Nigerian Medical Journal
NIGERIA MEDICAL ASSOCIATION
Print ISSN 0300-1652, E-ISSN 2229-774X

Original Study

The Burden of Thalassemia and Various Hemoglobinopathiesin Bihar: Trends and Patterns

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Abstract

Background: In India, the carrier frequency of the β-thalassemia trait (βTT) is substantially higher than the global average, estimated at 3.3% compared with 1.5% worldwide. The prevalence of βTT across India shows marked geographic variation, ranging from 0.5% to 17%, largely influenced by population migration, endogamy, and inter-caste marriages. This genetic and demographic diversity makes India a complex conglomerate of multiple biological populations. The present study aimed to evaluate the spectrum of hemoglobinopathies and thalassemia in a region of Eastern India using cation-exchange high-performance liquid chromatography (CE-HPLC), while also analyzing associated demographic characteristics and hematological parameters.

Methodology: This was a two-year (June 2022–May 2024), single-center, retrospective observational study involving 2,329 subjects who were screened for thalassemia and other hemoglobinopathies using CE-HPLC at the Department of Hematology of a tertiary care center in Northern India.

Results: Of the 2,329 subjects screened, 2,067 (88.7%) were diagnosed as normal, 167 (7.1%) had βTT, and 35 (1.5%) were double heterozygous for HbE and βTT. The mean red blood cell (RBC) count among individuals with βTT was 4.58 ± 1.11 million/cumm, the highest among all hemoglobinopathies except for two cases of HbD-Punjab trait, which demonstrated a mean RBC count of 4.62 ± 0.36 million/cumm. HbF fractions were highest in cases of β-thalassemia major/intermedia, followed by individuals with double heterozygous HbE and βTT. Categorical variables were expressed as percentages, while numerical variables were summarized as mean ± standard deviation (SD). Statistical analysis was performed using SPSS version 25.

Conclusion: This study underscores the high prevalence of β-thalassemia trait and other hemoglobinopathies in Eastern India, emphasizing the need for widespread screening programs and the adoption of improved diagnostic modalities.

Keywords: β-thalassemia trait, hemoglobinopathies, high-performance liquid chromatography, screening, prevalence, Indian population.

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How to Cite: Shuchismita, Iffat J, Ravi BR, Debaditya H, Jawed A, Vijayanand C, et al. The Burden of Thalassemia and Various Hemoglobinopathies in Bihar: Trends and Patterns.Niger Med J 2025; 66 (5): 1755-1765. https://doi.org/10.71480/nmj.v66i5.906

Quick Response Code:

Introduction

Hereditary haemoglobin disorders, including structural haemoglobin variants and thalassemias, are genetic conditions affecting the haemoglobin molecule. Structural variants often result from single amino acid substitutions in the α or β globin chains, sometimes leading to clinically significant issues due to altered haemoglobin function or stability.[1]

According to the WHO 2008 report, over 40,000 babies are born with β-thalassemia annually, and around 25,500 require regular transfusions. In India, 30–40 million individuals are carriers, and 10,000–15,000 children are born with thalassemia each year, giving the country the highest global burden of thalassemia major. Survival outcomes for thalassemia carriers differ markedly between high- and low-income countries. While individuals in wealthier nations may live with chronic conditions, in low-income countries, many affected children die before the age of five.[2]

India's carrier frequency of β-thalassemia trait (βTT) is significantly higher than the global average (3.3% vs. 1.5%) and varies by region, influenced by factors like population migration and inter-caste marriages.[3] For example, in Central India, βTT prevalence ranges from 1.4% to 3.4%, with β-thalassemia major (β-TM) found in 0.94% of anaemic patients. In South India, βTT ranges from 8.5% to 37.9%, and β-TM from 2.3% to 7.47%. In East India, especially among tribal populations, βTT ranges from 0% to 30.5%, and β-TM from 0.36% to 13.2%.[4] Additionally, Hb E/β-thalassemia is more common in tribal groups, with rates from 0.04% to 15.45%, emphasizing the impact of ethnic and geographic diversity on disease prevalence. While thalassemia is widespread, sickle cell anaemia remains confined to specific regions within India.[5]

