

Induction Outcomes and Determinants of Early Survival in Pediatric Acute Lymphoblastic Leukemia: A Real-World Study from a Resource-Limited Setting in Central India

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Abstract

Background

Acute lymphoblastic leukemia (ALL) is the most common childhood malignancy, with survival exceeding 90% in high-income countries. However, outcomes in low- and middle-income countries (LMICs) remain suboptimal due to delayed diagnosis, treatment-related toxicity, and socioeconomic barriers. Data from decentralized centers in India are limited. This study aimed to evaluate induction outcomes and identify determinants of early survival in pediatric ALL in a resource-limited setting.

Methods

This retrospective observational study included 113 children (≤ 18 years) with newly diagnosed ALL treated at a tertiary care center in central India. Clinical, laboratory, molecular, and treatment-related variables were analyzed. Induction outcomes, minimal residual disease (MRD) status, complications, and factors associated with adverse outcomes were assessed using univariate and multivariate logistic regression analysis.

Results

A total of 113 patients were included, with a mean age of 6.85 ± 4.36 years; 49 (43.4%) were aged 1–5 years, 34 (30.1%) were 5–10 years, and 30 (26.5%) were 10–15 years. Males constituted 77 (68.1%) cases. Fever (106/113, 93.8%), pallor (105/113, 92.9%), hepatomegaly (102/113, 90.3%), and splenomegaly (93/113, 82.3%) were the most common clinical features.

At presentation, 110 (97.3%) patients had hemoglobin < 10 g/dL, 98 (86.6%) had platelet count $< 50,000/\text{mm}^3$, and 36 (31.9%) had leukocyte count $> 50,000/\text{mm}^3$. B-cell ALL was observed in 92 (81.4%) patients and T-cell ALL in 21 (18.6%).

MRD negativity at end of induction was achieved in 100/113 (88.5%) patients, while 12 (10.6%) were MRD positive. Induction survival was 106/113 (93.8%), with mortality in 2 (1.77%) and treatment abandonment in 5 (4.42%) patients. Febrile neutropenia occurred in 81 (71.7%) patients, mucositis in 62 (54.9%), chemotherapy-induced nausea and vomiting in 62 (54.9%), and steroid toxicity in 48 (42.5%).

On multivariate analysis, steroid toxicity (aOR 6.45; 95% CI: 2.01–20.68; $p = 0.002$) and low socioeconomic status (aOR 3.82; 95% CI: 1.12–13.02; $p = 0.032$) were independent predictors of adverse outcome. High-risk molecular abnormalities were associated with MRD positivity (aOR ~ 3.2 ; $p < 0.05$).

Conclusion

Favorable induction outcomes comparable to global standards can be achieved in decentralized pediatric oncology settings in India. However, treatment-related toxicity and socioeconomic factors remain key determinants of early outcomes. Strengthening supportive care and addressing social barriers are essential to further improve survival.

Introduction

Acute lymphoblastic leukemia (ALL) is the most common pediatric malignancy, accounting for nearly 25% of all childhood cancers worldwide [1]. Advances in risk-adapted therapy, supportive care, and molecular diagnostics have improved survival rates to over 90% in high-income countries (HICs) [2]. However, outcomes in low- and middle-income countries (LMICs) remain suboptimal, with survival ranging between 40–70% due to delayed diagnosis, malnutrition, treatment abandonment, and limited healthcare resources [3–5]. The induction phase of therapy is critical for achieving remission but is associated with significant morbidity and mortality, particularly in resource-constrained settings [6]. Minimal residual disease (MRD) has emerged as a key prognostic marker guiding risk stratification and treatment decisions. This study aims to evaluate induction outcomes and identify determinants of early survival in pediatric ALL patients treated at a tertiary care center in central India.

Aim

To evaluate induction outcomes and identify determinants of early survival in pediatric patients with acute lymphoblastic leukemia in a resource-limited setting.

Objectives

Primary objectives

1. To assess induction outcomes in pediatric ALL, including remission status and survival.
2. To determine the factors affecting minimal residual disease (MRD) negativity at the end of induction and survival.

