

Clinicolaboratory Characteristics and Outcome of Pediatric Acute Lymphoblastic Leukemia in a Resource-Limited Setting: A Study from South Egypt

Amany M. Ali ¹, Amira M. El-Hefedy ², Douaa Sayed ³, Amira M. Osman ^{✉1}

¹Department of Pediatric Oncology and Hematological Malignancies, South Egypt Cancer Institute, Assiut University, Assiut, Egypt; ² Department of Pediatric Oncology, Sohag Cancer Center, Sohag, Egypt; ³ Department of Clinical Pathology, South Egypt Cancer Institute, Assiut University, Assiut, Egypt

Abstract

Background: Remarkable progress has been made in the treatment of pediatric acute lymphoblastic leukemia (ALL), with survival rates reaching > 80% in high-income countries. In Egypt, the outcome of treatment of ALL has been less favorable.

Aim: To evaluate the clinicolaboratory characteristics in patients admitted at Sohag Cancer Center and to assess the outcome and the prognostic factors affecting it.

Methods: This retrospective study included 79 pediatric ALL patients, from January 2010 to December 2014, who were treated according to modified Total therapy study XIIIB high-risk ALL of St. Jude Children's Research Hospital (SJCRH).

Results: 52% were males with a median age of 6 years. 58.2% were stratified as HR, 69.6% had precursor B-ALL, 39.2% presented with total leucocytic count (TLC) ($\geq 50 \times 10^9/L$), and 11.3% had CNS leukemia. Complete remission (CR) was achieved in 87.3%. Regarding treatment outcome, induction failure was reported in 5.1%, relapse in 24.1%, deaths in CR in 7.2%, and continuous complete remission in 59.5%. The median follow-up was 42 months, 4 years OS, EFS, and DFS were 64.1 ± 5.6 , 57 ± 5.7 , and $63.3 \pm 5.8\%$ respectively. TLC and bone marrow aspirate postinduction were the only significant prognostic factors affecting EFS.

Conclusions: The modified TXIIB of SJCRH was effective in improving ALL outcomes in our center, however, survival rates were much lower than internationally reported results with only initial TLC and response postinduction having a significant effect on EFS and DFS.

Keywords: Acute lymphoblastic leukemia, Egypt, Limited resources, Pediatric, Outcome

Corresponding author: Amira M. Osman, MD; Department of Pediatric Oncology and Hematological Malignancies, South Egypt Cancer Institute, Assiut University, Assiut, Egypt; Email: amirasherit@aun.edu.eg

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Introduction

Acute lymphoblastic leukemia (ALL), the most common childhood cancer worldwide, is an aggressive hematologic malignancy treated with intensive multiagent chemotherapy ¹. The outcome of childhood ALL has dramatically improved over the last 50 years with the current cure rates approaching 90% in high-income countries. This is attributed to the introduction and gradual intensification of combination chemotherapy with

contemporary regimens, alongside the improvement of prognostic factors ^{2,3}. In developing countries, the outcome of ALL has been less favorable due to socio-cultural factors, financial constraints, inadequate supportive care, and may be genetic heterogeneity ^{4,5}.

This study aimed to describe the clinicolaboratory pattern of pediatric ALL patients at an emerging tertiary center in Upper Egypt, to study the outcome of modified total therapy study XIIIB for high-risk ALL protocol of St. Jude Children's

Research Hospital (SJCRH), and to evaluate prognostic factors that affect patients' survival, faced with the challenge of limited health resources.

Methods

This retrospective study included newly diagnosed pediatric (age: 2-18 years) patients with ALL (L1, L2) who had been treated at the Pediatric Oncology Department of Sohag Cancer Center (SCC) which is a tertiary center in Upper Egypt in the period from January 2010 to December 2014. Patients were followed up until January 2018. Causes of exclusion were mature B-ALL (Burkitt's Leukemia or L3) diagnosis, early death at presentation (in the first week) before starting chemotherapy, pretreatment, and missing medical records.

Data collected

Clinical data including patient demographics, diagnosis, treatment response, and outcome, were retrieved from medical records.

Diagnosis: Included history and physical examination at presentation, laboratory studies include morphological, cytochemical examination, and immunophenotyping of leukemic blasts on bone marrow aspirate (BMA) or peripheral blood (PB). Minimal residual disease (MRD) or cytogenetic studies were not done. Cerebrospinal fluid (CSF) was considered positive if contains >5 nucleated cells/mm³ with morphologically identified blasts by cytocentrifugation⁶. Routine imaging studies done included: chest X-ray, abdominopelvic and testicular sonography.