Globally, the 2021 incidence of thalassemia was 119,679 cases, with 1.31 million total cases and an age-standardized prevalence rate (ASPR) of 18.28 per 100,000 people.[6] Approximately 250 million individuals (4.5% of the population) carry a potentially harmful hemoglobinopathy gene, with about 300,000 infants born annually with a major haemoglobin disorder. Due to the lack of national registries in many countries, these figures may be underreported.[7]

Timely and accurate diagnosis of haemoglobin variants is crucial. Traditionally, multiple tests were needed, which were labour-intensive, costly, and variable in accuracy. Cation-exchange high-performance liquid chromatography (CE-HPLC) has become a preferred method due to its rapidity, consistency, and precision in detecting hemoglobinopathies.[8]

Despite multiple regional studies, comprehensive national data on thalassemia and haemoglobin variants remain limited. Given the wide genotype-phenotype variability, effective screening programs are essential for identifying carriers and enabling genetic counselling. Clinical evaluation, family history, and hematologic parameters like CBC, reticulocyte count, and red cell morphology are important diagnostic tools.[9]This study aims to assess the spectrum of hemoglobinopathies and thalassemia in a segment of Eastern India using CE-HPLC, along with an analysis of demographic and hematologic factors, to address the lack of region-specific data in this populous state.

Materials and Methods:

Thistwo-year(June2022-May2024)single-centric,retrospectiveobservationalstudyinvolved 2,329subjects screenedforthalassemiaandotherhemoglobinopathiesusingCE-HPLCatthe DepartmentofHematologyinatertiarycarecenterinEasternIndia.Informedconsentwas obtainedfromallparticipants,andethicalclearancewasgrantedbytheinstitute'sethical committee.Thestudyincludedpatientsexhibitingrelevant clinicalfeaturesandhematological findingssuggestiveofvarioushemoglobinopathiesandthalassemia.Pregnant women coming for antenatal check-ups were also part of the study. Thedetaileddemographic,clinical,andfamily

historieswereextractedfrom medicalrecords.Completebloodcount(CBC) resultsandperipheralbloodsmear(PBS)findingswere retrievedfromelectronicmedical records.CBCwasperformedusing2mlofvenousbloodcollectedin Ethylene-diaminetetraacetic acid(EDTA)vialsandanalyzedwithafullyautomated six-partdifferentialSIEMENS ADVIA2120ianalyzer.Comprehensivescreeningwasbasedonredcellindices,hemoglobinpatternanalysis,and HbA2 levels.Additionally,peripheralbloodsmearswerepreparedandstainedwithLeishman'sstain. TheBio-RadD-10CationExchangeHigh-PerformanceLiquidChromatography(HPLC) HemoglobinTestingSystem(Beta-thalassemiashortprogram)[Bio-Rad,California,USA]was utilizedtodetectvarioushemoglobinfractionselutingatdifferentretentiontimewhenamixture ofhemoglobinsinsolutions ispassedthroughacolumnpackedwithsilicagelparticlesathigh pressureandabufferwithchangingpH andionicstrengthisaddedtothecolumn. Daily, both normal and high internal quality controls for HbF, HbA and HbA2 were run and subsequently verified. Molecular confirmation was not done due to financial and technical constraints. Genetic counselling was also given to those who tested positive.HbF>2%, HbA2-4-9% with MCV<70 fl, raised RBC count relative to the age and gender, reduced hemoglobin of <10 gm/dl and RDW within normal range (11-14.5%) or mildly increased.