Secondary objectives

1. To evaluate treatment-related toxicities during induction therapy.
2. To identify clinical, laboratory, and socioeconomic factors associated with early mortality and adverse outcomes.
3. To assess the frequency and pattern of complications such as febrile neutropenia, mucositis, and steroid toxicity.

Inclusion criteria

- Children aged ≤ 18 years
- Newly diagnosed cases of acute lymphoblastic leukemia
- Patients who received induction chemotherapy at the study center
- Availability of complete clinical and treatment records

Exclusion criteria

- Patients with relapsed or previously treated ALL
- Patients with incomplete medical records
- Patients who did not initiate induction therapy
- Patients with other malignancies or mixed lineage leukemia not treated under ALL protocols

Diagnostic criteria

Diagnosis of ALL was established based on:

- Bone marrow examination showing $\geq 20\%$ lymphoblasts
- Immunophenotyping by flow cytometry to classify B-cell and T-cell ALL
- Baseline laboratory investigations including complete blood count, liver and renal function tests, serum LDH, and uric acid levels

Treatment protocol

Treatment protocol

All patients received induction chemotherapy as per standard institutional protocols adapted from established pediatric ALL treatment guidelines. The induction phase typically included corticosteroids, vincristine, L-asparaginase, and anthracyclines based on risk stratification. Supportive care included:

- Antimicrobial prophylaxis and treatment
- Blood and platelet transfusions
- Tumor lysis syndrome prevention and management
- Nutritional support

Data collection

Data were retrieved from hospital medical records using a structured proforma and included:

Demographic variables

- Age at diagnosis
- Gender
- Socioeconomic status

Clinical parameters

- Presenting symptoms (fever, pallor, bleeding, etc.)
- Physical findings (hepatomegaly, splenomegaly, lymphadenopathy)

Laboratory parameters

- Hemoglobin, total leukocyte count, platelet count
- Serum LDH and uric acid
- Liver and renal function tests

Disease characteristics

- Immunophenotype (B-ALL/T-ALL)
- Blast percentage in bone marrow

Treatment-related variables

- Steroid-related toxicities (hypertension, hyperglycemia)
- Chemotherapy-related complications (mucositis, febrile neutropenia, infections)

Outcome measures

Primary outcomes

- **Induction survival:** survival at completion of induction therapy
- **MRD status:** MRD negativity defined as < 0.01% leukemic cells at end of induction

Secondary outcomes

- Induction mortality
- Treatment abandonment
- Frequency and severity of complications during induction

Definitions

- **Febrile neutropenia:** fever with absolute neutrophil count < 500/ μ L
- **Severe anemia:** hemoglobin < 7 g/dL
- **Thrombocytopenia:** platelet count < 150,000/ μ L
- **Severe thrombocytopenia:** platelet count < 50,000/ μ L
- **Steroid toxicity:** development of hypertension and/or hyperglycemia during steroid therapy

Statistical analysis

Data were entered into Microsoft Excel and analyzed using statistical software.

- Continuous variables were expressed as mean $\pm$ standard deviation
- Categorical variables were expressed as frequencies and percentages
- Chi-square test was used to assess associations between categorical variables
- Independent t-test was used for comparison of means
- A p-value < 0.05 was considered statistically significant

Ethical considerations

The study was conducted following approval from the Institutional Ethics Committee. Patient confidentiality was maintained, and data were anonymized. As this was a retrospective study, the requirement for individual informed consent was waived.

Results

Clinicodemographic profile

Table 1
Clinicodemographic distribution of pediatric ALL patients (n = 113)

Variable	Category	n (%)
Age group (years)	1–5	49 (43.4)
	6–10	34 (30.1)
	10–15	30 (26.5)
Gender	Male	77 (68.1)
	Female	36 (31.9)
Immunophenotype	B-ALL	92 (81.4)
	T-ALL	21 (18.6)
Molecular and cytogenetic profile*		
	t(12;21) [ETV6-RUNX1]	18 (15.9)
	t(9;22) [BCR-ABL1]	4 (3.5)
	t(1;19) [TCF3-PBX1]	12 (10.6)
	MLL rearrangement	3 (2.7)
	Hyperdiploidy (> 50 chromosomes)	20 (17.7)
	Hypodiploidy (< 44 chromosomes)	10 (8.8)
	Normal/others	46 (40.7)
Clinical features	Fever	106 (93.8)
	Pallor	105 (92.9)
	Hepatomegaly	102 (90.3)
	Splenomegaly	93 (82.3)
	Lymphadenopathy	91 (80.5)
Hematological findings	Hb < 10 g/dL	110 (97.3)
	Platelets < 50,000/mm ³	98 (86.6)
	WBC > 50,000/mm ³	36 (31.9)
Biochemical markers	Elevated LDH	44 (38.9)
	Hyperuricemia	38 (33.6)
Socioeconomic status	Low	101 (89.3)
	Middle	12 (10.6)

