Prognostic Value of Immunophenotyping in Acute Myeloid Leukemia

By Kenneth Bradstock, Jane Matthews, Elizabeth Benson, Fiona Page, James Bishop, and the Australian Leukaemia Study Group

The diagnostic and prognostic value of immunophenotyping with 18 murine monoclonal antibodies (MoAbs) to a variety of leucocyte differentiation antigens was assessed in 168 adults aged 15 to 60 years with acute myeloid leukemia (AML). Patients were entered on the multicentre Australian Leukaemia Study Group M4 protocol, and were randomized to receive either standard or high-dose Ara-C together with daunorubicin and etoposide as induction chemotherapy, followed by standard consolidation and maintenance therapy. Diagnostic bone marrow aspirate (152 cases) or peripheral blood samples (16) were analyzed by indirect immunofluorescence and flow cytometry. MoAbs used were directed at myeloid (CD11b, CD13, CD14, CD15, CD33, CD41), lymphoid (CD2, CD3, CD7, CD9, CD10, CD19), or stem cell (HLA-DR, CD34, c-kit receptor) antigens, as well as the leukocyte integrins CD18 and CD49e, and the transferrin receptor CD71. Of the myeloid markers, CD13 and CD33 were the most useful diagnostically (71% and 79% of cases positive, respectively), with CD11b, CD14, and CD15 less commonly positive. A majority of cases expressed lymphoid antigens, either T cell (CD2 16%, CD3 7%, CD7 28%) or B cell (CD10 2%, CD19 7%). CD34 was detected on 42% and c-kit receptor on 48%. When patients were analyzed for response to treatment, CD2, CD9, and CD14 were significantly associated with complete remission rate: cases expressing these antigens had a poorer response than negative cases. In univariate analysis, CD11b+ cases had shorter periods of remission (relative risk of relapse, 2.33; P = .003) and shorter survival (relative death rate, 1.97; P = .008). In multivariate analysis, adjusting for other prognostic factors, CD2 and CD11b were significantly predictive of shorter survival. No other marker had a significant predictive effect. We conclude that myeloid MoAbs are useful in confirming the diagnosis of AML, but their prognostic value may be limited to CD11b. Lymphoid antigen expression is a consistent phenomenon in a minority of cases of AML, but appears to have little clinical significance.

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entered on the trial. In 159 cases, the material analyzed was bone marrow (BM) aspirate; in 38, peripheral blood (PB) was used; whereas in 20 cases, both PB and BM were used. To exclude cases with low proportions of leukemic blast cells that might complicate the analysis, further morphologic eligibility criteria were applied to the trial. In 159 cases, the material analyzed was bone marrow aspirate or PB samples taken at diagnosis were diluted in phosphate-buffered saline and centrifuged on Ficoll-Isopaque (Pharmacia, Uppsala, Sweden). Washed mononuclear cells were re-suspended in a suitable volume of medium and incubated with predetermined amounts of MoAbs or appropriate isotype-matched negative controls, washed, then incubated with sheep antiserum to mouse Ig conjugated with fluorescein isothiocyanate (Silenus, Melbourne, Australia). MoAbs listed in Table 1 were obtained through participants (Westmead series, K. Brad- stock, Westmead Hospital, Sydney; FMC series, H. Zola, Flinders Medical Centre, Adelaide; PHM-2, W. Atkins, Prince Henry Hospital, Melbourne; CIMT, G. Pilkington, Peter MacCallum Cancer Institute, Melbourne; YB5.B8, L. Asisman, Royal Adelaide Hospi-

tal, Adelaide, Australia), or purchased commercially (B4, MY10, Coulter, Hialeah, FL; OKT-9, Johnson and Johnson, North Ryde, New South Wales, Australia). Labeled cells were examined by flow cytometry using instruments available at each institution. Results were recorded on both ungated and blast-gated populations (defined as 20% or more of cells positive above the isotype-matched negative control). Comparative analysis of 7 cases where both PB and BM were analyzed showed a low discrepancy rate (5/73 or 7%) between positive and negative results, thereby validating the use of PB cells in those cases were marrow aspirate was not available. Finally, to rule out the possibility that reactivity with CD2 and CD3 antibodies was caused by contamination with normal T lymphocytes, CD2+ and CD3+ cases were further examined to ensure an overlap of expression of these markers on the leukemic populations, as defined by the percentage of CD2+ or CD3+ cells exceeding 110%. This redefinition resulted in the reclassification of four CD2+ and four CD3+ cases.

