JOURNAL OF VIROLOGY, Nov. 2000, p. 10240–10244 Vol. 74, No. 21
0022-538X/00/$04.00+0

HLA Class I-Restricted Cytotoxic T-Cell Epitopes of the Respiratory Syncytial Virus Fusion Protein

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Received 30 May 2000/Accepted 1 August 2000

Virus-specific cytotoxic T lymphocytes (CTL) play a major role in the clearance of respiratory syncytial virus (RSV) infection. We have generated cytotoxic T-cell clones (TCC) from two infants who had just recovered from severe RSV infection. These TCC were functionally characterized and used to identify HLA class I (B57 and C12)-restricted CTL epitopes of RSV.

Respiratory syncytial virus (RSV) is a common cause of upper respiratory tract infections but may—especially in young infants, the elderly, or immunocompromised individuals—cause severe lower respiratory tract infections (12). In rodent models, $CD4^+$, as well as $CD8^+$, RSV-specific T lymphocytes proved to be involved in both recovery from and immune pathogenesis of the infection (1, 2, 8, 19). Therefore, a fine balance must exist in these models between protective and disease-enhancing effects of virus-specific T lymphocytes. RSV-specific $CD8^+$ cytotoxic T lymphocytes (CTL) against virtually all RSV proteins have been demonstrated to circulate in humans after RSV infection (4, 7, 9). CTL may be expected to play a crucial role in the clearance of RSV infections, but their role in protection and immune pathology remains unclear. Therefore, the identification of CTL epitopes of human RSV may contribute to future studies concerning the role of CTL in pathogenesis and protection from RSV infection. Here we describe the functional characterization of $CD8^+$ cytotoxic T-cell clones (TCC) generated from two infants who had just recovered from severe RSV infection. These TCC were also used to identify, for the first time, HLA class I-restricted CTL epitopes of RSV.

Peripheral blood mononuclear cells (PBMC) were collected from two infants 4 weeks after a severe, laboratory-confirmed RSV infection. At the time of infection, they were 1 and 2 months old and had both been admitted to the intensive care unit. B-lymphoblastic cell lines (B-LCL) were generated by Epstein-Barr virus transformation (22), infected with RSV A2 (ATCC VR1322), and UV irradiated (24) to serve as autologous antigen-presenting cells (APC). PBMC (3×10^4/well in 96-well round-bottom plates) were stimulated with APC (10^4/well) and expanded in RPMI 1640 medium supplemented with antibiotics, 10% pooled and heat-inactivated human serum, and recombinant human interleukin-2 (IL-2; 50 IU/ml). After 2 weeks, T cells were harvested and cloned by limiting dilution using phytohemagglutinin stimulation as previously described (25). TCC thus generated were expanded and tested for RSV specificity by [^{3}H]thymidine incorporation assays as previously described (22). All of the RSV-specific TCC proved to be of the $CD8^+$ phenotype in fluorescence-activated cell sorter analysis. TCC whose specificity for RSV was confirmed by a second proliferation assay were tested for protein specificity by a gamma interferon (IFN-γ) ELIspot assay (Mabtech AB, Stockholm, Sweden). In this test, paraformaldehyde-fixed autologous B-LCL that had been infected with recombinant vaccinia viruses (rVV) expressing different RSV proteins (F, G, N, P, M2, SH, M, 1B, or 1C) were used as APC. Briefly, TCC (5×10^3/well) were incubated with APC (10^4/well) for 4 h, transferred to anti-human IFN-γ-coated plates, and incubated for another 18 h. The ELIspot assay was further performed in accordance with the kit manufacturer's instructions. The results are shown as numbers of IFN-γ-producing cells (spots) per well.