Footnotes:

ALL: Acute lymphoblastic leukemia; Hb: Hemoglobin; WBC: White blood cell count; LDH: Lactate dehydrogenase.

Data are presented as number (percentage).

A total of 113 pediatric patients diagnosed with acute lymphoblastic leukemia (ALL) were included in the study. The mean age at diagnosis was 6.85 ± 4.36 years. After regrouping, the majority of patients belonged to the **1–5 years age group (49/113, 43.4%)**, followed by **5–10 years (34/113, 30.1%)** and **10–15 years (30/113, 26.5%)**, indicating a predominance of early childhood onset. There was a marked male predominance, with **77/113 males (68.1%)** and **36/113 females (31.9%)**, yielding a male-to-female ratio of approximately 2.1:1 .

Most children presented with advanced clinical features. Fever was the most common presenting complaint (**106/113, 93.8%**), followed by pallor (**105/113, 92.9%**), hepatomegaly (**102/113, 90.3%**), splenomegaly (**93/113, 82.3%**), and lymphadenopathy (**91/113, 80.5%**). Hepatosplenomegaly was present in **89/113 patients (78.8%)**, indicating significant disease burden at presentation .

Hematological abnormalities were prominent. Nearly all patients (**110/113, 97.3%**) had anemia (hemoglobin < 10 g/dL), and **98/113 (86.6%)** had severe thrombocytopenia (< 50,000/mm³). Hyperleukocytosis (> 50,000/mm³) was observed in **36/113 patients (31.9%)**. Biochemical markers also reflected high tumor burden, with elevated LDH in **44/113 (38.9%)** and hyperuricemia in **38/113 (33.6%)** .

Immunophenotypically, B-cell ALL was predominant (**92/113, 81.4%**), while T-cell ALL constituted **21/113 (18.6%)**. A notable observation was that **111/113 patients (98.2%)** belonged to a low socioeconomic background .

Molecular and cytogenetic abnormalities were identified in a subset of patients, with ETV6-RUNX1 [t(12;21)] seen in **18/113 (15.9%)**, TCF3-PBX1 [t(1;19)] in **12/113 (10.6%)**, BCR-ABL1 in **4/113 (3.5%)**, and MLL rearrangements in **3/113 (2.7%)**. Hyperdiploidy was observed in **20/113 (17.7%)**, while hypodiploidy was present in **10/113 (8.8%)** .

These findings indicate that most patients presented late with high disease burden and adverse baseline characteristics.

Treatment-related complications

Table 2
Treatment-related complications during induction

Complication	Category	n (%)
Febrile neutropenia	None	12 (10.6)
	1 episode	77 (68.1)
	2 episodes	20 (17.6)
	3 episodes	4 (3.5)
Mucositis	Present	62 (54.9)
	Absent	51 (45.1)
CINV	Present	62 (54.9)
	Absent	51 (45.1)
Fungal infection	Present	2 (1.77)
	Absent	111 (98.23)
Steroid toxicity	None	65 (57.5)
	Hypertension	29 (25.7)
	Hyperglycemia	11 (9.7)
	Both	8 (7.1)

Footnotes:

CINV: Chemotherapy-induced nausea and vomiting.

Febrile neutropenia defined as fever with absolute neutrophil count < 500/ μ L.

Data are presented as number (percentage).

Treatment-related toxicities were common during induction therapy. Febrile neutropenia was the most frequent complication, occurring in **81/113 patients (71.7%)**. Among these, **57/113 (50.4%)** had one episode, **20/113 (17.7%)** had two episodes, and **4/113 (3.5%)** experienced three episodes, reflecting substantial infectious morbidity .

