA (%) | MCV (fL) | MCH (pg) | RDW (%) | HbA2 (%) | HbE (%) | HbD (%) | Mutations | Genotype | Inference/clinical report | Technique(s) |
|-----|-------------|-----|---------|----------|----------|---------|----------|---------|---------|------------|----------|-------------------------|--------------|
| 1   | 24          | Female | 94.30 | 75.00   | 24.00   | 16.40  | 5.00     | 0.0     | 0.70   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 2   | 27          | Male    | 94.50 | 67.00   | 18.20   | 17.00  | 4.70     | 0.0     | 0.80   | c.47G>A (p.Trp16Ter) | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 3   | 25          | Female | 93.95 | 69.50   | 20.80   | 17.10  | 5.40     | 0.0     | 0.65   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 4   | 28          | Male    | 93.75 | 75.50   | 18.40   | 41.30  | 5.40     | 0.0     | 0.85   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 5   | 25          | Female | 94.61 | 69.00   | 21.00   | 17.80  | 4.80     | 0.0     | 0.59   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 6   | 5           | Female | 65.65 | 69.90   | 18.50   | 15.10  | 33.60    | 0.0     | 0.75   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 7   | 28          | Male    | 94.35 | 68.00   | 21.00   | 18.00  | 4.70     | –       | 0.95   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 8   | 28          | Female | 93.40 | 76.40   | 23.80   | 15.60  | 5.40     | –       | 1.20   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 9   | 30          | Male    | 92.50 | 75.00   | 22.40   | 14.70  | 6.60     | –       | 0.90   | Not detected | B/β      | Normal                  | SS and GE    |
| 10  | 25          | Female | 93.95 | 74.90   | 18.60   | 15.00  | 5.00     | –       | 1.05   | c.92+5G>C | B/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 11  | 30          | Male    | 96.80 | 79.90   | 28.00   | 14.00  | 2.60     | –       | 0.60   | Not detected | B/β      | Normal                  | SS and GE    |
| 12  | 33          | Female | 66.50 | 71.00   | 27.90   | 14.60  | 22.96    | 9.84    | 0.70   | c.79G>A (p.Glu27Lys) | B'/β      | HbE trait                | SS           |
| 13  | 33          | Male    | 92.80 | 70.10   | 20.90   | 16.90  | 6.60     | –       | 0.60   | c.47G>A (p.Trp16Ter) | B'/β      | β-thalassemia minor     | SS           |
| 14  | 20          | Female | 94.55 | 68.60   | 18.50   | 16.20  | 4.70     | –       | 0.75   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 15  | 28          | Male    | 94.00 | 76.30   | 19.40   | 17.40  | 5.20     | –       | 0.80   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 16  | 6           | Male    | 87.50 | 67.00   | 18.10   | 19.40  | 2.20     | –       | 10.30  | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 17  | 26          | Female | 93.80 | 68.50   | 19.40   | 16.20  | 5.70     | –       | 0.50   | 619 bp deletion | B'/β      | β-thalassemia minor     | GE           |
| 18  | 28          | Male    | 95.20 | 68.30   | 20.80   | 15.50  | 4.60     | –       | 0.20   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 19  | 1           | Male    | 94.90 | 70.20   | 19.20   | 16.90  | 2.70     | –       | 2.40   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 20  | 29          | Male    | 17.90 | 67.50   | 18.40   | 16.30  | 68.90    | 12.70   | 0.50   | c.79G>A (p.E27K) | B'/β      | HbE trait                | SS           |
| 21  | 24          | Female | 66.15 | 69.00   | 27.80   | 14.50  | 23.52    | 10.08   | 0.25   | c.79G>A (p.Glu27Lys) | B'/β      | HbE trait                | SS           |
| 22  | 31          | Male    | 94.35 | 74.20   | 21.00   | 16.40  | 5.20     | –       | 0.45   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 23  | 27          | Female | 93.45 | 67.00   | 22.80   | 17.70  | 5.90     | –       | 0.65   | c.92+5G>C | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |
| 24  | 1           | Male    | 6.70  | 69.20   | 21.40   | 38.20  | 3.30     | 90.0    | –       | c.47G>A (p.Trp16Ter) | B'/β      | β-thalassemia minor     | SS and PCR-ARMS |

