CONCISE REPORT

Analysis of T-Cell Receptor Beta Chain (Tβ) Gene Rearrangements Demonstrates the Monoclonal Nature of T-Cell Chronic Lymphoproliferative Disorders

By Robin Foa, Pier-Giuseppe Pelicci, Nicola Migone, Francesco Lauria, Giovanni Pizzolo, Frances Flug, Daniel M. Knowles II, and Riccardo Dalla-Favera

We investigated the rearrangement patterns of the gene coding for the beta chain of the T cell receptor (Tβ) in 11 patients with T-cell derived chronic lymphoproliferative disorders, including T-cell prolymphocytic leukemia (T-PLL) and T-cell chronic lymphocytic leukemia (T-CLL). We found that all five cases of T-PLL, and five of six cases of T-CLL, displayed Tβ-gene rearrangements, clearly establishing their monoclonal nature. Clonality could not be determined in one case of T-CLL where the Tβ gene was found unrearranged. Our results demonstrate that the majority of cases of both clinically aggressive T-PLL and clinically indolent T-CLL are monoclonal. These results suggest that the analysis of Tβ gene rearrangements represents a valid tool for the differential diagnosis and clinical monitoring of T-cell derived chronic lymphoproliferative diseases.

© 1986 by Grune & Stratton, Inc.

T-CELL chronic lymphoproliferative disorders are well recognized clinicopathologic diseases, which include T-cell prolymphocytic leukemia (T-PLL) and T-cell chronic lymphocytic leukemia (T-CLL). T-PLL is usually characterized by clinical features suggesting a malignant process, i.e., a high WBC count, marked splenomegaly, an aggressive clinical course and a limited therapeutic response.1 T-CLL, including large granular lymphocyte (LGL) proliferations (Tγ/δ-lymphoproliferative disease, T-CLL, TLPD),2 are generally characterized by a relatively low WBC count, an indolent, nonprogressive clinical course and prolonged survival.2,3 The benign clinical course of many cases of T-CLL has led some authors2,4 to question their neoplastic nature and to recommend the term chronic T-cell lymphocytosis4 unless disease progression is demonstrable. Difficulty in determining the neoplastic or the reactive nature of these cases has stemmed from the lack of an adequate marker of clonality for T-cell populations.

Recently, DNA sequences coding for the beta chain of the T-cell receptor (Tβ) have been isolated. It has been shown that the Tβ locus undergoes structural rearrangements that precede and are necessary for Tβ gene expression in T-cells,5 analogous to immunoglobulin gene rearrangements in B-cells.6,9 We and others have demonstrated that the patterns of Tβ gene rearrangement, identified by Southern blot hybridization analysis using Tβ gene probes,10-13 can be used to identify the mono- or polyclonality of a given T-cell population.12 We used this immunogenotypic approach, in the studies described here, to demonstrate that the vast majority of T-cell chronic lymphoproliferative disorders, including clinically aggressive T-PLL and clinically indolent T-CLL, are monoclonal T-cell proliferations.

PATIENTS AND METHODS

Patients and diagnosis. We studied six cases of T-CLL and five cases of T-PLL. Diagnoses were established by conventional clinical, morphological, and phenotypic criteria. All six patients with T-CLL exhibited a benign clinical course and a moderate lymphocytosis. The cells in five patients (Table 1, cases 2 through 6) displayed typical LGL morphology, i.e., abundant azurophilic granular rich cytoplasm, and absent nucleoli. The cells in one patient (Table 1, case 1) were small, mature appearing lymphocytes, without nucleoli and without LGL morphology. All five patients with T-PLL exhibited an aggressive clinical course and a lymphocytosis of intermediate sized cells with moderately basophilic cytoplasm, vesicular nuclei, and prominent nucleoli.

