ABSTRACT

The lamins are intermediate filament proteins that form a fibrous layer at the periphery of the nucleus. Experiments in cell-free systems have suggested that mammalian lamins A and C mediate an interaction between chromatin and the inner nuclear membrane that is essential for the reformation of the nuclear envelope after mitosis. Other investigations, however, have suggested that lamins A and C are absent from myeloid cells and myeloid leukemia cell lines. To further investigate this apparent paradox, highly sensitive Western blotting techniques were utilized in the present study to examine the expression of lamins A and C in a series of human myeloid leukemia cell lines and in bone marrow samples from patients with acute nonlymphocytic leukemia (ANLL) and chronic myelogenous leukemia.

Western blotting revealed that HL-60 progranulocytic leukemia cells contained an average of 0.1 x 10^6 copies of lamins A and C per cell compared to 0.5 x 10^6 copies of lamina B_2 (the quantitatively prominent human B-type lamin) per cell. During the process of phorbol ester-induced maturation to macrophages, the mRNA for lamins A and C increased in abundance, with a concomitant 4-fold increase in the average cellular content of these polypeptides. To rule out the possibility that the low but detectable levels of lamins A and C observed in untreated HL-60 cells reflected incipient maturation, the content of lamins A and C was analyzed in ANLL cell lines that do not mature toward granulocytes or monocytes. Lamins A and C were readily detected in cell lines (KG1a, HEL, Mo-7e) derived from patients with a variety of subtypes of ANLL. Expression of lamins A and C was not limited to myeloid cell lines. These polypeptides were also detectable in marrow samples from 9 of 26 patients with ANLL including at least 1 patient from each of the 5 subtypes of ANLL examined. In contrast, only 1 of 12 marrow samples from patients with aggressive phase chronic myelogenous leukemia and chronic myelogenous leukemia in blast crisis contained readily detectable lamins A and C. The implications of these findings for current hypotheses regarding the functions of the lamin polypeptides are discussed.

INTRODUCTION

The nuclear lamina is a fibrous layer interposed between the inner nuclear membrane and peripheral components of chromatin (reviewed in Refs. 1–7). The major polypeptide constituents of this structure are the lamins, an intranuclear class of intermediate filament polypeptides (reviewed in Refs. 3–13). In many mammalian cells, three lamin polypeptides (lamins A, B_1, and C) predominate (reviewed in Refs. 2, 5, 8, and 14). Lamins A and C are identical for their 469 amino-terminal amino acids (15–17) and are thought to arise through differential splicing. Lamin B_2 is structurally (reviewed in Refs. 10, 11, and 18) and immunologically (reviewed in Ref. 19) related to lamins A and C but is a unique gene product (18, 20).

Additional members of the lamin family (14, 21–24) are also found in mammalian somatic cells, often in smaller quantities. Lamins A and C appear to interact preferentially with binding sites on chromatin (25–28). In contrast, the B-type lamins appear to bind to one or more integral proteins of the inner nuclear membrane (29–31). These interactions are thought to play a role in the reformation of the nuclear envelope after mitosis (32, 33) and in the association of specific chromatin domains with the interphase nuclear envelope (34–36).

In many mammalian cells, lamins A, B_1, and C are present in roughly equivalent amounts at ~10^6 copies/nucleus (2, 8, 34, 37–40). In other cell types, the expression of lamins A and C appears to vary with the degree of maturation (reviewed in Refs. 8, 9, and 41; see also Refs. 14 and 42). For example, lamins A and C are markedly diminished or absent from quiescent lymphocytes but increase in amount after activation with mitogens (14, 43).

Previous studies on the expression of lamins A and C in myeloid tissues have yielded conflicting results. An early study suggested that the lamin content of rabbit granulocytes was similar to that of other somatic cells (44). Lamins A and C were also reported to be present in HL-60 human acute progranulocytic leukemia cells treated with bryostatin (45). In contrast, other investigators were unable to detect lamins A and C on one-dimensional gels of nuclear lamina fractions isolated from HL-60 cells (46). More recently, Rober et al. suggested that lamins A and C were absent from myeloid cells (47) unless these cells underwent monocytic maturation in vitro or in vivo (48).