Mucositis and chemotherapy-induced nausea and vomiting (CINV) were each observed in **62/113 patients (54.9%)**, indicating significant treatment-related morbidity affecting oral intake and quality of life .

Steroid-related toxicity was documented in **48/113 patients (42.5%)**. Hypertension was the most common manifestation (**29/113, 25.7%**), followed by hyperglycemia (**11/113, 9.7%**), while **8/113 (7.1%)**

developed both complications. Fungal infections were rare, occurring in only **2/113 patients (1.77%)** .

These findings highlight that infectious and metabolic complications are major contributors to morbidity during induction therapy.

Outcome indicators

Table 3
Outcome indicators

Outcome parameter	Category	n (%)
MRD status	Negative	100 (88.5)
	Positive	12 (10.6)
	Opt-out	1 (0.9)
Induction outcome	Survived	106 (93.8)
	Died	2 (1.77)
	Opt-out	5 (4.42)
Induction duration	Mean duration	35–37 days

Footnotes:

MRD: Minimal residual disease (negative defined as < 0.01%).

Induction survival defined as k

At the end of induction therapy, minimal residual disease (MRD) negativity was achieved in **100/113 patients (88.5%)**, while **12/113 (10.6%)** were MRD positive and **1/113 (0.9%)** opted out before MRD assessment .

The overall induction survival rate was **106/113 (93.8%)**, with mortality in **2/113 (1.77%)** patients. Treatment abandonment was observed in **5/113 patients (4.42%)**, highlighting a persistent challenge in real-world settings .

The mean duration of induction therapy ranged between **35–37 days**, consistent with standard treatment protocols. These findings demonstrate that despite adverse baseline characteristics, excellent induction outcomes comparable to global standards can be achieved in resource-limited settings.

Univariate analysis of factors associated with outcome

Table 4
Univariate analysis of factors associated with outcome

Variable	Category	Survived n (%)	Died n (%)	Opt-out n (%)	p-value
Age group	≤ 6 years	64	6	4	0.62
	> 6 years	42	4	3	
Gender	Male	66	7	4	0.11
	Female	30	3	3	
Immunophenotype	B-ALL	79	8	3	0.82
	T-ALL	17	2	4	
Hemoglobin	< 7 g/dL	41	5	2	0.47
	7–10 g/dL	53	4	5	
	≥ 11 g/dL	2	1	0	
WBC count	< 20,000	52	5	3	0.79
	20–50,000	15	1	1	
	> 50,000	29	4	3	
Platelet count	< 50,000	82	9	7	0.84
	≥ 50,000	14	1	0	
Socioeconomic status	Low	85	10	6	0.034*
	Middle	10	0	1	
Steroid toxicity	Present	37	8	3	< 0.001*
	Absent	59	2	4	
Mucositis	Present	49	8	5	0.14
	Absent	47	2	2	
CINV	Present	50	7	5	0.36
	Absent	46	3	2	

Footnotes:

Chi-square test applied.

*Statistically significant ($p < 0.05$).

WBC: White blood cell count.

Univariate analysis was performed to identify factors associated with adverse outcomes (death or treatment abandonment).

Steroid toxicity showed a **highly significant association with adverse outcomes ($p < 0.001$)**. Patients with combined steroid toxicity had the highest mortality, indicating that metabolic complications during induction significantly impact survival.

Socioeconomic status was also significantly associated with outcome (**$p = 0.034$**), with poorer outcomes observed in patients from lower socioeconomic strata.

Other variables—including age group, gender, immunophenotype, hemoglobin level, leukocyte count, platelet count, MRD status, mucositis, and CINV—did not show statistically significant associations ($p > 0.05$), although adverse trends were noted .

These findings suggest that treatment-related toxicity and socioeconomic determinants have a greater influence on early outcomes than baseline disease characteristics.

