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Flowcytometry Immunophenotyping: Role in Acute Leukemia and Detection of Aberrant Expressions in the Indian Population

Namrata Singh [a++*], Sanjay Gohil [a#], Jyothi Mathias [a†], Reshma Haryan [a‡], Shamika Dhole [a^], Shibani Ramchandran [b##], Raj Jatale [b#^] and Kirti Chadha [b§]

[a] Department of Hematology, Metropolis Healthcare Ltd, Mumbai, India.
[b] Metropolis Healthcare Ltd, Mumbai, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Aim: To study the distribution of Acute Leukemia cases, and the expression of commonly used Cluster of Differentiation (CD markers) in sub-classification of Acute Leukemia and aberrant expression of these markers.

[++] Consultant Pathologist;
[#] Scientific Business Head;
[†] Operations Manager;
[‡] Operations Supervisor;
[^] Senior Scientific Officer;
[##] Medical Writer, Medical Affairs;
[#^] Biostatistician, Medical Affairs;
[§] Chief Scientific Officer;
**Corresponding author: E-mail: namrata.singh@metropolisindia.com;*

Methods: The retrospective study was conducted at a Global Reference Lab in Mumbai from January 2017 to December 2021 on 1538 Acute Leukemia cases diagnosed based on 20% & more blasts on morphology and Flowcytometry immunophenotyping.
Results: Out of 1538 Acute Leukemia(AL) cases, Acute Myeloid Leukemia (AML) was found to be more common (59.49%) than Acute Lymphoid Leukemia (ALL) (39.27%). Age distribution showed that ALL was more common in paediatric age group whereas AML was seen more common in adults and old age. In further analysis of ALL, B-ALL was found higher as compared to T-ALL. CD33 (92.74%), CD19 (100%) and CD7 (97.79%) were most sensitive markers for AML, B-cell and T-cell respectively. CD7, CD33 and CD13 were most common expressed aberrant markers found in them respectively.
Conclusion: Flowcytometry immunophenotyping is indispensable, fastest and very precise tool in defining lineage of Acute Leukemia and identification of Mixed Phenotypic Acute Leukemia (MPAL) and Undifferentiated Leukemia. Aberrant expression of markers guides for further cytogenetic and molecular studies to great extent and identification of blasts during assessment of minimal residual disease.

Keywords: Acute leukemia (AL); Acute Myeloid Leukemia (AML); Acute Lymphocytic Leukemia (ALL); Flowcytometry; aberrant markers; cluster of differentiation (CD); Mixed Phenotypic Acute Leukemia (MPAL); Minimal Residual Disease (MRD).

1. INTRODUCTION

Acute Leukemia (AL) is one of the malignant haematological disorders, which is caused by uncontrolled proliferation of abnormal hematopoietic cells. On the basis of different methods of diagnosis Acute Leukemia has been divided into different types based on morphology, antigen presentation, genetic abnormalities. In today's era with advanced targeted therapy and study of Minimal Residual Disease, just morphological differentiation is not enough and there is a need of additional information for better prediction of prognosis and treatment [1,2,3]. WHO has broadly classified Acute Leukemia into AML, ALL and MPAL on the basis of flowcytometric presentation of Cluster of differentiation (CD) on hematopoietic cells and or immature cells and presence of 20% or more blasts except those with specific recurrent genetic abnormalities [4,5]. Other than above mentioned categories, Acute Leukemia of ambiguous or undifferentiated lineage are also described [5]. Flow cytometry immunophenotyping is a technique, which measures size, granularity and antigen presentation of every single cell present in suspension [6,7]. Continuous improvement and development in multi-colour cytometers, various sample processing techniques, wide range of antibodies, soft wares, gating strategies has made Flowcytometry immunophenotyping a method of choice for analysis of case of Acute Leukemia [8]. Flowcytometric immunophenotyping not only gives timely and accurate diagnosis by assigning their lineage, which helps in management of Acute Leukemia but also tells about presence or absence of aberrancy. Aberrancy in Acute Leukemia could be presence or absence of antigen different from that seen in normal maturation or of different lineage or expression of both mature and immature markers together [4]. These aberrancies are of great help in identification of abnormal blast in treated cases and assessment of Minimal / Measurable Residual Disease (MRD). It also guides to recurrent genetic abnormality and molecular studies, initiating targeted therapies and assessing prognosis [1,8]. The current study studied the data of cases diagnosed as Acute Leukemia, the expression of some common markers in these Acute Leukemia cases and some common aberrancies observed.

2. MATERIALS AND METHODOLOGY

The blood or bone marrow EDTA or Sodium heparin samples of all pediatric (>1yr) and adult cases registered and suspected of Acute Leukemia over a period of 4 years (January 2017 to December 2021) were included for the study. Overall, 1538 cases were collected retrospectively over 4 years at Global Reference Laboratory. Acute leukemia cases diagnosed registered for Flowcytometry immunophenotyping, and fulfilling the criteria >=20% blast cells on morphology were included.

Exclusion criteria:

- Samples with <20% blast cells on morphology were excluded.
- All Mixed Phenotype Acute Leukemia cases (MPAL) were excluded.

Flowcytometric immunophenotypic analysis was done on 8-color, BD FACS CANTO II, BD FACS DIVA software.

Acute Leukemic panel procedure is divided into 3 major steps:

1. Sample processing
2. Acquisition
3. Analysis

2.1 Sample Processing

Sample processing is stain-lyse-wash and starts once pathologist sees smear. Sample received after 24 hours is verified for cell viability by using BD cell viability kit (7AAD). Cell viability should be > 80%, but in case of Acute Leukemia with lesser viability, call is taken by pathologist, taking initial gating of SSC/CD45 into consideration. Sample dilution with sheath fluid is done when count is >25000cells/cumm, on either smear examination or sample run of cell counter. In case of count <2000cell/cumm in blood sample, taking smear findings into consideration, case is discussed with clinician and if required, processing is done with buffy coat.