(Continued)
| Nos | Age, Sex years | HbA (%) | MCV (FL) | MCH (pg) | RDW (%) | HbA2 (%) | HbE (%) | HbD (%) | Mutations | Genotype Inference/clinical report | Technique(s) |
|-----|----------------|---------|----------|----------|---------|----------|---------|---------|-----------|-----------------------------------|--------------|
| 25  | 30 Male        | 95.55   | 73.90    | 21.50    | 15.90   | 4.20     | 0.25    | c.47G>A (p.Trp16Ter) β²β² | β-thalassemia minor | SS          |
| 26  | 35 Female      | 93.70   | 69.50    | 20.80    | 17.20   | 5.70     | 0.60    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 27  | 5 Male         | 4.00    | 66.90    | 18.50    | 15.90   | 58.80    | 25.80   | c.79G>A (p.Glu27Lys) and c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 28  | 30 Female      | 93.20   | 68.00    | 22.30    | 16.60   | 6.20     | 0.60    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 29  | 32 Female      | 2.90    | 67.30    | 18.20    | 17.00   | 61.80    | 28.20   | c.79G>A (p.Glu27Lys) | β²β² | HbE trait | SS |
| 30  | 4 Male         | 4.00    | 69.50    | 21.60    | 37.50   | 1.10     | 94.90   | c.51delC | β²β² | β-thalassemia minor | SS |
| 31  | 26 Female      | 93.50   | 66.40    | 21.70    | 18.20   | 5.90     | 0.60    | c.27-28insG | β²β² | β-thalassemia minor | SS |
| 32  | 2 Female       | 1.40    | 65.30    | 18.40    | 16.70   | 2.20     | 96.40   | c.27-28insG | β²β² | β-thalassemia minor | SS |
| 33  | 27 Male        | 1.55    | 75.30    | 22.80    | 16.30   | 3.80     | 0.25    | c.94.40c.27-28insG and c.364G>C (p.E122Q) | β²β² | HbD/β-thalassemia | SS |
| 34  | 27 Female      | 96.10   | 70.30    | 21.90    | 17.20   | 3.60     | 0.30    | 619 bp deletion | β²β² | β-thalassemia minor | SS |
| 35  | 30 Male        | 95.40   | 68.50    | 21.20    | 17.70   | 4.10     | 0.50    | 619 bp deletion | β²β² | β-thalassemia minor | SS |
| 36  | 27 Female      | 94.75   | 62.20    | 20.40    | 16.80   | 4.80     | 0.45    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 37  | 30 Male        | 93.65   | 64.20    | 19.60    | 15.70   | 5.80     | 0.55    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 38  | 23 Female      | 93.45   | 69.80    | 22.50    | 14.70   | 6.20     | 0.35    | c.47G>A | β²β² | β-thalassemia minor | SS |
| 39  | 26 Male        | 97.10   | 75.90    | 24.50    | 13.40   | 2.80     | 0.10    | Not detected | ββ | Normal | SS and GE |
| 40  | 29 Female      | 94.95   | 68.90    | 22.30    | 16.90   | 4.80     | 0.25    | 92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 41  | 31 Male        | 96.10   | 69.30    | 20.50    | 15.70   | 3.90     | 0.00    | 92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 42  | 5 Female       | 94.75   | 69.70    | 22.40    | 15.80   | 5.00     | 0.25    | 92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 43  | 8 Female       | 80.00   | 68.50    | 21.60    | 16.80   | 14.00    | 6.00    | 0.00 | c.79G>A | β²β² | HbE trait | SS |
| 44  | 31 Female      | 94.27   | 64.20    | 19.50    | 15.80   | 5.28     | 0.45    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 45  | 33 Male        | 93.00   | 69.40    | 20.40    | 17.80   | 6.60     | 0.40    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 46  | 4 Female       | 3.70    | 67.00    | 19.20    | 15.50   | 1.60     | 94.70   | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 47  | 33 Female      | 94.40   | 69.50    | 20.70    | 17.60   | 5.40     | 0.20    | 619 bp deletion | β²β² | β-thalassemia minor | GE |
| 48  | 35 Male        | 94.50   | 64.10    | 19.70    | 16.90   | 5.20     | 0.30    | 619 bp deletion | β²β² | β-thalassemia minor | GE |
| 49  | 30 Female      | 95.60   | 63.10    | 19.90    | 16.00   | 4.20     | 0.20    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 50  | 32 Male        | 94.80   | 70.00    | 20.10    | 15.80   | 4.80     | 0.40    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 51  | 26 Female      | 94.40   | 68.90    | 19.40    | 17.10   | 4.90     | 0.70    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 52  | 26 Male        | 94.65   | 69.90    | 20.30    | 17.60   | 4.80     | 0.55    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 53  | 1/2 Female     | 94.70   | 68.10    | 18.90    | 17.90   | 2.40     | 2.90    | c.92>G>C | β²β² | β-thalassemia minor | SS and PCR-ARMS |
| 54  | 35 Female      | 91.10   | 69.50    | 20.80    | 17.00   | 8.20     | 0.70    | Not detected* | – | – | SS and GE |
| 55  | 38 Male        | 91.50   | 63.10    | 19.50    | 16.00   | 7.90     | 0.60    | Not detected* | – | – | SS and GE |

