Fully assembled Ig H and L chains are transported onto the surface of B cells, while free H chains are retained in the endoplasmic reticulum (ER) in association with BiP. However, in pre-B lines that produce only μ H chains, small amounts of μ chains are expressed on the cell surface, suggesting that some other proteins substitute for the missing L chain in these cells. In fact, proteins of 14-22 kD have been shown to bind to the cytoplasmic and surface μ chains in murine and human pre-B lines (2-4). The X5 and VpreB genes, which are specifically expressed in pre-B cells, have strong homology to the C and the V regions of the L chain genes, respectively (5, 6), and thus, are likely to encode the μ-binding proteins. Antibodies specific for the human λ5 and VprBL peptides react against μ-binding molecules of 22 and 18 kD, respectively, in human pre-B lines (7, 8). However, whether these proteins are expressed in association with the μ chain on the cell surface has not yet been shown.

We introduced expression vectors coding for the murine λ5 and VprBL genes, together with a vector (pSVμtm), into Ig- myeloma cells and demonstrate that the products of the two genes are required and sufficient for μ expression on the cell surface. This result suggests that λ5 and VprBL are essential components of sIg in pre-B cells.

Materials and Methods

The expression vectors coding for λ5 and VprBL, pEPλ5gpt and pEPVpBneo, are shown in Fig. 1, B and C. Genomic fragments of λ5 and VprBL genes were provided by Dr. A. Kudo, Basel Institute for Immunology, Basel, Switzerland. The BglII-PstI fragment of λ5 was cloned into a pSV2gpt vector containing the VH promoter and the IgH enhancer. The BglII fragment of VprBL gene was similarly cloned into a pSV2neo vector. pSVμtm (9) is an expression vector for a chimeric μ chain where the membrane exon of μm was replaced by the transmembrane and cytoplasmic part of the H-2Kk gene (Fig. 1 A). The vector for the λ5 L chain, pSVλ5neo, was described previously (10). The products were transfected into myeloma cells by electroporation. Cell surface expression of μ chains in the transfectants was analyzed by flow cytometry as described previously (9).

For biochemical analysis, biosynthetic labeling, and surface iodination were done as described previously (9, 10). Cells were then lysed in 0.5% NP40 lysis buffer and immunoprecipitated with rabbit anti-murine μ chain antibody by using protein G-Sepharose (Pharmacia, Uppsala, Sweden). The purified Ig chains were analyzed by SDS-PAGE as described previously (9, 10).

Results

To analyze requirements for cell surface expression of μ chains, we introduced the pSVμtm vector encoding for the chimeric μtm molecule into cells of the Ig- myeloma, X63Ag8.653. The μtm chain can be expressed on the cell surface in the absence of the IgM-associated heterodimer, IgM-α and Ig-β (9). The X63μtm transfectants were tested for cytoplasmic μ production by a Western dot assay (data not shown), and for surface μ expression by flow cytometry. None of the cytoplasmic μtm+ transfectants express μ chains on the surface (Fig. 2, A and B). If, however, a vector coding for the λ5 L chain is transfected into one of the μtm transfectants, IgM molecules are found on the cell surface (Fig. 2 C). These results indicate that, as is the case for the μm chain, binding to the L chains is necessary for surface expression of the μtm chain.
Figure 1. Structure of the (A) pSVμm, (B) pEPλsgpt, and (C) pEPpBneo vectors. Solid black segments represent exons for the chimeric μm chain where the membrane exon of the μ chain is replaced by the transmembrane and cytoplasmic part of H-2Kk (A), λ5 (B), and VpreB1 (C). These three vectors contain the IgH enhancer (E) and a 350-bp fragment from a VH promoter (indicated by arrows). B, BamHI; Bg, BglII; N, Ncol; P, PstI; Pv, PvuII; R, EcoRI.

To determine whether the products of the λ5 and VpreB genes also allow the μ chain to be expressed on the cell surface, we introduced the pEPpBneo and pEPλsgpt vectors together with the μtm vector into X63Ag8.653 cells. The transfectants were first screened for cytoplasmic μ production. All μtm+ lines were then tested for λ5 and VpreB expression by Northern blotting (data not shown). In 12 μtm+ lines, only one line (X63T14) expressed both the λ5 and the VpreB genes, and the same line also expressed μ chains on the surface (Fig. 2D). The other μtm transfectants were slg− (data not shown). Thus, λ5 and VpreB genes are likely to encode μ-binding proteins that are able to substitute for the L chain. This conclusion is supported by a biochemical analysis of metabolically labeled and anti-μ immunoprecipitated material from X63μtmλ and X63T14 cells. In X63μtmλ cells, the μtm chain is bound to the 28-kD λ1 light chain (Fig. 3, lane 1), while in X63T14 cells, the μtm is associated with proteins of 22 and 18 kD, presumably the products of the λ5 and VpreB genes, respectively, and with an 18.5-kD protein (Fig. 3, lane 2).

