Classifying Acute Leukemia by Immunophenotyping: A Combined FAB-Immunologic Classification of AML


A panel of commercially available monoclonal antibodies and five heteroantisera were used to distinguish and subtype 138 cases of acute leukemia (AL). The immunophenotype was compared with the French-American-British (FAB) classification obtained on the cases. The immunophenotype discriminated acute myelogenous leukemia (AML) from acute lymphoblastic leukemia (ALL) and recognized cases not distinguished by cytochemistry (22% of cases), mixed lineage phenotypes (13% of cases), and cases with separate populations of lymphoblasts and myeloblasts (one case). Using the immunologic panel and derived criteria to subtype AML, correspondence of the immunophenotype to the FAB subtypes M1, M2, M4, and M5 was possible in greater than 80% of cases. A combined classification of the immunophenotype and FAB morphology/cytochemistry was devised for AML subtyping. It is recommended that immunophenotyping should be done at least in all cases with negative or inconclusive cytochemistry. At present, we suggest that until a “gold standard” for identifying leukemic subtypes is developed, the best method for typing acute leukemia is by using a combination of morphology, cytochemistry and immunophenotyping.

MATERIAL AND METHODS

Morphologic, Cytochemical and Immunological Studies

The peripheral blood and bone marrows of 138 patients (122 adults, 16 children) with acute leukemia (AL) diagnosed over 2½ years, between December 1983 and June 1986, were tested for surface membrane, cytoplasmic, and nuclear antigens and were classified by the FAB Cooperative Group classification using Wright-stained smears and cytochemical stains. Cases of chronic myelogenous leukemia (CML) in blast crisis were not included in this study. The cytochemical stains used included periodic acid Schiff (PAS), SBB, MPO, nonspecific esterase-butyrate (NSE), and in some cases chloracetate esterase (CAE) and acid phosphatase (AP). According to the number of cells available, testing was done with the monoclonal antibodies and heteroantisera shown in Table I by using immunofluorescence microscopy. The monoclonal antibodies were selected for testing on the basis of previously reported type specificity. M5 was possible in greater than 80% of cases. A combined classification of the immunophenotype and FAB morphology/cytochemistry was devised for AML subtyping. It is recommended that immunophenotyping should be done at least in all cases with negative or inconclusive cytochemistry. At present, we suggest that until a “gold standard” for identifying leukemic subtypes is developed, the best method for typing acute leukemia is by using a combination of morphology, cytochemistry and immunophenotyping.

FAB Classification

The FAB Cooperative Group classification with minor modification was used on the peripheral blood and bone marrow smears. The myeloid leukemias were subclassified according to the following criteria:

M1: Predominance of myeloblasts with <10% granulocytic differentiation.

1355

From the Leukemia Management Group, Hamilton Regional Hospitals and McMaster University, Hamilton, Ontario, Canada. Submitted March 3, 1986; accepted July 5, 1986. P.B.N. is supported by the Hamilton Civic Hospitals Research Fund.

Address correspondence to Dr Peter B. Neame, 189 Wilkson Way, Lyne Paddock, Kidlington, Oxon, England. Address reprint requests to Dr Peter B. Neame, Department of Hematology, Hamilton General Hospital, Barton Street East, Hamilton, Ontario, Canada, L8L 2X2.