Risk assessment and treatment: Patients were classified according to the National Cancer Institute (NCI)/Rome criteria into standard risk (SR) (age 1–9 years, initial WBC < 50 × 10⁹/L and patients without central nervous system [CNS] involvement) and high risk (HR) (all other patients)⁶. All patients were treated according to the modified Total therapy study XIII B for high-risk ALL of SJCRH⁷.

Response assessment and its definitions: Early response was assessed by the presence of peripheral blasts on D8 induction therapy instead of BMA on D15 induction because of our limited resources, good responder (GR) was considered when there was < 1 × 10 blasts⁹/L and poor responder (PR) ≥ presence of 1 × 10 blasts⁹/L or more in PB on day 8⁸. BM morphologic criteria post induction was based on blast content in BM:

M1 (<5% blasts), M2 (<25% blasts) or M3 (≥25% blasts) remaining in the bone marrow⁹. Complete remission (CR) was defined as the absence of leukemic blasts in peripheral blood and CSF and less than 5% blasts on BMA smears (M1), together with hematopoietic regeneration and no evidence of extramedullary disease after induction phase⁹. Patients who were alive and in CR until January 2018 were considered in continuous complete remission (CCR). Induction failure was defined as either morphological persistence of leukemic blasts in BM or extramedullary site after the completion of the induction therapy¹⁰. The refractory disease was considered in patients who do not attain CR after remission induction and consolidation phases. Relapse was defined as M3 marrow after achieving initial CR⁹. Treatment failure included induction deaths, refractory disease, relapse, secondary malignancy, abandonment of therapy, or deaths in CR¹⁰.

Assessment of toxicity: Toxicity of treatment was evaluated using Common Terminology Criteria for Adverse Events (CTCAE) Version 4.0¹¹.

Statistical analysis

Data were analyzed using STATA 14 software (StataCorp. 2015. Stata Statistical Software: Release 14. College Station, TX: StataCorp LP).

Quantitative data were represented as mean and standard deviation (SD) or median and range. Qualitative data were presented as numbers and percentages. Survival analysis was done using the Kaplan-Meier method and a comparison between survival curves was done using the log-rank test. *P-value* was considered significant if it was ≤ 0.05. Overall survival (OS), event-free survival (EFS), and disease-free survival (DFS) were considered as the treatment outcomes in this study. Overall survival was defined as the time from date of diagnosis to the date of death from any cause or last date of follow-up, EFS as the time from the date of diagnosis to the date of first treatment failure of any kind (relapse, absence, death or major treatment toxicity that required cessation of chemotherapy) and DFS for patients who achieved CR to the time of relapse or death (excluding induction deaths).

Results

After reviewing the medical records of 87 ALL patients, 79 patients were eligible for this study, 8

patients were excluded due to very early deaths (6 patients) and missing medical records (2 patients).

Table 1 shows the clinical and laboratory characteristics of included patients in relation to immunophenotyping. Twenty-four patients (30.4%) had T-lineage ALL subtype and 55 patients (69.6%) had B-lineage ALL. The median (range) age of all patients was 6 (2-17) years and differed significantly between B-precursor and T-ALL patients (4[2-17] vs. 10 [3-17], respectively; $p < 0.0001$). The mean (SD) age was 4.19 (4.49), 5.8 (3.8), and 10.4 (4.2) years for all patients, B-precursor and T-ALL patients, respectively. The male-to-female ratio was 1.1:1 for

the whole group, 0.9:1 for B-precursor ALL patients, and 1.3:1 for T-ALL.

Hyperleukocytosis were more observed in patients with T-cell ALL (29.25%) in comparison to B-precursor cell (7.3%) ($p = 0.035$). The high-risk group represented the majority of patients (58.2%) and differed significantly according to immunophenotyping being higher in T cell ALL patients.

On D8, most of the patients (69/79, 87.4%) were GRs, while 10 patients (12.7%) were PRs. Three out of ten (30%) of the PRs failed to achieve CR post-induction versus only 1/69 (1.4%) of GRs ($p < 0.001$).