Thirty-four RSV-specific TCC were generated from the PBMC of patient 1, as detected in a [^{3}H]thymidine incorporation assay. Of these, 27 proved to be RSV F specific and 7 were RSV 1B specific in an IFN-γ ELIspot assay (Fig. 1A). Twenty-four RSV-specific TCC were generated from the PBMC of patient 2 as detected by a [^{3}H]thymidine incorporation assay. Of these, 10 were RSV F specific and 14 proved to be RSV 1C specific in an IFN-γ ELIspot assay (Fig. 1B). None of the clones detected by the [^{3}H]thymidine incorporation assay was found to be negative by the IFN-γ ELIspot assay. Since the F protein is considered to be a major CTL target (4, 7, 9), further efforts were focused on the identification of CTL epitopes in the F protein. To this end, 18-mer peptide amides overlapping by 12 amino acids, together spanning the entire F protein of RSV A2 (11, 18) ($n = 94$), were generated in an automated multiple-peptide synthesizer as previously described (26). The purity of the peptides varied between 50 and 90%, as determined by analytical reverse-phase high-performance liquid chromatography (C_8 column; gradient of 0.1% trifluoroacetic acid in water to 0.1% trifluoroacetic acid in acetonitrile). Autologous B-LCL of patients 1 and 2 were pulsed overnight with 1 and 3 μM peptide, respectively. RSV F-specific TCC of patient 1 reacted with peptides 17 and 18 (Fig. 2A). All of the RSV F TCC of patient 2 reacted with peptide 91 and marginally with peptide 90 (Fig. 2B). Subsequently, two additional sets of partially overlapping 8- to 12-mer peptides (80 to 95% purity) were generated to determine the respective minimal epitopes. Autologous B-LCL of patients 1 and 2 were pulsed for 1 h with the different peptides at 1 and 3 μM, respectively. All of the RSV F-specific TCC of patient 1 reacted with one nine-mer peptide (RARRELPRF) spanning residues 118 to 126 of the F protein (Fig. 2C). The RSV F TCC of patient 2 all reacted with one nine-mer peptide (IAVGLLLYC) spanning residues 551 to 559 of the F protein (Fig. 2D).