Results:

Duringthetwo-yearstudyperiod,2,329subjectswerescreenedforβ-thalassemia trait(βTT) andotherhemoglobinopathies.Ofthese,366(15.71%)weremales, and1,963(84.2%)were females,resultinginamale-to-femaleratioof0.18:1.Themeanageofthenormalpopulation was28.7±11.1years,whereas forβTTindividuals,itwas 25.41±11.6years.Mostabnormal caseswereidentifiedinindividualsduringtheirsecondandthirddecadesoflife.Thestudypopulation primarilyincluded 1017(43.6%)antenatalmothers,418(17.9%) premarital individuals,88(3.7%)children,and544(23.3%)post-maritalindividuals[Table1]. Premarital and postmarital individuals mean single and married individuals, respectively.

Table1:showingcomparativeevaluationofvarioussocio-demographicparametersin thalassemiaandotherhemoglobinopathies.

	HPLCDiagnosis (Frequencyofcases)													
Socio-demographicparameters	**N**	**βTT**	**HbE/βthal**	**HbEtrait**	**βthalmajor/intermed**	**HbS/βthal**	**HbStrait**	**HbEhomozygous**	**HbDPunjabrait**	**HbShomozygous**	**HbLepore**	**HbJtrait**	**HPFH**	**Deltabetathal**
Age(Years)														
Mean±SD	28.77 ±11.1	25.41 ±11.6	13.22 ±11.2	23.73 ±13.3	1.53 ±0.9	23.83 ±12.0	23.0 ±14.0	11.50 ±0.7	22.0 ±4.24	17.0 ±0.0	48 ±0.0	10 ±0.0	26 ±0.0	07 ±0.0
Sex														
Males	249	63	22	11	12	04	01	01	01	01	00	01	00	00
Females	1818	104	13	11	06	02	04	01	01	00	01	00	01	01
Religion														
Hindu	1715 (82.9)	136 (81.4)	29 (82.8)	18 (81.8)	14 (77.7)	5 (83.3)	4 (80)	2 (50)	2 (100)	1 (100)	1 (100)	1 (100)	1 (100)	1 (100)
Muslim	348 (16.8)	30 (17.9)	06 (17.1)	04 (18.1)	04 (22.2)	01 (16.6)	1 (20)	1 (50)	0	0	0	0	0	0
Christian	02 (0.09)	01 (0.59)	0	0	0	0	0	0	0	0	0	0	0	0
Sikh	01 (0.04)	0	0	0	0	0	0	0	0	0	0	0	0	0
Buddhist	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Others	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SubjectCategory														
Children	88	19	18	5	18	1	0	0	0	0	0	1	0	0
Antenatal mother	1017	59	2	7	0	1	1`	1	1	0	0	0	0	0
Premarital	418	35	10	3	0	3	1	1	1	1	0	0	1	1
Postmarital	544	54	5	7	0	1	0	0	0	0	1	0	0	0

Outofthetotalsubjects,2,067(88.7%)werediagnosedas normal,167(7.1%)as βTT,and35 (1.5%)as doubleheterozygous forHbEandβTT.Thedistributionofdifferenthemoglobin patternswithinthestudypopulationisdetailedin[Table2/ Figure 1].

Table2:showingdistributionofthalassemia and varioushemoglobinopathiesinourpopulation

Patternsofhaemoglobin	**Numberofcases**	**Percentage(%)**
Normal	2067	88.7
βthalassemia trait	167	7.1
HbE βthalassemia	35	1.5
HbEtrait	22	0.9
βthalassemia major/intermedia	18	0.7
HbSβthalassemia	06	0.2
HbStrait	05	0.2
HbEhomozygous	02	0.08
HbDPunjabtrait	02	0.08
HbShomozygous	01	0.04
HbLepore	01	0.04
HbJtrait	01	0.04
HPFH	01	0.04
Delta-betathalassemia	01	0.04

ForeachgroupthematologicalparametersandthepercentagesofvariousHbfractionsdetectedthroughHPLCarepresentedin [Table3].

Table3:showingcomparativeevaluationofvarioushematologicalparametersinthalassemiaandvarioushemoglobinopathies.