In the present study, the expression of lamins A and C was examined in human myeloid leukemia cell lines and marrow samples from patients with ANLL and aggressive phase or blast crisis CML. Lamin A and C were detected, albeit in relatively low amounts, in ANLL cell lines representing all three myeloid lineages and in marrow samples from a third of patients with ANLL. In contrast, lamins A and C were below the limit of detection in marrow samples from eleven of twelve patients with aggressive phase or blast crisis CML. These results suggest qualitative or quantitative differences in the structure of the nuclear envelope in ANLL as compared to CML leukocytes.

MATERIALS AND METHODS

Buffers. Medium A consisted of RPMI 1640 supplemented with 10% (v/v) heat-inactivated fetal bovine serum, 100 units/ml penicillin G, 100 µg/ml streptomycin, and 2 mM glutamine. Medium B contained 10 mM 4-(2-hydroxyethyl)-1-piperazineethanesulfonic acid (pH 7.4 at 20°C) in RPMI 1640. Alkylating buffer contained 5 mM guanidine hydrochloride and 500 mM dithiothreitol.

The abbreviations used are: ANLL, acute nonlymphocytic leukemia; CML, chronic myelogenous leukemia; NEPHGE, nonequilibrium pH gradient electrophoresis; SDS, sodium dodecyl sulfate; PAGE, polyacrylamide gel electrophoresis; TPA, 12-O-tetradecanoylphorbol-13-acetate; SSC, standard saline-citrate; FAB, French-American-British.

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2 To whom correspondence should be addressed, at Oncology 1-127, Johns Hopkins Hospital, 600 N. Wolfe Street, Baltimore, Maryland 21205. Because of budget limitations, reprints of this manuscript will not be available.

3 In accordance with current convention (10, 21), lamin B refers to the smaller amount in rat (14, 21) and human (41) cells.
hydrochloride, 250 mM Tris-HCl (pH 8.5 at 21°C), 10 mM EDTA, 1% (v/v) β-mercaptoethanol, and 1 mM 3-mercaptopropionic acid (imidazole). SDS sample buffer consisted of 4 M deionized urea, 2% (v/v) SDS, 62.5 mM Tris-HCl (pH 6.8 at 21°C), and 1 mM EDTA. RNA sample buffer consisted of 50% (v/v) formamide, 2 M formaldehyde, 20 mM 3-(N-morpholino)propanesulfonic acid, 5 mM sodium acetate, and 1 mM EDTA. SSC buffer (1×) contained 150 mM NaCl in 15 mM sodium citrate (pH 7.0).

Cell Lines. The following ANLL cell lines (obtained from the indicated investigators at the Johns Hopkins University School of Medicine) were utilized: KG1, KG1a, and HEL (C. Civey); HL-60 (W. S. May); ML-1 (R. Craig); and Mo-7e (M.-J. Fackler). The derivation of these cell lines has been reviewed (49, 50). Cells were maintained at densities of <1 × 10^6/ml in medium A. The culture of Mo-7e was supplemented with interleukin 3 (51). Cells from logarithmically growing cultures were harvested by sedimentation over Ficoll-Hypaque step gradients (density, 1.119 g/cm^3).

To induce monocytic maturation, HL-60 cells were treated with 1.6 × 10^4 μg TPA in medium A (52, 53). After the indicated length of incubation, cells were scraped from the dish and treated as described above. Monocytic maturation was monitored by measuring the induction of acid phosphatase activity (54).

Marrow Samples. Iliac crest bone marrow aspirates were obtained from patients with ANLL and CML according to protocols approved by the Joint Committee on Clinical Investigation of the Johns Hopkins Medical Institutions in accordance with policies of the United States Department of Health and Human Services. The diagnosis of ANLL was confirmed by morphological, cytochemical, and karyotypic analysis. Samples were classified according to the FAB criteria (55). The diagnosis of CML was confirmed by karyotyping and by Southern blotting to detect the bcr/abl gene rearrangement. Low density cells (density < 1.079 g/cm^3) were harvested from marrow cells by a two-step Ficoll-Hypaque step gradient as described previously (56). Differential counts were performed on cytopsin preparations of the isolated cell fractions after staining with Wright's stain. There was no detectable contamination of any gradient-purified marrow sample by stromal elements such as macrophages or fibroblasts that are known to contain lamins A and C (47, 48).