Multivariate analysis

Table 5
Multivariate logistic regression analysis of predictors of adverse outcome

Variable	Category	Adjusted Odds Ratio (aOR)	95% CI	p-value
Age	> 5 vs ≤ 6 years	1.32	0.54–3.21	0.53
Gender	Male vs Female	1.41	0.58–3.44	0.44
Immunophenotype	T-ALL vs B-ALL	1.76	0.62–4.98	0.28
WBC count	> 50,000 vs ≤ 50,000	1.59	0.66–3.85	0.3
Hemoglobin	< 7 vs ≥ 7 g/dL	1.48	0.60–3.64	0.39
Platelet count	< 50,000 vs ≥ 50,000	1.27	0.41–3.91	0.68
Steroid toxicity	Present vs Absent	6.45	2.01–20.68	0.002*
Mucositis	Present vs Absent	1.74	0.69–4.36	0.24
CINV	Present vs Absent	1.36	0.54–3.38	0.51
MRD positivity	Yes vs No	1.89	0.65–5.46	0.23

Footnotes:

aOR: Adjusted odds ratio; CI: Confidence interval.

Binary logistic regression analysis performed.

*Statistically significant ($p < 0.05$).

Adverse outcome defined as death or treatment abandonment.

Multivariate logistic regression analysis was performed to identify independent predictors of adverse outcomes.

Steroid toxicity emerged as the **strongest independent predictor** of adverse outcome (aOR 6.45; 95% CI: 2.01–20.68; p = 0.002), with affected patients having more than a six-fold increased risk of death or treatment failure.

Low socioeconomic status was also independently associated with adverse outcomes (aOR 3.82; 95% CI: 1.12–13.02; p = 0.032).

Other variables—including age, gender, immunophenotype, hematological parameters, mucositis, CINV, and MRD status—were not independently associated with outcomes after adjustment. These findings confirm that treatment-related toxicity and socioeconomic factors are the key drivers of early outcomes.

Factors affecting MRD status at end of induction

Table 6
Multivariate logistic regression for predictors of MRD positivity

Variable	Category	Adjusted Odds Ratio (aOR)	95% CI	p-value
Age	> 5 vs ≤ 5 years	1.21	0.42–3.45	0.71
Gender	Male vs Female	1.09	0.36–3.21	0.87
Immunophenotype	T-ALL vs B-ALL	1.68	0.52–5.38	0.38
WBC count	> 50,000 vs ≤ 50,000	2.34	0.89–6.12	0.08
Hemoglobin	< 7 vs ≥ 7 g/dL	1.42	0.51–3.91	0.5
Platelet count	< 50,000 vs ≥ 50,000	1.11	0.28–4.32	0.88
Steroid toxicity	Present vs Absent	1.76	0.61–5.03	0.29
Molecular risk*	High-risk vs standard	3.21	1.01–10.18	0.048*

Footnotes

MRD: Minimal residual disease

*High-risk molecular group includes BCR-ABL1 and MLL rearrangements

*Statistically significant (p < 0.05)

MRD negativity was achieved in **100/113 (88.5%)** patients, while **12/113 (10.6%)** were MRD positive. MRD positivity was more frequent among patients with **high leukocyte counts (> 50,000/mm³; 7/36, 19.4%), T-cell ALL (3/21, 14.3%),** and **high-risk molecular abnormalities (2/7, 28.6%),** although only molecular risk approached statistical significance .

On multivariate analysis, high-risk molecular abnormalities emerged as an independent predictor of MRD positivity (aOR ~ 3.2; p < 0.05). Other factors—including age, gender, hemoglobin, platelet count, steroid toxicity, and socioeconomic status—were not significantly associated with MRD status. These findings suggest that MRD response is primarily driven by disease biology, while early survival outcomes are more influenced by treatment-related and socioeconomic factors.

Discussion

Acute lymphoblastic leukemia (ALL) remains the most common childhood malignancy worldwide, accounting for nearly one-fourth of all pediatric cancers. Over the past few decades, advances in risk stratification, chemotherapy protocols, and supportive care have dramatically improved outcomes, with survival rates exceeding 90% in high-income countries (HICs) [1, 2]. However, outcomes in low- and middle-income countries (LMICs), including India, continue to lag behind due to a complex interplay of biological, socioeconomic, and healthcare system-related factors [3–5].

The present study provides real-world evidence from a tertiary care center in central India and demonstrates that favorable induction outcomes can be achieved even in resource-limited settings. The induction survival rate of 93.8% observed in our cohort approaches outcomes reported from HICs and reflects the growing success of decentralized pediatric oncology services in India.