Immunophenotypic analysis. Sheep erythrocyte (E) rosette formation was assayed with Vibrio Cholera neuraminidase-treated sheep erythrocytes. T-cell associated antigen expression was determined by indirect immunofluorescence using murine monoclonal antibodies OKT3, OKT4, OKT6, OKT8, OKT11, and Leu7.14 Cytoxicity assays. NK activity was measured using K562 leukemia cells as target cells, at effector to target cell (E:T) ratios ranging from 25:1 to 100:1, in a four hour 51Cr release assay. For ADCC, 11Cr-labelled TLX9 lymphoma cells, sensitized with rabbit antibody, were used as targets in a four hour test.

Gene rearrangement studies. DNA purification was performed by cell lysis, proteinase K digestion, extraction with phenol/chloroform and precipitation with ethanol.15 Fifteen micrograms of DNA extracted from each sample were digested with the appropriate restriction endonuclease, electrophoresed in a 0.8% agarose gel, denatured, neutralized, and transferred to a nitrocellulose filter as described.15 The probe used in this study is represented by a 440 base pair (bp) HindII fragment representative of the Constant region of the Tγ gene (TγC). The original clone and the generation of the probes have been described.6,17

Clinica Medica A, Istituto di Genetica Medica and Centro Nazionale Ricerche (CNR) Immunogenetica ed Istocompatibilità, University of Torino, Torino, Italy; Istituto di Ematologia “L.A. Seragnoli,” University of Bologna, Bologna, Italy; Cattedra di Ematologia, University of Verona, Verona, Italy; Department of Pathology, Pediatrics and Kaplan Cancer Center, New York University School of Medicine, New York.

Supported in part by C.N.R., Progetto Finalizzato, Oncologia Grant No. 84.00581.44 (R.F.), National Institutes of Health Grants No. CA37165, CA37295 (R.D.F.) and EY03357 (D.M.K.).

P.G.P. is supported by a Fellowship from the Italian-American Association for Cancer Research. D.M.K. is supported in part by the Cancer Research Institute, the New York State AIDS Institute (A0122), and by the Bernard and Frances Lerner Project Chai Philanthropic Trust. R.D.F. is a Scholar of the Leukemia Society of America.

Submitted July 22, 1985; accepted Sept 9, 1985.

Address reprint requests to Riccardo Dalla-Favera, MD, Department of Pathology, New York University School of Medicine, 550 First Ave, Rm 544, MSB, New York, NY 10016.

© 1986 by Grune & Stratton, Inc.

0006-4971/86/6701-250/0000-4971/86/6701-0039$03.00/0

FOA ET AL

RESULTS

In general, these 11 cases displayed the typical clinical and phenotypic characteristics of T-CLL or T-PLL (Table 1). In some cases, the cells displayed a relatively infrequent phenotype, the simultaneous expression of T4 and T8. This phenotype is exceptional in T-CLL and infrequent in T-PLL.16

We previously demonstrated that the analysis of Tα gene rearrangements by Southern blot hybridization using Tα probes, allows the definition of the lineage, ie, T-cell, and the mono- or polyclonal nature of a given lymphoid cell population.12 Figure 1 (lanes A) illustrates the pattern of hybridization bands obtained when human DNA from a non-T-cell population is digested with EcoRI or BamHI and hybridized to the TαC probe. The same analysis, performed on DNA obtained from a polyclonal T-cell population, represented by either normal thymocytes or peripheral blood T-lymphocytes, shows the biallelic deletion of the 12.0 kb band upon digestion with EcoRI and a conserved germline pattern upon digestion with BamHI (Fig 1, lanes B). In monoclonal T-cell populations, the restriction pattern of the gene is characterized by the same EcoRI band deletion and in addition, by the presence of one or more rearranged band(s), which can be detected by digestion with at least one restriction enzyme (see ref. 12 and below).