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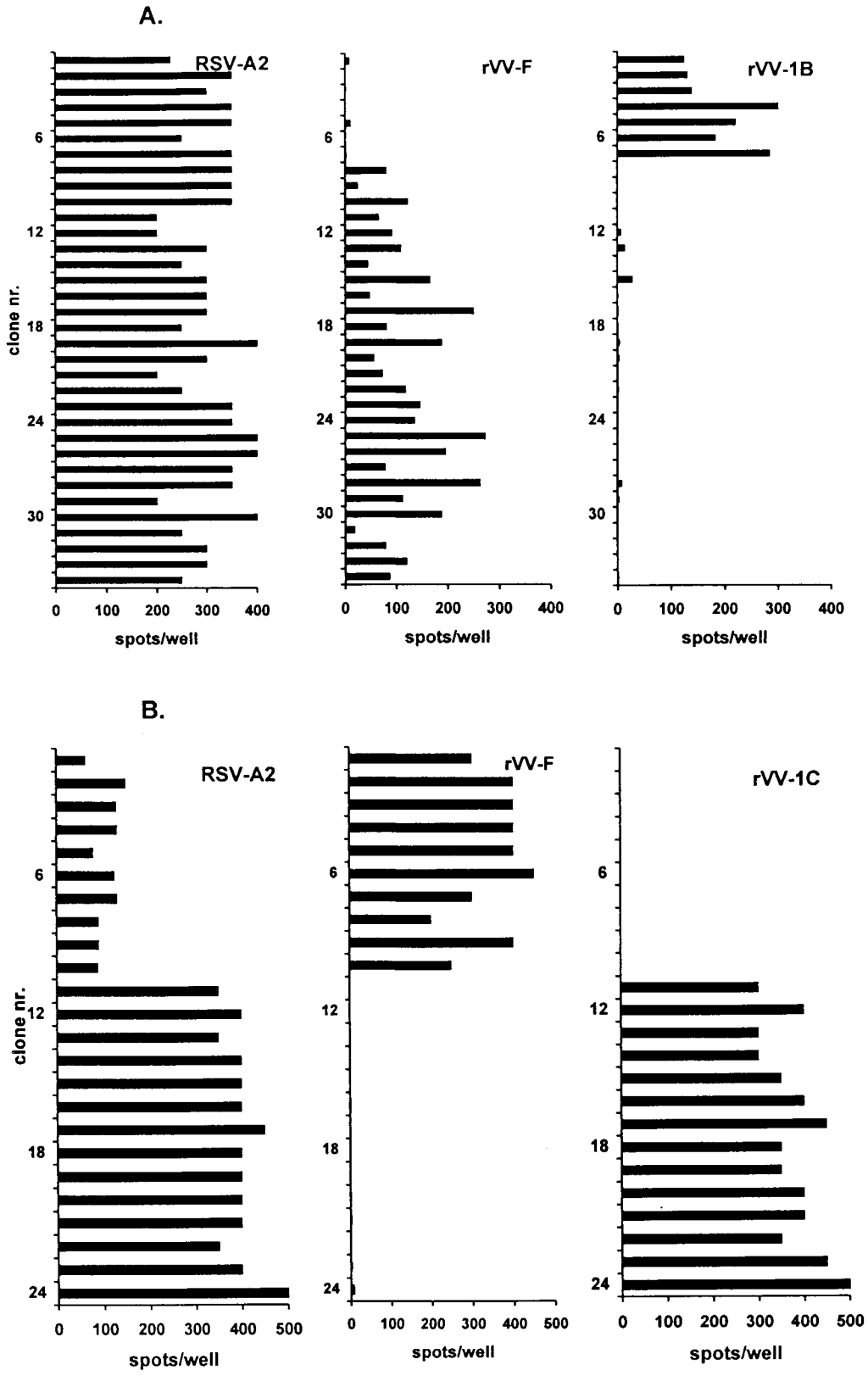

FIG. 1. Responses of RSV-specific TCC from patients 1 (A) and 2 (B) measured by an IFN-γ ELIspot assay using autologous B-LCL infected with RSV A2 or rVV expressing the RSV F, 1B, or 1C protein. Results are indicated as numbers of spots per well. No responses against the B-LCL infected with the other rVV were found (data not shown).