**Immunofluorescence analysis.** Isolation of leukemic cells, staining with MoAbs, and immunofluorescence analysis by flow cytometry were performed according to a common protocol in the laboratories associated with the 25 participating centres. Briefly, heparinized marrow aspirate or PB samples taken at diagnosis were diluted in phosphate-buffered saline and centrifuged on Ficoll-Isopaque (Pharmacia, Uppsala, Sweden). Washed mononuclear cells were incubated with predetermined amounts of MoAbs or appropriate isotype-matched negative controls, washed, then incubated with sheep antiserum to mouse Ig conjugated with fluorescein isothiocyanate (Silenus, Melbourne, Australia). MoAbs listed in Table 1 were obtained through participants (Westmead series, K. Bradstock, Westmead Hospital, Sydney; FMC series, H. Zola, Flinders Medical Centre, Adelaide; PHM-2, W. Atkins, Prince Henry Hospital, Melbourne; CIMT, G. Pilkington, Peter MacCallum Cancer Institute, Melbourne; YB5.B8, L. Asisman, Royal Adelaide Hospital, Adelaide, Australia), or purchased commercially (B4, MY10, Coulter, Hialeah, FL; OKT-9, Johnson and Johnson, North Ryde, New South Wales, Australia). Labeled cells were examined by flow cytometry using instruments available at each institution. Results were recorded on both ungated and blast-gated populations (defined as 20% or more of cells positive above the isotype-matched negative control). Comparative analysis of 7 cases where both PB and BM were analyzed showed a low discrepancy rate (5/73 or 7%) between positive and negative results, thereby validating the use of PB cells in those cases were marrow aspirate was not available. Finally, to rule out the possibility that reactivity with CD2 and CD3 antibodies was caused by contamination with normal T lymphocytes, CD2+ and CD3+ cases were further examined to ensure an overlap of expression of these markers on the leukemic populations, as defined by the percentage of CD2+ or CD3+ cells exceeding 110%. This redefinition resulted in the reclassification of four CD2+ and four CD3+ cases.

**Statistical methods.** The data were analyzed with a close-out date of February 1, 1993 to prevent bias in the follow-up of patients. The status of all patients with immunophenotyping done was known at this date. All data were censored at the close-out date. The median duration of follow-up was 2.6 (range, 1.5 to 5.4) years for patients who were lost to follow-up or censored at the close-out date. Overall survival was measured from the date of randomization. All deaths were included as failures. Duration of CR was measured from the date of achieving CR to the date of relapse for patients who relapsed, or from the date of last contact or close-out for patients who did not