Cytoplasmic Staining of blood or bone marrow sample is followed as per lab SOP and protocols: Required number of falcon tubes are labelled, CD45 is added to all tubes. Respective antibodies are added in labelled tubes.

2.2 Acquisition

The process is carried out as per BD operation manual. In all the cases, 50000 cell events were achieved.

2.3 Analysis

It can be divided into Dot plots and Gating.

DOT PLOTS: A dot plot of FSC (x-axis) and SSC (y-axis). Another dot plot with CD45 (x-axis) and SSC (y-axis) and FITC (x-axis) and PE (y-axis). Then dot plots for analysis of patient sample is made keeping x-axis for FITC labelled antibodies and y-axis for PE labelled antibodies.

Gating strategies: In case of Acute Leukemia SSC/CD45, gating is used to identify blast cluster. CD45 dim positive cells are gated. Other markers applied in the panel further assess this blast cluster. Blast cluster is also identified by back gating with lineage specific marker. Every dot plot is studied and percentage positivity or negativity is reported. There is no consensus on criteria for reporting antigen expression or defining whether marker is positive or negative on the leukemia blast cell.

We report antigen expression as percentage in gated cell and summaries the result as marker positive or negative. Expression of an antigen in at least 20% leukemic cells is used as a cut off to define marker positivity and negative for equals to or less than 10%. Values falling in between are considered dim positive expression. Monoclonal Antibodies detecting human antigen is used as per kit insert BD Bioscience.

2.4 Statistical Analysis

The data were analyzed using “R Studio version 1.4.1103”. Descriptive analyses were made to obtain the frequency and percentage of Acute Leukemia classification in this given population, in addition to the characteristics of the sample Age and Gender. Comparison of Acute Leukemia classification with Age and gender was done by Chi square test. Two sided p value of less than 0.05 was considered to be statistically significant.

List 1. Markers associated with Acute Leukemia

Fluorochrome	CD Markers
V500(AmCyan)	CD45, cytoplasmicCD3
PEcy7	CD8, CD19, CD117
V450(Pacific Blue)	CD20,CD64
APC H7	sCD3, HLA-DR
PerCP	CD4, CD5, CD34
APC	CD7, CD10, CD11c, CD33
PE	CD13, CD14, cytoplasmicCD79a
FITC	CytoplasmicMPO, TDT

Abb: SSC- Side Scatter, FSC- Forward side Scatter

3. RESULTS

Out of total 1538 cases with Acute Leukemia (AL), 915 (59.49%) were Acute Myeloid Leukamia (AML) and 604 (39.27%) were Acute Lymphoid Leukamia (ALL) whereas remaining 19 (1.24%) were undifferentiated (Fig. 1).

ALL were further sub classified into B-cell ALL and T-cell ALL. Maximum cases were of B-ALL 457(75.6%) and T-ALL were 147(24.3%) (Fig. 2).

Overall] distribution of Acute Leukemia showed that proportion of males were higher than females (57.8% vs 42.42%) and maximum cases (40.51%) belonged to patients >45 years of age (Table 1).

However, in further classification of AL it was observed that ALL were seen maximum in age group of 1 to 12 years while AML were seen maximum in age group of >60 years. Frequency of ALL was higher in males 43.44% while AML was commoner among females 65.44% (Table 2).

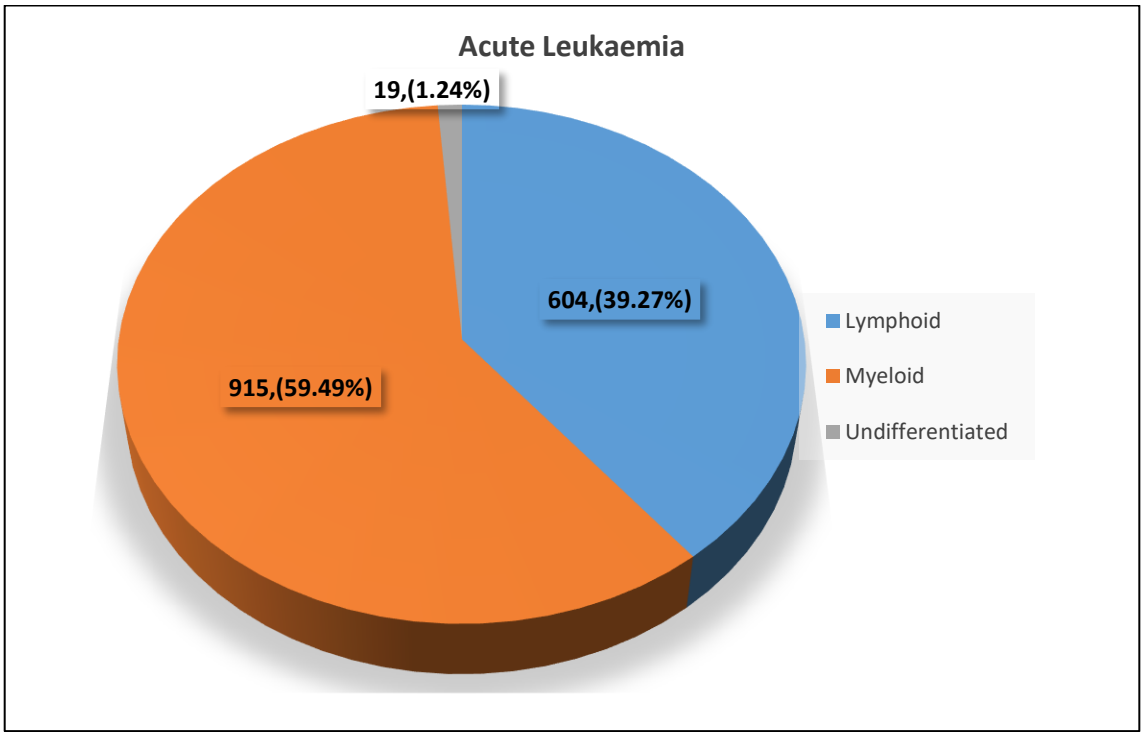

Fig. 1. Frequency distribution of Acute Leukemia classification
Data is represented as Percentage (%), Frequency (N)