To determine how λ5 and VpreB proteins associate with the μtm molecule, biosynthetically labeled material from the X63 transfectants was analyzed by nonreducing/reducing two-dimensional SDS-PAGE. In such a gel, monomeric proteins are found on a diagonal, whereas subunits of disulfide-bound proteins appear below the diagonal. In the control line, X63μtmλ, μtm, and λ1 L chain molecules derived from H2L2 and HL complexes were observed below the diagonal (Fig. 4A). When X63T14 cells were examined, the 22-kD protein (λ5) was observed below the spots for the μ dimer and the μ monomer, while the 18-kD (VpreB) and 18.5-kD proteins were observed on the diagonal (Fig. 4B), indicating that the 22-kD protein forms a disulfide-linked complex with the μ chain, while the 18.5- and 18-kD proteins bind noncovalently to this complex.

Finally, to test whether these proteins associate with the μ chain on the cell surface, X63T14 cells and X63μtmλ cells were labeled by surface iodination, immunoprecipitated, and examined by SDS-PAGE under reducing conditions. Surface-labeled μtm and λ1 L chain were precipitated from X63μtmλ cells (Fig. 3, lane 3). On the surface of X63T14 cells, however, only the 18-kD VpreB protein and the μtm molecules were labeled (Fig. 3, lane 4).
Discussion

The transport of H chains from the ER to the cell surface is dependent on whether the H chains are assembled with L chains (1). BiP seems to be involved in this process by trapping free H chains in the ER. Assembled HL complexes no longer bind to BiP and are transported to the Golgi apparatus. In the present study, we demonstrated that a μt-producing myeloma transfectant expressed μ chains on the surface, provided it co-expressed λ5 and VpreB. Thus, the products of λ5 and VpreB seem to form a L chain-like structure that binds to μ chains, resulting in the transport of the μ chains to the cell surface.

In the X63T14 transfectants, the μt chain was specifically associated with proteins of 22, 18.5, and 18 kD. The 22-kD protein is likely to be the product of the λ5 gene. It is covalently bound by the μ chain, presumably through a cysteine residue which is found at the COOH-terminal penultimate position of the λ5 sequence (5). A cysteine residue at this position in the L chain is involved in the interchain disulfide bond. Since the 22-kD protein binds to the μ chain covalently, this protein is likely to be expressed together with the μ chain on the cell surface. The failure to label the 22-kD protein on the cell surface of X63T14 cells may indicate that it does not contain solvent-exposed tyrosines. This possibility is supported by the analysis of the λ5 sequence. The 18-kD protein is very well labeled on the cell surface and noncovalently associated with the μ chain. It seems to be the product of the VpreB gene, whose sequence does not contain an interchain cysteine, but several exposed tyrosines. The above conclusions are supported by experiments showing that antibodies for human λ5 and VpreB peptides recognize 22- and 18-kD proteins, respectively (7, 8). The 18.5-kD protein seems to be a derivative of either λ5 or VpreB proteins, because it is found only in X63T14 cells. It may be a degradation product of λ5 or a modified form of VpreB that is not expressed on the cell surface.

Pillai and Baltimore (2, 3) have demonstrated the existence of two μ-binding proteins, t and ω in murine pre-B cells. The t chain is a noncovalently binding, 14-kD molecule, and the 18kD ω molecule binds covalently. While t is readily surface iodinated, ω is only poorly labeled. Thus, although the calculated molecular weights are slightly different, it is likely that what we see as a 22-kD molecule is the ω chain and as an 18-kD molecule the t chain.

Our present results strongly suggest that the products of λ5 and VpreB are essential components of κl in pre-B cells. Although the function of the λ5-VpreB-μt complex on the pre-B cell surface is still unclear, this complex, upon crosslinking, may generate a signal that is involved in the feedback regulation of Ig gene rearrangement (discussed in reference 11).

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Note added in proof: After submitting our manuscript, it was brought to our attention that Karasuyama et al., in a paper also published in this issue of the Journal, show that the transfection of the $\mu$ H chain gene and the genes coding for $\lambda_5$ and $V_{\text{preB}}$ into a fibroblast line leads to the secretion of $\mu$ half-monomers associated with $\lambda_5$ and $V_{\text{preB}}$ proteins.

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