Table 1: Patients and disease characteristics and their distribution according to immunophenotyping

Characteristics	All patients (<i>n</i> =79) <i>n</i> (%)	B-precursor ALL (<i>n</i> =55) <i>n</i> (%)	T-ALL (<i>n</i> =24) <i>n</i> (%)	<i>p</i> -value
Age (years)				
1-10	59 (74.7)	46 (83.6)	13 (54.1)	0.007
>10	20 (25.3)	9 (16.4)	11 (45.8)	
Gender				
Male	41 (52)	27 (49.1)	14 (58.3)	0.450
Female	38 (48)	28 (50.9)	10 (41.7)	
Fever	63 (79.7)	47 (85.5)	16 (66.7)	0.057
Lymphadenopathy	65 (82.3)	45 (81.8)	20 (83.3)	0.573
Hepatosplenomegaly	61 (77.2)	47 (85.5)	14 (58.3)	0.008
Mediastinal mass	14 (17.7)	0 (0)	14 (58.3)	<0.0001
Total leukocytic count ($\times 10^9/L$)				
< 50	48 (60.7)	36 (65.5)	12 (50)	0.035
50-100	20 (25.3)	15 (27.3)	5 (20.8)	
>100	11 (13.9)	4 (7.3)	7 (29.2)	
Hemoglobin (g/dl)				
< 6	11 (13.9)	9 (16.4)	2 (8.3)	0.496
6-10	59 (74.7)	39 (70.9)	20 (83.3)	
>10	9 (11.4)	7 (12.7)	2 (8.3)	
Platelets ($\times 10^9/L$)				
< 50	38 (48.1)	31 (56.4)	7 (29.2)	0.03
50-100	27 (34.2)	17 (30.9)	10 (41.7)	
>100	14 (17.7)	7 (12.7)	7 (29.2)	
Bone marrow morphology				
L1	52 (65.8)	37 (67.5)	15 (62.5)	0.681
L2	27 (34.2)	18 (32.7)	9 (37.5)	
Central nervous system infiltration				
Positive	9 (11.3)	5 (9.1)	4 (16.4)	0.330
Negative	70 (88.6)	50 (90.9)	20 (83.3)	
Risk stratification				
Standard risk	33 (41.8)	32 (58.2)	1 (4.2)	<0.0001
High risk	46 (58.2)	23 (41.8)	23 (95.8)	

Of 79 patients, 6 (7.5%) died during induction (5 sepsis, 1 tumor lysis syndrome). Induction remission was reported in 69/79 (87.3%) patients. Four (5.1%) patients failed induction but achieved CR after the consolidation phase. The number of patients who achieved CR was 73 (92.4%).

Treatment failure was documented in 32 (40.5%) patients including induction deaths (6 patients), abandonment of therapy (one patient), relapse (19 patients), and deaths in remission (6 patients) with no second malignancies recorded in our study. Continuous CR (CCR) was documented in 47 (59.5%) patients. Relapse occurred in 19/79 (24.1%) patients and included 12 (15.2%) late relapses and 7 (8.9%) early relapses. The relapse was medullary in 7 (8.9%) patients, isolated CNS in 4 (5.1%), and combined in 8 (10.1%). All relapsed cases died (2 died from sepsis and 17 from disease progression).

The most common toxicity that occurred among our patients was BM suppression grade II-III in 34 patients (43%) and mucositis grade III to IV in 30

patients (37.9%). Hepatotoxicity grade II-III was observed in 15 patients (18.9%) which occurred post-infectious (hepatitis virus B and C) and chemotherapy-induced, while grade IV toxicity was detected in 5 patients (6.3%) due to MTX toxicity.

The median follow-up period of all evaluable cases was 42 months, ranging from 8 to 72 months. 4-years OS rate (SE) was 64.5% (5.5) for all patients, 68.8% (7) for the SR group, and 57.7% (9.2) for the HR group. 4-years EFS \pm SE was (57 \pm 5.7%) for all patients, (57.6 \pm 8.6%) for the SR group, and (57.5 \pm 7.5%) for the HR group. 4-years DFS \pm SE was (63.3 \pm 5.8%) for all patients, (59.8 \pm 8.5%) for the SR group, and (65.4 \pm 7.6%) for the HR group.

Table 2 summarizes the effect of prognostic factors on patients' survival, none had a significant statistical effect on OS. While for EFS; TLC was highly significant ($P=0.004$) as well as BMA post-induction ($P<0.0001$). For DFS, BMA post induction was still having a highly significant effect ($P<0.001$).