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Table 1. Antibodies

<table>
<thead>
<tr>
<th>Antibody</th>
<th>Cluster Designation (CD Number)</th>
<th>Molecular Weight (kilodaltons, kd)</th>
<th>Specificity</th>
<th>Source</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leu 1</td>
<td>5, 67</td>
<td>T lineage</td>
<td>Becton Dickinson</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>T3, T4, T6, T8, T11</td>
<td>3, 4, 1, 8, 2</td>
<td>19-29, 55, 45/12, 32, 50</td>
<td>T lineage</td>
<td>Coulter Immunology</td>
<td>28</td>
</tr>
<tr>
<td>OKT9</td>
<td>NA 90</td>
<td>T lineage</td>
<td>Orthodiagnostic</td>
<td>28</td>
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<tr>
<td>B1, B2, B4</td>
<td>20, 21, 19</td>
<td>35, 140, 95</td>
<td>B lineage</td>
<td>Coulter Immunology</td>
<td>12</td>
</tr>
<tr>
<td>BA1, BA2</td>
<td>24, 9</td>
<td>45/65/65, 24</td>
<td>Call</td>
<td>Hybritech</td>
<td>29</td>
</tr>
<tr>
<td>J5</td>
<td>10</td>
<td>100</td>
<td>B lineage, monocytic, myeloblast</td>
<td>Coulter Immunology</td>
<td>7, 12</td>
</tr>
<tr>
<td>HLA-DR (la)</td>
<td>NA 29-34</td>
<td></td>
<td>Becton Dickinson</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Leu M1</td>
<td>NA NA (x-hapten)</td>
<td>Granulocytic, monocytic</td>
<td>Becton Dickinson</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>My7, My9, Mol</td>
<td>w13, NA, 11</td>
<td>160, 68-74, 155/94</td>
<td>Granulocytic, monocytic</td>
<td>Coulter Immunology</td>
<td>10, 32, 37</td>
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<tr>
<td>My4, Mo2</td>
<td>w14, w14</td>
<td>55, 55</td>
<td>Monocytic</td>
<td>Coulter Immunology</td>
<td>10, 33</td>
</tr>
<tr>
<td>AML 2.23</td>
<td>NA NA</td>
<td>Granulocytic, monocytic</td>
<td>Hybritech</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Leu M3</td>
<td>NA NA</td>
<td>Monocytic</td>
<td>Becton Dickinson</td>
<td>11</td>
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<tr>
<td>D5D6(CAML 1)</td>
<td>NA NA</td>
<td>Granulocytic, monocytic</td>
<td>UCLA Tissue Typing Lab</td>
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<td></td>
</tr>
<tr>
<td>PMN 6, PMN 29</td>
<td>NA NA, NA</td>
<td>Granulocytic</td>
<td>Hybritech</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>FMC10</td>
<td>15 NA</td>
<td>Granulocytic, pl. GP I/IIa mega-karyocytic</td>
<td>AMD-Cedarlane</td>
<td>34</td>
<td></td>
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<tr>
<td>PLT1</td>
<td>NA NA</td>
<td>Megakaryocytic</td>
<td>Coulter Immunology</td>
<td>37</td>
<td></td>
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<tr>
<td>FVIIIIR</td>
<td>NA NA</td>
<td>Megakaryocytic</td>
<td>Cappel</td>
<td>36, 38</td>
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<tr>
<td>EMcAb*</td>
<td>NA NA</td>
<td>Erythroid/Lymphoid</td>
<td>B.S. Clarke</td>
<td>McMaster University</td>
<td>39</td>
</tr>
<tr>
<td>TdT††</td>
<td>NA NA</td>
<td>Lymphoid</td>
<td>Pharmacia</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Immunoglobulin†, μ chain, kappa and lambda light chain</td>
<td>NA NA</td>
<td>B lineage</td>
<td>Tago</td>
<td>40, 41</td>
<td></td>
</tr>
</tbody>
</table>

*Erythroid monoclonal antibody—not commercially available.
†Polyclonal.
NA, Not available.

M2: More than 30% myeloblasts with >10% differentiating granulocytes, NSE <20%.  
M3: (a) Hypergranular promyelocytes with numerous Auer rods on Wright-stain or CAE. (b) A variant form showing cells with bilobed, multilobed or reniform nuclei (NSE-negative) and relative scarcity of hypergranular promyelocytes or of primitive cells with multiple Auer rods.  
M4: Monocytic cells with >20% but <80% NSE-butyrate positivity.  
M5: Monocytic cells with >80% NSE positivity. (a) Monoblastic, poorly differentiated. (b) Monocytic, differentiated.  
M6: More than 50% erythroblasts with >30% myeloblasts excluding the erythroid cells.

The criteria used for the myeloid subclassification were similar to the revised FAB classification recently published and were introduced in our laboratory in 1983 as a result of the FAB reports in 1981 and 1982 and from examination of our data.