Table 1. Overall distribution Age and Gender

	Frequency	Percentage
Age Group(in Years)		
1 – 12	244	15.86%
13 – 18	141	9.17%
19 – 30	246	15.99%
31 – 45	284	18.47%
46 – 60	296	19.25%
> 60	327	21.26%
Gender		
Female	654	42.52%
Male	884	57.48%

Table 2. Comparison of Acute Leukemia classification with age group and gender

	Acute Leukemia						
	Lymphoid		Myeloid		Undifferentiated		P value
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	
Age Group							
1 – 12	196	80.33%	48	19.67%	0	0.00%	
13 – 18	88	62.41%	53	37.59%	0	0.00%	
19 – 30	119	48.37%	124	50.41%	3	1.22%	<0.0001
31 – 45	88	30.99%	193	67.96%	3	1.06%	
46 – 60	65	21.96%	224	75.68%	7	2.36%	
>60	48	14.68%	273	83.49%	6	1.83%	
Gender							
Female	220	33.64%	428	65.44%	6	0.92%	0.0002
Male	384	43.44%	487	55.09%	13	1.47%	

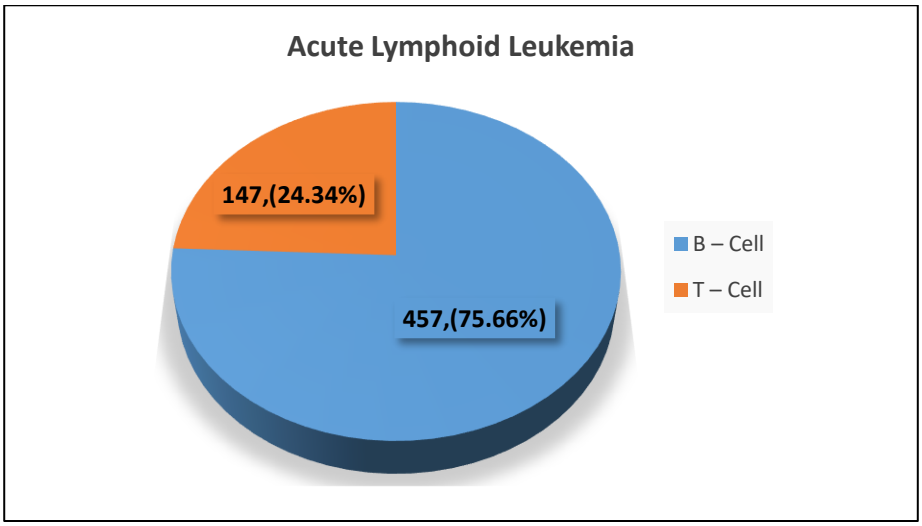

Fig. 2. Sub classification of Acute Lymphoid Leukamia
Data is represented as Percentage (%), Frequency (N)

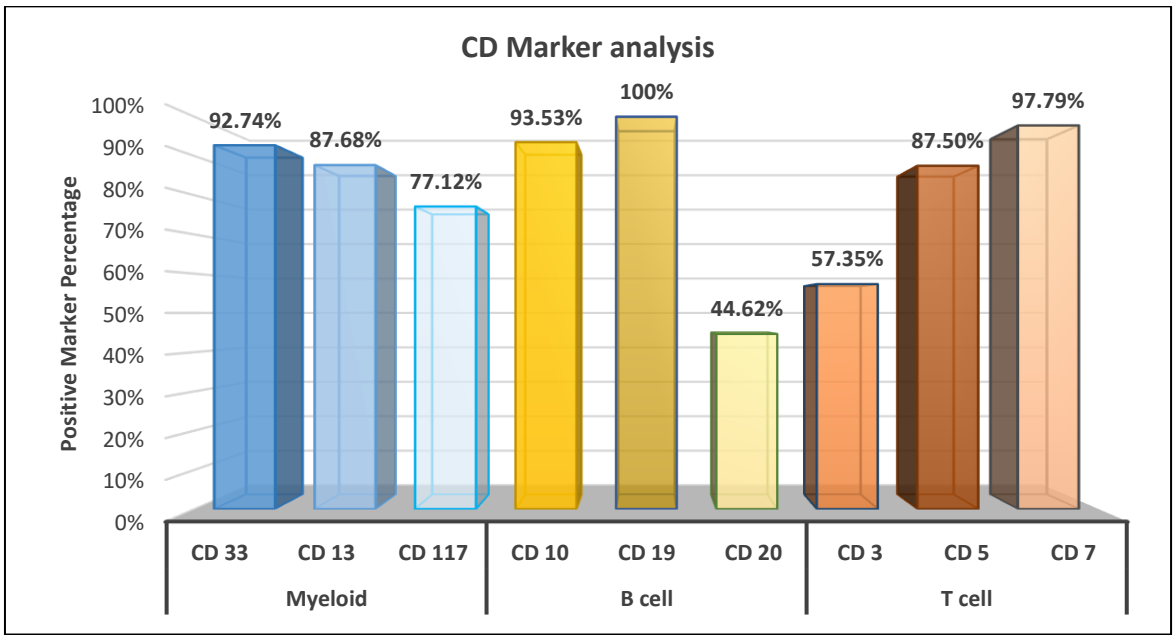

Fig. 3. CD Marker Analysis showing common positive markers

Table 3. Common aberrant markers seen

Aberrant Marker	Frequency	Percentage
CD 2	1	0.23%
CD 3	1	0.23%
CD 4	3	0.68%
CD 5	4	0.91%
CD 7	210	47.73%
CD 8	1	0.23%
CD 10	7	1.59%
CD 13	75	17.05%
CD 19	39	8.86%
CD 33	94	21.36%
CD 117	5	1.14%

CD Marker analysis for AML showed that CD33 (92.74%) was the most commonly expressed marker followed by CD13(87.68%) and CD117 (77.12 %). In B-ALL, CD19 expression is seen in all cases and CD10 (CALLA) and CD20 were expressed in 93.5% and 44.6% respectively. In T-ALL CD7 was the most frequent expression followed by CD5 and CD3. FurtherCD10 were seen expressed in 47.0% cases (Fig. 3).

