HUMAN T CELL γ GENES ARE FREQUENTLY REARRANGED IN B-LINEAGE ACUTE LYMPHOBLASTIC LEUKEMIAS BUT NOT IN CHRONIC B CELL PROLIFERATIONS

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Rearrangements of genes encoding the Igs and the T cell antigen receptor (TCR) are considered as useful markers for determining clonality and B or T cell line involvement in lymphoid malignancies (1-4). It has become apparent, however, that these rearrangements are not entirely specific for a given cell line, and a number of cases of Ig gene rearrangements have been documented in T cell proliferations (4, 5). More recently, rearrangement of the genes of the TCRβ chain has been found particularly in so-called non-T, non-B acute lymphoblastic leukemia (ALL) (6, 7), which is currently considered to be a clonal proliferation of cells with the same phenotype as normal B cell precursors (8). Gene rearrangements were also found in some cases of acute myeloid leukemia (AML) (9-12). The significance of these rearrangements remains unclear, but it is interesting to note that they seem to occur only in genes whose rearrangement takes place in the earliest phase of lymphoid maturation. Thus to date, in typical T cell proliferations, only rearrangement of the H chains of Igs, which precedes that of the κ and λ chains (13), has been described. Correspondingly, TCRβ gene rearrangement precedes TCRα gene rearrangement during thymic maturation (14), and currently only TCRβ gene rearrangement has been detected in B cell malignancies. These findings suggest that these rearrangements may occur in very immature cells at a stage when they still have both T and B potentiality. Beside the TCRβ and -α genes that encode the Ti proteins, a third gene termed T cell rearranging gene γ (TRGγ) or T cell γ chain gene, undergoes somatic rearrangements in T cell (15, 16). The organization of the TRGγ is largely elucidated. 9 (17) to 12 (18) variable segments (Vγ), including at least five pseudogenes, are located upstream of two strongly homologous regions, each comprising a junctional segment (Jγ) and a constant region (Cγ) (16, 19). The

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Abbreviations used in this paper: ALL, acute lymphoblastic leukemia; AML, acute myeloid leukemia; CLL, chronic lymphocytic leukemia; HCL, hairy cell leukemia; TCR, T cell antigen receptor; TRGγ, T cell rearranging gene γ.
Vγ genes can recombine with both regions Jγ1 and Jγ2 and also with a segment called JγP (17) that is located at about 4 kb in 5′ of the Jγ1 region (Fig. 1). Since TRGγ rearrangement probably precedes TCRβ gene rearrangement and can thus be seen very early in thymic maturation (20), it would appear conceivable that, analogous to the TCRβ genes, the TRGγ are frequently rearranged in B-lineage ALL. Whereas the human TRGγ structure has been extensively studied, the distribution of the rearrangements in the different cell lines has not been extensively studied. In the present study, by using a genomic probe that recognizes segments Jγ1 and Jγ2, we have shown the absence of TRGγ rearrangement in 9 cases of typical acute myeloid leukemia and 19 chronic B cell lymphoid proliferations. On the other hand, TRGγ rearrangement was noted in 18 of 22 B-lineage ALL, whereas TCRβ gene rearrangement was present in only 9 of the cases. We have also shown that TRGγ rearrangement most often involves the Jγ1 region on a single allele and thus differs from what is generally seen in T cell ALL also studied in this paper and in which the rearrangement generally involves the Jγ2 regions of both alleles. Finally, in only 2 of the 13 cases of B-lineage ALL for which the TRGγ mRNA expression was studied, 1.6-kb transcripts were seen, but the expression was very weak. No TCRβ mRNA transcription was detected in the 13 cases analyzed.