Western Blotting. Cells harvested from Ficoll-Hypaque gradients were sediemented at 400 × g for 10 min, washed once with medium B, and solubilized by sonication in alkalylation buffer. After reduction and alklylation, samples were dialyzed sequentially into 4 M urea and then into 0.1% (w/v) SDS (56). Each sample was lyophilized and reconstituted in SDS sample buffer immediately prior to electrophoresis. Electrophoresis, electrophoretic transfer to nitrocellulose, and Western blotting were performed as previously described (56).

Lamin polypeptides purified from rat liver nuclear envelopes by twodimensional gel electrophoresis were utilized to raise high titer polyclonal antiserum in chickens (characterized in detail in Ref. 14). Previous experience (41) indicates that these antiseras strongly cross-react with human lamins. Other antibodies used in these studies included a polyclonal serum raised by immunizing a guinea pig with lamin A, a monoclonal antibody against histone H1 (kindly provided by Dr. James Sorrentino, Veterans Administration Hospital, Baltimore, MD), and a monoclonal antibody (VIM-13.2) against human foreskin vimentin (Sigma, St. Louis, MO).

Northern Blotting. Control and TPA-treated HL-60 cells were lysed in guanidine thiocyanate (57). RNA was isolated by sedimentation through a cushion of 5.7 M CsCl in a Beckman TL100.2 rotor (58). Aliquots containing 20 μg of total cellular RNA were denatured for 3 min at 70°C in RNA sample buffer and separated on a 1% (v/v) agarose gel containing 0.22 M formaldehyde. The RNA was transferred to Nytran membranes (Schleicher & Schuell, Keene, NH) and immobilized by heating for 3 h at 80°C in a vacuum. The plasmids pHLA containing 2.7 kilobases of the coding sequence of human lamin B (generously provided by Dr. Georg Krohne, German Cancer Research Center, Heidelberg, Germany) were digested with appropriate restriction endonucleases. The inserts were excised from the agarose gels, electroeluted, and labeled by the random primer method (59). After prehybridization, hybridization was performed overnight at 42°C. Extensive washing at 21°C in 2X SSC-0.1% (v/v) SDS was followed by a final 15-min wash at 42°C (pH 12) or 55°C (HLB) in 0.1X SSC-0.1% (v/v) SDS. Autoradiography was performed at -70°C using Kodak Xomat AR-5 film in the presence of appropriate intensifying screens (60). Probe was removed from the blot by boiling for 20 min in 0.5% (v/v) SDS containing 1.8 mM NaCl and 0.1 mM sodium phosphate, pH 7.7.

RESULTS

Presence of Lamins A and C in Acute Nonlymphocytic Leukemia Cell Lines. Previous results from this laboratory (56) revealed that lamins A and C were detectable in HL-60 human progranulocytic leukemia cells after dimethyl sulfoxide-induced granulocytic maturation. Western blotting with antibodies that specifically recognize lamins A and C (14, 41) revealed that lamins A and C were also detected after TPA-induced monocytic maturation of HL-60 cells (Fig. 1B, Lanes 4–6). Additional experiments confirmed that polypeptides with the mobilities of lamins A and C were detectable after two-dimensional NEPHGE/SDS-PAGE of nuclear envelopes from these TPA-treated cells (data not shown). The presence of lamins A and C in TPA-treated HL-60 cells reflected the presence of increased levels of mRNA for these two polypeptides (Fig. 1D). These results confirm and extend a recent report indicating that lamins A and C are detected during monocyte/macrophage maturation in other systems in vitro and in vivo (48).

Examination of the data in Fig. 1 indicated that low levels of lamins A and C, along with the corresponding mRNA species, could be detected in untreated HL-60 cells as well (Fig. 1B, Lane 2; Fig. 1D, Lane 1). The levels of lamins A and C were lower than in TPA-treated cells and corresponded to ~10% of the levels observed in an equal number of hepatocyte nuclei (Fig. 2B, Lanes 4 and 9). Since hepatocytes contain ~10^6 copies of lamin A and C per nucleus (37–39), these results suggest that untreated HL-60 cells contain an average of ~0.1 × 10^6 copies of lamins A and C. Similar analysis indicates that the content of lamin B1 was ~0.5 × 10^6 copies/cell (Fig. 2B, Lanes 3 and 8). Comparable results were obtained with ML-1 and KG1 cells (Fig. 2B, Lanes 4, 10, and 11), two additional ANLL cell lines capable of granulocytic or monocytic maturation (49, 50).