Of the total AL cases, 378 cases (24.58%) has shown aberrant expression of markers (Fig. 5). With most commonly found aberrant marker in acute Leukemia was CD7 (47.73%) followed by CD33 (21.36%), CD13 (17.05%) and CD19 (8.86%) (Table 3).

In AML, CD7 (81.86%) was most aberrant marker followed by CD19 (14.77%) (Table 5).

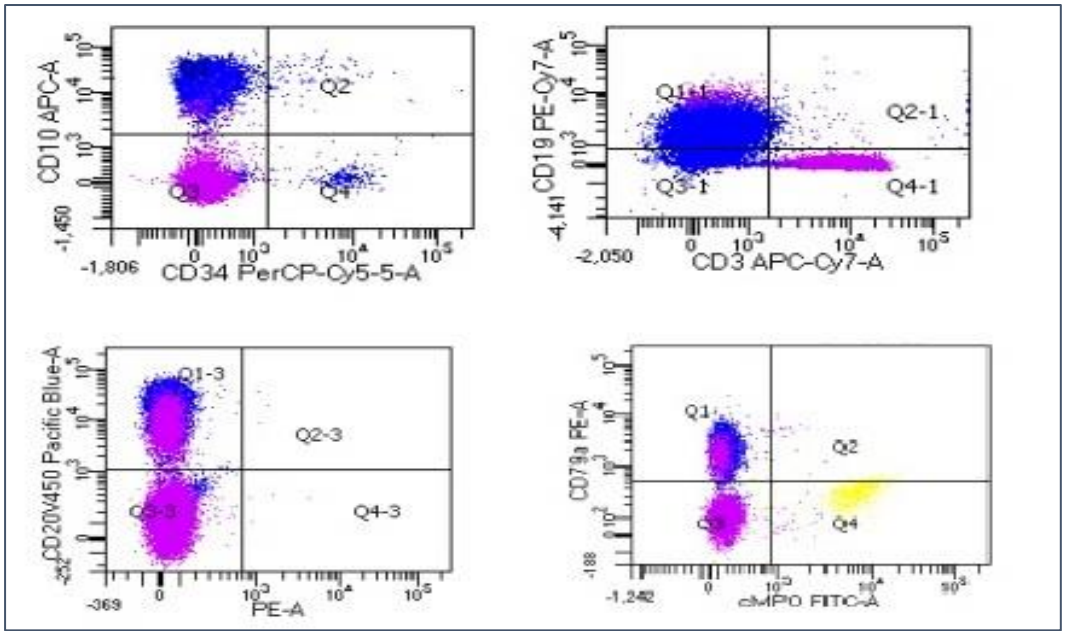

Fig. 4. Positive expression of CD19, CD10, CD20 and cytoplasmic CD79 alpha in a case of B-all. Blasts are represented with blue colour and lymphocytes with pink

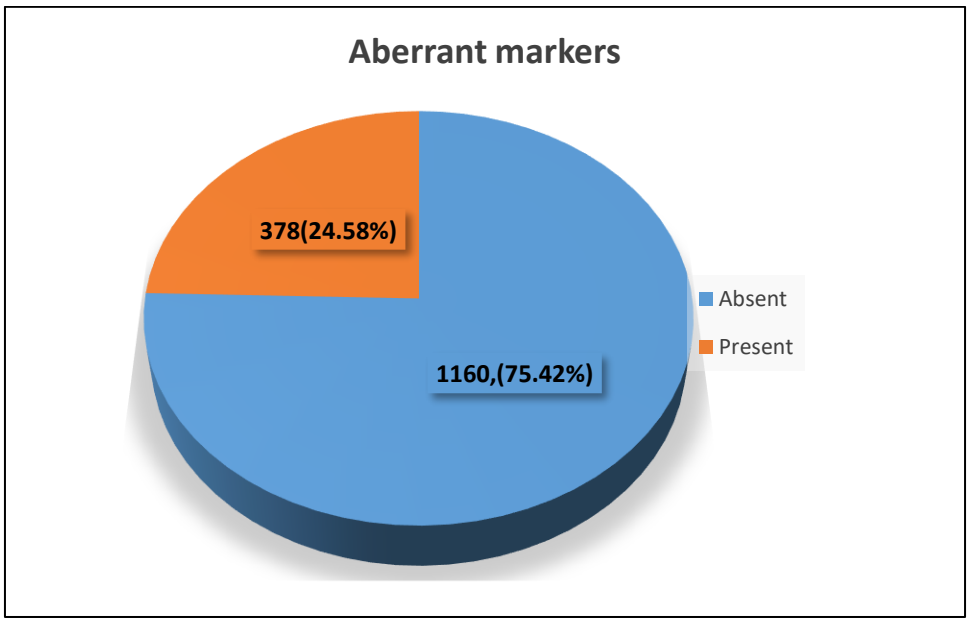

Fig. 5. Aberrant markers in AL
Data is represented as Percentage(%), Frequency (N)