(Continued)
Table 2 (Continued)

| Nos | Age, years | Sex | HbA (%) | MCV (fl) | MCH (pg) | RDW (%) | HbA2 (%) | HbE (%) | HbF (%) | HbD (%) | Mutations | Genotype Inference/clinical report | Technique(s) |
|-----|------------|-----|---------|---------|---------|---------|---------|---------|---------|---------|-----------|----------------------------------|--------------|
| 56  | 4          | Female | 94.50   | 75.00   | 23.10   | 14.00   | 5.00    | –       | 0.60    | –       | Not detected*                  | –                  | –                  | SS and GE |
| 57  | 5          | Female | 93.30   | 75.60   | 25.00   | 14.10   | 6.10    | –       | 0.60    | –       | Not detected*                  | –                  | –                  | SS and GE |
| 58  | 22         | Female | 93.80   | 69.00   | 21.40   | 38.20   | 5.80    | –       | 0.40    | –       | c.124_127delTTCT**              | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
|     |            |       |         |         |         |         |         |         |         |         | and c.92+5 G>C                 |                     |                                  |              |
| 59  | 26         | Male   | 94.30   | 63.20   | 19.50   | 16.00   | 5.20    | –       | 0.50    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 60  | 29         | Female | 93.55   | 67.40   | 20.30   | 14.40   | 20.70   | 9.30    | 0.60    | –       | c.79G>A                         | β/β                | β-thalassemia minor            | GE          |
| 61  | 30         | Female | 93.95   | 69.10   | 21.80   | 38.20   | 5.50    | –       | 0.55    | –       | 619 bp deletion                 | β/β                | β-thalassemia minor            | GE          |
| 62  | 28         | Female | 94.00   | 69.00   | 21.40   | 38.20   | 5.40    | –       | 0.60    | –       | 619 bp deletion                 | β/β                | β-thalassemia minor            | GE          |
| 63  | 30         | Male   | 93.60   | 69.40   | 20.70   | 17.00   | 5.90    | –       | 0.50    | –       | c.27_28insG                     | β/β                | β-thalassemia minor            | SS          |
| 64  | 27         | Female | 94.40   | 69.00   | 21.80   | 17.40   | 5.20    | –       | 0.40    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 65  | 30         | Male   | 94.30   | 67.10   | 19.20   | 14.60   | 5.50    | –       | 0.70    | –       | c.27_28insG                     | β/β                | β-thalassemia minor            | SS          |
| 66  | 24         | Male   | 93.20   | 69.00   | 21.70   | 17.80   | 6.10    | –       | 0.70    | –       | 619 bp deletion                 | β/β                | β-thalassemia minor            | GE          |
| 67  | 26         | Male   | 91.75   | 62.40   | 19.90   | 18.20   | 7.90    | –       | 0.35    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 68  | 26         | Female | 94.35   | 68.90   | 20.90   | 17.60   | 4.90    | –       | 0.75    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 69  | 23         | Male   | 93.80   | 73.90   | 20.10   | 14.60   | 5.50    | –       | 0.70    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 70  | 27         | Female | 94.40   | 74.30   | 19.30   | 15.90   | 5.00    | –       | 0.60    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 71  | 24         | Male   | 0.0     | 72.90   | 21.00   | 14.50   | 3.40    | –       | 96.60   | –       | c.51_51delC and c.124_127delTTCT** | β/β                | β-thalassemia minor            | SS          |
| 72  | 26         | Male   | 94.20   | 68.40   | 21.00   | 14.00   | 5.20    | –       | 0.60    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |
| 73  | 27         | Female | 69.80   | 74.20   | 20.30   | 14.40   | 20.73   | 8.97    | 0.50    | –       | c.79G>A (p.E27K)               | β/β                | HbE trait                       | SS          |
| 74  | 28         | Male   | 68.40   | 70.20   | 21.80   | 16.90   | 21.70   | 9.30    | 0.60    | –       | c.79G>A (p.E27K)               | β/β                | HbE trait                       | SS          |
| 75  | 27         | Male   | 95.40   | 64.20   | 20.10   | 16.40   | 3.90    | –       | 0.70    | –       | c.92+5G>C                      | β/β                | β-thalassemia minor            | SS and PCR-ARMS |

Notes: Total cases: 75; age range (1/2 to 38 years). Case nos: 24, 27, 33, 58, and 71 had double mutations (compound heterozygous). Mean HbA = 81.37 (96.8%–97.8%), mean MCV = 69.53 (83–100 fl), mean MCH = 20.92 (27–32 pg), mean RDW = 17.85 (11.5%–14.5%), mean HbA2 = 8.66 (2%–3.5%), mean HbE = 2.73% (absent), HbD = 1.25% (absent), and HbF = 7.21 (0.0%–1.0%). Figures in parentheses indicate normal range/values.