Cell Preparation and Immunofluorescence

Monoclonal antibodies. This has been described in detail in a previous paper. In brief: after Ficoll-Hypaque gradient separation, cells were incubated for 30 minutes with the monoclonal antibody (McAb). After three washes, the cells were then incubated for 30 minutes with fluorescein-conjugated antimouse immunoglobulin. To increase the reactivity of some monoclonal antibodies (My9, My7, My4, Leu M1, PMN 6/29, and B4) biotin-conjugated antimouse immunoglobulin was used as the second antibody and for the third stage fluorescein conjugated avidin was added. After three further washes, cytospin preparations were made and examined under the fluorescent microscope.

Heteroantisera

Surface immunoglobulin. Cells were incubated with fluorescein-conjugated antihuman immunoglobulin for 30 minutes. After three washes, cytospin preparations were made and examined using a fluorescent microscope.

Cytoplasmic immunoglobulin. After fixing for five minutes in acetone, cytospin preparations of cells were incubated for 30-50 minutes with fluorescein-conjugated antihuman immunoglobulin. After three washes, the preparations were examined using a fluorescent microscope.

Terminal deoxynucleotidyl transferase. An indirect immunofluorescent assay using rabbit anti-terminal deoxynucleotidyl transferase (anti-TdT) was performed as previously described.

Criterion for all methods. Cases where more than 25% of mononuclear cells were reactive with antibody were considered positive.

Comparison of the Derived Immunophenotype with the FAB Classification

Two experienced observers independently classified (using the FAB classification as described above), randomly ordered, and
IMMUNOPHENOTYPING ACUTE LEUKEMIA

The results of the formal evaluation of the initial 105 cases coded Wright-stained smears together with their cytochemical preparations. The results of the formal evaluation of the initial 105 cases were previously recorded by the two observers as described above.

RESULTS

Comparison of the FAB Classification by the Two Observers

Of the 138 cases, there was agreement in the FAB diagnosis of 83% of the cases (113 cases). In the remaining 17% (23 cases), 15 cases showed FAB subtype differences (M1/M2 [4], M1/M5 [1], M2/M4 [2], M4/M5 [2] or L1/L2 [6]) while eight cases were unclassifiable (AUL). In 30 cases (22%), there was negative cytochemical staining. The two observers were concordant in their FAB diagnosis in 20 of these cases. Of the remaining 10 cases, eight were undifferentiated and two were minor subtype differences.

Initial Selection of Antibodies

The reagents used to type acute leukemia are shown in Table 1. Some reagents showed a lack of specificity, poor reactivity, an irregular response to differentiation, or maturation or infrequent positivity in AML and were dropped from our panel. The reagents ultimately used to immunophenotype are shown in Tables 2, 3 and 4.

Relationship Between Immunophenotype and FAB Classification in AML

The reactivity pattern of 75 cases of AML with monoclonal antibodies against myeloid differentiation antigens is shown in Table 2. It will be noted that 87% of the cases were identified by My9 and 75% by My7. Of these 75 cases, 12 were My7+ and My9+; five My7+ and My9-; and three