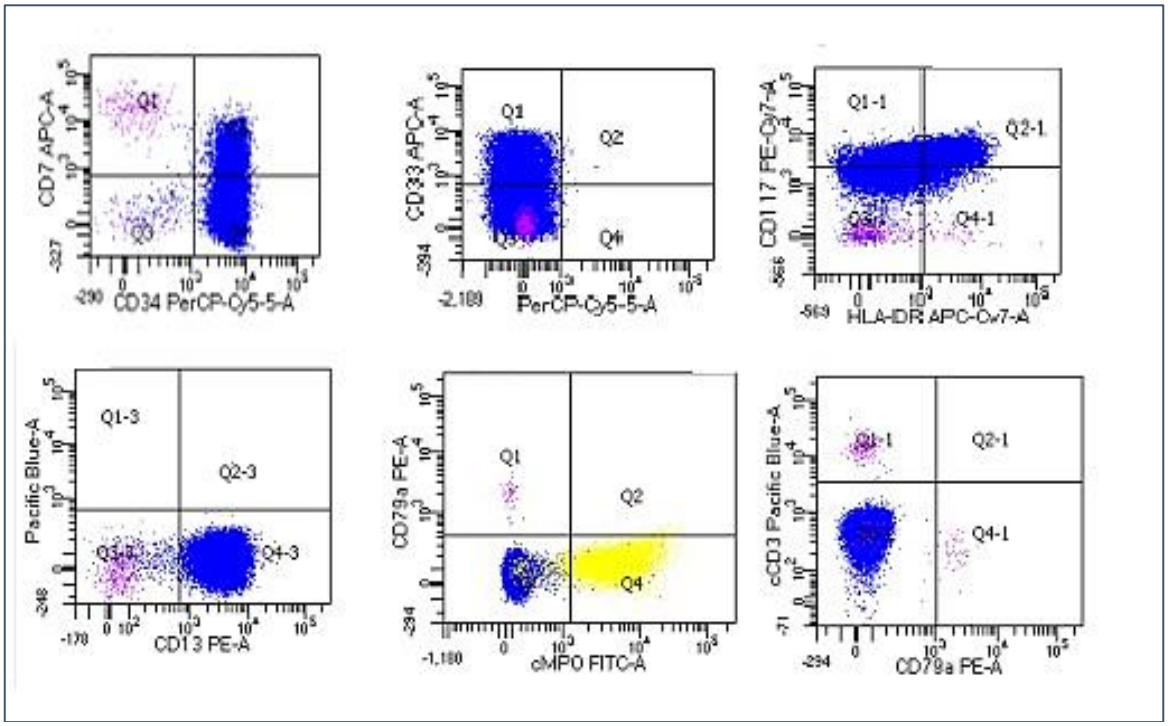

Fig. 6. Blasts (blue) showing positive expression of CD34, CD33, CD117, HLADR and CD13 and are negative for cytoplasmic MPO, cytoplasmic CD79alpha and cytoplasmic CD3 in a case of Acute Myeloid Leukemia. There myeloid blasts show aberrant expression of CD7 (CD34/CD7 plot). Lymphocytes are represented with pink colour

Table 4. Aberrant Markers in Acute Myeloid Leukemia (AML)

Aberrant markers	In Myeloid (AML)	
	Frequency	Percentage
CD 2	1	0.42%
CD 3	1	0.42%
CD 4	3	1.27%
CD 5	1	0.42%
CD 7	194	81.86%
CD 8	0	0.00%
CD 10	2	0.84%
CD 19	35	14.77%

Table 5. Aberrant Markers in T-ALL

Aberrant markers	In T-ALL	
	Frequency	Percentage
CD 13	20	50.00%
CD 19	5	12.50%
CD 33	10	25.00%
CD 117	5	12.50%

In ALL sub classification, CD33(52.83%) was most frequent aberrant marker in B-ALL followed by CD13(34.59%) and CD7(10.06%) were as in T-ALL, CD13 (50%) was most frequent aberrant marker followed by CD33(25%) and CD19, CD117 both 12.50%. (Tables 5,6).

Table 6. Aberrant Markers in B-ALL

Aberrant markers	In B-ALL	
	Frequency	Percentage
CD 2	0	0.00%
CD 3	0	0.00%
CD 4	0	0.00%
CD 5	3	1.89%
CD 7	16	10.06%
CD 8	1	0.63%
CD 13	55	34.59%
CD 33	84	52.83%
CD 117	0	0.00%

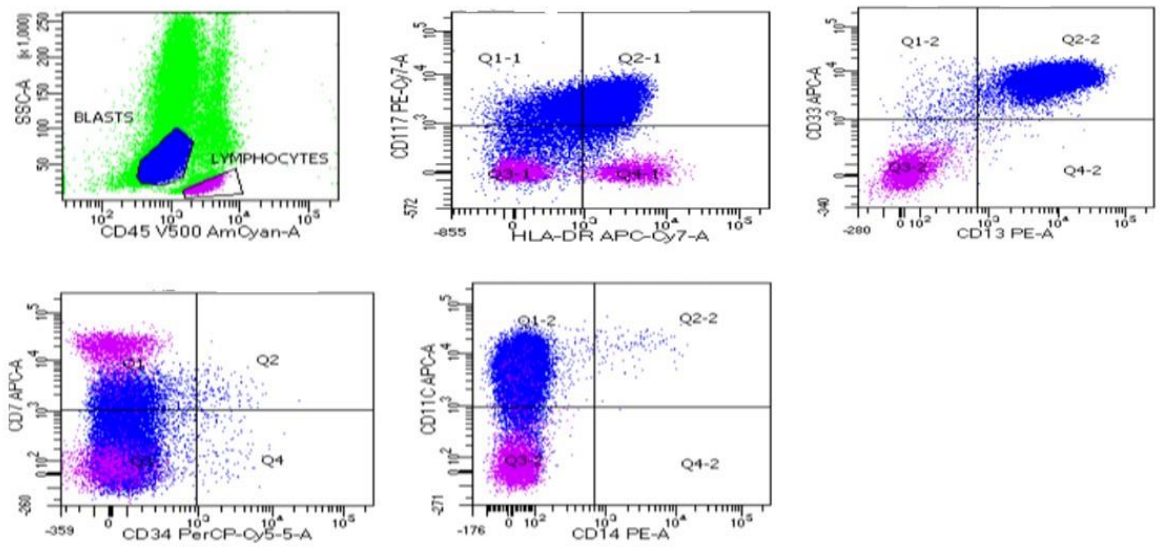

Fig. 7. Case of AML with aberrant expression of CD7

Myeloid markers (CD13, CD33, CD117, CD11c) were positive along with HLADR (stem cell marker) and CD7 (T-cell marker). Rest all markers including other T-cell markers were negative. Diagnosis made as per WHO criteria (2008), hence CD7 is considered aberrancy in AML.