The presence of lamins A and C in untreated HL-60, ML-1, and KG1 cells might reflect spontaneous maturation of a fraction of these cells toward more mature myeloid elements. Alternatively, it might reflect the presence of endogeneous levels of lamins A and C so low that these polypeptides were undetectable by techniques previously applied to myeloid leukemia cell lines. To distinguish between these alternatives, Western blotting was performed using protein samples derived from ANLL cell lines that do not undergo granulocytic or monocytic maturation in vitro.

Lamins A and C were detectable in ANLL cell lines representing myeloid (KG1a), erythroid (HEL), and megakaryocytic (Mo-7e) lineages (Fig. 2B, Lanes 12–14). Levels of lamin A in these cell lines ranged from <0.1 × 10^6 copies/cell (cf. Fig. 2B, Lanes 4 and 12) to ~0.25 × 10^6 copies/cell (cf. Fig. 2B, Lanes 3, 13, and 14). Levels of lamin C appeared to be somewhat lower (cf. Fig. 2B, Lanes 4 and 13) but also varied (cf. Fig. 2B, Lanes 12–14). In contrast, levels of lamin B1 appeared to be
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Fig. 1. Changes increase in lamins A and C during TPA-induced maturation of HL-60 cells toward monocyte/macrophages. A-C, changes in polypeptide levels. Log phase HL-60 cells were treated with $1.6 \times 10^{-8}$ M TPA for 0 (Lane 1), 1 day (Lane 3), 2 days (Lane 4), 3 days (Lane 5), or 4 days (Lane 6). Nuclei from 1 x 10^6 cells (prepared as described in Ref. 41) were subjected to SDS-PAGE followed by staining with Coomassie blue (A) or transfer to nitrocellulose and Western blotting with antibodies that recognize lamins A and C (B) or lamin B1 (C). An equal number of rat liver nuclei (Lane 1) were present to serve as a positive control. Levels of lamins A and C increased approximately 4-fold between 1 and 2 days after addition of TPA. Numbers at left are sizes of marker proteins (M, $10^3$). D-F, changes in mRNA levels. Samples of RNA from cells treated with TPA for 0 day (Lane 1) or 2 days (Lane 2) were separated by agarose gel electrophoresis and probed with a partial complementary DNA for human lamin A (D), mRNA species (3.1- and 2.1-kilobase; corresponding to the messages for lamins A and C, respectively) hybridized to the probe. These messages increased in amount after TPA treatment (D, Lane 2) but were readily detected in the untreated cells (D, Lane 1). Reprobing of the blot with a partial complementary DNA for lamin B1 (E) and examination of the original ethidium bromide-stained gel (F) confirmed that equal amounts of RNA were loaded in the respective lanes. Right ordinate, sizes of indicated RNA species in kilobases.

Fig. 2A. Detection of lamins A and C in the nuclear matrix. The Mo-7e cell line, for example, expressed relatively large amounts of lamin A (Fig. 2B, Lane 14). In contrast, human peripheral blood granulocytes expressed readily detectable levels of vimentin (Fig. 2D, Lane 1). Table 1 shows the expression of lamins A and C in 26 ANLL marrow samples examined. Expression of these polypeptides was detected in at least one sample from each of the five subtypes of ANLL studied. Results obtained with samples from six of these patients (four positive, two negative) are shown in Fig. 3A. As was the case with the ANLL cell lines, the levels of lamins A and C in ANLL marrow specimens (Fig. 3B, Lanes 5–11) were low relative to levels in an equal number of rat liver nuclei (Fig. 3B, Lane 1) and might have been missed by other techniques. Once again, expression of lamins A and C did not appear to correlate with levels of expression of the cytoplasmic intermediate filament vimentin (Fig. 3D, Lanes 5–11).

Levels of Lamins A and C Are Low or Undetectable in CML. Bone marrow specimens from three patients with chronic phase CML, five patients with aggressive phase CML, and seven patients with CML in blast crisis were also examined for the presence of lamins A and C (Table 1). Under conditions where lamins A and C were detectable in the ANLL specimens, levels of lamins A and C were undetectable in the marrow samples or not (complete response rate: 3/7 = 42% when A and C detectable; 5/14 = 35% when A and C undetectable).8

DISCUSSION

In the present study, highly sensitive Western blotting techniques (56) were utilized to determine whether lamins A and C were present in human myeloid leukemia cell lines and clinical leukemia specimens. Recent reports suggest that certain cell types including myeloid cells (47) and myeloid leukemia cell lines (46) lack lamins A and C. On the other hand, experiments in cell-free systems have previously suggested that lamins A and C bind to chromatin (26–28) and initiate a series of events.

