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Production of NY-ESO-1 peptide/DRB1*08:03 tetramers and ex vivo detection of CD4 T-cell responses in vaccinated cancer patients

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ABSTRACT

We established CD4 T-cell clones, Mz-1B7, and Ue-21, which recognized the NY-ESO-1 121–138 peptide from peripheral blood mononuclear cells (PBMCs) of an esophageal cancer patient, E-2, immunized with an NY-ESO-1 protein and determined the NY-ESO-1 minimal epitopes. Minimal peptides recognized by Mz-1B7 and Ue-21 were NY-ESO-1 125–134 and 124–134, respectively, both in restriction to DRB1*08:03. Using a longer peptide, 122–135, and five other related peptides, including either of the minimal epitopes recognized by the CD4 T-cell clones, we investigated the free peptide/DR recognition on autologous EBV-B cells as APC and peptide/DR tetramer binding. The results showed a discrepancy between them. The tetramers with several peptides recognized by either Mz-1B7 or the Ue-21 CD4 T-cell clone did not bind to the respective clone. On the other hand, unexpected binding of the tetramer with the peptide not recognized by CD4 T-cells was observed. The clone Mz-1B7 did not recognize the free peptide 122–135 on APC, but the peptide 122–135/DRB1*08:03 tetramer bound to the TCR on those cells. The failure of tetramer production and the unexpected tetramer binding could be due to a subtly modified structure of the peptide/DR tetramer from the structure of the free peptide/DR molecule. We also demonstrated that the NY-ESO-1 123–135/DRB1*08:03 tetramer detected ex vivo CD4 T-cell responses in PBMCs from patients after NY-ESO-1 vaccination in immunomonitoring.

1. Introduction

To analyze T-cell immunomonitoring after vaccination, peptide/MHC tetramers have become widely used [1]. Peptide/MHC tetramers identified and visualized antigen specific T-cells. MHC class I tetramers were originally developed by Altman and Davis [2], and used for various antigens including those of viral or tumor origin [3,4]. However, MHC class II tetramers have been used in only a few studies because of the difficulty in preparation [5]. The soluble form of MHC class II molecules is necessary to produce tetramers. However, production of such molecules using extracellular domains of MHC class II α and β chains is generally difficult because of a lack of assembly or aggregation [6]. These findings indicate the necessity of transmembrane regions for the proper assembly of the molecules. Kalandadze et al. [7] found that replacement of the hydrophobic transmembrane regions by the Fos and Jun leucine zipper dimerization motifs resulted in the assembly and secretion of DRαβ heterodimers in yeast. Novak et al. [8] developed MHC class II tetramers using DR molecules incorporating leucin zipper motifs to stabilize the DRα and β heterodimer. The procedure has been widely used, but successful production of MHC class II tetramers is still limited [9–13].

We recently analyzed CD4 T-cell responses against NY-ESO-1 in PBMCs from patients who were vaccinated with a complex of cholesterol-bearing hydrophobized pullulan and NY-ESO-1 protein (CHP-NY-ESO-1) in our clinical trial and determined three novel NY-ESO-1 CD4 T-cell epitopes: NY-ESO-1 87–100 bound to DRB1*09:01, NY-ESO-1 95–107 bound to DQB1*04:01, and NY-ESO-1 124–134 bound to DRB1*08:03 [14]. CD4 T-cells that

Abbreviations: APC, antigen-presenting cell; CHP-NY-ESO-1, complex of cholesterol-bearing hydrophobized pullulan and NY-ESO-1 whole protein; Fmoc, *N*-(9-fluorenyl)-methoxycarbonyl; HD, healthy donor; MFI, mean fluorescence intensity; OLP, overlapping peptide; PBMC, peripheral blood mononuclear cell.

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recognized these epitope peptides also recognized EBV-B cells or DC that were treated with recombinant NY-ESO-1 protein or an NY-ESO-1-expressing tumor cell lysate, suggesting that the epitope peptides are naturally processed. These CD4 T-cells had a cytokine profile with Th1 characteristics.

In this study, we showed that tetramers with several peptides recognized by the CD4 T-cell clones did not bind to the same clones. On the other hand, unexpected binding of the tetramer with a peptide not recognized by CD4 T-cells was observed. The failure of tetramer production and the unexpected tetramer binding could be due to a subtly modified structure of the peptide/DR tetramer from the structure of the free peptide/DR molecule. We also demonstrated that the NY-ESO-1 123–135/DRB1*08:03 tetramer detected ex vivo CD4 T-cell responses in PBMCs from patients after NY-ESO-1 vaccination in immunomonitoring.

2. Materials and methods

2.1. Patients and blood samples

Peripheral blood samples were drawn from esophageal cancer patients E-1 and E-2, and a prostate cancer patient P-3, who were vaccinated with CHP-NY-ESO-1, and a lung cancer patient TK-OLP-01, who was vaccinated with NY-ESO-1 OLP in our clinical trials [15,16] after obtaining written informed consent. PBMCs were isolated by density gradient centrifugation using Histopaque 1077 (Sigma–Aldrich, St. Louis, MO). CD4 T-cells and $CD19^+$ cells were purified from PBMCs using CD4 and CD19 microbeads, respectively, using a large scale column and a magnetic device (Miltenyi Biotec, Auburn, CA). The cells were stored in liquid N_2 until use. HLA typing was done using PBMCs with a sequence-specific oligo-nucleotide probe and sequence-specific priming of genomic DNA using standard procedures. Patient E-2 was found to possess homozygous alleles.

2.2. Peptides

Peptides were synthesized using standard solid-phase methods based on *N*-(9-fluorenyl)-methoxycarbonyl (Fmoc) chemistry on a Multiple Peptide Synthesizer (AMS422, ABIMED, Langenfeld, Germany) at Okayama University (Okayama, Japan).

2.3. Cell lines

E-2 bulk CD4 T-cells were stimulated in vitro twice as described previously [14]. Clones were then established by limiting dilution. EBV-B cells were generated from $CD19^+$ peripheral blood B cells using the culture supernatant from EBV-producing B95-8 cells.

2.4. Generation of HLA-DRB1*08:03 tetramers

HLA-DR tetramers were prepared as described previously [5]. The cDNA coding for the extracellular domains of the HLA-DRα chain was inserted by fusion PCR in a basic leucine zipper and His tag. The HLA-DRβ chain was fused with an acidic leucine zipper and the BirA substrate peptide for BirA enzyme-dependent biotinylation. The HLA-DRα and HLA-DRβ chimeric cDNA were cloned into the pcDNA3.1 vector, respectively. The expression vectors containing the HLA-DRα and HLA-DRβ chains were co-transfected into CHO cells.

2.5. ELISA

Supernatants (100 μl) from cultures of CD4 T-cells (5×10^3) stimulated for 18 h with autologous EBV-B cells (5×10^3) pre-pulsed for 30 min with peptide in a 96-well round bottomed culture plate, or with solid-phase peptide/HLA-DRB1*08:03 tetramers in a 96-well flat bottomed culture plate, were collected and the amounts of IFNγ were estimated by sandwich ELISA [14]. TNFα, IL-4, IL-10 and IL-17A in the culture supernatants were estimated by DuoSet Sandwich ELISAs (R&D Systems, Minneapolis, MN), according to the manufacturer's instructions.

2.6. Flow cytometry

FITC-conjugated anti-human TCRαβ mAb (BD), PerCP Cy5.5-conjugated anti-human CD3 mAb and APC-conjugated anti-human CD4 mAb (eBioscience, San Diego, CA) were used for T-cell surface staining. The stained cells were detected by FACS Canto II (BD). Flow cytometry results were analyzed with FlowJo (Tree Star, Ashland, OR).

2.7. Tetramer staining

CD4 T-cells were incubated with tetramers for 1 h at 37 °C in a 5% CO_2 atmosphere. FITC-conjugated anti-human CD4 mAb (Miltenyi Biotec) was added at the end of tetramer staining and incubated for an additional 20 min at 4 °C.

2.8. IFNγ capture assay

The method has been described previously [14].

2.9. TCR Vβ and CDR3 sequence analysis

For TCR Vβ analysis, the IOTest Beta Mark kit (Beckman Coulter, Brea, CA) was used. The CDR3 sequence was determined by PCR as described previously [17].

3. Results

3.1. Determination of NY-ESO-1 minimal epitopes recognized by CD4 T-cell clones Mz-1B7 and Ue-21 established from PBMCs of an esophageal cancer patient E-2 immunized with CHP-NY-ESO-1

We established CD4 T-cell clones from PBMCs of an esophageal cancer patient E-2 immunized with CHP-NY-ESO-1 which recognized the 18-mer NY-ESO-1 121–138 peptide. The CD4 T-cell clones Mz-1B7 and Ue-21 produced IFNγ, TNFα, but not IL-4, IL-10 or IL-17A (Supplementary Fig. 1), indicating that they have Th1 characteristics. We determined restriction molecules by antibody blocking and minimal epitopes using various N- and C-termini truncated peptides. Assays were done by ELISA examining IFNγ in the culture supernatant from responding T-cells using autologous EBV-B cells as antigen-presenting cells (APC). As shown in Fig. 1A, recognition of the 18-mer NY-ESO-1 121–138 by CD4 T-cell clones Mz-1B7 and Ue-21 was inhibited by addition of anti-HLA-DR mAb, but not anti-HLA-DQ mAb. Since patient E-2 possessed homozygous haplotypes (DRB1*08:03, DQA1*01:03, DQB1*06:01, DPB1*05:01) according to genetic analysis (see Section 2), the two clones Mz-1B7 and Ue-21 recognized the NY-ESO-1 peptide 121–138 in restriction to DRB1*08:03.

We then investigated recognition of various N- and C-termini truncated peptides and found that a core peptide region recognized by either clone Mz-1B7 or clone Ue-21 was made up of amino acids 125–134 (Fig. 1B). Further analysis revealed that a minimal peptide recognized by clone Mz-1B7 was peptide 125–134 (10-mer) and that recognized by clone Ue-21 was peptide 124–134 (11-mer) (Fig. 1C). Thus, clones Mz-1B7 and Ue-21 recognized

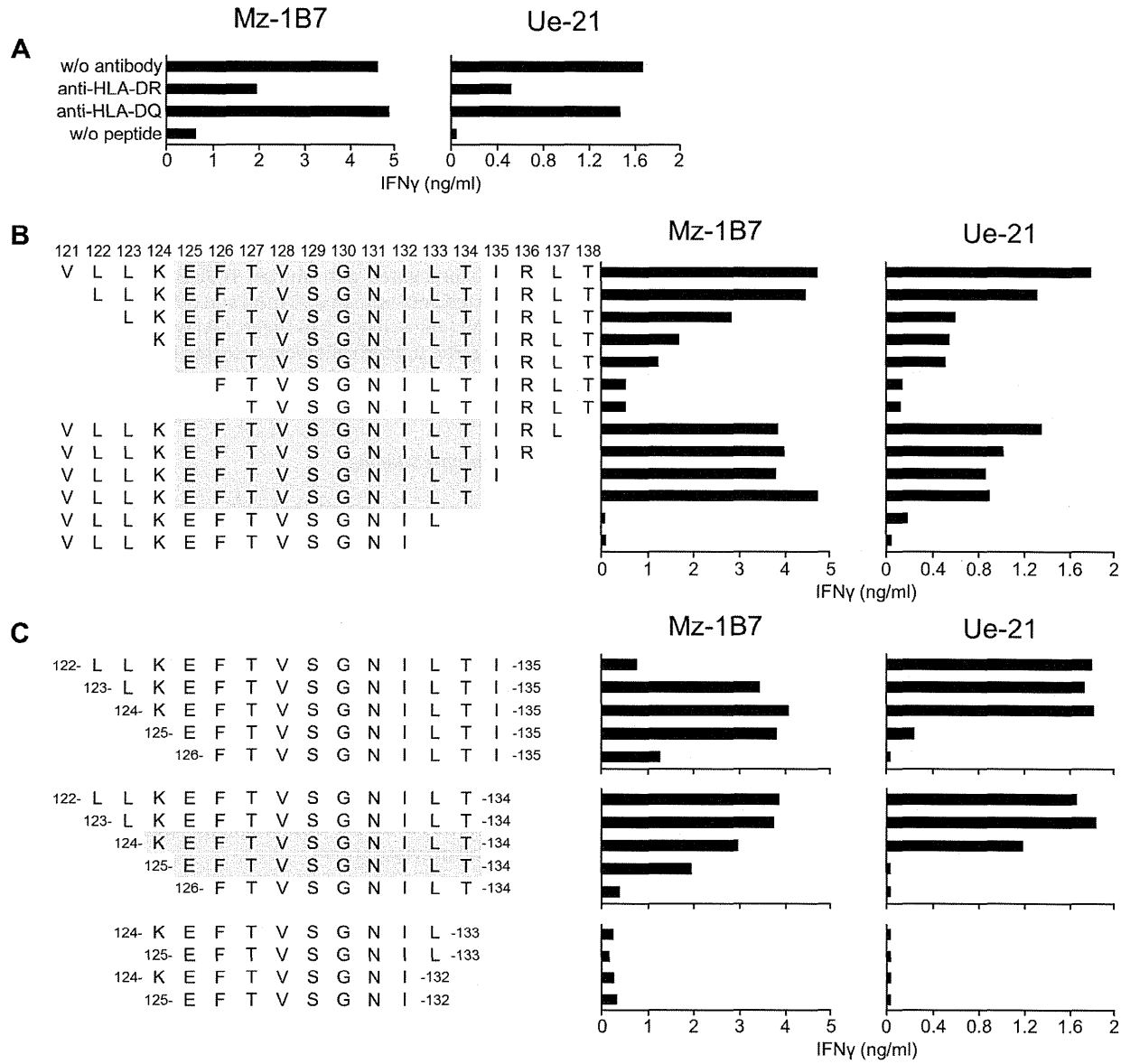

Fig. 1. Antibody blocking (A) and determination of NY-ESO-1 minimal epitopes ((B) and (C)) recognized by E-2 CD4 T-cell clones Mz-1B7 and Ue-21. In (A), CD4 T-cell clones (5×10^3) were stimulated for 18 h with autologous EBV-B cells (5×10^3) in the presence of NY-ESO-1 121–138 (VLLKEFTVSGNILTIRLT) peptide (100 nM), and anti-HLA-DR or anti-HLA-DQ mAb (5 μg/ml) in the culture. IFNγ in the culture supernatants was determined by ELISA. In B and C, CD4 T-cell clones (5×10^3) were stimulated for 18 h with autologous EBV-B cells (5×10^3) in the presence of truncated NY-ESO-1 121–138 peptides (100 nM). The core peptide region and each minimal epitopes recognized by CD4 T-cell clones are shown in gray boxes. IFNγ in the culture supernatants was determined by ELISA.