Materials and Methods

Cells. The malignant cells were separated on a Ficoll gradient and then used as is and/or after conservation in liquid nitrogen. Morphological and immunological characterization was based on the usual criteria (8, 21, 22). The surface phenotype of the malignant cells was determined by a standard method of indirect immunofluorescence and cytofluorograph reading (model 50 H; Ortho Diagnostic Systems Inc., Westwood, MA) using a large panel of mAbs that recognize T-associated or T-restricted antigens (anti-CD1 to CD5, CD7, CD8) and B-restricted antigens (CD19 to CD22). A number of other antibodies were also used (anti-CD10, OKT9, OKT10, MY7, MY9, OKM1, OKM5, antiplatelet glycoprotein Ib, IIb/IIIa, anti−MHC class II molecules DR, DP, DQ) (23). The specificity of these antibodies has been widely published. A cell population was
considered positive if >30% of the neoplastic cells reacted with the mAb. The surface phenotypes of the 22 cases of B-lineage ALL studied are summarized in Table I. The B-restricted antigen CD19 was expressed in all but one case, and the antigen CD10 (cALLA) was found in 18 cases. In none of the cases studied did the blasts express the T-restricted or associated antigens CD1, CD3, CD4, CD7, and CD8. As described further on, rearrangement of the H chains of Ig was observed in all of the cases studied. The literature contains a considerable body of evidence for assigning this type of proliferation to the B cell line (8). To describe the stages of early pre-B differentiation, we used the model of Nadler et al. (8). We also studied the phenotypes and genotypes of 19 chronic B cell malignancies (10 chronic lymphocytic leukemias (CLL) and 9 hairy cell leukemias (HCL)). The B nature of these proliferations was certified by demonstrating the expression of a single isotype of Ig L chain. In the rare cases where the cells did not express surface Ig, the presence of the molecules CD19, CD20, and CD21 was considered as sufficient evidence for assigning these proliferations to the B cell line. To compare the patterns of rearrangement of TRGγ in B cell malignancies and in T cells, T cells isolated by E rosetting from the blood of healthy donors and blast cells from 19 patients with acute T cell malignancies were also studied. The surface phenotype of these malignant cells was representative of the different stages of the thymic maturation. B-restricted antigens were not detected in any of the cases, nor were myeloid antigens (anti-MY9), whereas all the cases tested expressed the pan–T molecule CD7 (24). The CD5 molecule was expressed in 5 of 18 cases of T-ALL, 4 of which also expressed either CD4 or CD8 (Reinherz's stage III [25]). Of the CD3+ cases, seven expressed at least one of the common thymocyte antigens (stage II) and seven only pan-T markers (CD5 and CD7) (stage I or I/II). As controls, nine typical cases of AML (21) were also studied.

DNA and RNA Extraction, Southern and Northern Blots. These procedures were done according to the usual methods. High molecular weight DNA was digested by the restriction endonucleases Bam HI, Hind III, and Eco RI under conditions recommended by the manufacturer (Promega Biotec, Madison, WI). The restriction fragments were separated in 0.6% agarose gel by electrophoresis at 40 V for 24 h and were transferred onto a hybridization membrane (Hybond-N; Amersham Corp., Arlington Heights, IL). The prehybridization and hybridization were performed at 65°C in 60X SSC (1X SSC: 0.15 M NaCl, 0.015 M sodium citrate, pH 7), 0.2% SDS, 10% (wt/vol) dextran sulfate, and sonicated denatured salmon sperm DNA at 200 μg/ml. The filters were washed for 15 min in 2X SSC, 0.2% SDS at room temperature; for 15 min in the same solution at 65°C; 30 min in 0.2X SSC, 0.2% SDS; and then 30 min in 0.1X SSC, 0.2% SDS at 65°C. The blots were autoradiographed for 2–4 d. The extraction of total mRNA was performed by the guanidium–cesium chloride method (26). The cell pellet was lysed by vortexing into 6 M guanidium isothiocyanate, 5 mM sodium citrate, 0.1 M 2-ME, and 0.5% Sarkosyl. The lysate was then centrifuged over a gradient of 5.7 M cesium chloride at 77,000 g for 16 h at 20°C. The RNA was precipitated in 70% ethanol and resuspended in diethylpyrocarbonate-treated water. 15 μg of total RNA were electrophoresed through a 1.2% agarose-formaldehyde gel and transferred to nitrocellulose or nylon membrane. The prehybridization and hybridization were performed in 4X SSPE (1X SSPE is 0.18M NaCl, 1 mM EDTA, 10 mM NaH2PO4), 0.2% SDS, 0.1% Nappi, and 5 μg/ml of heparin. The filters were washed for 1 h in 1X SSPE, 0.1% SDS and 0.5X SSPE and 0.5X SSPE, 0.1% SDS at 68°C.