| Table 2. Reactivity Pattern of Acute Myeloid Leukemia with Monoclonal Antibodies |
|--------------------------------------|-----------------|-----------------|----------|-----------------|-----------------|-----------------|
| Reactivity pattern: No. positive/No. analyzed (percent positive) | My9 | My7 | Leu M1 | My4 | PMN | AML 2.23 | la |
| FAB (No.) | My9 | My7 | Leu M1 | My4 | PMN | AML 2.23 | la |
| M1 (18) | 14/17 (82) | 11/19 (65) | 0/18 (0) | 1/8 (5) | 0/10 (0) | 1/6 (17) | 9/15 (60) |
| M2 (17) | 12/15 (80) | 13/15 (87) | 15/17 (88) | 1/6 (6) | 2/10 (20) | 1/5 (20) | 7/11 (64) |
| M3 (8) | 6/6 (100) | 6/6 (100) | 3/6 (50) | 0/7 (0) | 4/6 (67) | 4/6 (100) | 1/6 (16) |
| M4 (15) | 15/15 (100) | 13/15 (87) | 13/15 (87) | 12/15 (80) | 7/13 (54) | 6/7 (86) | 14/15 (93) |
| M5 (14) | 11/13 (85) | 6/13 (46) | 13/14 (93) | 14/14 (100) | 1/9 (11) | 3/4 (75) | 13/13 (100) |
| M6 (2) | 1/2 | 1/1 | 1/1 | 0/1 | 0/1 | 0/1 | 0/1 |
| M7 (1) | 1/1 | 1/1 | 0/1 | 0/1 | 0/1 | 0/1 | 0/1 |
| Total Non-mono | 34/41 (83) | 32/40 (80) | 19/43 (44) | 2/42 (5) | 6/27 (22) | 0/6 (10) | 7/15 (49) |
| Total mono (M4, 5) | 26/28 (93) | 19/28 (68) | 26/29 (90) | 26/29 (90) | 8/22 (36) | 0/1 (0) | 7/28 (26) |
| Total AML (75) | 60/69 (87) | 51/68 (75) | 45/72 (63) | 28/71 (39) | 14/49 (29) | 15/27 (56) | 44/63 (70) |
| ALL | 6/65 (12) | 7/50 (14) | 5/47 (11) | 1/49 (2) | 0/19 (0) | 2/28 (25) | 34/44 (77) |

*Promyelocytic variant.  
†EMC> 25%.  
‡PLT1 and PLM1 > 25%.

From surveying our initial results we recognized that both My7 and My9 antibodies would be useful as an initial screen for acute myeloid leukemia. Pooling My7 and My9 antibodies was first undertaken when insufficient cells had been obtained by marrow aspirate or on peripheral blood. In 20 further cases pooled My7/My9 antibodies were compared with the results when the reagents were used individually. Using the pooled reagents, an increase in the intensity of the reaction, and sometimes in the number of positive cells, was observed in the majority of cases. In a similar manner, we now pool Leu 1 and Tll (see Table 4).

Table 2 shows that the immunophenotyping can distinguish between FAB M1 and M2. None of the 18 cases classified as FAB M1 by morphological examination were Leu M1-positive, whereas FAB M2 were positive in 15 of 17 cases (88%). The reactivity of the reagent AML 2.23 has not previously been reported in acute promyelocytic leukemia (FAB M3).
We found that all four cases of FAB M3 including a variant form gave a positive reaction with AML 2.23. All of these cases were My4- but the variant form was Ia+ in contrast to the hypergranular form which was Ia-. The combination of Ia-, AML 2.23-, and My4- was not observed in FAB M1, M2, M4, or M5.

As previously reported, My4 reacted positively in the majority (90%) of cases of FAB M4 and M5. It gave a positive reaction in only two of 42 cases (5%) classified as nonmonocytic by the FAB classification and a negative NSE reaction. In seven cases NSE-butyrate and My4 reactivity was not concordant.

Eighty-six cases which typed as AML were tested with antibodies specific for non-T lineage ALL being positive in all patients classified as ALL by the FAB classification. Eight of the cases were undifferentiated by cytochemical staining. Thirteen of 24% diagnosed as ALL by the FAB classification showed lymphoid markers and a myeloid marker on immunophenotyping (See Table 3).

By observing certain patterns using monoclonal antibodies against myeloid differentiation antigens, a myeloid immunophenotype corresponding to the FAB myeloid subclassification was recognized for M1, M2, M4, and M5 (Table 5). Figure 1 shows that by the immunophenotypic criteria, 85% of cases diagnosed as M1, 93% as M2, 81% as M4 and 100% as M5 corresponded to their appropriate FAB morphologic diagnosis. The hypergranular FAB M3 appeared to be Ia-, AML 2.23-, and My4-, but our numbers are too small to draw a firm conclusion. Criteria for the diagnosis of M6 and M7 have been published in the literature.