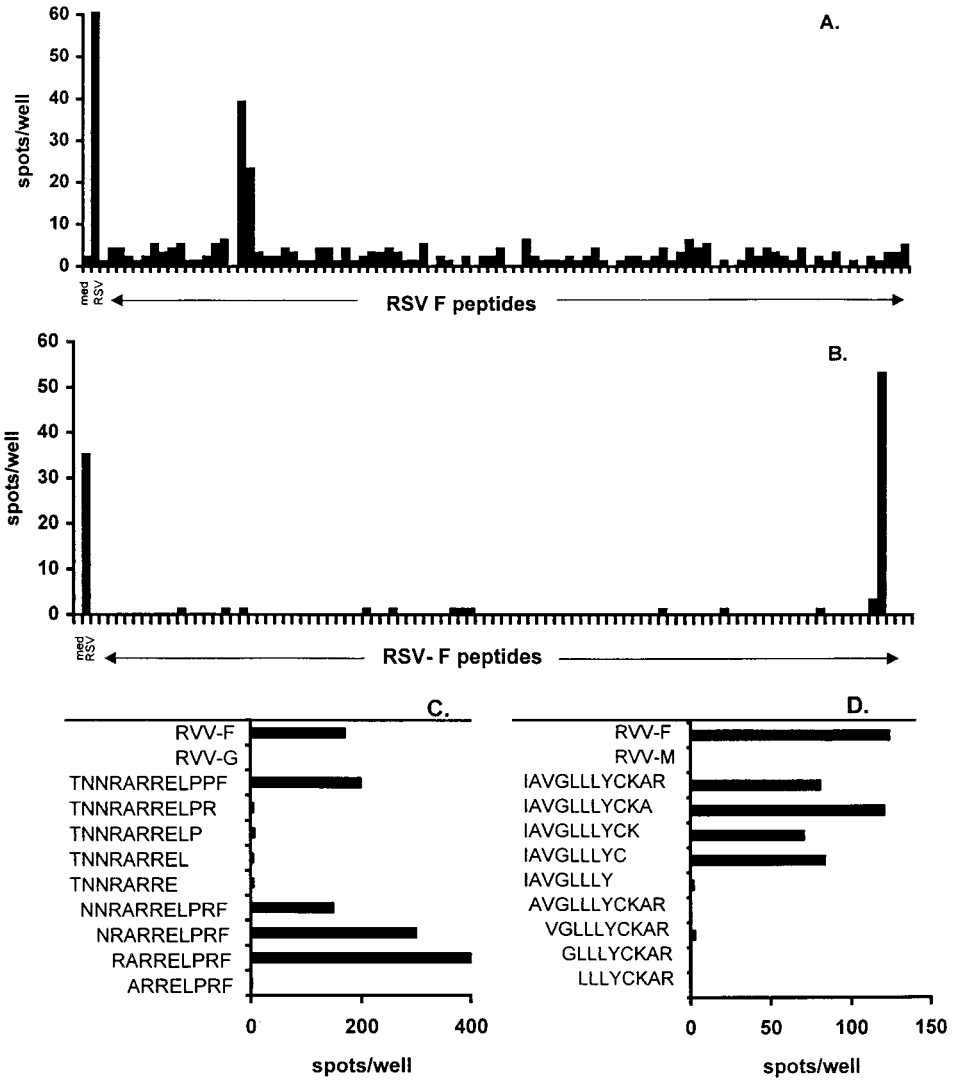

FIG. 2. Fine mapping of T-cell epitopes on the RSV F protein. Responsiveness of TCC from patients 1 (A) and 2 (B) to partially overlapping 18-mer peptide amides ($n = 94$) spanning the F protein was measured by an IFN-γ ELIspot assay. Minimal peptide activation of TCC from patients 1 (C) and 2 (D) was measured in an IFN-γ ELIspot assay using APC pulsed with two additional sets of overlapping 8- to 12-mer peptides. med, medium.

The HLA restriction of the recognition by the RSV F TCC was also determined by the IFN-γ ELIspot assay using a set of allogeneic B-LCL with partially matched HLA types loaded with the respective minimal peptides, as shown in Fig. 3. Recognition of the RSV F epitope of patient 1 proved to be HLA B57 restricted. Recognition of the epitope of patient 2 proved to be C12 restricted.

Well-growing TCC of both specificities from each of the

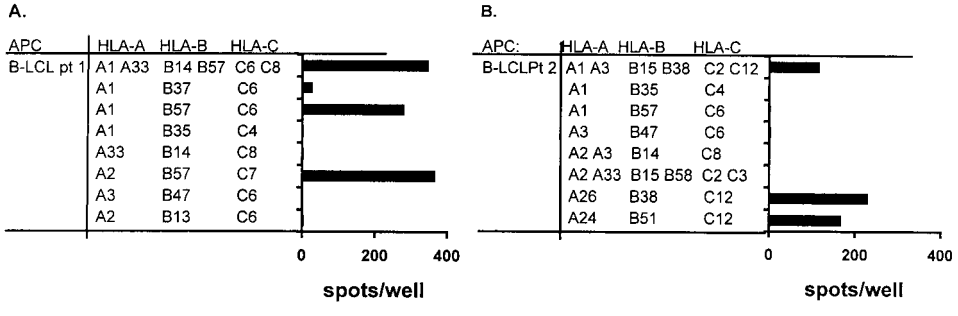

FIG. 3. Determination of HLA restriction of RSV F protein recognition by specific TCC using a set of autologous and partially HLA class I-matched B-LCL for patients 1 (A) and 2 (B) by an IFN-γ ELIspot assay.