closely related, but different, minimal NY-ESO-1 peptides in restriction to the same DRB1*08:03. Recognition of closely related, but different, peptides by these CD4 T-cell clones was further confirmed with responses to other peptides. Peptide 122–135 was recognized by Ue-21, but not Mz-1B7. On the other hand, peptide 125–135 and peptide 126–135 were recognized by Mz-1B7, but not Ue-21.

3.2. Differential recognition by clone Mz-1B7 and clone Ue-21 of the longer peptide 122–135, including minimal epitopes recognized by either clone

To confirm that the longer peptide 122–135 was recognized by only clone Ue-21, but not clone Mz-1B7, irrespective of including epitopes recognized by either clone, an IFNγ capture assay together with ELISA was performed examining IFNγ in the same culture stimulated with peptide 122–135 and five other related peptides using autologous EBV-B cells as APC as above. As shown in Fig. 2A, a response of clone Mz-1B7 was observed against the peptides 123–135, 124–135, 122–134, 123–134 and 124–134, but not 122–135 in either the IFNγ capture assay or ELISA. No response against peptide 122–135 was observed up to a peptide concentration of 100 nM in ELISA. On the other hand, a response of clone Ue-21 was observed against all of the peptides used. These results were consistent with the results shown in Fig. 1.

3.3. Tetramer binding

We produced tetramers using the longer peptide 122–135, and five other related peptides 123–135, 124–135, 122–134, 123–134 and 124–134. The DR molecule was constructed by combining the DRA*01:01 and DRB1*08:03 chains that fused the leucine zipper motif at the C-terminal ends [8]. In the DRA locus, seven alleles DRA*01:01:01:01, DRA*01:01:01:02,

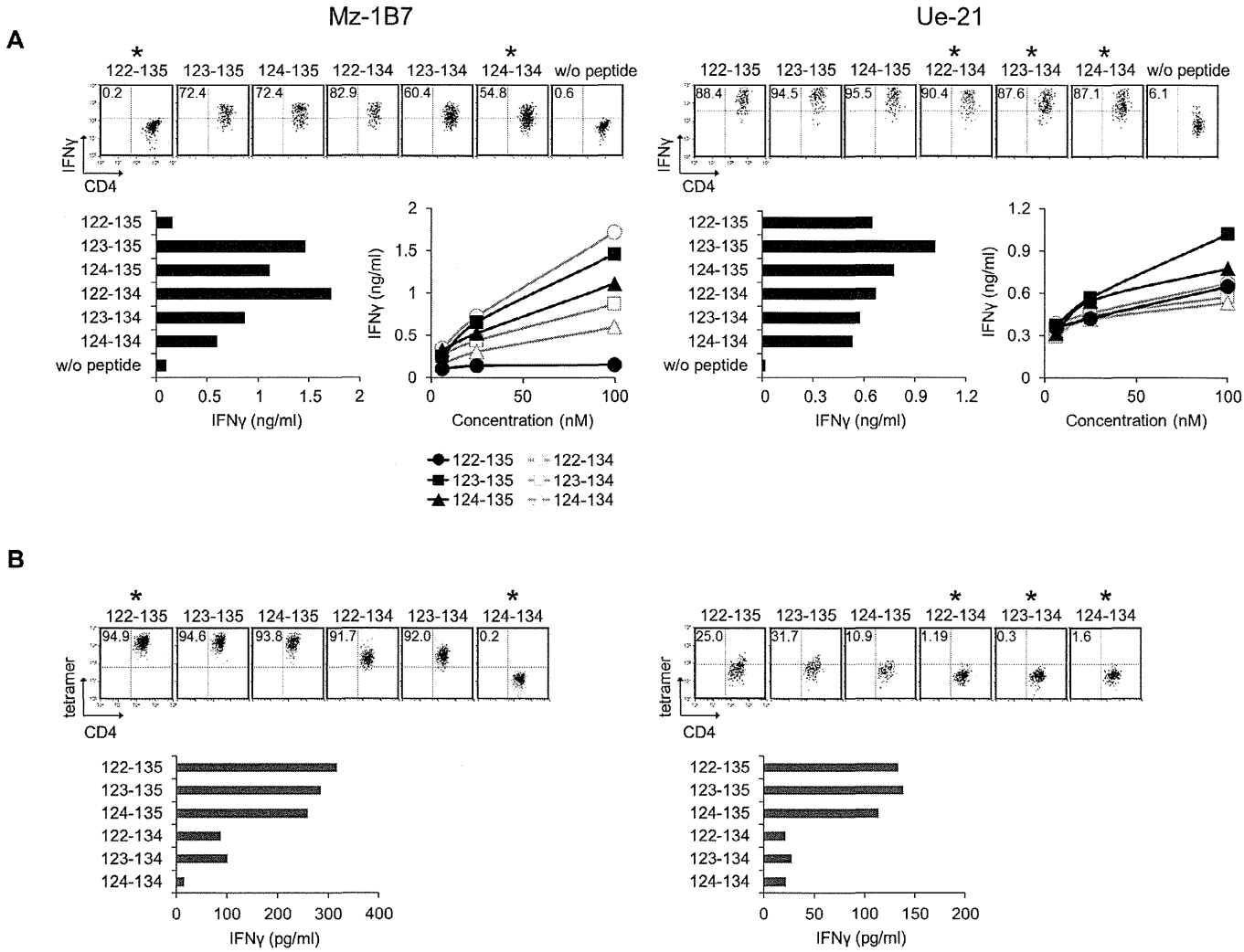

Fig. 2. Discrepancy between peptide recognition (A) and tetramer binding (B) in E-2 CD4 T-cell clones Mz-1B7 and Ue-21. In A top, CD4 T-cell clones (1×10^4) were stimulated for 4 h with the indicated peptides (1 μM) using autologous EBV-B cells (1×10^4) as APC. IFNγ-secreting CD4 T-cells were determined by an IFNγ capture assay using FACS Canto II. In A bottom, CD4 T-cell clones (5×10^3) were stimulated for 18 h with autologous EBV-B cells (5×10^3) pre-pulsed for 30 min with the indicated peptides (100 nM) (left) or with graded concentrations (6.25, 25 or 100 nM) of the indicated peptides (right). IFNγ in the culture supernatant was determined by ELISA. In B top, CD4 T-cell clones were stained with the indicated peptide/HLA-DRB1*08:03 tetramers (5 μg/ml) at 37 °C for 1 h followed by staining with an anti-CD4 mAb, and analyzed using FACS Canto II. In B bottom, CD4 T-cell clones (5×10^3) were stimulated for 18 h with the indicated peptide/HLA-DRB1*08:03 tetramers coated on wells in microculture plates. IFNγ in the culture supernatant was determined by ELISA. The peptides that show a discrepancy between recognition (A) and tetramer binding (B) are marked by *.

DRA*01:01:01:03, DRA*01:01:02, DRA*01:02:01, DRA*01:02:02 and DRA*01:02:03 have been identified. These alleles differ only at amino acid 217 in the cytoplasmic domain, which is included in the region replaced by a leucin zipper motif from amino acid residue 152 in the α2 domain. Therefore, any DRA allele can be used for tetramer production.

With these six peptide/DR tetramers, we examined binding to clones Mz-1B7 and Ue-21. As shown in Fig. 2B, to clone Mz-1B7, binding of tetramers with peptide 122–135, 123–135, 124–135, 122–134 and 123–134, but not 124–134, was observed. The peptide 122–135 including the minimal epitope 125–134 was not recognized by Mz-1B7, but a tetramer constructed using the same peptide bound to Mz-1B7. Furthermore, peptide 124–134 that also included the minimal epitope 125–134 was recognized by Mz-1B7, but a tetramer constructed using the same peptide did not bind to the same clone.

On the other hand, to clone Ue-21, weak binding of tetramers with peptides 122–135, 123–135 and 124–135, but only marginal binding of tetramers with 122–134, 123–134 or 124–134, was observed. The peptides 122–134 and 123–134, including the minimal epitope 124–134 and the peptide124–134 itself, were recognized by Ue-21, but the tetramers constructed using the same peptides bound to the same clone only marginally. IFNγ production by CD4 T-cell clones in stimulation with the tetramers was consistent with tetramer binding (Fig. 2B bottom).

We further examined the only marginal binding of a tetramer constructed using the peptide 124–134 to Mz-1B7 and Ue-21 under different culture conditions. As shown in Fig. 3A and B, efficient binding of the tetramer constructed using the peptide 123–135 to clone Mz-1B7 was observed at 25–37 °C after incubation for 10–120 min. However, only marginal binding was observed with the tetramer constructed using the peptide 124–134, even at 37 °C after incubation for 120 min. Only marginal binding of the tetramer with the peptide 124–134 to Mz-1B7 or Ue-21 was observed up to a concentration of 10 μg/ml (Fig. 3C and D).

3.4. Expression of CD4 and TCR on CD4 T-cell clones

Expression of CD4, CD3 and TCRαβ was analyzed by FACS. As shown in Fig. 4A, expression of CD4 was observed similarly on clones Mz-1B7 and Ue-21. On the other hand, expression of CD3 and TCRαβ was observed on Ue-21 strongly, but on Mz-1B7