Diagnosis	Hb (g/dl)	MCV(fl)	MCH (pg)	MCHC(%)	RBC count	HCT	RDW-CV	HbA(%)	HbF(%)	HbA2%	Variant Hb(%)
Normal	9.69±2.4	84.11±10.30	26.39±4.57	31.22±2.73	3.70±0.80	30.71±6.63	17.43±4.62	86.42±2.47	0.51±0.83	2.71±0.36	-
βTT	9.27±2.00	67.72±10.45	20.55±3.30	30.41±2.37	4.58±1.11	30.57±6.34	18.53±3.32	82.92±4.32	2.57±5.53	5.18±1.06	-
HbE+βTT	6.00±1.51	63.92±9.14	18.02±3.00	28.24±2.43	3.33±0.83	21`.09±4.38	27.16±4.82	11.35±21.54	29.47±15.94	-	55.65±17.72
HbEtrait	10.57±2.93	72.37±10.19	22.97±3.53	31.73±1.61	4.56±0.95	33.40±9.11	16.97±3.19	69.18±5.41	0.65±1.13	-	28.35±2.64
βthalassemiamajor/intermedia	4.64±1.12	68.85±6.31	22.26±3.74	31.08±3.00	2.15±0.71	14.78±4.71	29.34±6.03	20.95±22.12	71.28±23.03	2.93±1.06	-
HbSβthalassemia	7.56±2.03	71.80±8.94	22.45±3.85	31.20±2.25	3.40±6.29	24.31±6.29	21.65±4.35	15.86±22.98	12.33±8.02	4.01±1.10	66.18±23.14
HbStrait	9.16±3.65	78.30±11.62	23.80±5.81	30.10±3.13	3.71±0.68	29.66±9.14	21.50±7.82	70.64±12.88	0.42±0.93	2.56±0.35	26.32±12.14
Hb E homozygous	7.75±0.21	58.45±1.06	17.95±0.21	30.90±0.00	4.26±0.00	23.09±0.98	22.65±3.46	0.60±0.84	3.85±0.35	-	95.60±0.00
Hb D Punjab trait	13.10±2.12	82.95±11.80	28.65±6.85	34.20±3.25	4.62±0.36	39.15±0.8	14.85±0.35	50.75±5.30	2.60±3.67	3.75±0.49	37.25±5.30
HbShomozygOus	6.8	69.3	18.4	27.8	3.23	21.1	28.2	5.2	9.3	2.1	79.0
Hb Lepore	7.7	69.5	19.6	28.2	3.93	27.3	20.5	73.3	4.6	4	8.4
HbJtrait	6.9	71.7	17.4	24.3	3.98	28.5	20.1	70.5	0.8	1.7	17.8
HPFH	11.1±0.0	92.3±0.0	28	30.3	3.97	36.6	16.2	87.7	2.6	2.7	-
Delta betathal	8.6	101.9	32.1	31.5	2.68	27.3	19.4	77.2	10.5	2.0	-

ThemeanRBCcountforβTT individualswas4.58±1.11million/cumm,thehighestamongallhemoglobinopathiesexceptfortwocases ofHbD Punjabtrait,whichhadanRBCcountof4.62±0.36million/cumm.HbFfractionswerehighestinβ-thalassemiamajor/intermediacases,followedbydoubleheterozygousHbEandβTTindividuals.MCVwaslowestinHbEhomozygous(58.45±1.06fl),followedbyHbE+βTT(63.92±9.14fl)andβ-thalassemiamajor/intermedia(68.85±6.31fl).Redcelldistribution width(RDW)washighestinβ-thalassemiamajor/intermediacases(29.34±6.03),closelyfollowedbydoubleheterozygousHbEandβTT(27.16 ±4.82). ThemeanHbA2levelinHbDPunjabtraitwassignificantlyhigher(3.75±0.49)compared tonormalsamples (2.71 ±0.36)(p< 0.05). HbA2levels insicklecelltraitweresimilartonormalsamples (2.56±0.35;p>0.05).A comparativeanalysis ofnormalsamplesandβTTindividuals,coveringvariousCBCparametersandHbFandHbA2 valuesgeneratedbyHPLC,isshownin[Table4].