**Table 4. Monoclonal Antibodies for Classifying Acute Leukemia**

<table>
<thead>
<tr>
<th>First Line</th>
<th>Acute Myeloid Leukemia</th>
<th>Acute Lymphoid Leukemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>My 7/9</td>
<td></td>
<td>TdT*</td>
</tr>
<tr>
<td>Leu M1, My4, EMcAb§, Ia, PMN 6/29, AML 2.23</td>
<td>Ia</td>
<td></td>
</tr>
<tr>
<td>FVIII, PLT1 Gpllb/Illa</td>
<td>J5, cu*</td>
<td></td>
</tr>
</tbody>
</table>

§EMcAb, erythroid monoclonal antibody; not commercially available.

†Heteroantiserum.
‡Second and third line subsequently performed according to lineage established by the first line.

**Table 5. Myeloid Immunophenotypic Subclassification**

<table>
<thead>
<tr>
<th>Immunophenotype</th>
<th>M1</th>
<th>M2</th>
<th>M4</th>
<th>M5</th>
</tr>
</thead>
<tbody>
<tr>
<td>My7/9-positive, Leu M1- and My4-negative</td>
<td>17</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>My7/9-positive, Leu M1-positive, My4-negative</td>
<td>0</td>
<td>14</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Ia-negative, AML 2.23-positive, My4-negative</td>
<td>1</td>
<td>1</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>My4-positive but less than 45%</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>My4-positive greater than 55%</td>
<td>20</td>
<td>15</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Grey zone My4 (between 45-55%) and PMN 6/29-positive</td>
<td>85%</td>
<td>93%</td>
<td>81%</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Too few cases to draw a firm conclusion.

**Relationship Between Immunophenotype and FAB Classification in ALL**

As previously demonstrated, there was a lack of correlation between the FAB L1, L2 classification and the ALL immunophenotype. Furthermore, one case classified as FAB L3 showed no SIg positivity and typed as cALL (B4-, J5+, cu-, Slg+). Our immunophenotypic results with acute lymphoid leukemia correspond to those reported in the literature. The reactivity pattern with monoclonal antibodies of 51 patients classified as ALL are shown in Table 3. B4 was specific for non-T lineage ALL being positive in all patients tested, and negative in 13 cases of T-ALL. Anti-TdT was positive in all except six cases of B-ALL showing positive SIg. Because BA2 was positive in four out of nine cases of AML and two out of three cases of T-ALL, and because BA1 was considered less reliable than B4 for subtyping Null ALL, both antibodies were dropped from our panel. Twelve cases (24%) diagnosed as ALL by the FAB classification showed lymphoid markers and a myeloid marker on immunophenotyping.

**Cases With Disagreement Between the Morphological Diagnosis and the Immunophenotype**

Table 6 shows the results of 14 cases where there was disagreement between the morphologic diagnosis and the immunophenotype. Thirteen of the cases were undifferentiated by cytochemical staining. Eight of the cases were originally unclassifiable (AUL, M1, or L2) by morphology.

![Fig 1. Comparison of results of the immunophenotypic myeloid subclassification and the FAB-cytochemical classification.](image)
In the remaining six cases there had been FAB concordance but the result was in disagreement with the immunophenotype. One of these cases showed negative reactivity with all monoclonal antibodies used despite FAB M1 morphology and strong positivity with MPO and SBB. The immunophenotype included three cases with a mixed lineage phenotype and a single case with a dual population of lymphoid and myeloid cells. Two panels were devised and used in the Hamilton region (Table 4). Since its initiation, the panel has been tested prospectively on 58 AL cases. It was developed to obtain the maximum of information using the smallest number of tests. The subclassification of acute lymphoblastic leukemia by immunophenotyping is well-documented. To date all our cases of non-T-ALL have shown B4 reactivity. Null ALL was identified in the panel by reactivity with anti-TdT and B4 only, but Anderson et al. observed cases of non-T-ALL that were TdT+ and B4-. As previously reported the ALL immunophenotype did not correspond with the FAB classification.