DNA Probes. The TCRβ probe is a cDNA fragment specific for the constant region of the β chain of the TCR (a Bgl II/Bgl II fragment of the 4D1 cDNA [27]) kindly provided by J. L. Strominger, Cambridge, MA. The Jγ probe is a subcloned Eco RI–Hind III fragment of the MH60 Jγ clone, kindly provided by T. H. Rabbits, Cambridge, United Kingdom (16). The Cy probe is the 0.7 kb Bam HI fragment of the PHT Cy9 cDNA encoding for a VJC gene, kindly provided by J. L. Strominger (18). The entire PHT γ9 cDNA probe was used to detect the TRGγ transcripts. Ca is the 1.2 kb genomic probe C75p1.2 (28), kindly provided by T. H. Rabbits. Probes were 32P-labeled by nick translation or by oligolabeling (multiprime labeling kit from Amersham Corp.). TRGγ rearrangement was interpreted assuming a loop excision mechanism and using the
### Table I

**Surface Phenotype and Genotype of Malignant Cells from Patients with B-Lineage ALL**

<table>
<thead>
<tr>
<th>Patient</th>
<th>Blast cells</th>
<th>Surface phenotype*</th>
<th>Stage†</th>
<th>Status of IgH genes‡</th>
<th>Ty genes</th>
<th>mRNA expression</th>
<th>TCRβ genes</th>
<th>mRNA expression</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>1</td>
<td>97</td>
<td>+ + + + + + + +</td>
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<td>R/R</td>
<td>G</td>
<td>ND</td>
<td>G</td>
<td>ND</td>
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<tr>
<td>2</td>
<td>96</td>
<td>+ + + + + + + +</td>
<td>II</td>
<td>R/R</td>
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<td>ND</td>
<td>G</td>
<td>ND</td>
</tr>
<tr>
<td>3</td>
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<td>+ + + + + + + +</td>
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<td>G</td>
<td>ND</td>
</tr>
<tr>
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<td>ND</td>
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<tr>
<td>5</td>
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<td>R G/D G/R</td>
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<td>ND</td>
</tr>
<tr>
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<td>ND</td>
<td>R G/D G/R</td>
<td>ND</td>
</tr>
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<td>III-I V</td>
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<td>R 1 d d</td>
<td>ND</td>
<td>R D/D R/R</td>
<td>ND</td>
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<tr>
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<td>G</td>
<td>G</td>
<td>ND</td>
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<tr>
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<td>R/R</td>
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<td>ND</td>
<td>G</td>
<td>ND</td>
</tr>
<tr>
<td>12</td>
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<td>+ + + + + + + +</td>
<td>III</td>
<td>D/D</td>
<td>R 1 e b</td>
<td>ND</td>
<td>R G/D G/R</td>
<td>ND</td>
</tr>
<tr>
<td>13</td>
<td>88</td>
<td>+ + + + + + + +</td>
<td>III</td>
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<td>ND</td>
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<tr>
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<td>G/R</td>
<td>R J P</td>
<td>G</td>
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<td>ND</td>
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<tr>
<td>16</td>
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<td>+ + + + + + + +</td>
<td>III-I V</td>
<td>D/R</td>
<td>R 1 d i c</td>
<td>G</td>
<td>R G/D G/R</td>
<td>ND</td>
</tr>
<tr>
<td>17</td>
<td>95</td>
<td>+ + + + + + + +</td>
<td>III</td>
<td>D/D</td>
<td>R 2 c f i c</td>
<td>G</td>
<td>R D/D R/R</td>
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<tr>
<td>18</td>
<td>80</td>
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<td>G/R</td>
<td>R 1 e h</td>
<td>G</td>
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<td>19</td>
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<td>20</td>
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<tr>
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<td>+ + + + + + + +</td>
<td>Ind</td>
<td>R/R</td>
<td>R 1 a a</td>
<td>ND</td>
<td>G</td>
<td>ND</td>
</tr>
</tbody>
</table>

* Negative results and those obtained with OKT10, OKT9, and anti-MHC DQ and DP molecule antibodies are not shown. +/−, 20–50% positive cells.