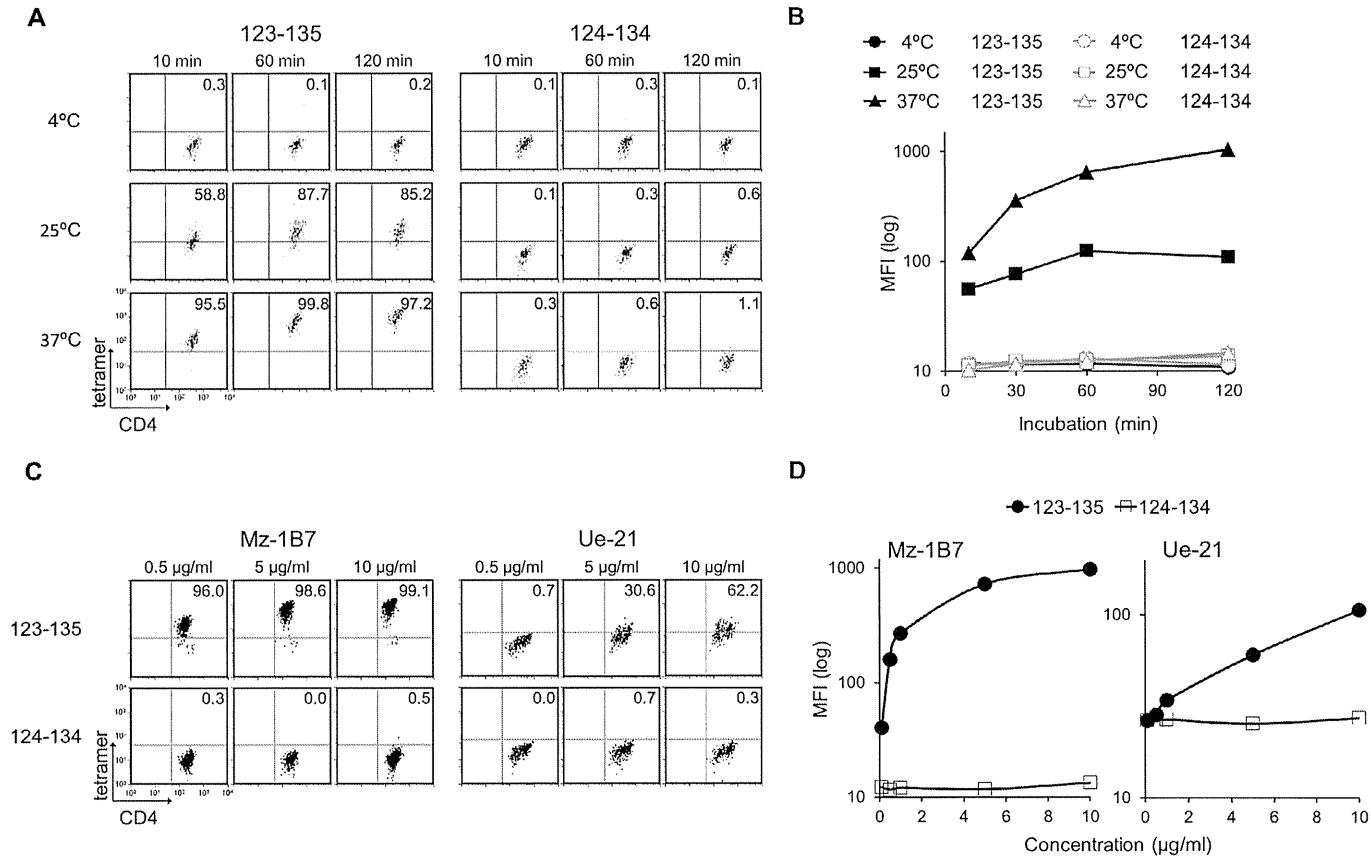

Fig. 3. Effect of temperature, incubation time and dose in tetramer staining. In (A) and (B), the E-2 CD4 T-cell clone Mz-1B7 was stained with NY-ESO-1 123–135 (LKEFTVSGNILTI) or NY-ESO-1 124–134 (KEFTVSGNILT) peptide/HLA-DRB1*08:03 tetramers (5 μg/ml) at 4, 25 or 37 °C for 10, 30, 60 or 120 min followed by staining with anti-CD4 mAb. In C and D, E-2 CD4 T-cell clones Mz-1B7 and Ue-21 were stained with NY-ESO-1 123–135 (LKEFTVSGNILTI) or NY-ESO-1 124–134 (KEFTVSGNILT) peptide/HLA-DRB1*08:03 tetramers (0.5, 1, 5 or 10 μg/ml) at 37 °C for 1 h followed by staining with an anti-CD4 mAb. Analysis was done using FACS Canto II. Dot plots (A and C) and the mean fluorescence intensity (MFI) (B and D) of tetramer staining are shown.

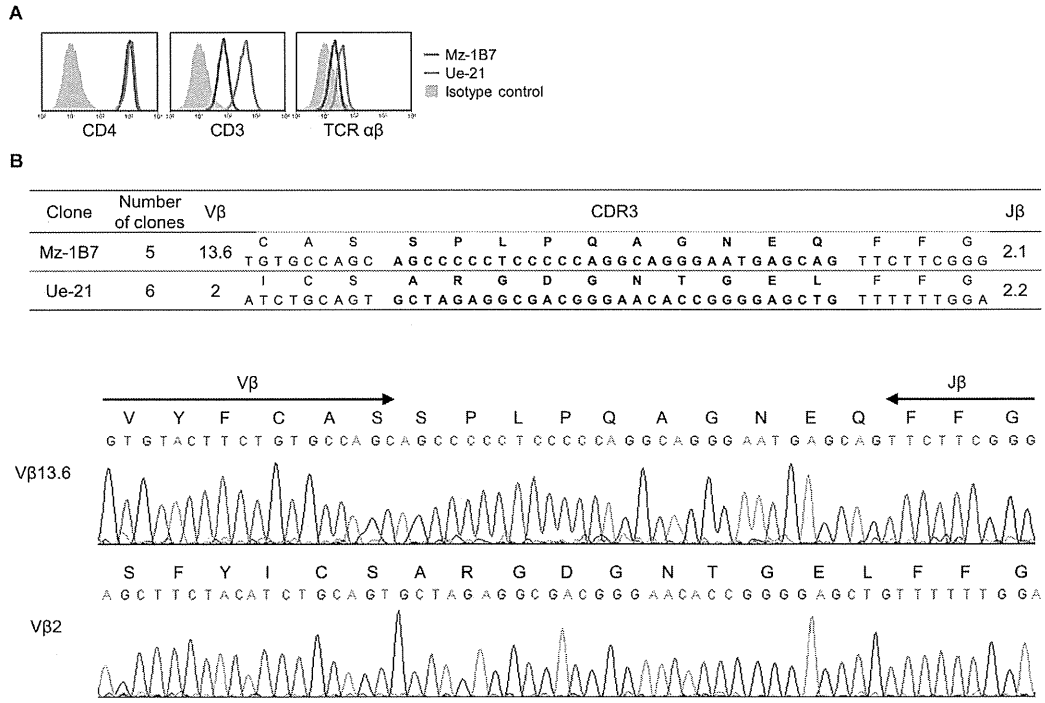

Fig. 4. Surface expression of the molecules on CD4 T-cell clones (A) and analysis of CDR3 sequences (B). In A, CD4 T-cell clones Mz-1B7 and Ue-21 stained with anti-CD4, CD3 and TCRαβ mAb were analyzed using FACS Canto II. In B, the nucleotide sequence and deduced amino acid sequences of the V–D–J junctional region of TCR β chain from the E-2 CD4 T-cell clones are shown.

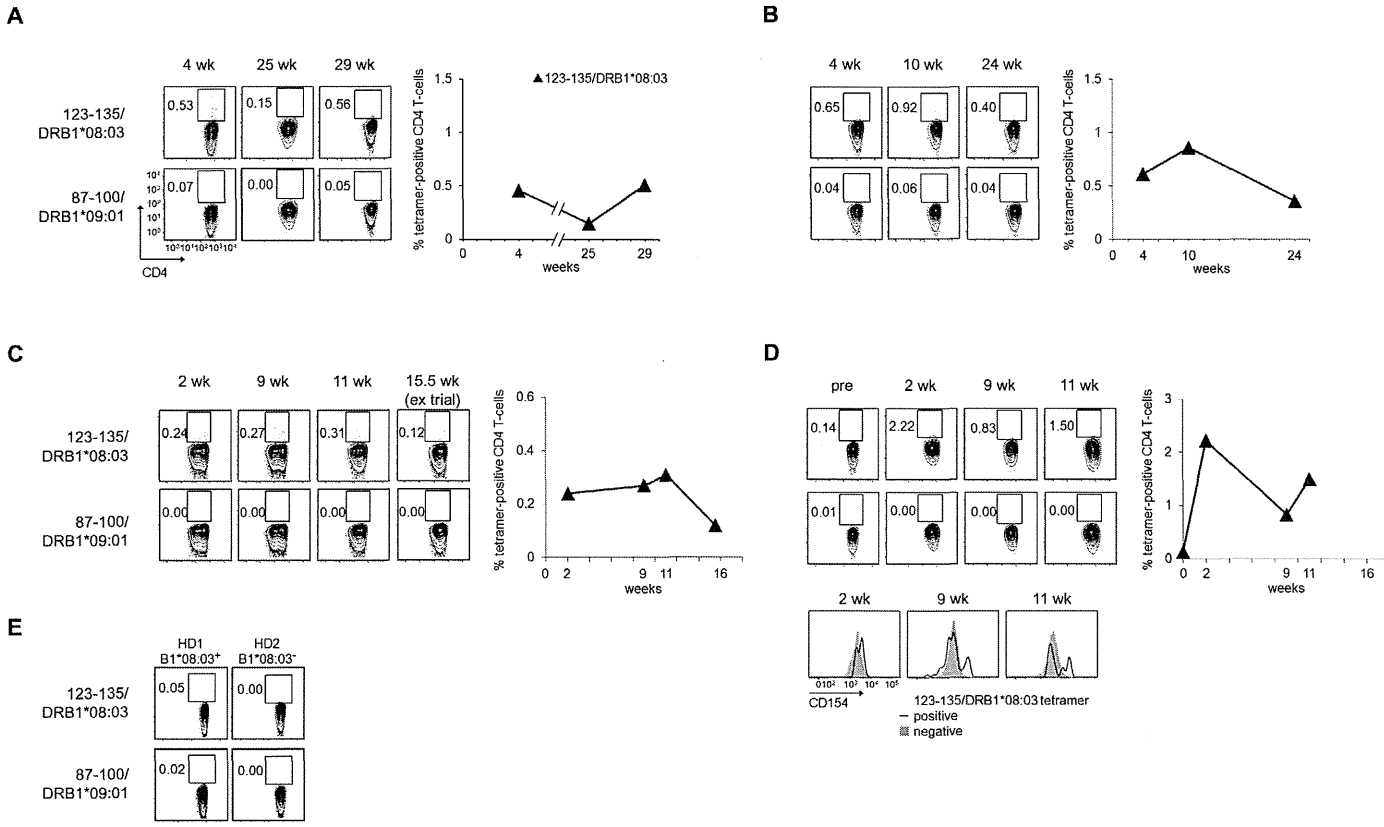

Fig. 5. Immunomonitoring of CD4 T-cell responses by the tetramer in cancer patients immunized with NY-ESO-1. CD4 T-cells from prostate cancer patient P-3 (A) and esophageal cancer patient E-1 (B) who were immunized with CHP-NY-ESO-1, and a lung cancer patient TK-OLP-01 (C) who was immunized with NY-ESO-1 OLP were stained ex vivo with the NY-ESO-1 123–135/HLA-DRB1*08:03 tetramer or a control NY-ESO-1 87–100/HLA-DRB1*09:01 tetramer (5 μg/ml) at 37 °C for 1 h followed by staining with an anti-CD4 mAb. In D, TK-OLP01 CD4 T-cells after in vitro stimulation twice were stained with the NY-ESO-1 123–135/HLA-DRB1*08:03 tetramer or a control NY-ESO-1 87–100/HLA-DRB1*09:01 tetramer and anti-CD154 mAb at 37 °C for 2 h followed by staining with an anti-CD4 mAb. The histogram shows CD154 expression on NY-ESO-1 123–135/DRB1*08:03 tetramer-positive (open) and negative (filled) CD4 T-cells. CD4 T-cells from two HDs were stained with tetramers as a negative control (E). HD1 and HD2 are DRB1*08:03-positive and -negative individuals, respectively. Analysis was done using FACS Canto II.

moderately. As shown in Fig. 4B, analysis of CDR3 sequences revealed that clone Mz-1B7 utilizes the Vβ13.6, SPLPQAGNEQ sequence for CDR3 and Jβ2.1. On the other hand, clone Ue-21 utilizes the Vβ2, ARGDGNTGEL sequence for CDR3 and Jβ2.2.

By cloning bulk CD4 T-cells from the E-2 patient, we obtained 58 DRB1*08:03-restricted clones. Within these, 5 clones utilized Vβ13.6 and 53 clones Vβ2. 5 clones with Vβ13.6 and 6 clones with Vβ2 were sequenced for CDR3. A combination of the same CDR3 sequence and Jβ was utilized by clones with each Vβ, respectively.

3.5. Monitoring of CD4 T-cell response by a tetramer constructed using the peptide 123–135 in cancer patients immunized with NY-ESO-1

Tetramers constructed using the peptide 123–135 (NY-ESO-1 123–135/DRB1*08:03) were used to monitor CD4 T-cell responses in DRB1*08:03-expressing cancer patients immunized with CHP-NY-ESO-1, or a mixture of NY-ESO-1 OLPs (NY-ESO-1 79–108, 100–129, 121–150 and 142–173) with Picibanil and Montanide. As shown in Fig. 5, the tetramer detected positive cells ex vivo in CD4 T-cells from PBMCs of a prostate cancer patient (P-3) (Fig. 5A) and an esophageal cancer patient (E-1) (Fig. 5B) who expressed DRB1*08:03 after immunization with CHP-NY-ESO-1. The tetramer also detected positive cells in CD4 T-cells from PBMCs of a lung cancer patient (TK-OLP-01) immunized with NY-ESO-1 OLP ex vivo (Fig. 5C) and after in vitro stimulation (Fig. 5D). Predominant detection of tetramer NY-ESO-1 123–135/DRB1*08:03-positive cells was observed after in vitro stimulation. Induction of CD154 (CD40L) expression on tetramer-positive cells was examined. At 9 and 11 weeks (3 and 4 vaccinations) after immunization, CD154 (CD40L)-positive cells were detected in tetramer NY-ESO-1 123–135/DRB1*08:03-positive, but not negative, cells suggesting their activation. No tetramer-positive cells were detected in CD4 T-cells from DRB1*08:03-positive or negative healthy donors (HD) (Fig. 5E). No clonal analysis of CD4 T-cells was possible because PBMCs from these patients were not available for further study.

