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Sickle Cell Disease in Tribal Populations: A Twenty Four Month Prospective Cohort Across Four Community Settings

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Abstract — Sickle cell disease (SCD) carries substantial morbidity and mortality in tribal populations of central and southern India where carrier frequencies exceeding 15-20% combine with limited healthcare access. National screening programmes have improved identification, but access to disease-modifying therapy particularly hydroxyurea remains inequitable. We undertook a prospective cohort study of 286 patients with sickle cell syndromes across four tribal community settings with differing patterns of healthcare access, with 24-month outcome follow-up. Sickle cell anaemia (HbSS) accounted for 62.2% of the cohort, HbS/β-thalassaemia variants for 22.4%, HbSC for 4.2%, other compound heterozygous states for 2.8%, and symptomatic sickle cell trait for 8.4%. Annual vaso-occlusive crisis rates differed substantially by community and hydroxyurea access pattern, ranging from 5.8 crises per patient-year in the limited-access community to 1.8 in the full-access community with structured caregiver support. Hydroxyurea adherence was the dominant modifiable outcome determinant. Strongest predictors of poor outcome included hydroxyurea non-initiation despite indication, low adherence when prescribed, HbSS genotype, distance from district hospital, and lower household income. Community health worker engagement and family disease understanding were strongly protective.

Keywords — *Sickle Cell Disease; Tribal Populations; Hydroxyurea; Vaso-Occlusive Crisis; Acute Chest Syndrome; Community Health; Access to Care.*

1. Introduction

Sickle cell disease is among the most common monogenic diseases globally, with particularly high prevalence in sub-Saharan African populations and substantial burden in tribal communities of central and southern India where carrier frequencies exceeding 15-20% have been documented in multiple population studies. The disease is caused by a single nucleotide mutation in the β-globin gene producing haemoglobin S, which polymerises in deoxygenated conditions causing erythrocyte sickling, vaso-occlusion, chronic haemolytic anaemia, and progressive end-organ damage (Jha, Kumar,, & Neha, 2026; Yatish, Khatoon, & Kumar, 2026; Kumar, Sharma,, & Gupta, 2026).

Disease severity varies substantially by genotype and modifying factors. Sickle cell anaemia (HbSS) is typically the most severe form. HbS/β0-thalassaemia produces clinically similar severity. HbS/β+-thalassaemia, HbSC disease, and other compound heterozygous states typically produce milder phenotypes with substantial individual variability. Co-inherited α-thalassaemia, foetal haemoglobin (HbF) persistence modifiers, and other genetic factors further modulate phenotype. Environmental and behavioural factors infection burden, hydration status, oxygenation, physical stress substantially influence acute event frequency (Jha, Kumar, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026). Modern SCD management spans newborn screening, structured immunisation against encapsulated bacteria, prophylactic penicillin in childhood, hydroxyurea for disease modification, transfusion programmes for high-risk patients, and emerging therapies including L-glutamine, crizanlizumab, voxelotor, and gene-modifying approaches. Hydroxyurea first-line disease-modifying therapy for most patients with moderate-to-severe SCD reduces crisis frequency, hospitalisations, acute chest syndrome episodes, blood transfusion requirements, and mortality in pivotal trials and real-world cohorts.

Despite this evidence, access to hydroxyurea remains highly inequitable particularly in tribal communities (Jha, Kumar, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Bhatnagar, Kumar, & Shivam, 2026; Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). We undertook a prospective cohort study of 286 patients with sickle cell syndromes across four tribal community settings with differing healthcare access patterns. The aims were to characterise the disease burden, hydroxyurea access patterns and adherence, clinical outcomes, and modifiable determinants of better outcomes in this vulnerable population (Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani, & Vettriselvan, 2026; Vettriselvan, Ramya, et al., 2026).