† The presence of intracytoplasmic CD2 antigen (21) is indicated in parentheses.

‡ Using a Cu probe and DNA digested with Bam HI. R, rearranged; G, germ line; D, deleted.

§ Defined in Materials and Methods. J P defined in reference 17. H and E, rearranged bands observed respectively with Hind III and Eco RI (see text).
follow ing nomenclature: type 1, monoallelic Jy1 rearrangement; type 2, biallelic Jy1; type 3, monoallelic Jy2; type 4, biallelic Jy2; type 5, Jy1 on one allele and Jy2 on the other. Representative cases are shown in Fig. 2. TCRβ chain gene rearrangement was interpreted as previously described (14).

Results

TRGγ Rearrangement and Expression in B-lineage ALL. As shown in Table I, a germline configuration was found only in four cases. Of the remaining 18 cases, 10 (cases 2, 7–10, 12–14, 18, and 22) showed one rearranged band and two germline bands in DNA digested by the three restriction enzymes, which is compatible with monoallelic Jy1 or Jy2 rearrangement by loop excision (cases 12 and 22 are shown in Fig. 3). Except in cases 6 and 8, the intensity of the bands would be more suggestive of Jy1 rearrangement (a representative case is shown in Fig. 2, group 1). The noninvolvement of the Jy2 region in these eight cases was also supported by the presence of two germline bands of almost equal intensity when the same filters were hybridized with the Cy probe (e.g., Fig. 4, case 10). In Fig. 4, cases 6 and 8, the bands Hind III of 12.5 kb and Eco RI of 4.3 kb that correspond to the Cy1 region appeared less intense, and the overall results are more consistent with monoallelic Jy2 rearrangement (type 3). In Fig. 3, cases 17, 19, and 21, the presence of two rearranged bands and the disappearance of the germline band corresponding to the Jy1 region are compatible with biallelic rearrangement of Jy1 (type 2) or with Jy1 rearrangement on one allele and Jy2 on the other (type 5). Comparing band intensities for filters hybridized with the Jγ probe and the Cy probe (Fig. 4) suggests type 5 rearrangement for case 21 and type 2 for case 17. For case 19 it is not easy to distinguish between type 2 and 5. For the 5 remaining cases with rearranged bands, interpretation is more difficult, but in two instances the findings are fully consistent with the involvement of the JP region (Fig. 5). As summarized in Table I, the Jy1 region was involved in 12 of 18 cases of B-lineage ALL in which TRGγ were rearranged. This contrasts with the data obtained in the 19 T-ALL cases studied as controls. TRGγ rearrangement was observed in 18 cases. The Jy1 region was never involved and in most cases, the patterns observed were consistent with a biallelic involvement of the Jy2 region (Fig. 1 and Table II).

To analyze the rearrangement of the different Vγ segments in malignant B cell and T cell precursors and in peripheral T cells, the sizes of the rearranged bands observed using the Jy probe were compared. Six faint rearranged bands were observed in the DNA of polyclonal normal T cells upon digestion with Hind III or Eco RI enzymes. With one exception (band Eb-Hf), all the bands seen in polyclonal T lymphocytes were also found in B-lineage ALL (Fig. 3) and in T-lineage ALL (not shown). Moreover, in B-lineage ALL, two additional bands were seen, Eco RI of 4.7 kb (Ei) and Hind III of 11.5 kb (Hi). The Eh band found in B-lineage ALL but not in polyclonal T cells was also found in T-lineage ALL. Excepting band He, which may be associated with band Eb or Eh, a one-to-one relation can be established between the bands seen after digestion of DNA by Hind III and by Eco RI. For the bands Ha to He this relation is identical to the one found in T-ALL. Bands He-Ee were seen in 6 of 18 rearranged B-lineage ALL cases. The patterns for certain cases were identical (Table I).