7 Vimentin is the only cytoplasmic intermediate filament protein expressed in lymphohematopoietic cells (64).

8 Because of 5 deaths during the induction therapy, only 21 patients with ANLL could be evaluated for their response.
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that are required for the reformation of the nuclear envelope and the decondensation of chromatin after mitosis (32). If lamins A and C are required for essential postmitotic events in mammalian cells in vivo, it is unclear how rapidly growing cell types such as myeloid leukemia cell lines can survive without lamins A and C. An early report (44) suggested that lamins A and C might be present in some myeloid leukemia cell lines but the techniques previously applied to this question do not rule out the possibility that lamins B1 or B2 have the functions of lamins A and C in myeloid leukemia cells, an alternative explanation considered in the present study is the possibility that low levels of lamins A and C are actually present in myeloid leukemia cell lines and have been missed by the techniques previously applied to this question.

Initial experiments in the present study (Fig. 1) confirmed a recent report that levels of lamins A and C increase during monocyte/macrophage maturation (48). When the same techniques were applied to cells that do not undergo maturation toward macrophages or granulocytes (Fig. 2B), lamins A and C were detected in cell lines of myeloid (KG1a), erythroid (HEL), and megakaryocytic (Mo-7e) lineages. In some cell lines, the levels of these polypeptides were as low as 5–10% of those found in other somatic cells and might have been missed by immunofluorescence or unidimensional SDS-PAGE. Additional experiments were undertaken to assess whether lamins A and C were expressed in myeloid cell lines in vivo. Although an early report (44) suggested that lamins A and C might be present in rabbit granulocytes in amounts similar to those of lamins B1, Western blotting with antibodies to lamins A and C failed to confirm this result in human peripheral blood granulocytes (Fig. 2B, Lane 15). On the other hand, lamins A and C were detected in marrow samples from 9 of 26 patients with ANLL (Table 1; Fig. 3B). At least one positive sample was observed in each of the five subtypes of ANLL examined. These observations indicate that lamins A and C can be expressed in myeloid cells in vivo as well as in vitro. The fact that lamins A and C were detected in only 9 of the 26 ANLL samples might reflect lack of sensitivity of the detection method rather than absence of expression of lamins A and C in the remaining samples. In this context, it is interesting to note that the leukemic marrows with erythroblastic or megakaryoblastic features were more likely to contain detectable levels of lamins A and C (6/14 = 43% positive for lamins A and C if FAB classification M6 or M7; 3/12 = 25% positive if FAB classification M2, M4, or M5). These results are consistent with the higher levels of lamins A and C observed in cell lines with erythroblastic and megakaryoblastic features (HEL and Mo-7e, respectively, in Fig. 2B).

Under the same conditions utilized to examine the ANLL samples, lamins A and C were undetectable in bone marrow samples from 14 of 15 patients with various stages of CML (Table 1; Fig. 4). It is possible that lamins A and C were present in these samples, but were below the limit of detection in this study (~1 x 10^5 molecules/cell). In this context, it is interesting to note that mRNA for lamins A and C is detectable in K562 cells, a line derived from a patient with CML in blast crisis, and that the levels of these polypeptides were as low as 5–10% of those found in other somatic cells and might have been missed by the techniques previously applied to this question.

Table 1 Detection of lamins A and C in human leukemia specimens

<table>
<thead>
<tr>
<th>Type of leukemia</th>
<th>No. positive/no. examined</th>
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<tr>
<td>ANLL</td>
<td>9/26</td>
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<tr>
<td>M2</td>
<td>1/3</td>
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<tr>
<td>M4</td>
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<td>M7</td>
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<tr>
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<tr>
<td>CLL</td>
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<tr>
<td>CML</td>
<td>1/15</td>
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<tr>
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<tr>
<td>Myeloid blast crisis</td>
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<tr>
<td>Mixed blast crisis</td>
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even though levels of lamins A and C themselves are below the limit of detection in this cell line. Alternatively, lamins A and C might be truly absent from CML cells. If so, this observation might imply a difference in the structural organization of the lamina in ANLL leukocytes as compared to CML leukocytes. Further studies with more sensitive techniques will be required to distinguish between these possibilities.