### Table 1. Reactivity of MoAbs With AML and Prognostic Significance

<table>
<thead>
<tr>
<th>Antibody</th>
<th>No. of Cases Tested</th>
<th>% of Cases Positive</th>
<th>Negative Reactivity</th>
<th>Positive Reactivity</th>
<th>Relative Relapse Rate* (95% CI)</th>
<th>Relative Death Rate† (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Myeloid lineage</strong></td>
<td></td>
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<tr>
<td>CD11b (WM-19)</td>
<td>120</td>
<td>40</td>
<td>81</td>
<td>69</td>
<td>2.33 (1.36-4.00)*</td>
<td>1.91 (1.21-3.01)†</td>
</tr>
<tr>
<td>CD13 (WM-15)</td>
<td>131</td>
<td>71</td>
<td>71</td>
<td>74</td>
<td>0.81 (0.46-1.44)</td>
<td>0.82 (0.52-1.31)§</td>
</tr>
<tr>
<td>CD14 (FMC-17)</td>
<td>124</td>
<td>14</td>
<td>79</td>
<td>53†</td>
<td>1.15 (0.79-3.90)</td>
<td>1.85 (1.01-3.37)‡</td>
</tr>
<tr>
<td>CD15 (FMC-13)</td>
<td>103</td>
<td>17</td>
<td>75</td>
<td>78</td>
<td>1.02 (0.50-2.11)</td>
<td>1.18 (0.64-2.16)§</td>
</tr>
<tr>
<td>CD33 (WM-53)</td>
<td>134</td>
<td>79</td>
<td>64</td>
<td>77</td>
<td>0.80 (0.41-1.55)</td>
<td>0.72 (0.44-1.18)§</td>
</tr>
<tr>
<td>CD41 (FMC-24)</td>
<td>99</td>
<td>12</td>
<td>76</td>
<td>75</td>
<td>1.41 (0.63-3.17)</td>
<td>1.44 (0.71-2.91)§</td>
</tr>
<tr>
<td><strong>T-cell lineage</strong></td>
<td></td>
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<tr>
<td>CD2 (WM-57)</td>
<td>117</td>
<td>16</td>
<td>78</td>
<td>53†</td>
<td>1.23 (0.56-2.74)</td>
<td>1.40 (0.78-2.51)§</td>
</tr>
<tr>
<td>CD3 (WM-48)</td>
<td>122</td>
<td>7</td>
<td>73</td>
<td>56</td>
<td>1.79 (0.64-4.99)</td>
<td>2.00 (0.96-4.16)§</td>
</tr>
<tr>
<td>CD7 (WM-31)</td>
<td>126</td>
<td>28</td>
<td>76</td>
<td>80</td>
<td>1.31 (0.78-2.26)</td>
<td>0.84 (0.50-1.40)†</td>
</tr>
<tr>
<td><strong>Stem cell</strong></td>
<td></td>
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<tr>
<td>HLA-DR (WM-2)</td>
<td>132</td>
<td>70</td>
<td>82</td>
<td>74</td>
<td>1.21 (0.70-2.09)</td>
<td>1.36 (0.83-2.21)†</td>
</tr>
<tr>
<td>CD34 (MY-10)</td>
<td>120</td>
<td>42</td>
<td>76</td>
<td>76</td>
<td>1.27 (0.73-2.19)</td>
<td>1.01 (0.64-1.62)§</td>
</tr>
<tr>
<td>c-kit (YB5/88)</td>
<td>80</td>
<td>48</td>
<td>83</td>
<td>74</td>
<td>0.84 (0.45-1.57)</td>
<td>0.77 (0.45-1.33)§</td>
</tr>
<tr>
<td><strong>B-cell lineage</strong></td>
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<tr>
<td>CD8 (FMC-8)</td>
<td>95</td>
<td>75</td>
<td>92</td>
<td>69†</td>
<td>1.66 (0.84-3.29)</td>
<td>1.82 (0.97-3.42)‡</td>
</tr>
<tr>
<td>CD10 (WM-21)</td>
<td>133</td>
<td>2</td>
<td>76</td>
<td>50</td>
<td>1.12 (0.97-1.29)</td>
<td>13.63 (3.09-60.01)§</td>
</tr>
<tr>
<td>CD19 (B4)</td>
<td>129</td>
<td>7</td>
<td>74</td>
<td>78</td>
<td>0.90 (0.36-2.25)</td>
<td>0.97 (0.27-1.66)§</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
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<tr>
<td>CD71 (OKT9)</td>
<td>58</td>
<td>57</td>
<td>76</td>
<td>76</td>
<td>0.79 (0.37-1.69)</td>
<td>0.71 (0.37-1.39)§</td>
</tr>
<tr>
<td>CD49e (PHM2)</td>
<td>81</td>
<td>84</td>
<td>85</td>
<td>76</td>
<td>0.61 (0.28-1.33)</td>
<td>0.66 (0.34-1.27)§</td>
</tr>
<tr>
<td>CD18 (CIMT)</td>
<td>76</td>
<td>72</td>
<td>90</td>
<td>73</td>
<td>1.40 (0.70-2.81)</td>
<td>1.22 (0.65-2.28)§</td>
</tr>
</tbody>
</table>

* Estimated relapse rates for patients with positive reactivity who achieved CR relative to patients with negative reactivity who achieved CR.
† Estimated death rate for patients with positive reactivity relative to patients with negative reactivity.
‡ P < .05 on univariate analysis.
§ P < .01 on univariate analysis.
relapse. Patients who died in CR had their response duration cen-

tered at the date of death.