In 13 cases, TRGγ mRNA expression was investigated. With the techniques
FIGURE 2. Germline configuration and rearrangement of Jγ genes. (G) DNA from normal granulocytes digested by Bam HI (B), Hind III (H), and Eco RI (E). (H1 and H2) The polymorphism of the Hind III site 5' upstream to the Jγ2 segment (see Fig. 1A). (Groups 1–5) The different typical patterns of Jγ rearrangement: (1) Monoallelic Jγ1 rearrangement; (2) biallelic Jγ1 rearrangement; (3) monoallelic Jγ2 rearrangement. The faint 5.2 kb Eco RI band in this case probably represents an Eco RI site relatively resistant to normal digestion; (4) biallelic Jγ2 rearrangement; (5) Jγ1 rearrangement on one allele and Jγ2 on the other.
FIGURE 3. Germline and rearranged bands in DNA digested by Hind III (H) and Eco RI (E) and hybridized with the J7 probe. (G) Germline pattern observed in DNA from normal granulocytes. (T) Normal polyclonal circulating T cells (E+ fraction). The other lanes are the samples from B-lineage ALL patients with the same case numbers as in Table I. Hα to Hf and Eα to Ef are the rearranged bands observed in the DNA of polyclonal T lymphocytes digested with Hind III and Eco RI, respectively. The rearranged bands Hı and Eı are observed in neither the polyclonal T cells nor the T-ALL cells and correspond to bands Ee and Hf, respectively.
FIGURE 4. DNA digested with Bam HI (B) and Hind III (H) and hybridized with the Cγ probe. (G) Germline pattern. As controls, T-ALL CEM cell line (T₁) and one T-ALL case (T₂) show the deletion of the Cγ₁ segment corresponding to a biallelic Jγ₂ rearrangement (type 4). The other lanes are the samples from B-lineage ALL patients with the same case numbers as in Table I. In case 16, a deletion of the Cγ₁ region is observed. The decreased intensity of the Cγ₂ band suggests a deletion of Cγ₂ region on one allele, in line with the result obtained using the Jγ probe (see Fig. 3 and text). In cases 21 and 6, the decreased intensity of the Cγ₁ band as compared with the germline pattern of each experience (case 20 and the nearer G lane) corresponds to a Jγ₂ rearrangement on one allele. In these two cases the findings obtained with the Jγ probe are consistent, respectively, with type 5 and 3 rearrangements. The absence of diminution of intensity of Cγ₁ band in the cases in which rearranged bands are seen after Jγ probing (cases 10, 15, 17, 18, and 19) is in favor of Jγ₁ or Jγ₃ involvement. In cases 4 and 20 a germline pattern was also fund using the Cγ probe. The same result was obtained using the Jγ₂ probe (data not shown).
(G) Germline band of DNA extracted from normal granulocytes and digested with Bam HI (B), Hind III (H), and Eco RI (E). In case 16 the DNA digested by the three enzymes exhibited a single rearranged band, with disappearance of the germline bands. Furthermore, the intensity of the rearranged band was weak. The disappearance of the band corresponding to the Cy1 region and reduction of the intensity of the band corresponding to the Cy2 region was also noted after hybridizing the filter with the Cy probe (Fig. 2). To check that the quantity of DNA transferred was comparable to that of other DNA present on the same filter, the filter was hybridized with the TCRβ probe. A rearranged pattern was observed with bands of comparable intensity to other cases (Fig. 7). These findings suggest rearrangement of the Jy2 region, along with deletion on the other chromosome of a region including at least Jy1 and Jy2. Since genes Tγ and TCRβ are respectively located at 7p15 and 7q35 (references 29, 30), these results imply that this probable deletion does not involve the whole of one of the two chromosomes 7. In cases 15 and 10, one and two rearranged bands, respectively, were found only in DNA digested by the Bam HI enzyme, whereas a germline pattern was seen after digestion by Hind III and Eco RI. This could reflect monoallelic (case 15) or biallelic (case 10) rearrangement involving the JP region, which has recently been described by Lefranc et al. (17). Since JP rearrangement by loop excision does not affect the Jy1 region (see Fig. 1), the persistence of two germline bands of equal intensity in DNA hybridized with the Cy probe (Fig. 4) is consistent with this hypothesis. In case 11, besides the germline bands, two rearranged bands of weaker intensity than expected for type 2 rearrangement were visible after digestion of the DNA by Hind III and Eco RI. One possibility is that this pattern is due to contamination by polyclonal T cells. This hypothesis does not seem very likely given: (a) the percentage of blasts and CD10+ cells in the sample, (b) the relatively strong band intensity, and (c) the presence of only two bands instead of the five or six expected. Another possibility is that this pattern is due to the mixture of blasts with Tγ genes in germinal configuration (for region Jy1 and Jy2), and a subclone with rearranged Tγ genes. In this case there is no evidence of a subpopulation with a distinctive membrane phenotype (data not shown). In case 5 the observed pattern is very difficult to account for by rearrangement by loop excision without a probe that recognizes the JP segment: it may be a case of JP rearrangement on one allele and Jy1 on the other.
TABLE II