Table4:showinga comparativestudyofhematologicalparametersinnormal individualsandβTTpatients.

Parameter	Normal	Beta-Thalassemiatrait	p-value
Haemoglobin(g/dl)	9.69±2.4	9.27±2.0	0.00
RBCcount(millions/cumm)	3.70±0.80	4.58±1.1	0.00
HCT(%)	30.71±6.6	30.57±6.3	0.33
MCV(fl)	84.11±10.3	57.7±10.4	0.06
MCH(pg)	25.39±4.5	20.55±3.3	0.00
MCHC(g/dl)	31.22±2.7	30.41±2.3	0.02
RDW-CV(%)	17.43±4.6	18.53±3.3	0.00
HbF (%)	0.51±0.8	2.57±5.5	0.00
HbA2(%)	2.71±0.36	5.18±1.0	0.00

Differentchromatogramsdepictingvarioushemoglobinopathiesareshownin[Figure1].

Fig1:CE-HPLCchromatogramshowing

Discussion:

Thalassemiaandhemoglobinopathiesareautosomalrecessivedisordersprimarily affectingthe globincomponentofhemoglobin.Whilethesedisorderswerehistoricallyconcentratedin specificregions,religions,castes,andtribes-particularlywhereconsanguineousmarriageswere common,theyhavenow becomewidespreadgloballyduetopopulationmigrationandresulting sociocultural,linguistic,andethnicdiversity. [7,10,11]

ThisstudyfocusedmainlyonpatientsfromBiharandthe surroundingareas.TheprevalenceofβTT inthis retrospective observational studywas7.1%,whichis higherthanthe4.60%reportedbyMondaletal. intheirten-yearstudyoftheEasternIndian population.[12]Colahetal.notedthat approximately 1.5%oftheglobalpopulationareβ-thalassemiacarriers.[7]Madanetal.reportedanoverallβ-thalassemiatraitgenefrequencyof4.05%innorthernandwesternIndia.[13] Prevalencerates ofβ-thalassemiatraithavebeenas highas 10.38%inruralWestBengaland9.59%incentral India.[13]

The prevalence of β-thalassemia major is 0.94% in Central India, whereas in South India, the prevalence of β-thalassemia major was reported to be between 2.30 and 7.47%.[11.12.14]In our study, the prevalence of β-thalassemia major was 0.7% which is comparable to that found in Central India. Inthis study,HbEtraitprevalencewas0.9%,lowerthanthat seeninruralWestBengalreportsof3.86%.[14]HbE is prevalent in the north-eastern region, where the frequencies of HbE carriers range from 3 to over 50% while HbS is predominantly seen among scheduled castes and scheduled tribes, with frequencies varying from 5 to 35% in many groups, and in our study, its prevalence was 0.2% only. Co-inheritance of these

hemoglobin variants with β-thalassemia is not uncommon, particularly in regions where both are prevalent.[14,15]

TheIndianCouncilofMedicalResearch(ICMR) reportedanincidenceofHbEβ-thalassemia(1.44%)inthegeneralpopulation.[14]An important finding in the study of Mondal et al. was a high incidence of HbE β-thalassemia (1.16%).[16] These patients present with a variable clinical picture ranging from a condition indistinguishable from β-thalassemia major requiring blood transfusions to a mild form of thalassemia having mild asymptomatic anemia. In our study, the prevalence of double heterozygous HbE β-thalassemia was 1.5 % similar to the previous studies.[13-15]

Deltaβ-thalassemiaandHPFHarerareinIndia,withtheICMRmulticenterstudy reporting incidencesof0.73%and 0.18%,respectively,comparedto 0.04%eachinthis study. [14]The HbDtrait wasdetectedin0.08%ofpatientsinourstudy.InIndia,thegenefrequencyofHbD is relatively low,clusteringmainlyinthenorthwesternregions.[14,15,16]HbDPunjab occurs with the greatest prevalence (2 %) in Sikhs of Punjab and in Gujarat (1 %). It is also found sporadically in blacks and Europeans, the latter usually seen in countries that have a close association with India in the past.[5,6]

We foundonlyasinglecase of HbJ-trait in our study.J chain hemoglobinopathy is a rare finding in previous studies. Mondal et al. in their study of 119336 cases, found a total of 36 cases with HbJ-Meerut.[16] These alpha chain hemoglobinopathies are clinically silent and are detected incidentally.