*Large deletion and duplication are not identified in our study. **Genotype novel.

Abbreviations: GE, gel electrophoresis; Hb, hemoglobin; MCV, mean corpuscular volume; PCR-ARMS, polymerase chain reaction-amplification refractory mutation system; RDW, red blood cell distribution width; SS, Sanger sequencing.

Figure 1 Percentage (%) distribution of β-thalassemia traits.
Mutation analysis

We have analyzed conventional mutations of eight in Indian population using PCR-ARMS and end point PCR allayed with using Codon code Aligner V6.0.2 and mutation survey 5.0 software for exact specific mutation nomenclature from 68 affected cases. The data showed that c.92+5 G>C was higher (41, 60.29%), followed by nine cases of deletion 619 bp (13.23%), eight cases of c.79G>A (p.E27K) (11.76%), and five cases each of c.27_28insG (7.35%) and c.47G>A (p.Trp16Ter) (7.35%) with two cases each of c.124_127delTTCT (2.94%) and c.51delC (2.94%) and one case each of c.364G>C (p.E122Q) and c.47G>A (p.Trp16Ter) (1.47%), respectively, with no sex difference as female and male ratio was (1:1.13) (Table 3). Deletion 619 bp was only detected by gel electrophoresis, and c.92+5G>C was identified using PCR-ARMS and also gene sequencing as that of others (Figure 2A–G). In Rajasthan and Gujarat, where more are accumulated (40 and 17) respectively, in both cases, the most frequent mutation is c.92+5G>C (26 and 10) followed by 619 bp (3 and 4) and 619 bp deletions (Table 3 and Figure 3).

Discussion

β-Thalassemia is one of the heterozygous inheritable disorders in India. It causes reduced or absence of β-chain synthesis of Hb. Its variants in addition to carrier identification and prenatal analysis are necessary for its management and to avoid marriages between carrier of mutated genes including consanguineous types. Hence, from 75 referral cases of Western and Eastern India, the blood was collected to identify various traits and mutations accurately using electrophoretic and molecular diagnostic techniques in our laboratory including coinheritance with β-thalassemia. Of the total referral patients, 68 cases were affected having 90.67% in this study. Of these, 65.33% of β-thalassemia traits (49) were detected followed by HbE trait and β-thalassemia major with HbE homozygous and their HbE/β-thalassemia and HbD/β-thalassemia coherited cases depending on altered Hb, MCH, red blood cell distribution width, and MCV values. It indicated that β-thalassemia cases (carriers) are maximum followed by others and support the data of previous workers in India. Similarly, Hb patterns were measured and presented in the study of Mondal and Mandal, who obtained few cases of HbE, HbD traits, and β-thalassemia major comparatively. This could be due to changing lifestyles, environmental and genetic factors, and coinherence of HbE, HbD, and/or α-thalassemia with β-thalassemia carriers. Further, these factors may also be the cause of β-thalassemia major with heterozygosities homozygosity who are less in number requiring blood transfusion. Similarly, coinherence of HbE/β-thalassemia and HbD/β-thalassemia and HbE homozygous cases were also reduced in number in our report. HbE trait had six cases having less severity of clinical condition. However, Olivieri et al mentioned that these conditions may vary from severe to mild depending upon genetic and environmental factors, and such patients are also less frequent to support our data. We detected one each of HbD/β-thalassemia and HbE/β-thalassemia cases in addition to HbE patients with variable phenotypic indices expressing mild heterozygous state. These patients may require transfusion in severe condition only, due to coinherence of the disease.