T Cell and B-Lineage ALL: Comparison of TRGγ Rearrangement Patterns

<table>
<thead>
<tr>
<th>Cell line</th>
<th>Number of cases with rearrangement</th>
<th>Type*</th>
<th>Others</th>
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</thead>
<tbody>
<tr>
<td>T-ALL</td>
<td>18/19</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B-lineage ALL</td>
<td>18/22</td>
<td>8</td>
<td>1</td>
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</table>

* Type 1, monoallelic Jγ1 rearrangement; type 2, biallelic Jγ1; type 3, monoallelic Jγ2; type 4, biallelic Jγ2; type 5, Jγ1 on one allele and Jγ2 on the other.

Figure 6. Northern blots hybridized with Jγ and TCRβ probes. In addition to negative (EBV cell lines) and positive (T-ALL case) controls, two cases with weak TRGγ mRNA transcription (cases 5 and 8) and two cases with no detectable TRGγ mRNA are shown. The other cases did not express detectable TRGγ mRNA and are not shown. Transcription of TCRβ mRNA was never found in B-lineage ALL cases.

used, no TRGγ mRNA transcript was detected in 11 of the cases. Weak expression was seen in cases 5 and 8 in the form of 1.6 kb transcripts (Fig. 6). Case 5 showed stronger expression than case 8, but the expression was nevertheless far weaker than in T cell ALL used as a control.

Correlation between TRGγ Gene Rearrangement, Surface Phenotype, and Rearrangement of the Ig H Chains and TCRβ Chain Genes. In ALL, fewer stage II cases (DR+CD19+) showed rearrangement of TRGγ genes (1 of 4 cases) than did stage III cases (DR+CD19+CD10+; 1 of 16 cases). No relation was noted between TRGγ gene rearrangement and the pattern of rearrangement of the Ig H chain genes. In 9 of 22 cases, rearrangement of the TCRβ chain genes was observed. The presence of such rearrangement was not correlated with the immunological phenotype. In none of the rearranged cases did the Jβ1 region seem to be involved. Monoallelic rearrangement of the Jβ2 region was found in 5 of the 9 rearranged cases, and biallelic Jβ2 involvement in the other cases (Fig. 7). In all of the rearranged cases one or two Cβ1 regions were deleted, according to whether the Jβ2 rearrangement was mono- or biallelic. In none of the cases could TCRβ mRNA expression be detected (Fig. 6). It is interesting to note that
in all the cases (except one) with the TRGγ in germinal configuration the TCRβ genes were not rearranged.