In2021,thehighestglobalprevalenceofthalassemiawasobservedinchildrenunderfiveyears old,withprevalenceratesdeclinigwithage.Maleshadhigherprevalenceratesthanfemalesup toage35,afterwhichthetrendisreversed,showingnosignificantgenderdifferencesbeyond age69.[6]Thiscontrastswiththepresentstudy,wherefemaleswerepredominantlyaffectedby thalassemiaandotherhemoglobinopathies.While thalassemiainheritanceisnotgender-dependentbutsocietal,cultural,biological,andhealthcareaccessibilityfactorscanindirectly influenceepidemiologyandhealth outcomes,potentiallyleadingtogenderdisparitiesin diagnosisandtreatment.

Since1990,therehasbeenadecreaseinthalassemiaprevalenceratesglobally,reflecting improvementsindiseasemanagement.Reproductive optionssuchasinvitrofertilizationwith preimplantationgeneticdiagnosishavereducedthenumberofthalassemia-affectedbirths in regionsliketheMediterranean,theMiddleEast,the Indiansubcontinent,andSoutheastAsia. Additionally,advancementsinnon-invasiveprenataldiagnostictechniquesareminimizingthe

needforinvasivesamplingmethods,providingsaferearlydetectionoptions.Despitethese advancements,challengespersistinoptimizingprenatalinterventionsandincreasing the coverageandacceptanceofscreeningandpreventionprogramsinsomecountries. These findingshighlightthenecessityforongoingevaluationandenhancementofthalassemia preventionandcontrolstrategiestoalignwithcurrentpopulationdynamicsand healthcarepractices.[6,17]

Ameta-analysisbySinhaetal.(2009)highlightedtheprevalenceofhemoglobinopathiesinthe Indiansubcontinent,emphasizingthe intricatepopulationstructuresandthelimitationsof existingstudies.India,withitspopulationexceeding1.25billion across29states,exhibits immensediversity ingeographical,environmental,linguistic,religious,caste,and triballines, compoundedbyendogamouspractices,makingitacomplexamalgamationofvariousbiologicalpopulations.[18]

Multicentricstudieshavereportedβ-thalassemiacarrierprevalenceratesbetween2.8%and 4.04%(Madanetal.,2010;Mohantyetal.,2013).[13,19]Colahetal.(2010) documented thalassemiacarrierfrequenciesbydistrictinGujarat andMaharashtra,rangingfrom0.7%to 9.5%.[7]Variationsinprevalence estimatesacrossstudiesmaystemfrominherentpopulation characteristicsormethodologicaldifferences,suchastheuseofvaryingscreeninganddiagnostic testsanddifferentdiagnosticcut-offs forHbA2levels(rangingfrom3.0%to4.5%).States like

Bihar,Chhattisgarh,Jharkhand,andeasternUttarPradeshgenerallyexhibitpoorhealthindices, withover60%ofthepopulationsufferingfromanemiaandhighrates ofpretermdeliveries,low birthweights,and child mortality.[18,19]