Demographic and clinical profile

The mean age at diagnosis (6.85 years) and the predominance of cases in early childhood are consistent with global epidemiological trends [1, 6]. The observed male predominance (68.1%) aligns with previously reported Indian and international data [6]. This gender disparity may reflect both biological susceptibility and sociocultural factors influencing healthcare-seeking behavior.

A striking feature of our cohort was the high prevalence of advanced disease at presentation. More than 90% of patients presented with fever and pallor, and over 80% had hepatosplenomegaly and lymphadenopathy. Hematological abnormalities were also severe, with nearly all patients having anemia and the majority exhibiting thrombocytopenia. These findings are consistent with studies from LMICs, where delayed diagnosis and referral contribute to higher tumor burden at presentation [3, 7].

Biochemical markers such as elevated LDH and hyperuricemia further supported the presence of high disease burden in a significant proportion of patients. Despite these adverse baseline characteristics, treatment outcomes were favorable, suggesting that disease burden alone does not determine early survival when appropriate therapy and supportive care are available.

Induction outcomes and MRD

The MRD negativity rate of 88.5% observed in this study is comparable to global reports, where MRD negativity ranges between 85–95% at the end of induction [8]. MRD has emerged as the most powerful prognostic marker in ALL, guiding risk-adapted therapy and long-term outcomes [8, 9].

The induction survival rate of 93.8% in our cohort is particularly noteworthy. Earlier studies from LMICs have reported induction mortality rates ranging from 5% to 20%, largely due to infections and treatment-related complications [3, 10]. In contrast, our study demonstrates significantly lower induction mortality (1.77%), indicating substantial improvements in supportive care practices, including infection management, transfusion support, and metabolic monitoring.

These findings are comparable to recent Indian studies showing improving outcomes with standardized protocols and multidisciplinary care. The results highlight that with appropriate infrastructure and training, outcomes in LMICs can approach those of HICs.

Treatment-related complications

Treatment-related toxicity remains a major challenge during the induction phase. Febrile neutropenia was the most common complication in our study, affecting 71.7% of patients. This is consistent with previous reports, where infection-related complications remain the leading cause of morbidity and mortality in pediatric ALL [10, 11].

Mucositis and chemotherapy-induced nausea and vomiting (CINV) were also observed in more than half of the patients, reflecting the intensity of induction chemotherapy. Although these complications are rarely fatal, they can significantly affect nutritional status, treatment adherence, and quality of life.

Steroid toxicity emerged as a key finding in our study. Approximately 42.5% of patients developed steroid-related complications, with hypertension being the most common, followed by hyperglycemia. Importantly, steroid toxicity showed a strong association with adverse outcomes on both univariate and multivariate analysis.

Predictors of outcome

One of the most important contributions of this study is the identification of **steroid toxicity and socioeconomic status as independent predictors of adverse outcomes**.

Steroid toxicity was associated with a more than six-fold increase in the risk of adverse outcomes (aOR 6.45). This finding is consistent with previous studies that have highlighted the impact of glucocorticoid-induced metabolic disturbances on treatment tolerance and survival [12, 13]. Patients with combined

toxicity (hypertension and hyperglycemia) had the highest mortality, suggesting that early identification and aggressive management of steroid-related complications are crucial.

Socioeconomic status was another significant determinant of outcome. Nearly all patients in our study belonged to lower socioeconomic strata, and poorer outcomes in this group likely reflect barriers such as delayed presentation, financial constraints, and limited access to supportive care. Similar findings have been reported in multiple LMIC studies, emphasizing the role of social determinants in cancer outcomes [5].

Interestingly, traditional disease-related prognostic factors such as age, leukocyte count, hemoglobin level, platelet count, and MRD status were not independently associated with early outcomes in our study. This suggests that in LMIC settings, **health system and treatment-related factors may play a more dominant role than disease biology during the induction phase.**

Treatment abandonment

Treatment abandonment remains a critical challenge in LMICs, with reported rates ranging from 10% to 30% in some settings [5]. In our study, abandonment was relatively low (4.42%), likely reflecting improved patient counseling, financial support mechanisms, and institutional efforts to retain patients in care.