Data were analyzed using BMDP statistical software.78 Survival
curves were estimated using the Kaplan-Meier product-limit method
and compared using the Cox proportional hazards model. Complete
response rates were compared using Fisher’s exact test. The progno-
sis of the 168 cases selected for analysis was compared with that of
the 133 excluded cases. There was no evidence of selection bias.
The CR rates for the 2 groups were 73% and 71%, respectively (P
= .7), and there was no significant difference in the duration of CR
(P = .11) or in overall survival distribution (P = .87). Prognostic
factors were identified using stepwise regression methods for all
eligible patients in the trial using a logistic regression model for the
probability of achieving CR and the Cox proportional hazards model
for the duration of CR and overall survival. A screening level of
significance of .01 was chosen. All major on-study factors were
tested, together with an indicator variable for the treatment arm.
Factors were treated as continuous and/or indicator variables with
breakpoints determined by univariate analyses and a review of the
relevant literature. The only significant factor identified for increas-
ing the probability of achieving CR was age less than 40. The
significant factors increasing the duration of response were treatment
with the HIDAC-37 arm and an on-study peripheral blast count less
than 10 × 10^9/L. The significant factors increasing the duration of
survival were age less than 40, an on-study white blood cell count
less than 100 × 10^9/L, and female sex. The significance of an indivi-
dual antigen adjusting for the relevant prognostic factors was calcu-
lated on the basis of the difference in the values of the likelihood
functions before and after including the antigen in a model con-
taining these factors. Two-tailed P values have been reported
throughout the text with no adjustment made for multiple compar-
isons. Results with a significance level (P value) less than .05 have
been presented as being statistically significant. However with 18
antigens studied, the screening level of significance for a single
endpoint (eg, survival duration) should be set at .0028 (0.05/18) to
ensure that the overall probability of a type I error is less than .05.
Ninety-five percent confidence intervals (CIs) have been reported
for the main results.

RESULTS

Reactivity pattern of antibodies with AML. The reactiv-
ity of the panel of MoAbs with cases of AML is presented
in Table I. Among the myeloid lineage antibodies, CD13
and CD33 were most often positive (71% and 79% of cases
positive, respectively). CD11b reacted with 40% of cases,
whereas CD14 and CD15 were positive on less than 20%. The
hemopoietic progenitor cell markers CD34 and c-kit
receptor were detected on 42% and 48%, respectively,
whereas HLA-DR was present on 70%. The platelet glyco-
protein CD41 was found on only a small percentage (12%).

A minority of cases showed expression of lymphoid line-
age markers. Apart from the high proportion of cases reac-
tive with CD9 antibody (a marker known to be present on
both normal platelets and B lymphocytes87), 2% to 28% of
cases were positive with MoAbs to T- or B-cell antigens.
CD7 was the T-cell marker most frequently detected (28%),
with 16% of cases CD2+ and 7% CD3+, whereas of the B-
cell markers, 7% of cases were CD19+ and 2% CD10+.

Of the other markers tested, the beta-1 integrin CD49e
and the beta-2 integrin CD18 were shown on most cases
(84% and 72%). The transferrin receptor CD71 was also
found on 57% of cases.

Relationship between immunophenotype and treatment
outcome. The association between phenotype and response
to initial induction therapy is shown in Table I. Only CD9,
CD14, and CD2 showed a significant association with CR
rate (P = .03, .03, and .04, respectively, in the univariate
analysis). CD14 and CD9 remained significant in the multi-
variable analysis adjusting for age (P = .02 and .01, respec-
tively), but CD2 was no longer significant (P = .11). No
other marker was predictive for achieving CR. In view of
the recent report that CD34− cases of AML respond poorly
to conventional dose therapy, but have a better response to
protocols containing high-dose Ara-C40, we examined the
group of CD34− cases for a difference in response on the
737 versus HIDAC-37 protocols. No difference in CR rate
was seen; 19 (73%) of 26 cases treated with 737 achieved
CR, whereas 19 (79%) of 24 cases treated with HIDAC-37
achieved CR (P = .7).

CD11b was the only marker that was significantly associ-
ated with shorter duration of CR (P = .003 on univariate
analysis, P = .002 adjusting for the significant on-study
factors). CD11b was also significantly associated with shorter
overall survival duration (Table I, Fig 1), both on univariate
analysis (P = .006) and multivariate analysis (P
= .003). The only other markers that were significantly pre-
dictive of shorter overall survival duration in univariate or
multivariate analysis were CD9 (P = .04 on univariate
analysis, P = .014 on multivariate analysis) and CD10 (P = .011
on univariate analysis, P = .002 on multivariate analysis),
however, only two patients were CD10+. No other marker
was predictive of survival duration.