Eradicatingthalassemia,aninheriteddisorderwithvariablegenotype-phenotype correlations, necessitatesrobustscreeningprogramscapableof accuratelydetecting carrierstatesand facilitatinggeneticcounsellingforcouplesplanningfamilies.The cruxofgeneticcounsellingistomake theaffectedfamilyawareofthisgeneticdisorder,itsclinicalsymptomsand severity,alongwiththeriskofrecurrence,morbidityandmortalityassociatedwiththedisease.Micromappingofth epopulationforhemoglobinopathies,thalassemiacarrierdetection,androutineprenatalandcommunitycarriersc reeningusingNESTROFT(nakedeyesingletuberedcellosmoticfragilitytest)andredcellindicesareessentialinp reventing theseinheriteddisorders.Futurescreening methodsmayinvolvedevelopingadvanced computeralgorithms utilizingmachinelearningandartificialintelligencetoanalyzeRBCparameters,distinguishing thalassemiacarriers fromnormalindividuals withhighaccuracy.[20,21,22]TheWestBengalThalassemiaControlProgrammehasdevelopedasoftwarecalledTh alamantomaintain recordsandassimilate largescreeningandpatientdatafromdifferent locationsintothe statedatabaseforreportingandanalysis. Thereisalsoa country-specific web-basedinformaticsresourcecalledThallandtoincorporatedataonmoleculargenetics,populationgenetics,genoty pe-phenotypecorrelationsandthediseaseburdeninIndia.[14]Such softwarecouldbeintegratedintohematologyauto-analyzers,mobileapplications,andweb-basedplatforms,offeringacost-effectivealternativetoHPLC.Consequently,HPLCcouldbereservedforconfirming carrierstatusinflagged individuals.

Strengths of the Study:

Thisstudyaddressesasignificantknowledgegapinexistingineasternregions ofIndia,where around25%ofthe Indianpopulationresides,andtheseareas havenotbeeninvestigatedadequately. Tothebestofmyknowledge,suchastudyofscreeningofthis largepopulationwas missinginthis region,soitwilladdvaluableinsights totheexistingknowledgeon hemoglobinopathiesandthalassemiainthisregion.

LimitationsoftheStudy:

Beingahospital-basedstudy,itonlyrepresentsaspecificsegmentofthepopulation,whichmay notaccuratelyreflectthetrueprevalenceofhemoglobinopathiesandthalassemiaacross the entirecountry.Additionally,thestudypopulation waspredominantlycomposedofantenatal mothers,potentiallyskewingtheprevalencedata.HPLC'slimitationsincludeitsinabilityto detectα-thalassemiaanddifferentiateHbvariantswithoverlappingretentiontimes. Furthermore, HbA2levelscanbeinfluencedbynutritionalanemias,leadingtofalse-negativeorfalse-positive diagnosesofβTT.Specifically,irondeficiencyanemiacanmaskβTTbyloweringHbA2 levels, whilecobalaminorfolatedeficienciescanfalselyelevateHbA2levels,complicatingaccurate diagnosis.Therefore,whennecessary,HPLCresultsshouldbeconfirmedwithmolecular studies suchaspolymerasechainreaction(PCR)oramplificationrefractorymutationsystem(ARMS)to identifyspecificmutations responsiblefortheHbdisorder.Butduetothe limitedavailabilityand affordabilityofgenetictestingatourcenter,furtherconfirmationcouldnotbedone.

Conclusion:

Thisstudyunderscoresthehighprevalenceofβ-thalassemiatraitandother hemoglobinopathies inNorthernIndia,highlightingthenecessityforwidespreadscreeningprogramsand improved diagnosticmethods.Addressingthe limitationsofcurrentscreeningtechniquesandexpanding moleculardiagnostic capabilitiesare essentialstepstowardeffectivethalassemiacontrol and

prevention.Continuedresearchandtargetedpublichealthinterventionsarevitaltoreducethe burdenofhemoglobinopathiesandimprovehealthoutcomesforaffected populations.

Recommendations:

Bytheendofthisstudy,wecouldfindoutthataconcentratedefforttowards educationand awarenessgenerationisrequiredtodealwiththiscomplexandheterogenoushealthmenace coveringbothruralandurbanregions ofourstate.A nationalthalassemiacontrolprogramme shouldbeinitiatedsoonforscreeningwithappropriatequalitycontrolandat leastonecenterin thegovernmentsetupineverystatewouldberequiredforofferingprenataldiagnosis.

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