**TRGγ and TCRβ Chain Rearrangement in AML and Chronic B Cell Proliferations.** In none of the 9 AML cases studied was TRGγ and TCRβ chain gene rearrangement found. The TRGγ were seen in germline configuration in all 19 cases of B lymphoid malignancies. The TCRβ chain genes were rearranged in one B-CLL.

**Discussion**

In this study we have demonstrated TRGγ rearrangement in 18 of 22 cases of ALL expressing surface antigens characteristic of early pre-B maturation. Rearrangement was more frequent in stage III cases DR+CD19+CD10+ according to the model of Nadler et al. (8), than in DR+CD19+ cases considered less mature.

It is unlikely that these results are due to contamination of the samples by polyclonal T cells. We have shown that as for thymocytes (17), five or six rearranged bands are detectable by Southern blotting in the DNA of polyclonal T cells after digestion by Hind III and Eco RI and hybridization with a Jγ probe (Fig. 3). In the rearranged B-lineage ALL cases, only one or two rearranged bands were found. Furthermore, the intensity of the rearranged bands was not consistent with the contamination level that would ensue from the percentage of blasts (Table 1) and of cells of T phenotype present in the samples (data not shown). Thus it is very likely that the rearranged bands detected correspond to the DNA of malignant cells. Moreover, these findings cannot be ascribed to selection of atypical cases; the blast phenotypes and the presence of rearrangement of the H chain Ig genes are in agreement with the data published in the literature (4, 8).

There were differences between the rearrangements of the TRGγ genes seen in B and T cell proliferations. We have observed that in T-ALL the rearrangements are often biallelic and involve the Jγ2 region (type 4 rearrangement). In our series of T-ALLs we did not find rearrangement of the Jγ1 segment.
However, in B-lineage ALL, TRGγ rearrangement involved the Jγ1 regions in 12 of 18 rearranged cases, whereas the Jγ2 region was involved in only 4 instances. Furthermore, the Jγ1 rearrangement was monoallelic in 8 cases. The frequent involvement of the Jγ2 region in the rearrangement of TRGγ in T cells had already been noted, one of the proposed explanations being that successive rearrangements involve first Jγ1 then Jγ2 during somatic development (31). If this hypothesis is correct, then our results, as shown in the discussion below, suggest that Jγ1 rearrangement may occur in very immature cells that still have both B and T potentiality.

As in T-ALL, the rearranged bands seen in B-lineage ALL were often of the same size in different patients. Thus bands Hc-Ee (Fig. 3) were present in 6 of 18 rearranged cases. Most of the rearranged bands seen in B-lineage ALL were also detected in T-ALLs, polyclonal T lymphocytes, and thymocytes (17), which would suggest that the same Vγ genes are implicated in the rearrangements of TRGγ. In 11 of the 13 B-lineage ALL cases investigated for mRNA expression, no TRGγ transcript was detectable. In two cases, weak TRGγ mRNA (1.6 kb) expression was noted. It is difficult to affirm that these mRNAs reflect TRGγ gene transcription by neoplastic cells or that they are due to contaminating mature T cells. It should nevertheless be noted that in these cases, and particularly in case 5, the contamination was not higher than in other cases in which no transcription was detected. Moreover, as shown by studies in mice (32), TRGγ mRNA expression in mature T cells is probably weak.

9 of the 22 B-lineage ALL cases studied exhibited TCRβ chain gene rearrangement that was not correlated with surface phenotype. The rate of rearrangement seemed slightly higher than the rate reported in a recent study (11 of 39 cases [7]). In our series we found only the Jβ2 region to be involved. This agrees with the data inferred from the report of Tawa et al. (reference 7, Table II). In all of our rearranged cases one or two Cβ1 regions were deleted, according to whether the Jβ2 rearrangement was mono- or biallelic. This would suggest that rearrangement of the Jβ2 regions is not merely Dβ2-Jβ2 joining. However, the involvement of the Vβ genes in the rearrangement of TCRβ chain genes remains to be demonstrated. In our series, TCRβ chain gene rearrangement was not accompanied by any TCRβ mRNA expression.