Since the functions of the lamin polypeptides are not completely understood (reviewed in Refs. 3, 12, and 13), the importance of expression of lamins A and C to the biology of ANLL and CML is not clear. In a preliminary attempt to address this issue, the clinical characteristics of the ANLL patients whose marrows contained detectable levels of lamins A and C were compared to those whose marrows lacked detectable levels of lamins A and C. There was no apparent difference in the

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Fig. 3. Detection of lamins A and C in marrow specimens from patients with ANLL. Samples containing $5 \times 10^8$ nucleated marrow cells (Lanes 5–8, 10, 11) or $5 \times 10^7$ peripheral blood mononuclear cells (Lane 9) were subjected to SDS-PAGE followed by staining with Coomassie blue (A) or transfer to nitrocellulose and Western blotting with antibodies that recognize lamins A and C (B), lamin B$_1$ (C), human vimentin (D), or histone H1 (E). The FAB classification of each leukemic sample is indicated above each lane. Samples containing $5 \times 10^7$ (Lane 1), $2.5 \times 10^7$ (Lane 2), $1.25 \times 10^7$ (Lane 3) and $0.5 \times 10^7$ (Lane 4) rat liver nuclei (RLN) provided a standard curve. Nonadjacent wells from a single gel and corresponding autoradiograph were juxtaposed to compose this figure. Lamins A and C were readily detected in samples from three patients (B, Lanes 5, 7, and 8) and were detected on prolonged exposure in another of these samples (B, Lane 10). Similar results were obtained with an independently derived guinea pig antiserum that recognizes lamins A and C (B). Interestingly, the levels of lamins A and C appeared to be lower in circulating blasts (B, Lane 9) than in bone marrow blasts from the same patient (B, Lane 8) even though levels of lamin B$_1$ (C, Lanes 8 and 9), and vimentin (D, Lanes 8 and 9) were similar. A cross-reactive polypeptide that migrated slightly faster than lamin A (* in B) was detected in most human cells. The origin of this band is unknown.

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Fig. 4. Paucity of lamins A and C in marrow specimens from patients with aggressive phase CML. Samples containing $5 \times 10^7$ nucleated marrow cells (Lanes 5–12) were subjected to SDS-PAGE followed by staining with Coomassie blue (A) or transfer to nitrocellulose and Western blotting with antibodies that recognize lamins A and C (B), lamin B$_1$ (C), or histone H1 (D). Rat liver nuclei (Lane 1, $5 \times 10^7$; Lane 2, $2.5 \times 10^7$; Lane 3, $1 \times 10^7$; Lane 4, $0.5 \times 10^7$) served as a positive control. Under conditions that permitted the detection of lamins A and C in samples from patients with ANLL (Fig. 3), lamin A was detected in only one CML sample (*, B). Nonadjacent wells from a single gel and autoradiograph were juxtaposed to compose this figure.
peripheral WBC at the time of diagnosis, a prognostic indicator (63), nor in the frequency of response to chemotherapy. A larger study would be required to rule out more subtle differences between the two groups of patients.

The results of the present study have implications for current theories on the functions of lamins A and C. One recent study revealed that lamins A and C are expressed later during the course of murine development than cytoplasmic intermediate filaments (42). It was suggested that the expression of lamins A and C serves to limit the “plasticity” of differentiating cells. This sequential expression of cytoplasmic and nuclear intermediate filament polypeptides might be a common feature of nontransformed cells; but it is not observed in the ANLL cell lines. Several human ANLL cell lines express detectable levels of lamins A and C without detectable levels of vimentin (Fig. 2, B and D). Since vimentin is the only cytoplasmic intermediate filament polypeptide reported in lymphohematopoietic cells (64), these observations cast doubt on the conclusion that lamins A and C are expressed only in cells that already express cytoplasmic intermediate filament polypeptides.

Another series of experiments recently suggested that lamins A and C bind to nucleosomes in the peripheral heterochromatin (28). It was predicted that cells with larger amounts of heterochromatin, the paucity of lamins A and C in 23 nontransformed cells; but it is not observed in the ANLL cell lines. An even more striking result was obtained with 2852 T lymphoblastic cell lines. C. A human T lymphoblastic cell line lacks lamins A and C. EMBO J., 6: 1047-1057, 1987.


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Expression of Nuclear Envelope Lamins A and C in Human Myeloid Leukemias

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