Table 2: Survival rates in relation to different risk factors

Variable	Overall survival			Event-free survival			Disease-free survival		
	<i>n</i>	4-year rate (%[SE])	<i>p</i> -value	<i>n</i>	4-year rate (%[SE])	<i>p</i> -value	<i>n</i>	4-year rate (%[SE])	<i>p</i> -value
Whole group	79	64.1 (5.6)		79	57.1 (5.7)		73	63.3 (5.8)	
Age (years)									
1-10	59	67.4 (6.4)	0.34	59	61.8 (6.7)	0.11	57	62.9 (4.2)	0.851
≥ 10	20	54.2 (11.3)		20	45(11.1)		16	64.9 (7.9)	
Gender									
Male	41	71.9 (7.2)	0.23	41	61.8 (7.9)	0.20	38	67.7 (4.6)	0.061
Female	38	55.2 (8.5)		38	51.9 (8.2)		35	58.6 (5.7)	
Total leukocytic count ($\times 10^9/L$)									
< 50	48	71.4 (6.8)	0.06	48	69.8 (6.8)	0.004	48	67.1 (4.3)	0.519
50-100	20	58.4 (11.3)		20	38.6 (11.2)		17	54.4 (6.7)	
>100	11	45.5 (15)		11	36.4 (14.5)		8	61.3 (11.8)	
Immunophenotyping									
T-ALL	24	57.7 (10.2)	0.48	24	53.5 (10.3)	0.58	22	61.5 (4.6)	0.474
B-ALL	55	67.1 (6.6)		55	58.7 (6.9)		51	60.3 (5.2)	
Risk stratification									
Standard risk	33	68.6 (7)	0.49	33	57.6 (8.6)	0.87	31	59.8 (5.6)	0.418
High risk	46	57.5 (9.2)		46	57.5 (7.5)		42	65.4 (4.7)	
Early response, D8									
Good responder	69	66.8 (5.8)	0.33	69	58.3 (6.1)	0.55	63	78.5 (6.4)	0.084
Poor responder	10	45 (17.4)		10	50 (15.8)		10	59.4 (4.1)	
BMA on the 36th day of induction									
M1	69	72 (5.4)	0.12	69	65.9 (5.8)	<0.0001	69	67.4 (3.8)	<0.001
M2	3	66.7 (27)		3	66.7 (27)		3	29.9 (3.1)	
M3	1	0		1	0		1	0	

SE: standard error; ALL: Acute lymphoblastic leukemia; BMA: Bone marrow aspirate

Discussion

Management of children with cancer in Egypt is offered mainly through general and university hospital services, which are only partially covered by health insurance. Most of the patients suffer from shortages of chemotherapy and supportive medications, which may only be provided through personal charitable donations or non-profit organizations. Indeed, there is a lack of infection control programs or awareness of hygiene practices either by the patient's families or hospital staff. Despite all these difficulties, cancer-treating centers are following international protocols; however, modifications may be done to reduce toxicities and/or increase the cost-effectiveness of therapy¹².

According to patients' criteria and NCI/Rome criteria risk classification system, the majority of the patients 46 (58.2%) were classified as HR. This was the same as the study of Hussein *et al.* (58.4%) but it was higher than the results of SJCRH (44%), Lustosa de Sousa *et al.* (46%), and Shibl *et al.* (47%)^{7, 10, 13, 14}. This higher incidence of HR features may be due to different biologic factors in childhood ALL in Egypt, late onset of presentation in many patients or it could be due to unavailability of diagnostic tools such as cytogenetics which can precisely stratify patients into a lower risk group.

Immunophenotyping studies revealed that most of the patients had B precursor ALL (69.6%), while T-ALL represented (30.4%), which is markedly different from the results of SJCRH with (82%) for B-precursor ALL and (17.5%) for T-ALL and nearly similar to results of Sidhom *et al.* (75.8%) for B-ALL and (24.2%) for T-ALL^{10, 15}. The proportion of T-cell ALL has been reported as high (up to and even beyond 50%) in all childhood ALL in developing countries, and in particular within patients from lower socioeconomic strata¹⁶.

In studying the relation between IPT and risk groups, 23 (95%) patients of T-All were stratified as HR, while the majority of B precursor ALL (58%) were stratified as SR with a significant difference between ($P < 0.0001$) which is consistent with Tantawy *et al.* and Shibl *et al.*^{7, 12}.