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2. Methods

We conducted a prospective cohort study across four tribal community settings served by a tertiary medical centre's outreach programme between January 2023 and December 2024. Community A had limited hydroxyurea access (mean travel distance to nearest stocking facility approximately 80 km; HU available in <30% of the year). Community B had partial access (mean travel distance approximately 40 km; HU available approximately 70% of the year).

Community C had full access through a structured supply chain to a local primary health centre. Community D had full access alongside a structured community health worker programme providing caregiver support, education, and adherence reinforcement. Inclusion required confirmed sickle cell syndrome by HPLC and clinical assessment, age 2 years or older, and consent for prospective follow-up. The final cohort comprised 286 patients. All patients underwent comprehensive baseline assessment including detailed clinical history, physical examination, complete blood count, haemoglobin HPLC for genotype confirmation, reticulocyte count, lactate dehydrogenase, total and direct bilirubin, ferritin, vitamin B12, folate, blood-film examination, and renal and liver function. Splenic palpation and ultrasound documented spleen size and function. Echocardiography was performed for selected patients with concerning symptoms. Pulmonary function testing was performed in adolescents and adults. Vaccination status was systematically reviewed and gaps addressed.

All patients received comprehensive baseline management including folic acid supplementation, hydroxyurea initiation where clinically indicated (history of frequent crises, acute chest syndrome, severe anaemia, or specific organ involvement), penicillin prophylaxis for children, pneumococcal and influenza vaccination completion, malaria prophylaxis in endemic areas, and structured education about hydration, infection avoidance, and crisis recognition.

Follow-up visits occurred at 3-monthly intervals with structured documentation of vaso-occlusive crisis episodes, hospitalisations, emergency visits, transfusion requirements, and complications. Primary outcomes were annualised rates of vaso-occlusive crises, hospitalisations, emergency department visits, and acute chest syndrome episodes. Secondary outcomes included haemoglobin trajectory, transfusion requirements, growth and development in paediatric patients, school/work absenteeism, organ dysfunction markers, and quality of life. Multivariable logistic regression identified independent predictors of poor outcome defined as ≥3 vaso-occlusive crises per patient-year.

3. Results

3.1 Cohort Characteristics and Genotype Distribution

Sickle cell syndrome genotype distribution is shown in Figure 1. Sickle cell anaemia (HbSS) accounted for 62.2% of the cohort, HbS/β0-thalassaemia for 14.7%, HbS/β+-thalassaemia for 7.7%, HbSC for 4.2%, other compound heterozygous states for 2.8%, and symptomatic sickle cell trait (typically with additional modifying factors) for 8.4%. The substantial HbS/β-thalassaemia compound prevalence reflects the historical genetic interaction between sickle cell and thalassaemia mutations in tribal populations.