4. Discussion

In this study, we demonstrated that HLA class II tetramers produced using minimal epitope peptides efficiently recognized by CD4 T-cell clones did not bind to cognate CD4 T-cell clones. Furthermore, we showed that a tetramer produced using a peptide which included the epitope sequence, but was not recognized by the cognate CD4 T-cell clone, could bind to the same CD4 T-cell clone.

It has long been observed that production of HLA class II tetramers is extremely difficult when compared to the production of MHC class I tetramers [5,6]. HLA class II tetramers produced using minimal epitope peptides and HLA class II molecules dimerized by a leucine zipper motif incorporated in the molecule generally failed to bind cognate CD4 T-cell clones. There have been only a few reports of successful binding of MHC class II tetramers to CD4 T-cells in which long peptides which were recognized by those T-cells were used for tetramer production [9–11].

The reason for the difficulty in producing MHC class II tetramers has generally been considered to be due to inappropriate accommodation of the peptide in the groove of the MHC class II molecule, resulting in unnatural conformation. One of the constraints for MHC class II tetramer production is derived from the ambiguity of determining epitopes for CD4 T-cells. Peptides with the addition of various lengths of N- and C-terminal ends to the minimal core sequence are recognized by CD4 T-cells. Moreover, it is difficult to determine whether the minimal peptide is a naturally presenting epitope or not [18,19]. Lack of accurate information about natural HLA class II epitopes appears to be one of the reasons for the difficulty in HLA class II tetramer production.

Moreover, low binding affinity/avidity of the peptide to MHC class II molecules may also be involved. In this study, we confirmed successful tetramer production with differential retention time by HPLC. For example, the prolongation of the retention time was 0.554 min with the addition of the 12-mer NY-ESO-1 123–134 peptide (LKEFTVSGNILT) to the DRB1*08:03 monomer, but was 0.039 min with the addition of a negative control peptide to DRB1*08:03. The prolongation of the retention time was 0.246 min with the positive control 15-mer CLIP peptide (PVSKMRMATPLLMQA). However, the possibilities discussed above were also considered for the failure to produce a tetramer using the minimal epitope peptides. First, the use of an inappropriate epitope may have been involved. Defining the precise length of natural epitopes bound to class II molecules is extremely difficult as described above. Second, the epitope peptide may have weak binding affinity for the MHC class II molecules used for tetramer production (see below). With the core 9-mer peptides bound to HLA-DRB1*08:03, hydrophobic residues at P1 as phenylalanine (F) or tyrosine (Y) and residues at P6 as proline (P), serine (S), arginine (R) or asparagine (N) are relevant as anchor residues [20,21]. F at position 126 and N at position 131 in NY-ESO-1 121–138 may contribute to binding. Addition of isoleucine (I) at position 135 strongly stabilized tetramer production. Third, binding instability of the peptide to class II molecules may also be involved.

In addition to the failure to produce MHC class II tetramers using the epitope peptides, this study showed unexpected binding of the tetramer with a peptide not recognized by CD4 T-cells. The clone Mz-1B7 did not recognize the free peptide 122–135 on autologous EBV-B cells as APC, but the peptide 122–135/DRB1*08:03 tetramer bound to the TCR on those cells. The possibility of a lack of binding of the free peptide 122–135 to the DRB1*08:03 molecule on autologous APC is unlikely because clone Ue-21 recognized it efficiently. Rather, the tetramer binding could be due to a subtly modified structure of the 122–135 peptide/DRB1*08:03 tetramer from the structure of the free 122–135 peptide/DRB1*08:03 molecule. This could result from structural modification of either the peptide or the DR molecule, or both, during preparation of the peptide/DR tetramer, or simply be due to a subtle conformational change in the DR molecule itself due to fusion of the leucine zipper motif [8]. In the latter, it is possible that association of DRα and DRβ chains by the leucine zipper motif on each chain caused a subtle difference in the conformation of the natural DR molecule, although there was no convincing evidence to support this idea in this study.

Here, we also demonstrated that the NY-ESO-1 123–135/DRB1*08:03 tetramer detected ex vivo CD4 T-cell responses in PBMCs from a prostate cancer patient P-3 and an esophageal cancer patient E-1 after CHP-NY-ESO-1 vaccination, and a lung cancer patient TK-OLP-01 after NY-ESO-1 OLP vaccination. These patients possessed the DRB1*08:03 allele. Patient P-3 was positive for the NY-ESO-1 antibody before vaccination (sero-positive) and patients E-1 and TK-OLP-01 were sero-negative [15]. In these patients, tetramer-positive CD4 T-cells were detected after vaccination.

Based on the discussion above, a possible difference in CD4 T-cell clones recognizing the epitope peptides from those detected by the respective peptide/HLA class II tetramer should be taken into consideration in HLA class II tetramer analysis.

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Conflict of interest: There is no conflict of interest.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.vaccine.2013.12.042.

References

[1] Guillaume P, Dojcinovic D, Luescher IF. Soluble MHC-peptide complexes: tools for the monitoring of T cell responses in clinical trials and basic research. Cancer Immunity 2009;9.
[2] Altman JD, Moss PA, Goulder PJ, Barouch DH, McHeyzer-Williams MG, Bell JI, et al. Phenotypic analysis of antigen-specific T lymphocytes. Science 1996;274:94–6.
[3] Bakker AH, Schumacher TNM. MHC multimer technology: current status and future prospects. Current Opinion in Immunology 2005;17:428–33.
[4] Chattopadhyay PK, Melenhorst JJ, Ladell K, Gostick E, Scheinberg P, Barrett AJ, et al. Techniques to improve the direct ex vivo detection of low frequency antigen-specific CD8+ T cells with peptide-major histocompatibility complex class I tetramers. Cytometry Part A 2008;73:1001–9.
[5] Cecconi V, Moro M, Del Mare S, Dellabona P, Casorati G. Use of MHC class II tetramers to investigate CD4+ T cell responses: problems and solutions. Cytometry Part A 2008;73:1010–8.
[6] Vollers SS, Stern LJ. Class II major histocompatibility complex tetramer staining: progress, problems, and prospects. Immunology 2008;123:305–13.
[7] Kalandadze A, Galleno M, Foncerrada L, Strominger JL, Wucherpfennig KW. Expression of recombinant HLA-DR2 molecules. Journal of Biological Chemistry 1996;271:20156.
[8] Novak EJ, Liu AW, Nepom GT, Kwok WW. MHC class II tetramers identify peptide-specific human CD4+ T cells proliferating in response to influenza A antigen. Journal of Clinical Investigation 1999;104:R63.
[9] James EA, LaFond R, Durinovic-Bello I, Kwok W. Visualizing antigen specific CD4+ T cells using MHC class II tetramers. Journal of Visualized Experiments 2009.
[10] Nepom GT, Buckner JH, Novak EJ, Reichstetter S, Reijonen H, Gebe J, et al. HLA class II tetramers: tools for direct analysis of antigen-specific CD4+ T cells. Arthritis & Rheumatism 2002;46:5–12.
[11] Wooldridge L, Lissina A, Cole DK, Van Den Berg HA, Price DA, Sewell AK. Tricks with tetramers: how to get the most from multimeric peptide-MHC. Immunology 2009;126:147–64.
[12] Ayyoub M, Dojcinovic D, Pignon P, Raimbaud I, Schmidt J, Luescher I, et al. Monitoring of NY-ESO-1 specific CD4+ T cells using molecularly defined MHC class II/His-tag-peptide tetramers. Proceedings of the National Academy of Sciences 2010;107:7437.
[13] Ayyoub M, Pignon P, Dojcinovic D, Raimbaud I, Old LJ, Luescher I, et al. Assessment of vaccine-induced CD4 T cell responses to the 119–143 immunodominant region of the tumor-specific antigen NY-ESO-1 using DRB1* 0101 tetramers. Clinical Cancer Research 2010;16:4607.
[14] Mizote Y, Taniguchi T, Tanaka K, Isobe M, Wada H, Saika T, et al. Three novel NY-ESO-1 epitopes bound to DRB1* 0803, DQB1* 0401 and DRB1* 0901 recognized by CD4 T cells from CHP-NY-ESO-1-vaccinated patients. Vaccine 2010;28:5338–46.
[15] Uenaka A, Wada H, Isobe M, Saika T, Tsuji K, Sato E, et al. T cell immunomonitoring and tumor responses in patients immunized with a complex of cholesterol-bearing hydrophobized pullulan (CHP) and NY-ESO-1 protein. Cancer Immunity 2007;7.
[16] Wada H, Sato E, Uenaka A, Isobe M, Kawabata R, Nakamura Y, et al. Analysis of peripheral and local anti-tumor immune response in esophageal cancer patients after NY-ESO-1 protein vaccination. International Journal of Cancer 2008;123:2362–9.
[17] Genevée C, Diu A, Nierat J, Caignard A, Dietrich PY, Ferradini L, et al. An experimentally validated panel of subfamily-specific oligonucleotide primers (V_α1-w29/V_β1-w24) for the study of human T cell receptor variable V gene segment usage by polymerase chain reaction. European Journal of Immunology 1992;22:1261–9.

[18] Chicz RM, Urban RG, Gorga JC, Vignali DA, Lane WS, Strominger JL. Specificity and promiscuity among naturally processed peptides bound to HLA-DR alleles. Journal Experimental Medicine 1993;178:27–47.
[19] Chicz RM, Urban RG, Lane WS, Gorga JC, Stern LJ, Vignali DA, et al. Predominant naturally processed peptides bound to HLA-DR1 are derived from MHC-related molecules and are heterogeneous in size. Nature 1992;358:764–8, a–z index.
[20] Rapin N, Hoof I, Lund O, Nielsen M. The MHC motif viewer: a visualization tool for MHC binding motifs. Current Protocols in Immunology 2010. Chapter 18:Unit 18.17.
[21] Southwood S, Sidney J, Kondo A, del Guercio M-F, Appella E, Hoffman S, et al. Several common HLA-DR types share largely overlapping peptide binding repertoires. The Journal of Immunology 1998;160:3363–73.

Vaccination With NY-ESO-1 Overlapping Peptides Mixed With Picibanil OK-432 and Montanide ISA-51 in Patients With Cancers Expressing the NY-ESO-1 Antigen

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Summary: We conducted a clinical trial of an NY-ESO-1 cancer vaccine using 4 synthetic overlapping long peptides (OLP; peptides #1, 79–108; #2, 100–129; #3, 121–150; and #4, 142–173) that include a highly immunogenic region of the NY-ESO-1 molecule. Nine patients were immunized with 0.25 mg each of three 30-mer and a 32-mer long NY-ESO-1 OLP mixed with 0.2 KE Picibanil OK-432 and 1.25 mL Montanide ISA-51. The primary endpoints of this study were safety and NY-ESO-1 immune responses. Five to 18 injections of the NY-ESO-1 OLP vaccine were well tolerated. Vaccine-related adverse events observed were fever and injection site reaction (grade 1 and 2). Two patients showed stable disease after vaccination. An NY-ESO-1-specific humoral immune response was observed in all patients and an antibody against peptide #3 (121–150) was detected firstly and strongly after vaccination. NY-ESO-1 CD4 and CD8 T-cell responses were elicited in these patients and their epitopes were identified. Using a multifunctional cytokine assay, the number of single or double cytokine-producing cells was increased in NY-ESO-1-specific CD4 and CD8 T cells after vaccination. Multiple cytokine-producing cells were observed in PD-1 (−) and PD-1 (+) CD4 T cells. In conclusion, our study indicated that the NY-ESO-1 OLP vaccine mixed with Picibanil OK-432 and Montanide ISA-51 was well tolerated and elicited NY-ESO-1-specific humoral and CD4 and CD8 T-cell responses in immunized patients.

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The study was registered in the University hospital Medical Information Network Clinical Trials Registry (UMIN-CTR) Clinical Trial (Unique trial number: UMIN000001857) on April 7, 2009 (UMIN-CTRURL: http://www.umin.ac.jp/ctr/index.htm).

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The NY-ESO-1 antigen was originally identified in esophageal cancer by serological expression cloning (SEREX) using autologous patient serum.[1] NY-ESO-1 expression is observed in a wide range of human malignancies, but the expression is restricted to germ cells in the testis in normal adult tissues.[2] Therefore, NY-ESO-1 has emerged as a prototype of a class of cancer/testis (CT) antigens.