Further, we extended our investigation on molecular analysis of mutations of β-thalassemia and systematically using latest molecular biology tools such as PCR-ARMS, end point

| Nos | Mutation types | Mutation nos (73)* | Male (34) | Female (39) | Mutation percentage | Region (state) wise mutation |
|----|----------------|--------------------|-----------|-------------|---------------------|-----------------------------|
| 1  | c.92+5G>C      | 41                 | 18        | 23          | 60.29               | Rajasthan 26, Gujarat 10, West Bengal 3, Maharashtra 2 |
| 2  | 619 bp deletion | 9                  | 3         | 6           | 13.23               | Gujarat 4, Rajasthan 3, Maharashtra 2 |
| 3  | c.79G>A (p.E27K)| 8                  | 4         | 4           | 11.76               | Assam 3, Rajasthan 2, Maharashtra 1, West Bengal 2 |
| 4  | c.47G>A (p.Trp16Ter) | 5                 | 4         | 1           | 7.35                | Gujarat 2, Rajasthan 2, Maharashtra 1 |
| 5  | c.364G>C (p.E122Q)| 1                 | 1         | 0           | 1.47                | Rajasthan 1 |
| 6  | c.27_28insG    | 5                  | 2         | 3           | 7.35                | Rajasthan 2, Gujarat 1, Maharashtra 1, West Bengal 1 |
| 7  | c.51delC       | 2                  | 2         | 0           | 1.47                | Rajasthan 2 |
| 8  | c.124_127delTTCT| 2                  | 0         | 2           | 1.47                | Rajasthan 2 |

Notes: State/region wise mutations: Rajasthan: 40, Gujarat: 17, Maharashtra: 7 (Western India: 40 + 17 + 07 = 64), West Bengal: 6, Assam: 3 (Eastern India: 06 + 03 = 09). *Five with compound heterozygous (double mutations); M:F = 1:1.13 (32/36 = 88).

Abbreviations: F, female; M, male.
Mutation analysis of β-thalassemia in East-Western India

PCR, and Sanger Gene Sequencing. Data revealed 92+5 G>C (IVS-1–5) is the maximum in cases (60.29%), of Rajasthan and Gujarat followed by deletion 619 bp and is conformed with others documented earlier in Gujarat, Maharashtra, and Rajasthan.2,9,12,15,24–26 But Hassan et al,27 from Thailand, found cd26 (A-G) HbE and cd41/42 (TTCT) were higher in their studies. Thong et al28 presented cd41/42 (TTCT) and IVS-2 654 (C-T) were maximum in Chinese population. Similarly, second highest mutation was 619 bp in (9, 13.23%) this study similar to that of other studies in Western India conducted by Sheth et al,10 Grow et al,13 Colah et al,29 and Nigam et al.16 The third largest mutation in our study was c.79G>A (p.E27K) followed by c.47G>A (p.Trp16Ter) and c.364G>C (p.E122Q). The incidence of these mutations

**Figure 2** Seven common mutations identified by direct DNA sequencing. Notes: (A) c.92+5G>C, (B) c.79G>A (p.E27K), (C) c.47G>A (p.Trp16 Ter), (D) c.364G>C (p.E122Q), (E) c.27_28insG, (F) c.51delC, and (G) c.124_127delTTCT. Nucleotide colors: A = green, T = red, G = black, and C = blue. Abbreviations: S, G/C; R, G/A; K, G/T; M, C/A; Y, C/T.
does not seem to be related to sex, as our sex ratio was 1:1.13 (M:F). The variation in occurrence of these mutations is related to regional, ethnic, migration, interracial marriages, study plan, and other factors as mentioned by others.12,29,30

Conclusion

Our study showed that 68 cases were affected by β-thalassemia in our referral cases (75), from East-Western Indian region. β-Thalassemia carriers were 49 (65.33%) followed by HbE trait and β-thalassemia major with heterozygous and homozygous condition using hematological profiles. Detection of molecular analysis of mutations using PCR-ARMS, end point PCR, and gene sequencing methods revealed c.92+5G>C mutation exhibited higher incidence (26+10+2) followed by deletion 619 bp (3+4+2) in Rajasthan, Gujarat, and Maharashtra (Western India) as compared to West Bengal and Assam (3:0; 0:0) of Eastern India, respectively. This requires further elucidation. The variation in incidence of these mutations is dependent on ethnic diversity, migration, genetic factors, and other lifestyles. We, hence, recommend the mass screening, Prenatal Diagnostic Techniques, genetic counseling, transfusion programs and clinical management made available to these populations before adopting assisted reproductive and preimplantation technologies in India.

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Author contributions

Parth S Shah and Nidhi D Shah have contributed to writing results and discussion in the manuscript preparation when they visit India. Hari P Ray, Nikunj B Khatri, Ketan K Vaghasia, and Rutvik J Raval are involved in collection of blood from the patients after duly filled consent forms, blood analysis, DNA extraction, DNA sequencing, PCR-ARMS, end point PCR, and data analysis of 75 patients. Dr Sandip C Shah and Dr Mandava V Rao have contributed to preparation of reports after finalization of the results and preparation of the manuscript finally for submission to the journal. All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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