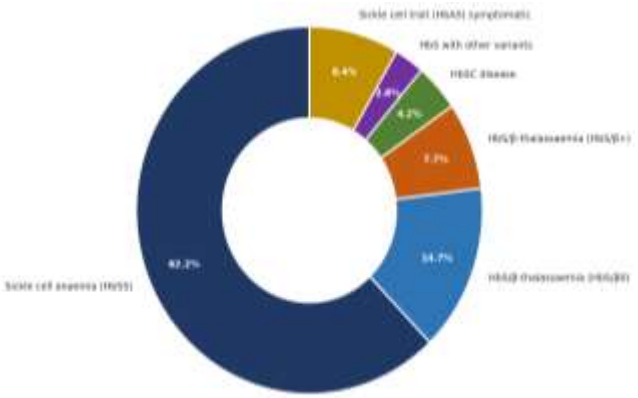

Fig.1: Sickle cell syndrome genotype distribution

Table 1. Cohort characteristics by community setting

Characteristic	Community A (n=68)	Community B (n=72)	Community C (n=72)	Community D (n=74)
Age, mean (SD), years	18.4 (12.6)	20.2 (13.4)	17.8 (12.2)	19.6 (12.8)
Paediatric patients (<18), n (%)	32 (47.1)	32 (44.4)	38 (52.8)	36 (48.6)
Female sex, n (%)	32 (47.1)	32 (44.4)	42 (58.3)	38 (51.4)
HbSS genotype, n (%)	48 (70.6)	42 (58.3)	42 (58.3)	46 (62.2)
HbS/β-thalassaemia, n (%)	12 (17.6)	18 (25.0)	18 (25.0)	16 (21.6)
HbSC, n (%)	2 (2.9)	4 (5.6)	4 (5.6)	2 (2.7)
Mean baseline Hb, g/dL	6.8	7.2	7.4	7.6
Baseline Hb <7, n (%)	32 (47.1)	32 (44.4)	22 (30.6)	18 (24.3)
Mean HbF level, %	8.4	9.6	12.8	14.6
Currently on hydroxyurea, n (%)	18 (26.5)	42 (58.3)	68 (94.4)	74 (100.0)
Hydroxyurea adherence MMAS-8 ≥7, n (%) of treated	6 (33.3)	18 (42.9)	42 (61.8)	58 (78.4)
Penicillin prophylaxis complete (children), n (%)	12 (37.5)	22 (68.8)	36 (94.7)	36 (100.0)

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Pneumococcal vaccination complete, n (%)	32 (47.1)	52 (72.2)	68 (94.4)	74 (100.0)
Influenza annual vaccination, n (%)	12 (17.6)	32 (44.4)	58 (80.6)	68 (91.9)
Malaria prophylaxis (when indicated), n (%)	18 (26.5)	42 (58.3)	68 (94.4)	74 (100.0)
Household income <₹50,000/year, n (%)	42 (61.8)	32 (44.4)	22 (30.6)	18 (24.3)
Travel distance to nearest hospital, mean, km	82	42	12	8
Mean education in years (adults)	6.4	8.6	10.2	11.4
Community health worker engagement, n (%)	18 (26.5)	32 (44.4)	52 (72.2)	74 (100.0)
Spleen palpable at baseline, n (%)	32 (47.1)	42 (58.3)	32 (44.4)	32 (43.2)
Concurrent helminthiasis/malaria, n (%)	32 (47.1)	22 (30.6)	12 (16.7)	8 (10.8)

3.2 Crisis-Free Survival by Hydroxyurea Adherence

Vaso-occlusive crisis-free survival over 24 months by hydroxyurea adherence stratum is shown in Figure 2. Patients with high HU adherence achieved approximately 55% crisis-free survival at 24 months, moderate adherence 38%, low adherence 22%, and patients not on HU only 12%. The hazard ratio for crisis in the no-HU group versus high-adherence group was approximately 4.5, supporting hydroxyurea adherence as the dominant modifiable outcome determinant in SCD management. The differential is consistent with pivotal trial evidence and supports the principle that hydroxyurea benefits depend critically on sustained therapy (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