Numerous cancer vaccine strategies are under development.[3,4] For patients with hormone-resistant prostate cancer, a dendritic cell (DC) vaccine has recently been approved.[5] The therapy is based on loading autologous DCs ex vivo with a lysate of a cultured prostate cancer cell line transfected with the genes of acid phosphatase and GM-CSF, with subsequent administration to patients to induce specific T-cell responses. However, its clinical efficacy seems to be limited.[6,7] Cancer vaccines using recombinant proteins and peptides are thought to involve DCs in vivo and have advantages in that materials are easy to secure, there is little toxicity, and there are no complex regulatory matters when compared with cell therapy.[8] As cancer vaccines using short peptides showed only limited efficacy, cancer vaccines using synthetic long peptides have been introduced.[4,9–11] Synthetic peptides of 25–50 amino acids are internalized and processed by DCs efficiently, and presented the antigens on MHC class I and II for T cells.[12,13] Maturation of DCs is associated with upregulation of costimulatory molecules on their surfaces and is crucial for efficient induction of T-cell responses. Adjuvants such as TLR ligands induce DC maturation and strongly augment the immunogenicity of cancer vaccines.[3,14]

Detection of pathogen-associated molecular patterns by the pattern recognition receptors on DCs and activation of subsequent signaling induce specific CD4 and CD8 T-cell responses.[15,16] Thus, the stimulatory effect of innate immunity on adaptive immune responses is useful for cancer vaccines. TLRs, nucleotide-binding oligomerization domain–like receptors, the retinoic acid-inducible gene-I-like or RIG-like receptors, and the C-type lectin receptors are the 4 known families of pattern recognition receptors.[17] In this study, we immunized patients with advanced cancers expressing the NY-ESO-1 antigen with 30–32-mer NY-ESO-1 overlapping long peptides (OLP), and Picibanil

OK-432 and Montanide ISA-51 as immunomodulators. OK-432 is a penicillin-killed and lyophilized preparation of a low-virulence strain (Su) of *Streptococcus pyogenes*.[9,18,19] It was developed as a nonspecific immune stimulant, TLR2, 4, and/or 9 agonist. OK-432 induces various cytokines including tumor necrosis factor-α (TNF-α), interferon (IFN), interleukin (IL)-2, and IL-6.[20] Recently, it was shown that in vivo administration of OK-432 overcame regulatory T-cell suppression in mice.[21] The vaccine also induced efficient NY-ESO-1 immunity in patients.

MATERIALS AND METHODS

NY-ESO-1 OLP Vaccine

NY-ESO-1 OLPs [peptide #1: NY-ESO-1 79–108 (GARGPESRLLEFYLAMPFATPMEAELARRS), peptide #2: NY-ESO-1 100–129 (MEAELARRSLAQDAPPLP VPGVLLKEFTVS), peptide #3: NY-ESO-1 121–150 (VLLKEFTVSGNILTIRLTAADHRQLQLSIS), and peptide #4: NY-ESO-1 142–173 (HRQLQLSISSCLQQL SLLMWITQCFLPVFLAQ)] were synthesized by Multiple Peptide Systems (San Diego, CA). The vaccine, consisting of 1 mg of NY-ESO-1 OLP including 0.25 mg each of the 4 peptides, 0.2 KE OK-432 (Picibanil; Chugai Pharmaceutical Co., Ltd., Tokyo, Japan) and 1.25 mL ISA-51(Montanide; Seppic, Paris, France), was emulsified under sterile conditions. Synthesis, production, formulation, and packaging of the investigational agent were in accordance with current Good Manufacturing Practices and met the applicable criteria for use in humans.

Study Design

A pilot, open-label, multi-institutional clinical trial of the NY-ESO-1 OLP vaccine was designed to evaluate the safety, immune response, and clinical response. Patients eligible for entry were those who had advanced cancers that were refractory to standard therapy and expressed NY-ESO-1 as assessed by immunohistochemistry (IHC), a performance status of 0, 1, or 2, were 20 years old or above, had a life expectancy of 4 months or more, and did not have impaired organ function. Patients ineligible were those who were positive for HIV antibodies, had multiple cancers, autoimmune disease, serious allergy history, or active brain metastasis, or received chemotherapy, systemic steroid, or immunosuppressive therapy in the last 4 weeks. Nine patients, including 7 patients with esophageal cancer, a patient with lung cancer, and a patient with malignant melanoma, were enrolled in a washout period after surgery, chemotherapy or radiation therapy. The vaccine was administered subcutaneously once every 2 (esophageal cancer patients) or 3 (lung cancer and malignant melanoma patients) weeks to achieve better performance status in esophageal cancer patients to complete a cycle of 6 vaccinations. Four weeks after the last administration, the safety, immune response, and clinical response were evaluated. Thereafter, the vaccine was administered additionally. The 9 patients received 5–18 immunizations. Clinical response was assessed according to the Response Evaluation Criteria in Solid Tumors (RECIST ver1.1)[22] and the immune-related response criteria (irRC).[23] Safety was evaluated according to the National Cancer Institute Common Terminology Criteria for Adverse Events ver.3.0 (NCI-CTCAE ver.3.0) (http://ctep.cancer.gov/). The protocol was approved by the Ethics Committee of Osaka, Tokyo and Okayama Universities in light of the Declaration of Helsinki. Written informed consent was obtained from each patient before enrollment in the study. The study was conducted in compliance with Good Clinical Practice. The study was registered in the University hospital Medical Information Network Clinical Trials Registry (UMIN-CTR) Clinical Trial (unique trial number: UMIN000001857) on April 7, 2009 (UMIN-CTRURL: http://www.umin.ac.jp/ctr/index.htm).

Blood Samples

Peripheral blood was drawn from the patients at baseline, at each time point of immunization, and 4 weeks after the last immunization. Peripheral blood mononuclear cells (PBMCs) and plasma were isolated by density gradient centrifugation using lymphoprep (AXIS-SHIELD Poc AS, Oslo, Norway). A CD8 T-cell–enriched population was obtained from PBMCs using CD8 microbeads with a large-scale column and a magnetic device (Miltenyi Biotec, Auburn, CA). A CD4 T-cell–enriched population was then obtained from the residual cells using CD4 microbeads. The final residual cells were used as a CD4-depleted and CD8-depleted population. The 3 populations were stored in liquid N_2 until use. HLA typing of PBMCs was performed by sequence-specific oligonucleotide probing and sequence-specific priming of genomic DNA using standard procedures.

NY-ESO-1 18-Mer Series Peptides

The following series of 28 overlapping NY-ESO-1 18-mer peptides spanning the protein were synthesized: 1–18, 7–24, 13–30, 19–36, 25–42, 31–48, 37–54, 43–60, 49–66, 55–72, 61–78, 67–84, 73–90, 79–96, 85–102, 91–108, 97–114, 103–120, 109–126, 115–132, 121–138, 127–144, 133–150, 139–156, 145–162, 149–166, 153–170, and 156–173. A 30-mer peptide, 151–180, was also synthesized. These 29 peptides (NY-ESO-1 18-mer series peptides) were synthesized using standard solid-phase methods based on N-(9-fluorenyl)-methoxycarbonyl (Fmoc) chemistry on a Multiple Peptide Synthesizer (AMS422; ABIMED, Langenfeld, Germany) at Okayama University.

ELISA

Recombinant NY-ESO-1 protein was prepared as described previously.[24] Recombinant protein (1 μg/mL) or peptide (10 μg/mL) in a coating buffer (15 mM Na_2CO_3, 30 mM $NaHCO_3$, pH 9.6) was adsorbed onto 96-well Polysorp immunoplates (Nunc, Roskilde, Denmark) and incubated overnight at 4°C. Plates were washed with PBS and blocked with 200 μL/well of 5% FCS/PBS for 1 hour at room temperature. After washing, 100 μL of serially diluted plasma was added to each well and incubated for 2 hours at room temperature. After extensive washing, horseradish peroxidase-conjugated goat anti-human pan-IgG, IgG_1, IgG_2, IgG_3, IgG_4, or IgM (Medical & Biological Laboratories, Nagoya, Japan) was added to the wells, and the plates were incubated for 1 hour at room temperature. After washing and development, absorbance at 490 nm was read. Recombinant murine Akt protein[24] and ovalbumin (albumin from chicken egg white; Sigma, St. Louis, MO) were used as control proteins.

In Vitro Stimulation of CD4 and CD8 T Cells

Frozen cells were thawed and resuspended in AIM-V (Invitrogen, Carlsbad, CA) medium supplemented with 5% heat-inactivated pooled human serum (CM), and kept at room temperature for 2 hours. CD4-enriched and CD8-enriched populations (2×10^6) were cultured with irradiated

(30 Gy), autologous CD4-depleted and CD8-depleted PBMCs (2×10^6) in the presence of 29 NY-ESO-1 18-mer series peptides in 2 mL of CM supplemented with 10 U/mL rIL-2 (Takeda Chemical Industries, Osaka, Japan) and 10 ng/mL rIL-7 (Peprotech, London, UK) in a 24-well culture plate at 37°C in a 5% CO_2 atmosphere for 12 days. For the second stimulation, 1×10^6 instead of 2×10^6 responder cells were used in the culture described above. For nonspecific immune activation, T cells were stimulated with 50 ng/mL PMA and 1 μg/mL ionomycin with GolgiStop (BD Biosciences, Franklin Lakes, NJ) for 6 hours at 37°C.

IFN-γ Catch Assay

Responder CD4 or CD8 T cells (5×10^4) from the stimulation culture were cultured for 4 hours with autologous EBV-B cells (5×10^4) pulsed with mixed, or one of the 29 NY-ESO-1 18-mer series peptides. The cells were then treated with a bispecific CD45 and IFN-γ antibody (IFN-γ catch reagent; 2 μL) for 5 minutes on ice. The cells were diluted in AIM-V medium (3 mL) and placed on a slow rotating device (Miltenyi Biotec, Bergisch Gladbach, Germany) to allow IFN-γ secretion at 37°C in a 5% CO_2 atmosphere. After incubation for 1 hour, the cells were washed with cold buffer and treated with PE-conjugated anti-IFN-γ (detection reagent), and FITC-conjugated anti-CD4 or anti-CD8 mAb. After incubation for 10 minutes at 4°C, the cells were washed and analyzed by FACS Canto II (BD Biosciences).

IHC

IHC was performed as described previously.[9] E978[25] and EMR8-5 (Funakoshi, Tokyo, Japan) mAbs were used to analyze NY-ESO-1 and HLA class I expression, respectively. The reaction was evaluated as + + + (> 50% stained cells), + + (50%–25% stained cells), + (25%–5% stained cells), and − (< 5% stained cells).

Intracellular Staining (ICS) of Cytokines

CD4 or CD8 T cells were washed and treated with Cytofix and Perm Wash (BD Biosciences) according to the manufacturer instructions to stain them with IFN-γ-APC (BD Biosciences), IL-2-APC (BD Biosciences), IL-5-PE (BD Biosciences), IL-10-APC (BioLegend, San Diego, CA), IL-17 A-PerCP-Cy5.5 (eBioscience, San Diego, CA), and/or TNF-α-FITC (eBioscience) intracellularly. For Foxp3 staining, a human Foxp3 staining kit, Alexa 488 (BD Biosciences), was used. Cells were analyzed using a FACS Canto II (BD Biosciences) and FlowJo software (Tree Star, Ashland, OR).

Reverse Transcription-Polymerase Chain Reaction (RT-PCR) Analysis

To amplify the *NY-ESO-1* cDNA segment, primers specific for *NY-ESO-1* were designed as described previously.[26] Primers for RT-PCR were: *NY-ESO-1 5′-AGT TCTACCTCGCCATGCCT-3′* (forward), *5′-TCCTCCT CCAGCGACAAACAA-3′* (reverse), *GAPDH 5′-ACCACA GTCCATGCCATCAC-3′* (forward), *5′-TCCACCACC CTGTTGCTGTA-3′* (reverse). The amplification program for *NY-ESO-1* was 1 minute at 94°C, 1 minute at 60°C, and 1.5 minutes at 72°C for 35 cycles after denaturing at 94°C for 1 minute. These cycles were followed by a 10-minute elongation step at 72°C. The amplification program for *GAPDH* was 1 minute at 94°C, 1 minute at 66°C, and 1.5 minutes at 72°C for 30 cycles after denaturing at 94°C for 1 minute. These cycles were followed by a 10-minute elongation step at 72°C. The PCR products were analyzed on a 1.3% agarose gel.

RESULTS

Patient Characteristics

Nine patients with advanced cancers expressing the NY-ESO-1 antigen were enrolled (Table 1). Seven were esophageal cancer patients. One was a malignant melanoma patient and 1 was a lung cancer patient. Eight patients completed a cycle of 6 vaccinations. One esophageal cancer patient, P-5, did not complete a cycle of vaccination due to disease progression and was given only 5 vaccinations, but was included in the analysis. Two patients, P-6 and P-7, were given additional vaccinations because of stable disease (SD) during treatment (Table 2).

Safety

Injection site reactions were observed in all patients (Table 1). The reaction was grade 1 in 7 patients and grade 2 with induration in 2 patients, but resolved without any treatment several months after vaccination. Fever (grade 1) was observed in 3 patients. No other adverse events either related or nonrelated to the vaccine were observed. The vaccine was well tolerated.