4. DISCUSSION

The immunophenotyping of Acute Leukemia not only differentiates leukemia into two different types, AML or ALL but further subcategories as well. ALL into B-ALL or T-ALL. AML can also be sub-categorized into specific sub-type such as M0, M1, M2, M3, AML with monocytic differentiation or Megakaryocytic Leukemia in conjunction with morphology and availability of markers. Flowcytometry also plays an important role in diagnosing cases of Acute Leukemia with mixed phenotypes.

We studied distribution of Acute Leukemia in different age group, gender, and role of CD markers in AL. It was found that Acute Leukemia is seen in all age groups; however, its distribution varies with age. In our study we found that Acute Leukemia cases increase with increase in age with maximum cases seen in age group of >60 years followed by 46 to 60 years. On further sub-classification analysis of AL it was observed that AML had increasing trend with age group, with highest trend observed in age group of >60 years, similar to a study by Raza H et al where maximum cases were seen in patients >50 years of age [9]. Contrary to this, ALL showed a decreasing trend with respect to age, with age group 1 to 12 year showing maximum frequency of cases. In our study B-ALL was seen more in age group 1 to 12 years, a similar observation was found in study done by Seegmiller AC et al [10]. In our study, the proportion of AML cases were higher compared to ALL 57.48% vs

42.52%. This coincided with the findings by Monika Gupta et al where 43% of ALL and 53% of AML cases were observed [4]. However, Gujral S et al found higher ALL cases as compared to AML, with 58% of acute lymphoblastic Leukemia (ALL) cases and 38% of acute myeloid Leukemia (AML) cases [11]. However, ALL subtypes were similar to our study. The study done by Gujral S et al. observed 76% B cell phenotype while 24% T cell phenotype which coincide with our study finding of 75.66% in B-ALL and 24.34% in T-ALL [11].

In our study, ALL cases were more common among males (43.44%) and AML were more common among females (65.44%). In a study done by Raza et al on 120 AML patients, the percentage of males was higher as compared to females with the male to female ratio being 2:1 [9]. Some recent studies have shown some male predominance in AML cases [12], but the reason for this gender bias has been largely unknown [13]. It was observed that in B-ALL, while blasts showed CD10 expression in majority of the cases, CD10 negative B-ALL comprise 6.47% of the cases, which is similar to study conducted by Anja Möricke et al. where it was observed that 5.2% were CD10 negative [14]. In another study conducted by D.A Salem et al. also showed around 10% CD10 Negative in B-ALL cases [15]. A study done by Gujral et al. found CD10 positivity be to 43% in T-ALL cases which was similar to our finding of CD10 positivity (47.10%) in T-ALL [11]. CD19 is a Pan-B marker and is present on B cell from very early stage of maturation till completely mature B-cell formation [5,16].

WHO 2008 mentions CD19 as one of the lineages specific markers along with any two of the other B lineage specific makers like CD10, CD20, cyto CD79a, cytoCD22. We found B-ALL CD19 expression in all (100%) cases. Expression of CD20 was seen in 44.6% of B-ALL and 55.38% are CD20 negative, which matches with study done by Saghir A. Jafri [17]. In contrast to our study, Jeevan Kumar et al. mentioned 62% patients expressed CD20 while 38% patients were negative for CD20 and another study has shown 26.3% CD20 positive B-ALL [18,19]. CD34 is one of the immaturity markers and was seen in major proportion of AML cases (67.04%), B-ALL (73.95%) and some T-ALL (48.53%) which was similar with the study done by Saghir A. Jafri [17]. CD34/CD7 co-expression seen in 47.06% of T-ALL, 21.20% of AML and 3.12% of B-ALL. CD7 originate from stem cell and its expression has been seen with immaturity markers such as CD34 and HLADR [4]. Gujral S et al observed that HLADR negativity was seen mostly in T-ALL (89.63%), 37.14% of AML and only 2.23% of B-ALL [11]. We found CD33 and CD13 positivity in 92.74% and 87.68% AML and CD117 positivity seen in 76.24% of AML, similar pattern was seen in study by D.A Salem et al. which found CD33 as most commonly expressed marker (89.45%) followed by CD13 (77.9%) and CD117 (74.3%) . Their study also found that CD7 was most expressed in T-ALL followed by CD5 and CD3 [15]. Our observations were also similar, with CD7 expression seen in 97.79%, CD5 in 87.50% and CD3 in 57.35% of T-ALL. CD7 is the first T-cell marker to appear during maturation of T-cell and described as the most sensitive markers of T-cell in T-ALL in most studies [19].

Aberrant markers can be explained as the expression of markers different from its natural course of maturation for that lineage. This could be expression of marker from different lineage such as expression of myeloid markers on lymphoblastic leukemia or vice versa, or absence of marker which represent its lineage or expression of both mature and immature markers on same neoplastic cell giving asynchronous presentation (4,15,,17,19).In our study aberrancy was seen in 24.5%. of the cases. Most of these were frequently observed in AML (59.7%), followed by B-ALL (32.2%) and T-ALL (7.9%). Venugopal et al also observed highest incidence of aberrations in acute myeloid leukemia (60.7%) [20]. Few other studies have also reported the percentage of aberrancies to be highest among AML cases [21-24].

AML associated CD7 aberrancy in our study is 81.86%. In a study done by Gupta et al, out of 53 AML cases, aberrancy was seen in 14 cases (26.4%) with CD7 being the commonest [4]. Raza et al in their study on 120 AML cases also saw CD7 aberrancy in 30% cases [9]. Asif et al observed an aberrancy of 40.3% (25/62) among the total cases seen [25]. CD7 (81.86%) was found to be more frequent aberrant marker, followed by CD19 (14.7%), CD4 (1.27%), CD10 (0.84%), CD2(0.42%), CD3(0.42%), CD5(0.42%) and no aberrancy for CD8. CD7 has been seen as the most frequent marker in previous studies as well but with variable but comparable percentages [4,9].