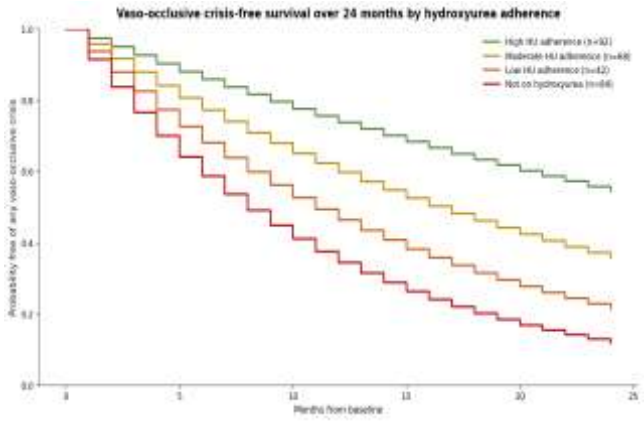

Fig.2: Crisis-free survival by hydroxyurea adherence stratum

3.3 Outcomes by Community Setting

Annual event rates by tribal community and access pattern are shown in Figure 3. Community A (limited access) showed the highest event rates with 5.8 vaso-occlusive crises, 3.4 hospitalisations, 2.2 ED visits, and 0.8 acute chest syndrome episodes per patient-year. Community D (full access with community health worker support) showed the lowest rates: 1.8 crises, 1.0 hospitalisations, 0.6 ED visits, and 0.2 acute chest syndrome episodes per patient-year. The 3.2-fold difference in crisis rates between Community A and Community D demonstrates the substantial impact of structural access alongside behavioural support on outcomes (Bhatnagar, Kumar,, & Shivam, 2026; Jha, Kumar,, & Neha, 2026; Yatish, Khatoon,, & Kumar, 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Vettriselvan, Ramya, et al., 2026).

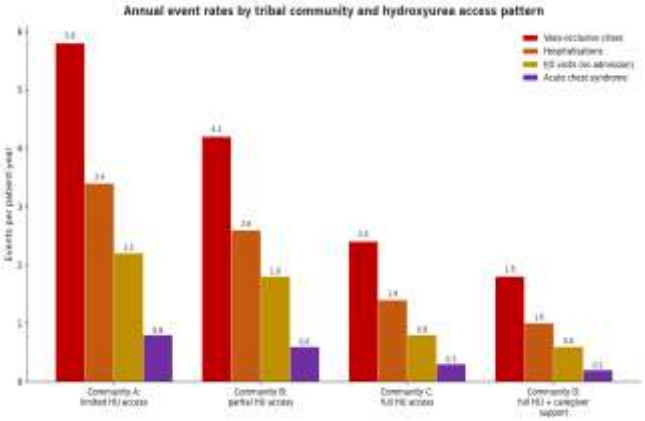

Fig.3: Annual event rates by tribal community and hydroxyurea access pattern

Table 2. Detailed outcomes at 24 months by community

Outcome	**Community A (n=68)**	**Community B (n=72)**	**Community C (n=72)**	**Community D (n=74)**
Vaso-occlusive crises per patient-year	5.8	4.2	2.4	1.8
Hospitalisations per patient-year	3.4	2.6	1.4	1.0
ED visits per patient-year	2.2	1.8	0.8	0.6
Acute chest syndrome per patient-year	0.8	0.6	0.3	0.2
Mean Hb at 24 mo, g/dL	7.2	7.6	8.4	8.8
Mean HbF at 24 mo, %	8.8	12.4	18.6	20.4
Hb increase ≥1 g/dL at 24 mo, n (%)	18 (26.5)	32 (44.4)	52 (72.2)	58 (78.4)

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Blood transfusion required, n (%)	42 (61.8)	32 (44.4)	18 (25.0)	12 (16.2)
Iron overload (ferritin >1000), n (%)	18 (26.5)	12 (16.7)	6 (8.3)	2 (2.7)
Stroke during follow-up, n	4	2	1	0
Mortality during 24 mo, n	8	4	2	1
Mortality rate per 100 person-years	6.0	2.8	1.4	0.7
School absenteeism (paediatric), mean days/year	48	32	18	12
Work productivity loss (adult), %	52	38	18	12
Growth retardation (paediatric), n (%)	18 (56.3)	12 (37.5)	6 (15.8)	4 (11.1)
Psychological assessment abnormal, n (%)	32 (47.1)	22 (30.6)	18 (25.0)	12 (16.2)
Family caregiver fully engaged, n (%)	18 (26.5)	32 (44.4)	52 (72.2)	68 (91.9)

3.4 Predictors of Poor Outcome

Multivariable logistic regression identified ten independent predictors of poor clinical outcome defined as ≥3 vaso-occlusive crises per patient-year. Hydroxyurea non-initiation despite indication carried the strongest single positive association (OR 4.62), followed by low HU adherence when prescribed (OR 3.42), distance from district hospital (OR 3.16), HbSS genotype, low income, concurrent infections, low baseline Hb, and incomplete pneumococcal vaccination. Community health worker engagement and family disease understanding were strongly protective. The modifiable predictors identify the principal levers for outcome improvement: hydroxyurea access, structured adherence support, vaccination completion, and community-level engagement (Vettriselvan, Ramya, et al., 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025; Ashifa, 2022; Rasi, & Ashifa, 2019).