Monitoring of Humoral Immune Response

Serum antibodies against full-length NY-ESO-1 protein and also against 4 individual NY-ESO-1 OLP (peptides #1, 79–108; #2, 100–129; #3, 121–150; and #4, 142–173) used for the vaccine were investigated (Fig. 1). Three patients, P-2, P-3, and P-4, had antibodies against the NY-ESO-1 protein at the baseline (seropositive). Of those, P-2 and P-3 showed no antibodies against the 4 peptides, whereas P-4 showed antibodies against peptide #1 (79–108),

TABLE 1. Patient Characteristics

Patients	Age/Sex	Cancer	Vaccination	Vaccine-related Toxicity
P-1	69/M	Malignant melanoma	6	Injection site reaction (grade 1)
P-2	55/M	Lung cancer (adenocarcinoma)	6	Fever (grade 1), injection site reaction (grade 1)
P-3	66/M	Esophageal cancer (squamous cell carcinoma)	6	Injection site reaction (grade 1)
P-4	70/M	Esophageal cancer (squamous cell carcinoma)	6	Injection site reaction (grade 1)
P-5	58/M	Esophageal cancer (squamous cell carcinoma)	5	Injection site reaction (grade 1)
P-6	67/M	Esophageal cancer (squamous cell carcinoma)	18	Injection site reaction (grade 1)
P-7	74/M	Esophageal cancer (squamous cell carcinoma)	8	Injection site reaction (grade 1)
P-8	69/M	Esophageal cancer (squamous cell carcinoma)	6	Fever (grade 1), injection site reaction (grade 2)
P-9	70/F	Esophageal cancer (squamous cell carcinoma)	6	Fever (grade 1), injection site reaction (grade 2)

TABLE 2. Immune Responses and Tumor Responses After Vaccination With the NY-ESO-1 OLP Peptide

Patients	IHC*		Antibody‡		CD4§		CD8§		Target Tumor		
	MHC	NY-ESO-1	Pre	Post	Pre	Post	Pre	Post	Region	Total Diameter (mm)	Clinical Response‖ (Duration)¶
P-1	ND	+ †	−	+ + +	−	+	−	+	abLN + axLN	48	PD
P-2	+ +	+	−	+ + +	−	+ + +	−	+ +	meLN	24	PD
P-3	+ +	+	−	+ + +	−	+ + +	−	+ + +	abLN	32	PD
P-4	+ + +	+ + +	+ +	+ + +	ND	ND	ND	ND	liver	20	PD
P-5	+ +	+ + +	−	+ + +	−	−	−	−	pleura	28	PD
P-6	+ +	+ + +	−	+ + +	−	+	−	−	abLN + liver	33	SD (7 mo)
P-7	+ +	+	−	+ + +	−	+ +	−	+	neLN	18	SD (4 mo)
P-8	+ +	+ + +	−	+ + +	−	+	−	+	pleura	30	PD
P-9	+ +	+ +	−	+ + +	ND	ND	ND	ND	pleura	25	PD

*IHC was performed using EMR8-5 mAb for MHC class I (MHC) and E957 mAb for NY-ESO-1. IHC-positive cells: + + + + > 50%; 50% ≥ + + + > 25%; 25% ≥ + > 5%; 5% ≥ −.
†NY-ESO-1 expression of P-1 was determined by RT-PCR.
‡Antibody response was determined by ELISA (see Materials and methods section) using OD values at 25 × dilution for each OLP peptide and at 100 × or 1600 × dilution for NY-ESO-1 protein. Antibody response shown here represents OD for NY-ESO-1 OLP: + + + + > 2; 2 ≥ + + + > 0.5; 0.5 ≥ + + > 0.1; 0.1 ≥ −.
§CD4 and CD8 T-cell responses were determined by an IFN-γ catch assay with the cells stimulated in vitro once (1°IVS). IFN-γ-positive cells: + + + + > 10%; 10% ≥ + + + > 5%; 5% ≥ + + > 1%; 1% ≥ −. The response was confirmed by cells stimulated in vitro twice (2°IVS).
‖Clinical response was evaluated by RECIST and irRC.
¶SD duration was measured from the start of the immunization until the patients were defined as PD by RECIST (P-6) or removed due to disease progression (P-7).
Ab indicates abdomen; ax, axilla; LN, lymph node; me, mediastinum; ne, neck; ND, not done; PD, progressive disease; SD, stable disease.

but not against the others. After vaccination, antibodies against peptide #3 (121–150) were detected firstly and strongly in all patients. Antibodies against peptide #4 (142–173) were also detected in 7 of 9 patients. In contrast, the antibody responses against peptides #1 (79–108) and #2 (100–129) were relatively weak. The antibody responses against the NY-ESO-1 protein also increased in parallel, or with a delay, compared with antibody responses against the peptides in all patients. Notably, in patients P-6 and P-7 who showed SD, strong antibody responses against the peptides and the protein were observed. The dominant Ig subtypes were IgG_1 and IgG_3. An increased IgM response against peptide #3 after vaccination was observed in 6 patients.

Monitoring of CD4 and CD8 T-Cell Responses

CD4 and CD8 T cells purified from PBMCs using antibody-coated magnetic beads were cultured for 12 days with a mixture of 29 NY-ESO-1 18-mer series peptides spanning the entire NY-ESO-1 protein [stimulated in vitro once (1°IVS)] and assayed for IFN-γ production by an IFN-γ catch assay after stimulation with a mixture of 29 NY-ESO-1 18-mer series peptides for 4 hours. CD4 and CD8 T cells harvested from 1°IVS were again cultured in a similar way to 1°IVS, except using 1×10^5 instead of 1×10^6 responder cells [stimulated in vitro twice (2°IVS)] and assayed by an IFN-γ catch assay to confirm weak response. As shown in Figure 2, an increase in the CD4 T-cell response was observed in all 7 patients investigated in 1°IVS. In contrast, an increase in the CD8 T-cell response was observed in 5 of 7 patients in 1°IVS. A CD8 T-cell response was detected after 2°IVS in 2 patients (P-5 and P-6), who showed only a marginal response in 1°IVS. The Supplementary Figure (Supplemental Digital Content 1, http://links.lww.com/JIT/A313) shows the representative results of the IFN-γ catch assay for P-3 and P-7.

Next, the peptides recognized by CD4 and CD8 T cells were investigated by an IFN-γ catch assay using cells stimulated in 2°IVS and testing against individual 29 NY-ESO-1 18-mer series peptides. As shown in Figure 3, CD4 T cells dominantly recognized 18-mer peptides #15 and #21 and their adjacent peptides. A CD8 T-cell response was observed against various peptides, including 18-mer peptides #15 and #21, which were recognized relatively dominantly. In the case of CD8, a response against peptides (1–78) not included in the vaccine preparation was also observed. The Supplementary Table (Supplemental Digital Content 2, http://links.lww.com/JIT/A314) shows patient HLA.

$Foxp3^+$ CD4 cells were also examined by ICS. As shown in Figure 2, a decrease after vaccination was observed in 4 of 6 patients investigated. In contrast, a slight increase followed by a decrease was observed in 2 patients.

Clinical Observation

As shown in Table 2, patients P-6 and P-7 showed SD during vaccinations and were given additional 12 and 2 vaccinations, respectively. The other 7 patients showed PD during vaccinations. There was no discrepancy in evaluation between RECIST and irRC and no evidence of clinical benefit after immunizations. The results of immunomonitoring and clinical responses are summarized in Table 2. As previously described, in patients P-6 and P-7 who showed SD, strong antibody responses against the peptides and the protein were observed.

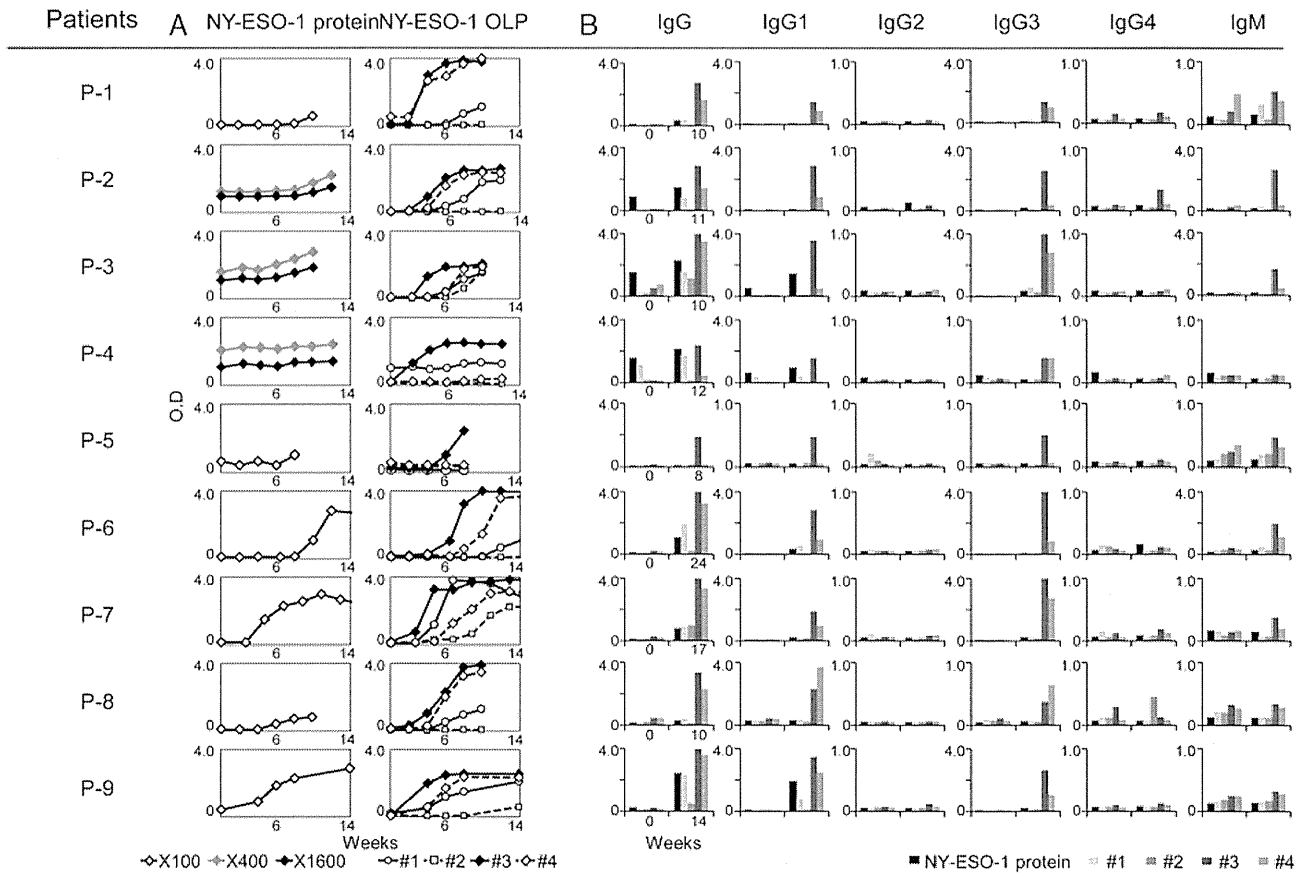

FIGURE 1. Immunomonitoring of humoral immune responses after NY-ESO-1 OLP vaccination. NY-ESO-1 antibody responses against recombinant NY-ESO-1 protein for each of the NY-ESO-1 OLP peptides were evaluated using plasma obtained before and after vaccination with NY-ESO-1 OLP from the 9 patients. A, Whole IgG antibody responses against recombinant NY-ESO-1 protein or each peptide included in the NY-ESO-1 OLP vaccine at a dilution of 1:100 (open diamond) or 1:1600 (closed diamond) for the protein and at a dilution of 1:25 for the peptides at the baseline (week 0) and at each vaccination. B, Whole IgG, IgG_1, IgG_2, IgG_3, IgG_4, and IgM antibody responses against the protein or each peptide at a dilution of 1:25 at the baseline and at the indicated week after vaccination.

Multiple Cytokine Production by CD4 and CD8 T Cells After Stimulation With NY-ESO-1 OLP

CD4 and CD8 T cells from patient P-3 and P-7 PBMCs purified by antibody-coated magnetic beads were stimulated in vitro with a mixture of 29 NY-ESO-1 18-mer series peptides for 12 days as previously shown and assayed for IL-2, TNF-α, and IFN-γ-producing cells by ICS using FACS. As shown in Figure 4, an increase in the number of single cytokine-producing cells was observed in CD4 and CD8 T cells after vaccination. A slight increase in double cytokine-producing cells was also observed. No triple cytokine-producing cells were observed. In addition, an increase in CD4 T cells producing IL-5 or IL-17, but not IL-10, was observed after vaccination, suggesting activation of Th2 and Th17, as well as Th1 (Fig. 4B).

Nonspecific Immune Activation by the Vaccine

In addition, nonspecific immune activation by the vaccine preparation was investigated using CD4 T cells from patient P-7 obtained before and after vaccination, and stimulated with PMA/ionomycin by ICS. As shown in Figures 4C and D, while no triple cytokine-producing cells were observed in either PD-1 (–) or PD-1 (+) CD4 T cells at day 0, these cells appeared even after a single vaccination (day 15). No further increase in these cells was observed in CD4 T cells obtained after the 10th vaccination (day 78). No significant change in PD-1 (–) or PD-1 (+) CD4 T-cell populations was observed during the vaccination period.