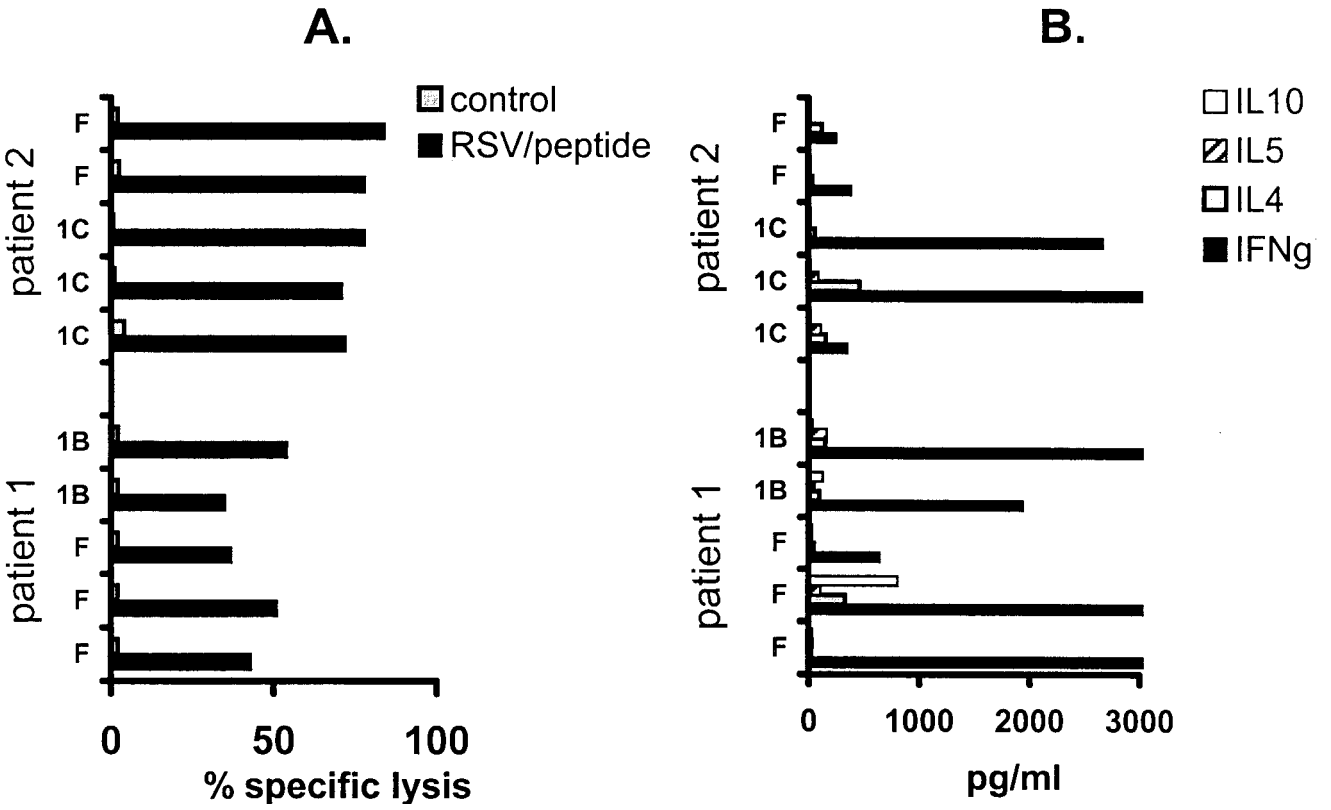

FIG. 4. Cytotoxic responses (A) and cytokine production (B) of selected TCC with different protein specificities from patients 1 and 2. TCC were stimulated with autologous RSV-infected or control B-LCL and in the case of the F-specific TCC of patient 2, minimal-peptide- or control (measles virus) peptide-loaded B-LCL. Cytotoxic responses were measured in a chromium release assay using an effector-to-target cell ratio of 10. Cytokines in cell-free culture supernatant (IFN-γ, IL-4, IL-5, and IL-10) were measured by enzyme-linked immunosorbent assay. Levels of cytokines in the supernatant of TCC stimulated with control B-LCL were all below the detection limit and are not shown.