DISCUSSION

In this large multicentre study, the diagnostic value of
MoAbs directed at myeloid and progenitor cell-related anti-
gens was similar to that described in other studies.52-58 CD13
and CD33 most frequently identified cases of AML, with
CD11b, CD14, and CD15 less diagnostically useful. Consider-
able variability in the reactivity of CD14 and CD15 MoAbs
with AML has been noted by other investigators, partly be-
cause of the known epitopic heterogeneity of these anti-
gens.59-67 The reactivity of the CD14 and CD15 antibodies
used in our study was at the lower end of the reported range,
and may have limited any clinical significance associated with
these markers. The incidence of positivity with CD34
and c-kit antibodies is similar to that previously pub-
lished.12,15,16,19,30,38 Our study also confirmed the phenomenon
of lymphoid antigen expression on a minority of cases,
within the range noted by other investigators (see review by
Drexler et al).69

The prognostic significance of immunophenotyping in
AML has been a controversial issue, with a number of con-

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been associated with a significantly low rate of CR in two studies, but not in others. There was no suggestion of an association in our study: 71% of CD13− cases achieved CR compared with 74% of CD13+ cases. CD14+ cases have been reported to have a lower CR rate in two series as well as our own, and poorer survival in two other studies. However in one of these studies, cases were divided on the basis of a second phenotype (CD14+/HLA-DR or CD14-/CD16+), whereas in the other study, survival was only significantly different when a 50% threshold was used for positivity. With this threshold, CD14 was not significantly associated with survival in our series (P = .14 in univariate analysis and P = .38 in multivariate analysis). None of the other series reported a correlation of CD14 with prognosis. CD10 has been associated with a significantly shorter duration of remission and with a shorter survival in one study; survival rates at 1 year were reported to be 54% (SE 6%) for CD11b− cases and 41% (SE 5%) for CD11b+ cases. The comparable rates in our study were 75% (SE 5%) and 54% (SE 7%), respectively. The marker with perhaps the strongest reported negative effect on CR is CD34. However, we could not confirm this finding, nor document a difference in CR rate for CD34− patients treated on protocols of different intensity, as noted by others. The expression of CD15 has been associated with an improved survival in one study, and longer remission duration in another. Although the proportion of CD15+ patients was low, we did not observe any difference in treatment outcome in CD15+ cases.

The clinical relevance of lineage infidelity, or lymphoid antigen expression, in AML has been highly controversial. Although most patients could be salvaged with alternative protocols, initial reports in pediatric AML suggested that cases expressing CD2 and CD7 antigens were biologically different to other forms of AML, and had a poor response to standard induction chemotherapy protocols. Similar findings were reported by another group. The inferior CR rate observed in CD2+ cases in our study is in keeping with these results. In contrast, Ball and colleagues described a high remission rate and improved remission duration and survival in adult AML patients expressing CD2 and/or CD19 antigens, suggesting an improved outcome for these patients. With regard to the other lymphoid-associated markers in our series, CD9 was associated with lower remission rate and poorer survival. CD9+ cases were reported to have a significantly lower response rate in one of two series, in which this marker was studied, but no reduction in overall survival has been reported before. No significant correlations of CD10 with prognosis have been reported. In our series, only two cases were CD10+. No prognostic significance of lymphoid antigen expression in adult AML was found in five other studies.

Although the results from various studies have appeared conflicting, it is possible that some antibodies are not being reported as being significant because of the relatively small sample sizes involved in the studies. For example, if a particular antigen is positive in 50% of cases studied and positivity is associated with a 50% increase in the death rate, a total sample size of 192 patients (all followed until death) would be required to have a probability (power) of 0.8 of detecting an overall survival difference between positive and negative cases using a log-rank test with a two-tailed significance level of 0.05. If only half the patients will have died at the time of a planned analysis, twice as many patients will be
needed. If the percentage of positive cases differs from 50%, even more cases will be required. On the other hand, when many different antigens are being studied and no adjustments for multiple comparisons are made, the risk of a type I (false-positive) error is greatly increased. Because many of the studies provide summary statistics only for the significant results, it is difficult to determine if there has been a consistent pattern in the results for individual antigens. More detailed reporting of results is required to enable the outcomes from various studies to be compared.

In conclusion, CD11b was the only myeloid marker with major predictive value in this large adult AML series, and it is likely that other prognostic variables such as indicators of tumor burden and cytogenetics are of greater importance. The prognostic significance of CD2 expression on leukemic myeloblasts requires further examination.

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