We analyzed the six cases of T-CLL and five cases of T-PLL based upon this scheme. Southern blot analysis demonstrated the presence of Tα gene rearrangements in all five cases of T-PLL and in five of six cases of T-CLL (Table 1). All of the cases but one displayed the disappearance of the 12.0 kb EcoRI band and the appearance of new hybridization bands upon DNA digestion with EcoRI and/or BamHI (or HindIII, not shown) restriction enzymes. Three cases displaying Tα gene rearrangements are illustrated in Fig 1. Cases 3 and 11 showed the appearance of rearranged bands upon DNA digestion with both EcoRI and BamHI. In Case 3, the absence of the EcoRI and BamHI germline fragments together with the appearance of a single rearranged band, suggests the deletion of one allele of the Tα gene and the rearrangement of the other. A rearranged band in Case 10 is apparent only upon DNA digestion with BamHI restriction enzyme. The single case without rearranged bands also showed conservation of the EcoRI 12.0 kb band (see 6 in Fig 1), indicating that the Tα gene is unarranged in these cells. This finding was confirmed by digestion of the same DNA with BamHI (Fig 1, Lane 6) and HindIII (not shown) restriction enzymes. Analysis of the immunoglobulin heavy chain locus showed a germline configuration in all 11

Table 1. Diagnoses, Phenotypic Markers, Relevant Clinical Features, and Summary of Tα Gene Studies

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Diagnosis</th>
<th>TαGene*</th>
<th>E/T11</th>
<th>T3</th>
<th>T4</th>
<th>T6</th>
<th>T8</th>
<th>Leu7</th>
<th>NK</th>
<th>ADCC</th>
<th>Total</th>
<th>Lymphocytes</th>
<th>Spleen</th>
<th>Liver</th>
<th>Lymph Nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>T-CLL</td>
<td>R</td>
<td>+/-NT</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>NT</td>
<td>NT</td>
<td>NT</td>
<td>17.2</td>
<td>75</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>T-CLL</td>
<td>R</td>
<td>+/-NT</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>NT</td>
<td>8.2</td>
<td>65</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>T-CLL</td>
<td>R</td>
<td>-/+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>NT</td>
<td>7.4</td>
<td>62</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>T-CLL</td>
<td>R</td>
<td>+/-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>NT</td>
<td>+</td>
<td>-</td>
<td>25.1</td>
<td>70</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>T-CLL</td>
<td>R</td>
<td>+/-</td>
<td>+</td>
<td>NT</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>9.1</td>
<td>73</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>T-CLL</td>
<td>G</td>
<td>+/-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>NT</td>
<td>15.2</td>
<td>78</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>T-PLL</td>
<td>R</td>
<td>+/-</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NT</td>
<td>59</td>
<td>84</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>T-PLL</td>
<td>R</td>
<td>+/NT</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NT</td>
<td>79</td>
<td>92</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>T-PLL</td>
<td>R</td>
<td>+/NT</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NT</td>
<td>120</td>
<td>90</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>T-PLL</td>
<td>R</td>
<td>+/NT</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NT</td>
<td>259</td>
<td>99</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>T-PLL</td>
<td>R</td>
<td>+/-NT</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>NT</td>
<td>49</td>
<td>77</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

*R, rearranged; G, germline
†NT, not tested.
‡WBC, white blood cell count expressed as WBC number x 10^9/μL.

Fig 1. Autoradiographs showing representative results of analysis of Tα gene rearrangements in chronic T-cell derived lymphoproliferative disorders. (A) DNAs from normal human fibroblasts. (B) normal human peripheral blood T-lymphocytes, and from pathologic samples (Cases 3, 6, 10, 11) (see Table 1) were digested with EcoRI and BamHI as indicated and hybridized to TαC probe. Dashes indicate germline bands, arrows indicate rearranged bands.
cases (data not shown). Thus, our data indicate that ten of the 11 T-cell chronic lymphoproliferative disorders are monoclonal T-cell proliferations, since the cells display clonal T₄ gene rearrangements. Clonality could not be determined by this approach in one case of T-CLL, since the T₈ gene was found to be unarranged.

**DISCUSSION**

This study sought to determine the mono- or the polyclonal nature of T-cell chronic lymphoproliferative disorders, including T-PLL and T-CLL. In contrast with most other neoplasms, the monoclonality of some of these cases, particularly T-CLL, cannot be assumed or easily established in view of: (1) their nonaggressive, clinical behavior; (2) the lack of cytogenetic markers to confirm both their clonality and, by analogy with other neoplasms, their malignancy; and (3) the lack of clearly identifiable morphologic or immunophenotypic features to distinguish them from their normal, benign counterparts.