patients were arbitrarily selected and tested for cytotoxic activity by a chromium release assay as previously described (23). Briefly, autologous ^{51}Cr-labeled, RSV-infected B-LCL and control B-LCL or, in the case of the F-specific TCC of patient 2, minimal-peptide-loaded B-LCL and control B-LCL were incubated with TCC for 4 h at 37°C at an effector-to-target cell ratio of 10:1, which was found to be the most discriminative ratio in preliminary experiments. Spontaneous ^{51}Cr release (target cells plus medium) and maximum ^{51}Cr release (target cells plus Triton X-100) were determined in 12 identical wells. Supernatants were harvested and analyzed in a gamma counter. Assay results were accepted only when the spontaneous-to-maximum release ratio was <25%. All of the TCC tested showed RSV-specific lysis (Fig. 4A). Virus-specific production of cytokines in cell-free culture supernatant was measured as previously described (6). TCC were stimulated with RSV-infected B-LCL or control B-LCL or, in the case of the F-specific TCC of patient 2, with minimal-peptide-loaded B-LCL or control B-LCL for 48 h. The concentrations of the following cytokines were measured using commercially available sandwich enzyme-linked immunosorbent assay systems in accordance with the manufacturers' instructions: IL-4 (CLB, Amsterdam, The Netherlands; detection limit, 7 pg/ml), IFN-γ (Medgenix Diagnostics, Fleurs, Belgium; detection limit, 25 pg/ml), IL-10 (Pharmingen, San Diego, Calif.; detection limit, 20 pg/ml). All of the TCC produced predominantly IFN-γ, indicating a type 1 phenotype in vitro (Fig. 4B).

In the present study, we identified two nine-mer CTL epitopes on the RSV fusion protein. To our knowledge, these are the first HLA class I-restricted CTL epitopes described for RSV in humans. We found CTL epitopes with an HLA restriction with a low prevalence in the population. But using the techniques described here on samples of more children with a recent RSV infection, CTL epitopes with more prevalent HLA restrictions may be identified.

The TCC found in the children studied were all CD8$^+$ CTL with a type 1-like cytokine profile. No RSV-specific CD4$^+$ T cells were detected in the samples of these infants, while the use of similar stimulation protocols did result in the identification of such cells in other systems (14, 17, 20, 22). Virus-specific CTL responses play a major role in the clearance of RSV infections but may also be involved in pathogenesis (1, 3, 5, 8, 15). In mice, enhanced lung pathology induced by priming with formalin-inactivated RSV has been associated with the absence of a CTL response (13, 21). In young children, a CTL response against RSV has been described but poor responses were found in younger and more severely ill patients (10, 16). The poor CTL response in young children has been suggested to be one of the possible causes of more severe disease. In these two patients, it was possible to detect RSV-specific cytotoxic TCC, showing that also in very young children with clinically severe infections, priming of a CTL response does occur, although we cannot say anything about the quantitative responses.

In conclusion, use of the IFN-γ ELIspot assay to determine epitope specificity proved to be sensitive and convenient, since only small numbers of T cells and APC were needed. This and similar studies may be important for future studies concerning

the role of CTL in the pathogenesis of RSV infection in children.

This study was financially supported by the Sophia Foundation for Medical Research, Rotterdam, The Netherlands (grant 214).

We thank Humphrey Brugghe and Bea van't Land for technical assistance and Conny Kruyssen for assistance in preparing the manuscript.

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