Second most common aberrancy in AML is of CD19 (14.77%), similar to few studies [9,11,15]

and in contrast to other studies [4,13]. Aberrancy of CD19 has been found to be associated with t [8,21] AML [13,16]. Aberrancy of myeloid antigen in B-ALL is frequently seen. Most common myeloid marker observed in our study is CD33 (52.83%), followed by CD13 (34.59%). CD117 is not seen in any of our cases. Higher percentages showing similar trend have been found in another study by Sharma et al with 89% B-ALL showing CD33 expression, 53% expressed CD13 and 5% has shown CD117 (22). In contrast to our study, a study by Saghir A et al has shown very low frequency of expression of CD13 (9.09%) in B-ALL with no case showing aberrancy of CD33 [17]. Monika Gupta et al has shown frequency of CD13 (50%) and CD33 (3%) [4]. The reason for variable expression of markers could be sample size of study, age distribution, combination of antibodies and fluorochromes used. Different study has shown equal expression of CD13 and CD33 (20.7% each) and 10.3% cases with CD117 as aberrant marker in ALL [15].

In T-ALL, aberrancy of myeloid markers has been observed to be commoner than B-cell markers. Aberrancy of CD13 (50%) is higher thanCD33 (25%), followed by CD117 (12.5%) [15]. In a study by Gupta DG et al among pediatric B-ALL cases, frequency of expression of aberrant CD13 observed was 26.85%, CD33 was seen in 22.22% and CD117 in5.55% [26]. Another study has shown 1 out of 13 cases i.e. 7.6% showing CD33 expression in T-ALL and none shown positive expression of CD13 [13]. Few study findings have shown that abberrant expression of myeloid markers in ALL has been described to have poor prognosis compared to one that does not show aberrations [27,28]. In our study, expression of CD19 in T-ALL is seen in 10.26% cases in contrast to other studies, which has not shown any case with aberrant expression of CD19 in T-ALL [13].

5. CONCLUSION

In our study we found expression of markers comparable to different studies done in India & other countries with a few variations. We observed CD7 and CD19 were most common aberrant markers in AML, CD33 was common in B-ALL and CD13 in T-ALL. Also, the most sensitive lineage marker for AML is CD33, CD19 for B-ALL and CD7 for T-ALL. Flowcytometry immunophenotyping is indispensable, fastest and very precise tool in defining lineage of acute Leukemia and identification of MPAL and undifferentiated Leukemia. Aberrant expression of markers guides further cytogenetic and molecular studies to great extent and identification of blasts during assessment of Minimal Residual Disease. Our study directs evaluation of aberrant expression with genetic phenotype and prognostic and therapeutic implication.

6. STUDY LIMITATIONS

The study did not include the Mixed-phenotype Acute Leukemia cases (MPAL). The data for some CD markers were not available hence were not included for the analysis.

CONSENT

The study was conducted on data collected retrospectively. All patients sign an written consent at time of sample collection for the anonymous presentation of their data in a medical journal.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Ouyang G, Xu Z, Jiang D, Zhu H, Wang Y, Wu W, Sun Y, Sheng L, Xu K, Lou Y, Mu Q, Zhang Y, Wu N, Cheng J, Duan S. Clinically useful flow cytometry approach to identify immunophenotype in acute leukemia. The Journal of International Medical Research. 2019;47(4):1483–1492. Available:https://doi.org/10.1177/0300060518819637
2. Li W. Flow cytometry in the diagnosis of hematological neoplasms and other cancers. In: Rezaei, N. (eds) Handbook of Cancer and Immunology. Springer, Cham; 2023. Available:https://doi.org/10.1007/978-3-030-80962-1_145-1
3. Peters JM, Ansari MQ. Multiparameter flow cytometry in the diagnosis and management of acute leukemia. Archives of Pathology and Laboratory Medicine. 2011;135(1):44–54. Available:https://doi.org/10.5858/2010-0387-RAR.1