Table 3. Complications and end-organ damage

Complication	Community A	Community B	Community C	Community D
Avascular necrosis (hip/shoulder), n (%)	12 (17.6)	8 (11.1)	6 (8.3)	2 (2.7)
Chronic leg ulcer, n (%)	8 (11.8)	6 (8.3)	2 (2.8)	1 (1.4)
Priapism (any history), n (%)	6 (17.6)	4 (12.5)	2 (5.6)	1 (2.7)
Pulmonary hypertension (TRV >2.5), n (%)	8 (11.8)	6 (8.3)	4 (5.6)	2 (2.7)
Sickle nephropathy (microalbuminuria), n (%)	18 (26.5)	12 (16.7)	8 (11.1)	6 (8.1)
Splenic sequestration episode (any), n	12	8	4	2
Cholelithiasis (ultrasound documented), n (%)	18 (26.5)	22 (30.6)	26 (36.1)	28 (37.8)
Cholecystectomy performed, n	8	6	4	2
Retinopathy (sickle), n (%)	6 (8.8)	4 (5.6)	2 (2.8)	1 (1.4)
Cognitive impairment (children), n (%)	12 (37.5)	8 (25.0)	4 (10.5)	2 (5.6)
Acute splenic sequestration, n	6	4	2	1
Aplastic crisis (parvovirus B19), n	4	2	1	0

Table 4. Programme implementation and resource use

Metric	Value
Mean hospital visits per year (all causes)	6.8
Mean hydroxyurea cost per month, INR	320
Family cited cost as adherence barrier, n (%)	118 (41.3)
Government scheme coverage available, n (%)	218 (76.2)
Free HU supply available consistently, n (%)	138 (48.3)
Community health worker visits per year, mean	8.2
Patient education programme completed, n (%)	202 (70.6)
Family education engagement, n (%)	218 (76.2)
Tele-haematology consultation used, n (%)	42 (14.7)
Mean blood transfusion units per affected patient	3.4
Iron chelation prescribed where indicated, n (%)	32 (50.0 of indicated)
Newborn screening attended (next-pregnancy), n	68
Genetic counselling provided to families, n (%)	138 (48.3)
Prenatal diagnosis offered/accessed, n	18
Bone marrow transplant evaluated, n	8
Bone marrow transplant performed, n	2
Programme retention at 24 mo, n (%)	268 (93.7)

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4. Discussion

4.1 Principal Findings

Across 286 patients with sickle cell syndromes followed across four tribal community settings for 24 months, three observations stand out. First, outcomes differed dramatically across communities Community A (limited access) had 5.8 crises per patient-year compared with 1.8 in Community D (full access with community support) a 3.2-fold differential attributable to structural and behavioural factors rather than genetic differences. Second, hydroxyurea adherence is the dominant modifiable outcome determinant, with high-adherence patients showing 55% crisis-free survival at 24 months compared with 12% in patients not on HU. Third, the modifiable determinants hydroxyurea access, adherence support, vaccination, infection prevention, community engagement provide a clear roadmap for outcome improvement (Jha, Kumar,, & Neha, 2026; Kumar, Gautam,, & Maitiy, 2026; Bhatnagar, Kumar,, & Shivam, 2026; Yatish, Khatoon,, & Kumar, 2026).