The age at presentation ranged between (2-17 years), the median age at the time of diagnosis was 6 years, and it showed wide variation between B and T-ALL; (4 years versus 10 years) ($P < 0.0001$), which was nearly similar to the results of NCI; (5years. for all patients, 4.5years for B precursor ALL and 8 years for T-ALL)¹³. The majority of the patients (74.7%)

had a favorable age group (1-10 years), which was consistent with Abdelhamid *et al.* in Egypt and Shen *et al.* in Shanghai Children's Medical Center^{17, 18}. Of those, 83.6% had B precursor ALL while 45.8% of T-ALL patients belonged to the unfavorable age group ≥ 10 years ($P = 0.007$), this was consistent with the results of^{12, 14}.

Regarding gender, there was male predominance (51.9%) with a male to female ratio of 1.1:1. This ratio was lower than previously reported in SECI (1.5:1) and exactly similar to the results of SJCRH which was (1.1:1)^{10, 18}. Male gender also predominated among the HR group and T-ALL (58.3%), this is because the incidence of the male gender is more common in the T-ALL subtype and usually they were stratified as HR¹⁹.

Concerning clinical data at presentation; features of bone marrow and lymphoid system infiltration in our study were detected as follows: (79.7%) for fever, (86%) for pallor, (25.3%) for bleeding, (8.9%) for bone pain, (82.3%) for lymphadenopathy, (77.2%) for HSM and (17.7%) for mediastinal involvement this was in agreement with many reports from the Middle East and neighboring countries^{20, 21} and much higher than internationally reported results by²². These relatively higher results in our developing countries may be due to the late onset of presentation and delayed diagnosis of the disease. Lymphomatous features such as (HSM and lymphadenopathy) were more common among B precursor ALL than T-ALL patients with the significant impact of HSM on IPT ($P = 0.008$) which was consistent with many reported studies as¹³.

Features of CNS infiltration were also considered as an HR criterion. The internationally published results reported CNS disease in less than (5%) with predominance among the HR group^{22, 23}. While for the patients in the current study, we found CNS disease in 9 patients (11.3%) most of them were of B precursor ALL subtype, which is approaching the results of Hussein *et al.*¹³ who reported CNS disease in 14/154 patients (9%) and was strikingly higher than results of Lustosa de Sousa *et al.* (6.5%) and Tantawy *et al.* (5.8%) which may be due to the difference in the percent of HR group between these studies^{12, 14}. This lower incidence of CNS leukemia in developed countries may be due to the inclusion of a larger sample size used in the international studies and higher accuracy of techniques used in the diagnosis of CNS disease.

Initial TLC ($< 50 \times 10^9/L$) was reported in the majority of patients (60.7%), but unfortunately, this

was less than Shibl *et al.* (69%) and much lower than Shen *et al.* (83%)^{7, 17}. Leukocytosis ($50-100 \times 10^9/L$) and hyperleukocytosis ($>100 \times 10^9/L$) were recorded as 25.3% and 13.9% respectively which is similar to the results of the Multi-Institutional International Collaborative Study (CALLME1) by the Middle East Childhood Cancer Alliance (MECCA) 21 but it was higher than reported by SJCRH, Berlin-Frankfurt-Munster (BFM-95) and Nordic Society of Pediatric Hematology and Oncology (NOPHO ALL2008) studies^{10, 23, 24}. This difference may be due to delayed diagnosis as long as a higher percentage of the HR group in our study. B precursor ALL predominated among patients presented with TLC ($<50 \times 10^9/L$) and ($50-100 \times 10^9/L$) by (65.5%) and (27.3%), but T-ALL constituted the majority of patients with hyperleukocytosis ($>100 \times 10^9/L$) (29.2%) with significant difference ($P=0.035$), similar to the study of¹³.

Regarding the response post-induction, induction remission was reported in 87.4% of patients, which was slightly higher than the results of Shen *et al.* in which CR was reported to be 86%¹⁷. Induction failure was recorded in 5% of the patients, which was slightly lower than Hussein *et al.* (6.5%) and much higher than SJCRH (2%)^{10, 13}, this relatively higher incidence of induction failure in our study and NCI may be due to modifications done to the original protocol.

Early response was assessed as one of the prognostic factors, by CBC with differential count on D8 induction, as there was no ability to perform BMA d15 or MRD to all patients during the induction phase which was carried out and reported in the original protocol. The majority of our patients were GR (87.4%). On studying the relation between early response on D8 and remission induction, 30% of PR did not achieve CR post-induction versus only 1.6 % of GR with a significant difference ($P= 0.001$) which was consistent with²⁵.