DISCUSSION

In this study, we showed that an NY-ESO-1 OLP vaccine with Picibanil OK-432 and Montanide ISA-51 was safe and induced NY-ESO-1 humoral and cellular immune responses in all patients. In our previous study on cancer vaccines with NY-ESO-1 protein[24–29] and the NY-ESO-1f peptide,[9] NY-ESO-1-specific humoral immune responses appeared to be useful as an immunological marker to predict the clinical responses of the patients vaccinated. This study showed that of the 4 peptides used, the antibody response against peptide #3 (121–150) was the most useful for monitoring than the responses against other peptides. The dominant epitope recognized by CD4 T cells (18-mer peptide #21, NY-ESO-1 121–138) in Figure 3 is included in the sequence of peptide #3. It is interesting to note that, the epitope peptide recognized by the antibody induced spontaneously in patients with NY-ESO-1-expressing tumors or in patients vaccinated with the NY-ESO-1 protein was NY-ESO-1 91–108, and was not included in peptide #3.[23] A mixture of four 30–32-mer long peptides used for the vaccine included a hydrophobic sequence located in a region approximately 121–170 amino acid, which is normally buried in the molecule[23] and therefore altered the immunological dominance of the antibody response to NY-ESO-1.

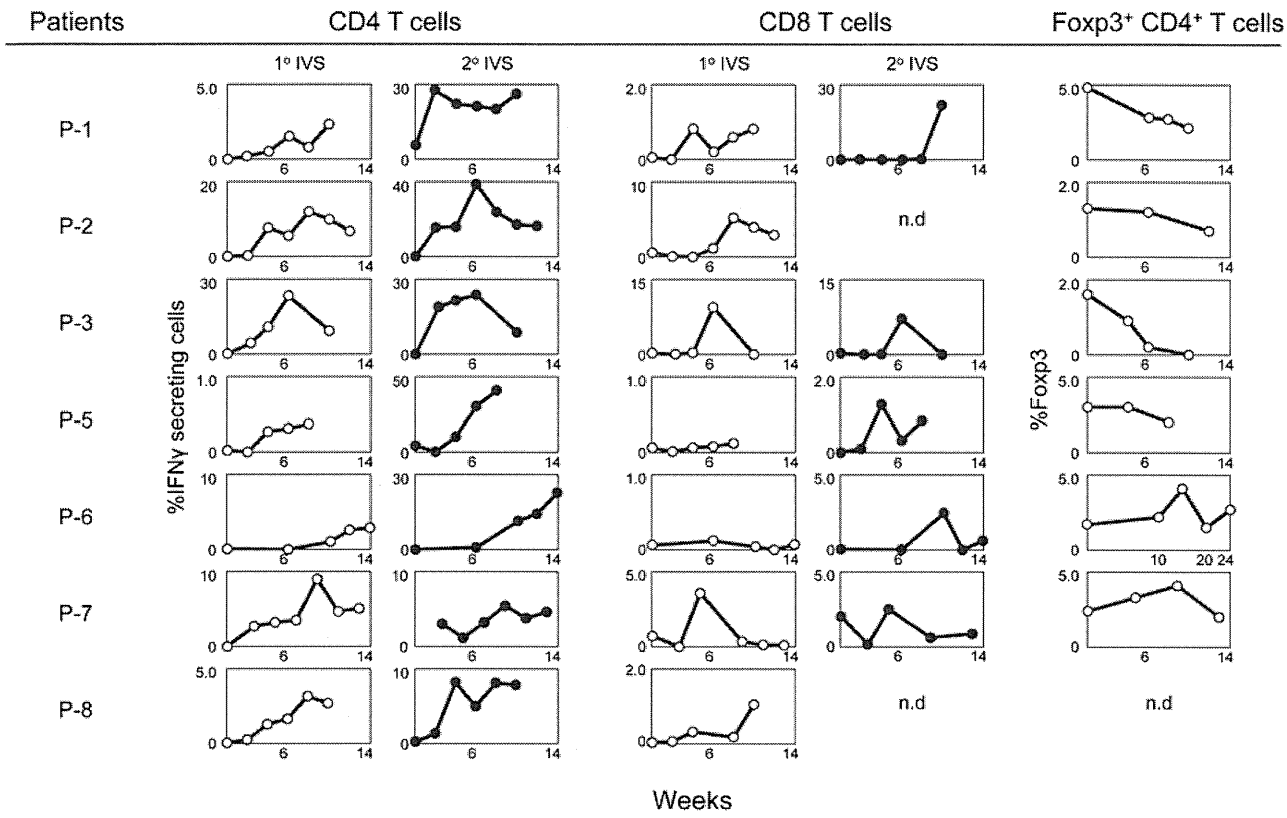

FIGURE 2. Immunomonitoring of CD4 and CD8 T-cell responses and Treg cells. CD4 and CD8 T cells were stimulated with 29 NY-ESO-1 18-mer series peptides once (1°IVS) or twice (2° IVS) and the net percentage of interferon (IFN)-γ-secreting cells was evaluated by an IFN-γ catch assay using bispecific CD45 and an IFN-γ antibody. Foxp3$^+$ CD4 Tregs were evaluated by ICS. The data are plotted with time. The analysis was conducted by FACS Canto II. ND indicates not done.

We used an IFN-γ catch assay to detect antigen-specific cellular responses using PBMCs in immunomonitoring. The assay can potentially give rise to false-positive reactions due to neighboring cells picking up IFN-γ by the bystander effect. However, it could be avoided by carefully performing the assay using a larger volume in a limited

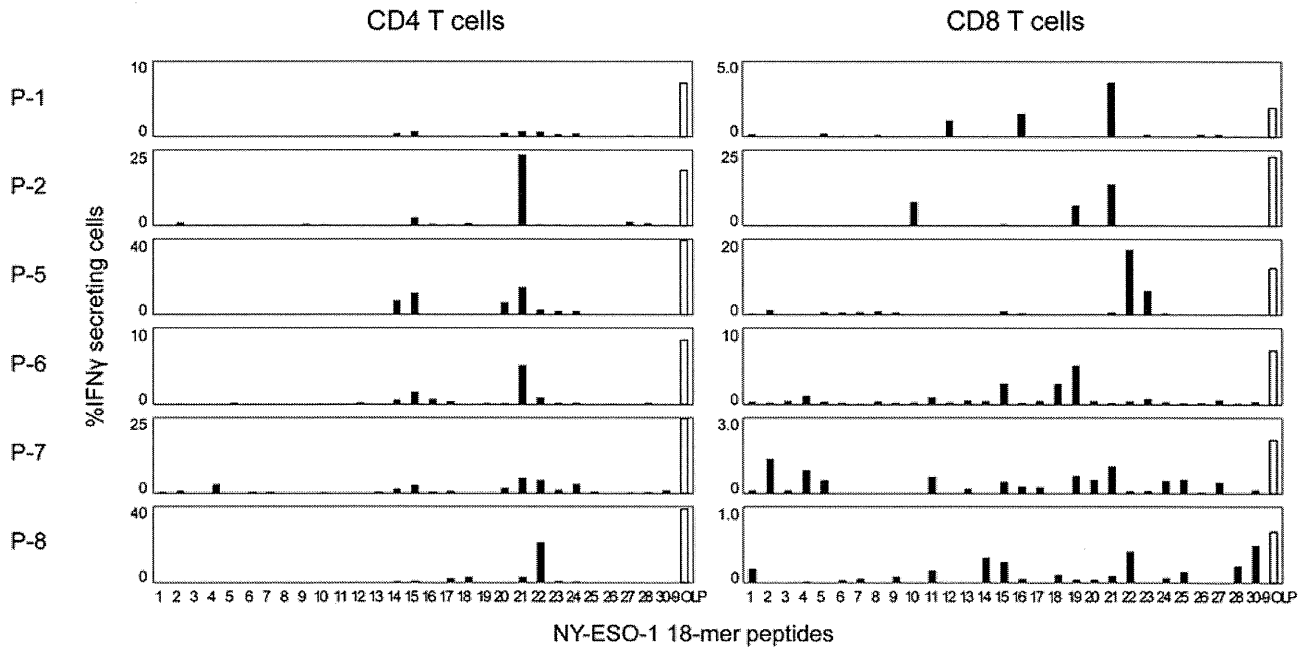

FIGURE 3. Epitope peptides recognized by CD4 and CD8 T cells. Using CD4 and CD8 T cells stimulated twice for 26 days with irradiated (30 Gy) autologous CD4-depleted and CD8-depleted PBMCs in the presence of 29 NY-ESO-1 18-mer series peptides, the epitope peptides recognized were determined by an interferon (IFN)-γ catch assay. In the assay, the cells were stimulated with autologous EBV-B cells pulsed with each 29 NY-ESO-1 18-mer peptide individually. The analysis was conducted by FACS Canto II.

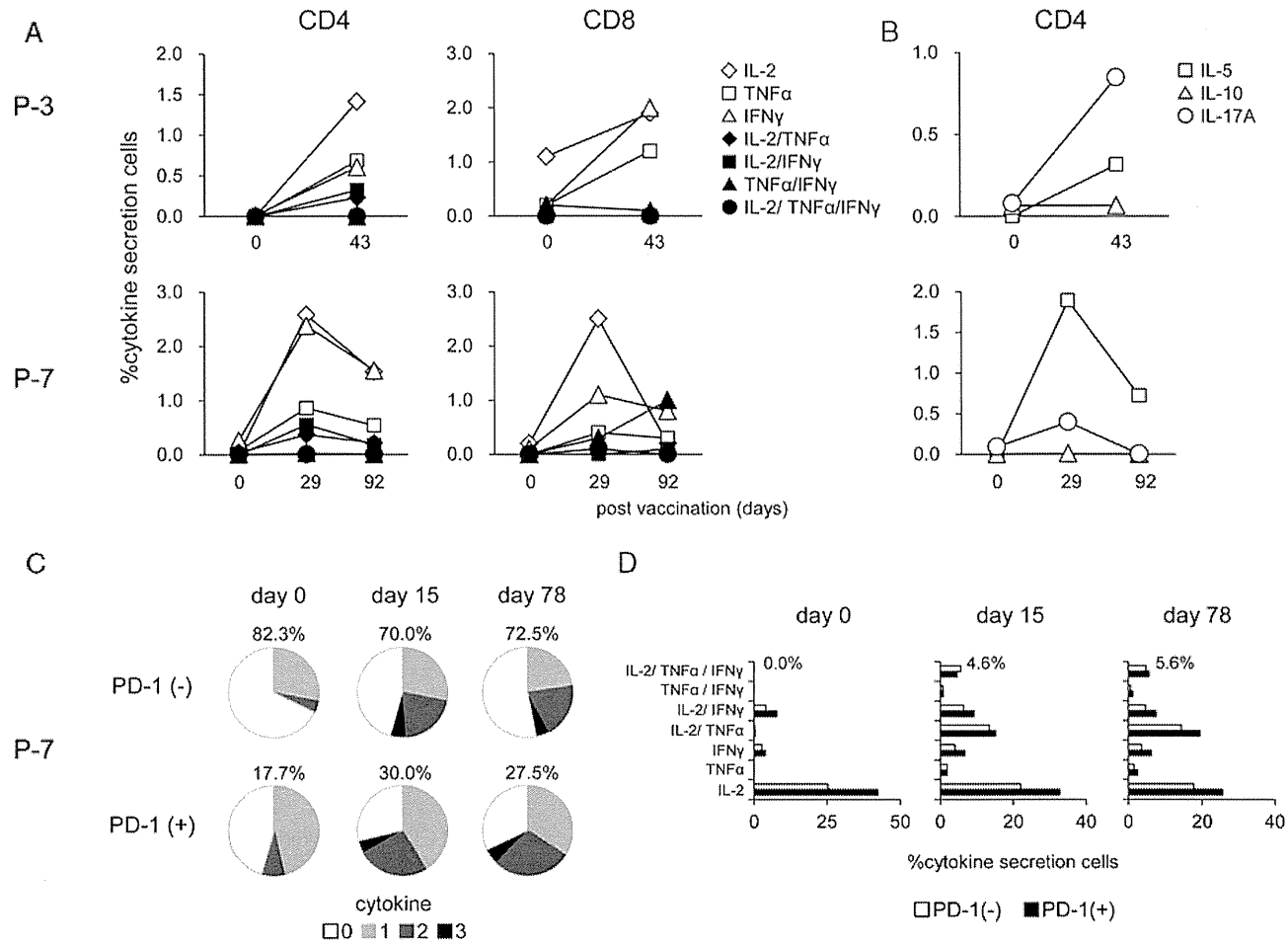

FIGURE 4. Multiple cytokine production by CD4 and CD8 T cells and nonspecific immune activation after NY-ESO-1 OLP vaccination. Multiple cytokine production by CD4 and CD8 T cells stimulated with a mixture of 29 NY-ESO-1 18-mer series peptides (A, B) or PMA/ionomycin (C, D) was analyzed. The cells from patients P-3 (A, B) and P-7 (A, B and C, D) obtained before and after vaccination were assayed for IL-2, TNF-α, and interferon (IFN)-γ-producing cells (A, C, D) or IL-5, IL-10, and IL-17A-producing cells (B) by intracellular staining. Frequency of single, double, and triple cytokine-producing cells in CD4 and CD8 T cells (A, B) or in PD-1 (–) or (+) CD4 T cells (C, D) before and after vaccination are depicted.

concentration of IFN-γ. The assay was highly reproducible and sensitive compared with intracytoplasmic staining or an ELISPOT assay. In the ELISPOT assay, it should be noted that the response resulting from a minor CD4 T-cell population contaminated in a purified CD8 population can sometimes make the interpretation of results difficult, especially after stimulation with longer peptides. Induction of CD4 T-cell responses was observed in all patients vaccinated and their increase during the vaccination period was consistent with the results in our previous study on a cancer vaccine with NY-ESO-1 protein and NY-ESO-1f peptide. For induction of NY-ESO-1-specific CD4 T cells, overlapping peptides appeared to be much more efficient than protein.[10] In contrast, induction of CD8 T-cell responses was similarly observed in all patients vaccinated with NY-ESO-1 OLP. However, the responses were relatively weak and fluctuated a lot during vaccination compared with the CD4 T-cell response. In our previous study with NY-ESO-1 protein, even a patient with a tumor that almost completely disappeared showed only a marginal CD8 T-cell response in PBMCs.[25,29] We observed some Foxp3$^+$ CD4 T cells infiltrating tumor tissue from this patient. In this study, we detected Foxp3$^+$ CD4 T cells in PBMCs from all patients analyzed during vaccination with NY-ESO-1 OLP. No increase in regulatory T cells was observed during vaccination in PBMCs. It is possible that those cells suppress CD8 T-cell responses in tumor microenvironments. Future studies combining cancer vaccines and inhibition of regulatory T-cell function will be intriguing.