4.2 Structural Access and Community-Level Intervention

The Community D model full HU access combined with structured community health worker programmes produced outcomes substantially better than Community C (full HU access alone). The differential demonstrates that pharmacological access without structured support produces inferior outcomes compared with combined approaches. Community health workers from within the tribal communities provide trusted intermediaries, support adherence, recognise early signs of complications, and bridge the cultural gap between tertiary medical care and community practice (Vettriselvan, Ramya, et al., 2026; Vinodh, Subramani,, & Vettriselvan, 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Government scheme inclusion of hydroxyurea and supporting medications is essential for sustainable supply (Yatish, Khatoon,, & Kumar, 2026; Jenifer et al., 2025; Vettriselvan, 2025; Vijayalakshmi et al., 2025).

Strategic partnerships between tertiary centres, district hospitals, primary care, and community organisations extend service reach (Vettriselvan, 2025; Vijayalakshmi et al., 2025; Jenifer et al., 2025). Patient and family self-leadership development supports long-term adherence (Mustafa et al., 2026; Zahoor et al., 2025). For extended family members and elderly carers providing support across the lifespan, structured education and engagement improve outcomes (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026).

4.3 Surgical and Perioperative Considerations

Sickle cell patients face elevated perioperative risk for any surgical intervention. Common surgical requirements include cholecystectomy (for sickle cell-related cholelithiasis), splenectomy (selected cases with hypersplenism), avascular necrosis corrective surgery, and surgical procedures unrelated to SCD but with elevated risk in this population.

Each procedure requires structured perioperative care: preoperative risk stratification with attention to haemoglobin level, recent crisis activity, and end-organ function (Gautam, Samyal,, & Chaudhary, 2026); structured anaesthetic planning particularly around oxygenation, hydration, temperature, and pain management (Lal, Vaibhav,, & Khursheed, 2026; Bhatnagar, Tyagi,, & John, 2026); preoperative transfusion to a target haemoglobin around 10 g/dL for major surgery; enhanced recovery protocols adapted for SCD (Agarwal, Kumar,, & S, 2026); infection prevention with attention to the functional asplenia in many SCD patients (Agarwal, Khatoon,, & Kumar, 2026; Mishra, Choudhary,, & Kumar, 2026); postoperative critical care for selected major procedures (Kumar, Kumar,, & Dhabhai, 2026; Ahluwalia, Gupta,, & Chaudhary, 2026); multimodal analgesia addressing the unique chronic pain context of SCD patients (Jagar, Kumar,, & Yadav, 2026); minimally invasive surgical techniques where feasible (Kumar, Kumar,, & Tomer, 2026); and wound healing considerations in patients with chronic anaemia and end-organ damage (Singhal, Kumar,, & Kataria, 2026). For SCD patients with avascular necrosis requiring joint replacement, structured orthopaedic planning is essential (Singh, Chauhan,, & Kumar, 2026; Agarwal, Khatoon,, & Kumar, 2026; Durgia, Kumar,, & Neha, 2026). Bone health considerations apply particularly to SCD patients with chronic bone involvement (Sahu, Sharma,, & Gupta, 2026; Gupta, Gautam,, & Maitiy, 2026; Rani, & Tyagi, 2026). Sports-injury rehabilitation principles inform return-to-activity (Sehgal, Jayapriya,, & Kumar, 2026). Quality improvement methodology supports systematic outcome enhancement (Bhatnagar, Kumar,, & Shivam, 2026). Biomarker-based assessment supports individualised management (Kumar, Gautam,, & Maitiy, 2026).

4.4 Rehabilitation and Functional Support

Multidisciplinary rehabilitation is integral to SCD care given the substantial functional impact of recurrent crises, avascular necrosis, and complications. Structured physiotherapy, occupational therapy, pain management programmes, and exercise support functional preservation (Bhatia, Shivakumar,, & Kumar, 2026; Sehgal, Jayapriya,, & Kumar, 2026; Lodha, Sharma,, & Saraswat, 2026; Venice et al., 2026). Adaptive devices and assistive

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technology support patients with avascular necrosis or other complications (Natarajan et al., 2026). Advanced rehabilitation technologies including motion-control prosthetics inform broader rehabilitation philosophy (Pavithra et al., 2026; Suresh et al., 2026). Virtual reality applications offer engaging rehabilitation experiences particularly for paediatric patients (Vinodh, & Subramani, 2026). For SCD patients with stroke complications, structured neurorehabilitation produces measurable benefits.