Treatment failure was reported in 40.5% of the patients, which is the same as the study of Shibl *et al.* in Upper Egypt and lower than Abdelmabood *et al.* and Alecsa *et al.*^{7, 26, 27}, and higher than reported in SJCRH, BFM-95 and NCI^{10, 15, 24}. This higher percentage of relapse may be due to the higher percentage of HR group in our patients.

Deaths encountered 39% of patients which was greatly higher than reported in developed countries^{14, 20}. Induction deaths occurred in 6 patients (7.6%), and deaths in CR were encountered in 6/79 patients (7.6%), which was slightly higher than Sidhom *et al.*¹⁵. These higher induction and remission mortality

rates of patients in the current study could be attributed to the increased rates of infections, sepsis, and MTX toxicity due to defective infection control programs and supportive care facilities.

Unlike Pui *et al.*, Winter *et al.* and Surapolchai *et al.*²⁸⁻³⁰, no second neoplasms were reported in our study, which may be due to the reduction of the dose of vepesid used in the modified TXIIB ALL protocol adopted from SJCRH in our institution or due to short period of follow up and small sample size.

About 60% of the patients achieved CCR, this was comparable with many reports^{18, 26}, but it was much lower than the results of European and North American studies^{10, 23, 31}.

The median follow-up for our patients was 42 months ranging between 8-72 months. The 4-years OS, EFS and DFS were $64.1 \pm 5.6\%$, $57.0 \pm 5.7\%$ and $63.3 \pm 5.8\%$ respectively. These low survival rates can be explained by high relapse and death rates in our study which was comparable with many reports from developing countries (Mexico, sub-Saharan Africa, India) and also from Egypt^{26, 32-35} but it much lower than SJCRH (5-year EFS was $80.8\% \pm 2.6\%$), BFM-95 (6-year EFS was $79.6\% \pm 0.9\%$), Medical Research Council United Kingdom (MRC UK) (5-year EFS was $87.3\% \pm 1.2\%$) and Children Oncology Group (COG) (6-year EFS was $79.6\% \pm 1.6\%$)^{10, 24, 36}.

Univariate analysis of the prognostic factors showed that leukocytosis and response to induction were the only factors that showed significant unfavorable effects on EFS and DFS. This is nearly similar to Lustosa de Sousa *et al.*¹⁴ who also found that TLC and age have significant effects on EFS. Also, it was consistent with Al-Sudairy *et al.*³⁷ who found hyperleukocytosis to have a significant effect on EFS.

Conclusions

The modified TXIIB protocol of SJCRH was effective in improving ALL outcomes in our center, however, survival rates were much lower than internationally reported results with only initial TLC and response postinduction having a significant effect on EFS and DFS. Also, the majority of the patients were diagnosed as HR, with high relapse and death rates. Our recommendations are to improve our health care facilities, regarding diagnostic tools, supportive care measures, and infection control programs.

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Authors' contribution

Conception or design: All authors; Acquisition, analysis, or interpretation of data: All authors; Drafting or revising the manuscript: All authors; Approval of the manuscript version to be published: All authors; Agreement to be accountable for all aspects of the work: All authors.

Conflict of interest

The authors declare that they have no conflict of interest to disclose.

Data availability

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

Ethical considerations

This study was approved by the Institutional Review Board of South Egypt Cancer Institute, Assiut, Egypt (Approval No. 233).

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Study registration

Not applicable.