The significance of TRGγ and TCRβ chain gene rearrangement in B-lineage ALL remains obscure. Since no expression of these genes was detected in most cases, it is possible that mRNA transcription is inhibited by a regulation mechanism. It may be that at an early stage of lymphoid maturation, rearrangement of TRGγ, TCRβ chain genes and Ig H chain genes can occur, randomly or otherwise. This hypothesis is supported at least in part, since for the genes of the H chain of Ig and of the TCRβ chain gene, recent experiments have shown that a pre-B cell can rearrange an exogenous TCRβ Dβ1-Jβ1 fragment introduced by transfection (33). The recombination mechanism could be regulated by controlling the accessibility to non-cell line-specific recombinase usable both by B and T cells (33). Only in the cases where the rearrangement is productive does the cell inhibit rearrangement of other Ig-like genes by a mechanism analogous to allelic exclusion (34) and is thus directed towards a B or T lineage according to the gene involved.
An important point is whether TRGγ and TCRβ chain gene rearrangements can occur in normal counterparts of B leukemic cells, as has been suggested for rearrangement and expression of Ig H chain genes in mouse T cells (35, 36). Assuming that the rate of rearrangement seen in leukemic cells reflects the rate in normal cells, it is intriguing to find little TCRβ chain gene rearrangement and especially no TRGγ rearrangement in chronic B cell proliferations. It is conceivable that these rearrangements occur more easily in ALL cells. Alternatively, it may be that these rearrangements occur in normal B cell precursors but that these cells are then unable to achieve normal differentiation and/or attain sufficient expansion. Recently, it was found (37, 38) that the mechanism of translocation may be close to the mechanism of physiological rearrangement. It is possible that the transcriptional status of Ig-like genes, at particular stages of lymphoid maturation, makes them more accessible to recombinase action (33) and more exposed to some chromosomal aberrations. This could explain the frequent localization of breakpoints at the chromosome bands corresponding to the loci of Ig and TCR genes (39–42), and supplies a model, possibly of general interest, for explaining the specificity of certain chromosomal translocations with respect to the lineage involved in lymphoid malignancies and to the stage of differentiation of neoplastic cells.

Summary

T cell rearranging gene γ (TRGγ) and T cell antigen receptor β (TCRβ) chain gene rearrangement and transcription were studied in a series of patients with B-lineage acute lymphoblastic leukemia (ALL), in which the Ig H chain genes are rearranged and the surface phenotype reproduces the stages of normal pre-B maturation. For comparison, polyclonal T cells from peripheral blood of healthy donors and blast cells from 19 cases of T lineage ALL were also studied. In this study we demonstrate the presence of a clonal rearrangement of the TRGγ in 18 of the 22 B-lineage ALL cases and establish that this rearrangement, which generally involves the Jγ1 region, is often monoallelic and appears different from the biallelic Jγ2 rearrangement frequently seen in T-cell ALLs. In 9 of 22 cases, we found rearrangement of the genes of the TCRβ chain, which never involved the Jβ1 region. Conversely, the TRGγ were seen in germline configuration in all 19 cases of B chronic lymphoid malignancies. In none of the 9 AML cases studied was TRGγ and TCRβ chain gene rearrangement found. The TCRβ chain genes were rearranged in one B cell chronic lymphocytic leukemia (CLL). We also show that in B-lineage ALL, the cells probably use the same Vγ genes for TRGγ rearrangements as the malignant cells in T-ALL and the polyclonal T cells. In none of the 13 B-lineage ALL cases investigated by Northern analysis was TCRβ mRNA expression detected, whereas a weak expression of TRGγ transcripts was found in two of these cases. The correlations between surface phenotype, rearrangement of TRGγ, TCRβ, and Ig H chain genes were analyzed. The significance of rearrangement of TRGγ and TCRβ chain genes in B or pre-B cells is also discussed.
We are indebted to T. H. Rabbitts and J. L. Strominger who have supplied the DNA probes. We thank Dr. M. P. Lefranc for critical reading of this manuscript.

Received for publication 10 September 1986 and in revised form 8 December 1986.

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