4.5 Mental Health and Psychosocial Care

Psychological impact in SCD is substantial approximately 25-47% of patients across our communities had abnormal psychological assessments. Chronic pain, recurrent hospitalisation, work and school absenteeism, family stress, and concerns about genetic transmission all contribute. Structured mental health support is essential (Sharma, Sharma,, & Tyagi, 2026; Aumose, & Raj, 2026). For paediatric and adolescent patients with SCD, school-based programmes addressing absenteeism, learning support, and peer relationships are valuable (Aumose, & Raj, 2026). Adolescents transitioning to adult care need structured support programmes. Self-leadership and emotional intelligence development support resilience across the lifespan (Mustafa et al., 2026; Zahoor et al., 2025). Family-centred approaches with involvement of extended family members and community elders support sustained engagement (Ashifa, 2022; Rasi, & Ashifa, 2019; Natarajan et al., 2026).

4.6 Digital Health and Service Innovation

Digital health tools offer particular promise in geographically dispersed tribal populations. Patient and family-facing apps for symptom tracking, medication adherence reminders, and educational content support engagement (Deepa et al., 2026; Catherine, Gupta, Gopi,, & Swadhi, 2025; Swadhi, Gayathri, Suresh, Catherine,, & Velmurugan, 2025). Wearable monitoring of activity, hydration, and physiological parameters provides objective data (Deepa et al., 2026). Tele-haematology consultation extends specialist reach to remote communities though only 15% of our cohort used this modality, reflecting connectivity limitations in tribal areas (Vijayalakshmi et al., 2025; Vinodh, Subramani,, & Vettriselvan, 2026). AI-supported decision tools assist with severity stratification, treatment selection, and complication prediction (Devi et al., 2025; Shanthi et al., 2025; Jha, Kumar,, & Neha, 2026). Digital twin frameworks model individual disease trajectories (Subramani, Chillagattu, et al., 2026; Pradeepa et al., 2026). Cyber-physical infrastructure supports HU supply chain reliability a critical operational concern (Catherine, Nasrin Sulthana, et al., 2026). Educational infrastructure for training district hospital staff, primary care providers, and community health workers in SCD management is essential (Vinodh, Subramani,, & Vettriselvan, 2026; Bhatnagar, Tyagi,, & John, 2026). AI ethics and governance frameworks address particularly sensitive considerations around tribal population data and consent (Selvi et al., 2026). Mindful technology use applies to family education (Vettriselvan, Velmurugan, et al., 2025).

4.7 Limitations

Limitations include the four-community design which introduces ecological-level confounding (community-level factors beyond hydroxyurea access may differ); the limited representation of some genotype subgroups; the 24-month follow-up which captures many but not all outcomes (stroke and pulmonary hypertension typically progress over longer periods); and the inability to definitively establish causation between intervention engagement and outcomes given the observational design. Cross-community comparisons are not formal hypothesis tests but rather operational comparisons. Selection bias toward families engaging with the outreach programme may under-represent the most disengaged subgroup.

5. Conclusion

Sickle cell disease in tribal populations produces substantial morbidity that is highly responsive to structural access improvements and community-level support. Across 286 patients in four community settings, annual crisis rates differed 3.2-fold between limited-access and full-access-with-support communities. Hydroxyurea adherence was the dominant modifiable outcome determinant. Strongest predictors of poor outcome included HU non-initiation, low adherence, distance from hospital, low income, and incomplete vaccination. Community health worker engagement and family disease understanding were strongly protective. The findings support sustained investment in tribal health infrastructure, government scheme inclusion of hydroxyurea, community health worker programmes, and integrated medical-social care models for these vulnerable populations.

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