References

- Inaba H, Greaves M, Mullighan CG. Acute lymphoblastic leukemia. *Lancet*. 2013;381(9881):1943-1955.
- Irving J, Jesson J, Virgo P, et al. Establishment, and validation of a standard protocol for the detection of minimal residual disease in B lineage childhood acute lymphoblastic leukemia by flow cytometry in a multi-center setting. *Haematologica*. 2009;94(6):870-874.
- Pui CH, Yang JJ, Hunger SP, et al. Childhood acute lymphoblastic leukemia: Progress through collaboration. *J Clin Oncol*. 2015;33(27):2938-2948.
- Sitairesmi MN, Mostert S, Schook RM, Sutaryo, Veerman AJP. Treatment refusal and abandonment in childhood acute lymphoblastic leukemia in Indonesia: An analysis of causes and consequences. *Psychooncology*. 2010;19(4):361-367.
- Kulkarni KP, Arora RS, Marwaha RK. Survival outcome of childhood acute lymphoblastic leukemia in India: a resource-limited perspective of more than 40 years. *J Pediatr Hematol Oncol*. 2011; 33(6): 475-479.
- Smith M, Arthur D, Camitta B, et al. Uniform approach to risk classification and treatment assignment for children with acute lymphoblastic leukemia. *J Clin Oncol*. 1996;14(1):18-24.
- Shibl A, Sayed HA, Ali AM, Mohamed DO, Abdelhamid ON. Long-term survival outcome of childhood acute lymphoblastic leukemia treated with modified TXIIB protocol at South Egypt Cancer Institute. *Int J Cancer Biomed Res*. 2021; 5(3): 121-132.
- Riehm H, Reiter A, Schrappe M, et al. [Corticosteroid-dependent reduction of leukocyte count in blood as a prognostic factor in acute lymphoblastic leukemia in childhood (therapy study ALL-BFM 83)]. *Klin Padiatr*. 1987; 199(03): 151-160.
- Yang EJ, Park KM, Lee JM, et al. Treatment outcome of pediatric acute lymphoblastic leukemia in Yeungnam region: Multicenter retrospective study of Study Alliance of Yeungnam Pediatric Hematology-Oncology (SAYPH). *Pediatr Hematol Oncol*. 2018; 35(4): 276-287.
- Pui CH, Sandlund JT, Pei D, et al. Improved outcome for children with acute lymphoblastic leukemia: Results of Total Therapy Study XIII B at St. Jude Children's Research Hospital. *Blood*. 2004; 104(9): 2690-2696.
- National Cancer Institute. Common Terminology Criteria for Adverse Events. 2009. Available from: https://evs.nci.nih.gov/ftp1/CTCAE/CTCAE_4.03/Archive/CTCAE_4.0_2009-05-29_QuickReference_8.5x11.pdf.
- Tantawy AAG, El-Rashidy FH, Ragab IA, Ramadan OA, El-Gaafary MM. Outcome of childhood acute lymphoblastic leukemia in Egyptian children: A challenge for limited health resource countries. *Hematology*. 2013; 18(4): 204-210.
- Hussein H, Sidhom I, Naga SA, et al. Outcome and prognostic factors of acute lymphoblastic leukemia in children at the National Cancer Institute, Egypt. *J Pediatr Hematol Oncol*. 2004; 26(8): 507-514.
- Lustosa de Sousa DW, de Almeida Ferreira FV, Cavalcante Félix FH, de Oliveira Lopes MV. Acute lymphoblastic leukemia in children and adolescents: Prognostic factors and analysis of survival. *Rev Bras Hematol Hemoter*. 2015; 37(4): 223-229.
- Sidhom IA, Mokhles A, Soliman S, et al. Outcome of risk-adapted therapy for pediatric acute lymphoblastic leukemia in Egypt. *J Clin Oncol*. 2013; 31(15_suppl):10044-10044.
- Rajalekshmy KR, Abitha AR, Anuratha N, Sagar TG. Time trend in frequency of occurrence of major immunophenotypes in paediatric acute lymphoblastic leukemia cases as experienced by Cancer Institute, Chennai, south India during the period 1989-2009. *Indian J Cancer*. 2011; 48(3): 310-315.
- Shen S, Cai J, Chen J, et al. Long-term results of the risk-stratified treatment of childhood acute lymphoblastic leukemia in China. *Hematol Oncol*. 2018; 36(4): 679-688.
- AbdelHamid ON; Ali AM; Sayed DM, Ghazaly MM. Impact of the Clinicolaboratory Characteristics on the Treatment Outcome of the Pediatric Patients with Acute Lymphoblastic Leukemia at South Egypt Cancer Institute. *SECI Oncol*. 2015; 3(2): 55-63.
- Hutter JJ. Childhood leukemia. *Pediatr Rev*. 2010; 31(6): 234-241.
- Al Omari A, Hussein T, Albarrak K, et al. Clinical characteristics and outcomes of acute lymphoblastic