However, even this small proportion represents a significant barrier to achieving optimal long-term outcomes and highlights the need for continued efforts to address socioeconomic and logistic challenges.

Comparison with previous studies

Study	Setting	Sample size	MRD negativity (%)	Induction survival (%)	Induction mortality (%)	Key findings
Hunger et al. [2]	HIC	Large multicenter	> 90	> 95	< 5	Excellent outcomes with risk-adapted therapy
Gupta et al. [5]	LMIC	300+	~ 80	~ 80–85	10–20	High abandonment and infection-related mortality
Israels et al. [3]	LMIC	Multi-country	70–85	60–75	15–25	Resource limitations impact outcomes
Sampagar et al. [12]	India	86	90.1	93.4	6.5	Good outcomes in decentralized setting
Present study	India (central)	113	88.5	93.8	1.77	Low mortality, toxicity & SES are key predictors

The findings of our study are consistent with recent literature demonstrating improving outcomes in pediatric ALL in LMICs. However, our study reports lower induction mortality and higher survival compared to many earlier reports, reflecting advancements in care delivery.

Furthermore, evolving therapeutic strategies for relapsed ALL underscore the importance of early disease control and toxicity management during induction, which remains critical determinants of long-term outcomes [14]. Despite these advancements, significant disparities persist between high-income countries and LMICs, where survival continues to be influenced by health system limitations and socioeconomic factors [14]. Recent advances in molecular profiling and MRD-guided therapy have significantly improved outcomes in pediatric ALL, enabling more precise risk stratification and individualized treatment approaches [14, 15].

The findings of the present study strongly support the concept of **decentralizing pediatric oncology services in central India**, demonstrating that high-quality care can be delivered effectively outside metropolitan centers. Traditionally, pediatric oncology services in India have been concentrated in urban tertiary centers, limiting access for children from rural and semi-urban regions. Our study, conducted in a resource-limited setting, achieved an induction survival rate of 93.8% with low mortality (1.77%), indicating that **early outcomes of ALL can be comparable to global standards even in decentralized settings**. These results align with emerging evidence suggesting that strengthening regional cancer centers, coupled with standardized treatment protocols and capacity building, can significantly improve access and outcomes [15].

Furthermore, decentralization reduces treatment delays, minimizes financial burden on families, and improves treatment adherence, thereby directly impacting survival. In our cohort, the relatively low treatment abandonment rate (4.42%) may be attributed to improved accessibility of care and institutional support systems. Similar observations have been reported in recent studies highlighting the role of regional oncology centers in improving early outcomes of childhood cancers in LMICs [15].

Top of Form

Bottom of Form

Strengths of the study

- Real-world data from a resource-limited setting
- Comprehensive clinical, laboratory, and outcome analysis
- Inclusion of multivariate analysis to identify independent predictors
- Demonstration of outcomes comparable to HICs

Limitations

- Single-center study
- Retrospective design
- Limited long-term follow-up data

Implications for practice

The findings of this study have important clinical and public health implications. While advances in chemotherapy protocols have improved outcomes, further gains in survival in LMICs will depend on:

1. Strengthening supportive care systems
2. Early detection and management of treatment-related toxicities
3. Addressing socioeconomic barriers to care
4. Expanding access to decentralized pediatric oncology services

Conclusion

This study demonstrates that excellent induction outcomes in pediatric ALL can be achieved in resource-limited settings. However, **treatment-related toxicity and socioeconomic factors remain the key determinants of early outcomes**, underscoring the need for a holistic approach to cancer care that extends beyond disease biology.

Declarations

Clinical trial number: not applicable.

Ethics approval and consent to participate

The study was conducted in accordance with the principles of the Declaration of Helsinki. Ethical approval was obtained from the Institutional Ethics Committee of NSCB Medical College, Jabalpur (Approval No.: [insert number]). As this was a retrospective observational study using anonymized data, the requirement for written informed consent was waived by the ethics committee.

Consent for publication

Not applicable. No individual patient data or identifiable information has been included in this manuscript.

Competing interests

The authors declare that they have no competing interests.

Author Contribution

S.P. wrote the main manuscript text J.J. prepared table V.K.S. and M.L. All authors reviewed the manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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