The studies presented here demonstrate that the vast majority of T-cell chronic lymphoproliferative disorders are monoclonal. The monoclonal and probable malignant nature of T-PLL is strongly suggested by its typical aggressive clinical course. However, the monoclonal nature of T-CLL was also established in five of six cases. The latter cases display a nonaggressive clinical course and immunophenotypic features, which pose reasonable doubts in terms of the differential diagnosis between a benign chronic lymphocytic features, which pose reasonable doubts in terms of the nonaggressive, clinical behavior; (2) the lack of cytogenetic markers to confirm both their clonality and, by analogy with other neoplasms, their malignancy; and (3) the lack of clearly identifiable morphologic or immunophenotypic features to distinguish them from their normal, benign counterparts.

The studies presented here demonstrate that the vast majority of T-cell chronic lymphoproliferative disorders are monoclonal. The monoclonal and probable malignant nature of T-PLL is strongly suggested by its typical aggressive clinical course. However, the monoclonal nature of T-CLL was also established in five of six cases. The latter cases display a nonaggressive clinical course and immunophenotypic features, which pose reasonable doubts in terms of the differential diagnosis between a benign chronic lymphocytic illness and a true lymphoid malignancy. For instance, Case 2 displayed a particularly benign clinical course during three years of follow-up. We also demonstrated that some chronic lymphoid proliferations which display a mixed T₄/T₈ phenotype are monoclonal. These cases may be more frequent than previously reported, and may have often been inappropriately classified as chronic T-cell lymphocytes by immunophenotypic analysis.

One case of T-CLL exhibited an unarranged T₄ gene configuration. The cells from this case exhibited LGL morphology and NK function, although their T₃- T₄- T₈- phenotype (Table 1) differed from the other cases of T-CLL displaying LGL features. These observations suggest that LGL-derived T-CLLs are immunogenotypically and immunophenotypically heterogeneous. They may be derived from more than one lineage and/or different stages of differentiation. This heterogeneity may reflect the heterogeneity of the normal LGL population and is consistent with our preliminary observations that T₄ gene rearrangement and expression is found in only a subpopulation of normal peripheral blood LGL cells (Pellici PG et al, manuscript in preparation). With respect to the present study, we conclude that the large category of T-CLL may include a distinct subset of cases with LGL morphology, the monoclonal nature of which remains to be established.

Establishing the monoclonal nature of these cases bears important implications for their differential diagnosis, prognosis, and therapeutic management. First, it is important to note that the monoclonality of these diseases does not necessarily imply their complete malignancy. At least some of these cases may represent early, yet persisting stages of a multi-step leukemogenic process. The existence of cases that undergo a progressive change in their clinical course switching toward a more aggressive and malignant phenotype supports this notion. Analysis of T₄ gene rearrangements in longitudinal studies is likely to be useful in determining the derivation of these more malignant clones, by comparing their genotype and phenotype with those cells of earlier stages of the disease. The determination of clonality by T₄ gene rearrangement analysis may be of significant diagnostic and prognostic value. Although our study suggests that even the most clinically chronic T-cell proliferations are of monoclonal origin, immunogenotypic analysis may still be needed to clarify difficult diagnostic situations. Once the determination of monoclonality has been made, the immunogenotypic marker would appear to represent a convenient tool with which to follow the biologic behavior and the therapeutic response of the pathologic clone, thus allowing improved monitoring of the patients' clinical course.

**ACKNOWLEDGEMENT**

We thank Dr Tak Mak for providing the T₄ probe, Michel Brathwaite and Angela Ubriaco for excellent technical assistance, and Diane Nazario and Margaret Walden for preparing the manuscript.

**REFERENCES**

Analysis of T-cell receptor beta chain (T beta) gene rearrangements demonstrates the monoclonal nature of T-cell chronic lymphoproliferative disorders

R Foa, PG Pelicci, N Migone, F Lauria, G Pizzolo, F Flug, DM 2d Knowles and R Dalla-Favera