4. Gupta M, Monga L, Mehrotra D, Chhabra S, Singhal S, Sen R. --Immunophenotypic Aberrancies in Acute Leukemia: A Tertiary Care Centre Experience. Oman Medical Journal. 2021;36(1):e218.
Available:https://doi.org/10.5001/omj.2021.03
5. WHO Classification of Haematolymphoid Tumours, 5th edition; 2022.
6. Craig FE, Foon KA. Flow cytometric immunophenotyping for hematologic neoplasms. Blood. 2008;111(8):3941–3967.
Available:https://doi.org/10.1182/blood-2007-11-120535
7. Adan A, Alizada G, Kiraz Y, et al. Flow cytometry: Basic principles and applications. Crit Rev Biotechnol. 2017; 37(2):163–176.
Available:https://doi.org/10.3109/07388551.2015.1128876. Epub 2016 Jan 14. PMID: 26767547
8. Gajendra S. Flowcytometry in Acute Leukemia. Clin Oncol. 2016;1:1166.
9. Raza H, Fatima M, Noor T, et al. The Frequency of Aberrant CD7 Antigen Expression in Acute Myeloid Leukemia Patients. Cureus. 2022;14(2):e22309.
DOI: 10.7759/cureus.22309
10. Seegmiller AC, Kroft SH, Karandikar NJ, McKenna RW. Characterization of immunophenotypic aberrancies in 200 cases of B acute lymphoblastic leukemia. American Journal of Clinical Pathology. 2009;132(6):940–949.
Available:https://doi.org/10.1309/AJCP8G5RMTWUEMUU
11. Gujral S, Badrinath Y, Kumar A, Subramanian PG, Raje G, Jain H, Pais A, Kadam PSA, Banavali SD, Arora B, Kumar P, Hari Menon VG, Kurkure PA, Parikh PM, Mahadik S, Chogule AB, Shinde SC, Nair CN. Immunophenotypic profile of acute leukemia: Critical analysis and insights gained at a tertiary care center in India. Cytometry Part B. 2009;76B:199–205.
12. De-Morgan A, Meggendorfer M, Haferlach C, et al. Male predominance in AML is associated with specific preleukemic mutations. *Leukemia*. 2021;35:867–870.
Available:https://doi.org/10.1038/s41375-020-0935-5
13. Ozga M, Nicolet D, Mrózek K, et al. Sex-associated differences in frequencies and prognostic impact of recurrent genetic alterations in adult acute myeloid leukemia (Alliance, AMLCG). *Leukemia*. 2024;38: 45–57.
Available:https://doi.org/10.1038/s41375-023-02068-8
14. Möricke Anja, Ratei, Richard, Ludwig, Wolf-Dieter, Harbott, Jochen, Borkhardt, Arndt, Viehmann, Susanne, Zimmermann, Martin, Gadner, Helmut, Riehm, Hansjörg, Schrappe, Martin. Prognostic Factors in CD10 Negative Precursor B-Cell Acute Lymphoblastic Leukemia in Children: Data from Three Consecutive Trials ALL-BFM 86, 90, and 95. Blood. 2004;104:1957-1957.
DOI: 10.1182/blood.V104.11.1957.1957.
15. Salem DA, Abd El-Aziz SM. Flowcytometric immunophenotypic profile of acute leukemia: mansoura experience. Indian J Hematol Blood Transfus. 2012; 28(2):89-96.
DOI: 10.1007/s12288-011-0110-2. Epub 2011 Sep 21. PMID: 23730015; PMCID: PMC3332273.
16. Sarma A, Hazarika M, Das D, Kumar Rai A, Sharma JD, Bhuyan C, Kataki AC. Expression of aberrant CD markers in acute leukemia: A study of 100 cases with immunophenotyping by multiparameter flowcytometry. Cancer biomarkers: Section A of Disease Markers. 2015;15(4):501–505.
Available:https://doi.org/10.3233/CBM-150482
17. Saghir A. Jafri, Abdul Mannan, Aftab Nadeem, Asif Jamal. Frequency of aberrant expression of cd markers in cases of acute Leukemia. Med J Islamic World Acad Sci. 2010;18(2):55-60.
18. Kumar J, Khan AA, Saraf A, Bhargava M. Expression of CD20 in B Cell Precursor Acute Lymphoblastic Leukemia. Indian Journal of Hematology and Blood Transfusion: An Official Journal of Indian Society of Hematology and Blood Transfusion. 2014;30(1):16-18.
DOI: 10.1007/s12288-012-0216-1. PMID: 24554814; PMCID: PMC3921324.
19. Terwilliger T, Abdul-Hay M. Acute lymphoblastic leukemia: A comprehensive review and 2017 update. Blood Cancer Journal. 2017;7(6):e577.
Available:https://doi.org/10.1038/bcj.2017.53
20. Venugopalan, Radhika K, Singh, Neha, Anthony, Michael, Kunnumbrath, Arathi, Gupta, Arvind K, Nath, Uttam K, Chowdhury, Nilotpal, Chandra, Harish.

Leukemia- associated aberrant immunophenotype: A flow cytometry-based experience of 110 cases from a tertiary care center in Northern India. Journal of Cancer Research and Therapeutics. 2023;19(5):1335-1339.
DOI: 10.4103/jcrt.jcrt_809_21

21. Abdul Hamid, Gamal, Akrabi, Mayson. Aberrant Antigen Expression in Patients with Acute Leukemia in National Oncology Center Aden; 2019.
22. Sharma M, Varma N, Singh Sachdeva MU, Bose PL, Varma S. Clinical and hematological correlates of aberrant immunophenotypic profiles in adult and pediatric acute myeloid leukemia at presentation. Journal of Cancer Research and Therapeutics. 2020;16(1):105-109.
23. Mazher N, Malik N, Imran AK, Chughtai O. (2013). Aberrant expression of cd markers in acute Leukemia. Ann Pak Inst Med Sci. 2013;9(2):99-102.
24. Suggs JZ, Cruse JM, Lewis RE. Aberrant myeloid marker expression in precursor B-cell and T-cell leukemias. Experimental and Molecular Pathology. 2007;83(3):471–473.
Available:https://doi.org/10.1016/j.yexmp.2007.08.012
25. Asif Rashed, Shirin Tarafder, Humayun Sattar, Sadia Hossain. Expression of aberrant antigens in adult acute leukemia: A study in Bangladesh. International Journal of Cancer Research. 2020;16:28-34.
26. Gupta DG, Varma N, Naseem S, Sachdeva MUS, Bose P, Binota J, Kumar A, Gupta M, Rana P, Sonam P, Malhotra P, Trehan A, Khadwal A, Varma S. Characterization of Immunophenotypic Aberrancies with Respect to Common Fusion Transcripts in B-Cell Precursor Acute Lymphoblastic Leukemia: A Report of 986 Indian Patients. Turk J Haematol. 2022;39(1):1-12.
DOI: 10.4274/tjh.galenos.2021.2021.0326. Epub 2021 Oct 7. PMID: 34617433; PMCID: PMC8886275.
27. Supriyadi E, Veerman AJ, Sutaryo, Purwanto I, Vd Ven PM, Cloos J. Myeloid Antigen Expression in Childhood Acute Lymphoblastic Leukemia and Its Relevance for Clinical Outcome in Indonesian ALL-2006 Protocol. Journal of Oncology. 2012;135186.
Available:https://doi.org/10.1155/2012/135186
28. Shahni A, Saud M, Siddiqui S, Mukry SN. Expression of aberrant antigens in hematological malignancies: A single center experience. Pak J Med Sci. 2018; 34:457–62.

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