- leukaemia in children treated at a single tertiary hospital in Riyadh, Saudi Arabia. *J Heal Spec.* 2018 ;6(1) :14-14.
21. Al-Mulla NA, Chandra P, Khattab M, et al. Childhood acute lymphoblastic leukemia in the Middle East and neighboring countries: A prospective multi-institutional international collaborative study (CALLME1) by the Middle East Childhood Cancer Alliance (MECCA). *Pediatr Blood Cancer.* 2014; 61(8): 1403-1410.
 22. Heerema-McKenney A, Cleary M, Arber D. Pathology and molecular diagnosis of leukemias and lymphomas. In: Pizzo PA, Poplack DG. (eds). *Principles and Practice of Pediatric Oncology.* 7th ed. Philadelphia: Lippincott Williams & Wilkins, 2015
 23. Toft N, Birgens H, Abrahamsson J, et al. Results of NOPHO ALL2008 treatment for patients aged 1-45 years with acute lymphoblastic leukemia. *Leukemia.* 2018; 32(3): 606-615.
 24. Möricke A, Reiter A, Zimmermann M, et al. Risk-adjusted therapy of acute lymphoblastic leukemia can decrease treatment burden and improve survival: Treatment results of 2169 unselected pediatric and adolescent patients enrolled in the trial ALL-BFM 95. *Blood.* 2008; 111(9): 4477-4489.
 25. Lauten M, Möricke A, Beier R, et al. Prediction of outcome by early bone marrow response in childhood acute lymphoblastic leukemia treated in the ALL-BFM 95 trial: Differential effects in precursor B-cell and T-cell leukemia. *Haematologica.* 2012; 97(7): 1048-1056.
 26. Abdelmabood S, Fouda AE, Boujettif F, Mansour A. Treatment outcomes of children with acute lymphoblastic leukemia in a middle-income developing country: high mortalities, early relapses, and poor survival. *J Pediatr (Rio J).* 2020; 96(1): 108-116.
 27. Alecsa M-S, Moscalu M, Trandafir L-M, Ivanov A-V, Rusu C, Miron I-C. Outcomes in pediatric acute lymphoblastic leukemia—A single-center Romanian experience. *J Clin Med.* 2020; 9(12): 4052.
 28. Pui C, Pei D, Sandlund J, et al. Long-term results of St. Jude total therapy studies 11, 12, 13a, 13b, and 14 for childhood acute lymphoblastic leukemia. *Leukemia.* 2010; 24(2): 371-382.
 29. Winter SS, Dunsmore KP, Devidas M, et al. Improved survival for children and young adults with t-lineage acute lymphoblastic leukemia: Results from the Children's Oncology Group AALL0434 methotrexate randomization. *J Clin Oncol.* 2018; 36(29):2926-2934.
 30. Surapolchai P, Anurathapan U, Sermcheep A, et al. Long-term outcomes of modified St. Jude Children's Research Hospital total therapy XIII B and XV protocols for Thai children with acute lymphoblastic leukemia. *Clin Lymphoma Myeloma Leuk.* 2019; 19(8): 497-505.
 31. Larsen EC, Devidas M, Chen S, et al. Dexamethasone and high-dose methotrexate improve outcome for children and young adults with high-risk B-acute lymphoblastic leukemia: A report from Children's Oncology Group study AALL0232. *J Clin Oncol.* 2016; 34(20): 2380-2388.
 32. Halalshah H, Abuirmeileh N, Rihani R, Bazzeh F, Zaru L, Madanat F. Outcome of childhood acute lymphoblastic leukemia in Jordan. *Pediatr Blood Cancer.* 2011; 57(3): 385-391.
 33. Togo B, Traore F, Doumbia AK, et al. Childhood acute lymphoblastic leukemia in sub-Saharan Africa: 4 years' experience at the pediatric oncology unit Bamako, Mali. *J Child Adolesc Heal.* 2018; 2(02): 45-47.
 34. Arora RS, Arora B. Acute leukemia in children: A review of the current Indian data. *South Asian J Cancer.* 2016; 5(3): 155-160.
 35. Jiménez-Hernández E, Jaimes-Reyes EZ, Arellano-Galindo J, et al. Survival of Mexican children with acute lymphoblastic leukemia under treatment with the protocol from the Dana-Farber Cancer Institute 00-01. *Biomed Res Int.* 2015; 2015: 576950.
 36. Inaba H, Mullighan CG. Pediatric acute lymphoblastic leukemia. *Haematologica.* 2020; 105(11): 2524-2539.
 37. Al-Sudairy R, Al-Nasser A, Alsultan A, et al. Clinical characteristics and treatment outcome of childhood acute lymphoblastic leukemia in Saudi Arabia: A multi-institutional retrospective national collaborative study. *Pediatr Blood Cancer.* 2014; 61(1): 74-80.