In most previous reports using different antibodies there has been little correlation between the FAB myeloid subtypes and antigenic phenotype in AML. However, the expression of certain antigens have correlated with the FAB classification. Using our immunologic panel and derived criteria to subtype AML, correspondence of the immunophenotype to the FAB subtypes M1, M2, M4, and M5 was...
M7 >30% Blasts

<table>
<thead>
<tr>
<th>M</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>+ / - 90% Blasts</td>
</tr>
<tr>
<td>M2</td>
<td>&gt;30% Blasts with maturation</td>
</tr>
<tr>
<td>M3a</td>
<td>Multiple Auer rods (Wright-stain, CAE, or phase contrast microscopy)</td>
</tr>
<tr>
<td>M4</td>
<td>Monocytic differentiation</td>
</tr>
<tr>
<td>M5</td>
<td>Monocytic differentiation</td>
</tr>
<tr>
<td>M6</td>
<td>&gt;30% Blasts (Nonerythroid population)</td>
</tr>
<tr>
<td>M7</td>
<td>&gt;30% Blasts</td>
</tr>
</tbody>
</table>

Possible in over 80% of cases (Fig 1). Using the immunophenotype together with the FAB morphology and cytochemistry (Table 7) it is possible to obtain almost perfect concordance between observers. It should be emphasized that this scheme is based on the testing of a relatively small sample (75 AML cases). Combining FAB M1, M2, and M4 as so-called M7 is unnecessary when using the combined FAB/immunophenotypic classification as the various myeloid subtypes can be distinguished.

Should all cases of acute leukemia be immunophenotyped? A major difficulty of the FAB classification is encountered in cases with negative cytochemical staining. This was found in 30 of our 138 cases (22%). Though our two observers were concordant in 20 of these 30 cases, in five of the concordant observations there was disagreement between the concordant FAB classification and the immunophenotype. Of the remaining ten cases, eight were undifferentiated (M1 or L2). Immunophenotyping may therefore be useful in the cases with negative cytochemistry. Clarifying the diagnosis in this group of patients will allow therapy to be given according to the type of leukemia diagnosed. A controlled study will be required to ascertain whether this results in an improved therapeutic outcome. Acute mixed lineage leukemia is found in 13% of our cases and could rarely be recognized without immunophenotyping. If therapeutic outcome with standard therapy is found to be inferior to outcome in single lineage leukemia in future studies (in progress), an argument could be made for applying immunophenotyping to all cases of AL.

At this time, the immunophenotype cannot be regarded as the "gold standard" for classifying all cases of acute leukemia. Unfortunately, there is no "gold standard." To date, the most widely accepted classification system has been the FAB classification and for this reason the design of this study was to compare the immunophenotyping of acute leukemia with the FAB classification. The purpose of our paper is to provide data which may improve current systems. The process will hopefully help to establish a classification with biologic meaning or prognostic relevance; however, further controlled studies will have to be done to determine whether therapeutic decisions based upon immunophenotyping in adults improve the outcome as is possible in ALL in childhood. Such studies cannot be done until the classification is firmly established.

The possibility that the antigenic phenotyping of AML with monoclonal antibodies may identify groups which are of prognostic importance has been recently reported. A correlation with My1 reactivity and successful remission induction has been suggested. In addition, Griffin has noted a correlation of My7 reactivity with poor prognosis in AML, an observation noted previously with My4. The FAB classification has only been minimally successful in identifying groups of clinical relevance.

Following the recent introduction of probes to test for rearrangement of the immunoglobulin or T cell antigen receptor genes, it seemed that a test would be available to distinguish acute lymphoid from myeloid leukemia with certainty; however, recently immunoglobulin and T cell antigen receptor rearrangement have been noted in cases with the AML phenotype. Thus in cases with a somatic rearrangement of the immunoglobulin or T cell antigen receptor gene, acute lymphoid leukemia may be suspected but is not proven. Cases with a germ-line configuration on DNA analysis would suggest nonlymphoid leukemia. The addition of karyotyping to the morphologic and immunologic assessment should also contribute to the detailed cellular phenotype in acute leukemia.

ACKNOWLEDGMENT

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Classifying acute leukemia by immunophenotyping: a combined FAB-immunologic classification of AML

PB Neame, P Soamboonsrup, GP Browman, RM Meyer, A Benger, WE Wilson, IR Walker, N Saeed and JA McBride