TLRs are expressed either on the cell surface (TLR1, 2, 4, 5, 6, and 10) or on the membrane of intracellular organelles such as endosomes (TLR3, 7, 8, and 9). The bacterial CpG motif is the ligand for TLR9. Viral single-stranded RNAs are ligands for TLR7 and 8, and double-stranded viral RNAs such as PolyI:C are ligands of TLR3. Molecular patterns of extracellular microbes are recognized by the cell surface-expressed TLR1, 2, 4, 5, 6, and 10.[30] OK-432 is a ligand for TLR2, 4, and/or 9.[9] Triggering of TLR signaling leads to the activation of nuclear factor κB, activating protein-1, and/or IRF3, which results in secretion of type 1 IFNs and/or proinflammatory cytokines such as IL-1β, IL-12, and TNF-α.[17] We used OK-432 as an immunemodulator for the NY-ESO-1f peptide, CHP-NY-ESO-1 and CHP-HER2 cancer vaccine and observed efficient induction of tumor antigen-specific immune responses.[9,18,31] Sabbatini et al[32] used an NY-ESO-1 OLP vaccine with or without poly-ICLC in ovarian cancer patients. They observed that an efficient antibody response against NY-ESO-1 OLP was

induced with its use in combination with poly-ICLC and Montanide, but not without poly-ICLC. In this regard, OK-432 could be a feasible immune-modulator for a cancer vaccine with tumor antigens.

Two out of 9 vaccinated patients showed SD in the clinical response. Although strong induction of the NY-ESO-1 antibody against both the peptides used for the vaccine and the NY-ESO-1 protein was observed in these patients, there is no convincing evidence as to whether the strong antibody response is related to the clinical response.

Recently, it was shown that antibodies against immune checkpoint molecules had a significant antitumor effect, and a combination of different antibodies augmented this effect. With the proviso of control of immunosuppression in the tumor microenvironment, the use of immunogenic vaccines will be relevant. Thus, the use of both reagents controlling immunosuppression and immunogenic vaccines will be important in the future. We are planning combination therapies of immune checkpoint modulators with NY-ESO-1 vaccine.

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CONFLICTS OF INTEREST/ FINANCIAL DISCLOSURES

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All authors have declared there are no financial conflicts of interest with regard to this work.

REFERENCES

1. Chen YT, Scanlan MJ, Sahin U, et al. A testicular antigen aberrantly expressed in human cancers detected by autologous antibody screening. *Proc Natl Acad Sci U S A.* 1997;94:1914–1918.
2. Gnjatic S, Nishikawa H, Jungbluth AA, et al. NY-ESO-1: review of an immunogenic tumor antigen. *Adv Cancer Res.* 2006;95:1–30.
3. Kirkwood JM, Butterfield LH, Tarhini AA, et al. Immunotherapy of cancer in 2012. *CA Cancer J Clin.* 2012;62:309–335.
4. Quakkelaar ED, Melief CJ. Experience with synthetic vaccines for cancer and persistent virus infections in nonhuman primates and patients. *Adv Immunol.* 2012;114:77–106.
5. Thara E, Dorff TB, Pinski JK, et al. Vaccine therapy with sipuleucel-T (Provenge) for prostate cancer. *Maturitas.* 2011;69:296–303.
6. Gajewski TF, Fuertes M, Spaapen R, et al. Molecular profiling to identify relevant immune resistance mechanisms in the tumor microenvironment. *Curr Opin Immunol.* 2011;23:286–292.
7. Lesterhuis WJ, de Vries IJ, Schreibelt G, et al. Route of administration modulates the induction of dendritic cell vaccine-induced antigen-specific T cells in advanced melanoma patients. *Clin Cancer Res.* 2011;17:5725–5735.
8. Trumpfheller C, Longhi MP, Caskey M, et al. Dendritic cell-targeted protein vaccines: a novel approach to induce T-cell immunity. *J Intern Med.* 2012;271:183–192.
9. Kakimi K, Isobe M, Uenaka A, et al. A phase I study of vaccination with NY-ESO-1f peptide mixed with Picibanil OK-432 and Montanide ISA-51 in patients with cancers expressing the NY-ESO-1 antigen. *Int J Cancer.* 2011;129:2836–2846.
10. Melief CJ. Treatment of established lesions caused by high-risk human papilloma virus using a synthetic vaccine. *J Immunother.* 2012;35:215–216.
11. Zeestraten EC, Speetjens FM, Welters MJ, et al. Addition of interferon-α to the p53-SLP® vaccine results in increased production of interferon-γ in vaccinated colorectal cancer patients: a phase I/II clinical trial. *Int J Cancer.* 2013;132:1581–1591.
12. Bijker MS, van den Eeden SJ, Franken KL, et al. CD8 + CTL priming by exact peptide epitopes in incomplete Freund's adjuvant induces a vanishing CTL response, whereas long peptides induce sustained CTL reactivity. *J Immunol.* 2007;179:5033–5040.
13. Melief CJ, van der Burg SH. Immunotherapy of established (pre)malignant disease by synthetic long peptide vaccines. *Nat Rev Cancer.* 2008;8:351–360.
14. Dunne A, Marshall NA, Mills KH. TLR based therapeutics. *Curr Opin Pharmacol.* 2011;11:404–411.
15. Flynn BJ, Kastenmüller K, Wille-Reece U, et al. Immunization with HIV Gag targeted to dendritic cells followed by recombinant New York vaccinia virus induces robust T-cell immunity in nonhuman primates. *Proc Natl Acad Sci U S A.* 2011;108:7131–7136.
16. Morse MA, Chapman R, Powderly J, et al. Phase I study utilizing a novel antigen-presenting cell-targeted vaccine with Toll-like receptor stimulation to induce immunity to self-antigens in cancer patients. *Clin Cancer Res.* 2011;17:4844–4853.
17. Kawai T, Akira S. Toll-like receptors and their crosstalk with other innate receptors in infection and immunity. *Immunity.* 2011;34:637–650.
18. Aoki M, Ueda S, Nishikawa H, et al. Antibody responses against NY-ESO-1 and HER2 antigens in patients vaccinated with combinations of cholesteryl pullulan (CHP)-NY-ESO-1 and CHP-HER2 with OK-432. *Vaccine.* 2009;27:6854–6861.
19. Okamoto M, Oshikawa T, Tano T, et al. Mechanism of anticancer host response induced by OK-432, a streptococcal preparation, mediated by phagocytosis and toll-like receptor 4 signaling. *J Immunother.* 2006;29:78–86.
20. Hironaka K, Yamaguchi Y, Okita R, et al. Essential requirement of toll-like receptor 4 expression on CD11c + cells for locoregional immunotherapy of malignant ascites using a streptococcal preparation OK-432. *Anticancer Res.* 2006;26:3701–3707.
21. Hirayama M, Nishikawa H, Nagata Y, et al. Overcoming regulatory T-cell suppression by a lyophilized preparation of *Streptococcus pyogenes*. *Eur J Immunol.* 2013;43:989–1000.
22. Eisenhauer EA, Therasse P, Bogaerts J, et al. New response evaluation criteria in solid tumours: revised RECIST guideline (version 1.1). *Eur J Cancer.* 2009;45:228–247.
23. Wolchok JD, Hoos A, O'Day S, et al. Guidelines for the evaluation of immune therapy activity in solid tumors: immune-related response criteria. *Clin Cancer Res.* 2009;15:7412–7420.
24. Kawabata R, Wada H, Isobe M, et al. Antibody response against NY-ESO-1 in CHP-NY-ESO-1 vaccinated patients. *Int J Cancer.* 2007;120:2178–2184.
25. Uenaka A, Wada H, Isobe M, et al. T cell immunomonitoring and tumor responses in patients immunized with a complex of cholesterol-bearing hydrophobized pullulan (CHP) and NY-ESO-1 protein. *Cancer Immun.* 2007;7:9.
26. Kawada J, Wada H, Isobe M, et al. Heteroclitic serological response in esophageal and prostate cancer patients after NY-ESO-1 protein vaccination. *Int J Cancer.* 2012;130:584–592.
27. Fujiwara S, Wada H, Kawada J, et al. NY-ESO-1 antibody as a novel tumour marker of gastric cancer. *Br J Cancer.* 2013;108:1119–1125.
28. Tsuji K, Hamada T, Uenaka A, et al. Induction of immune response against NY-ESO-1 by CHP-NY-ESO-1 vaccination and immune regulation in a melanoma patient. *Cancer Immunol Immunother.* 2008;57:1429–1437.

29. Wada H, Sato E, Uenaka A, et al. Analysis of peripheral and local anti-tumor immune response in esophageal cancer patients after NY-ESO-1 protein vaccination. *Int J Cancer*. 2008;123:2362–2369.
30. Gay NJ, Gangloff M. Structure of toll-like receptors. *Handb Exp Pharmacol*. 2008;181–200.
31. Eikawa S, Kakimi K, Isobe M, et al. Induction of CD8 T-cell responses restricted to multiple HLA class I alleles in a cancer patient by immunization with a 20-mer NY-ESO-1f (NY-ESO-1 91-110) peptide. *Int J Cancer*. 2013;132:345–354.
32. Sabbatini P, Tsuji T, Ferran L, et al. Phase I trial of overlapping long peptides from a tumor self-antigen and poly-ICLC shows rapid induction of integrated immune response in ovarian cancer patients. *Clin Cancer Res*. 2012;18:6497–6508.

Hepatology Research

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Case Report

Reactivation of hepatitis B virus in a patient with adult T-cell leukemia–lymphoma receiving the anti-CC chemokine receptor 4 antibody mogamulizumab

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The introduction of molecularly targeted drugs has increased the risk of reactivation of hepatitis B virus (HBV), which is a potentially fatal complication following anticancer chemotherapy even in patients who have previously resolved their HBV infection. CC chemokine receptor 4 (CCR4) has been identified as a novel molecular target in antibody therapy for patients with adult T-cell leukemia–lymphoma (ATL) and peripheral T-cell lymphoma, and the humanized anti-CCR4 monoclonal antibody mogamulizumab has been developed. We reported HBV reactivation of an ATL patient with previously resolved HBV infection after mogamulizumab treatment in a dose-finding study for this antibody. Our retrospective analysis using preserved samples also revealed the detailed kinetics of HBV DNA levels before and just after HBV reactivation.

Key words: CC chemokine receptor 4, hepatitis B virus, mogamulizumab, reactivation

INTRODUCTION

REACTIVATION OF HEPATITIS B virus (HBV) following anticancer chemotherapy and immunosuppressive therapy is a potentially fatal complication that needs to be followed up carefully.[1] The advent of molecularly targeted drugs, which have immunosuppressive or immunomodulating actions, has increased the risk of HBV reactivation. The anti-CD20 monoclonal antibody rituximab, which forms part of the standard regimen for B-cell non-Hodgkin's lymphoma, has the potential to cause HBV reactivation, even in patients who have previously resolved their HBV infection and are hepatitis B surface antigen (HBsAg) negative at baseline.[2–6] CC chemokine receptor 4 (CCR4) has been identified as a novel molecular target in antibody therapy for patients with adult T-cell leukemia–lymphoma (ATL) and peripheral T-cell lymphoma, and the humanized anti-CCR4 monoclonal antibody mogamulizumab, the Fc region of which is de-fucosylated to enhance antibody-dependent cellular cytotoxicity, has been developed.[7–10] We herein report HBV reactivation of an ATL patient with previously resolved HBV infection after mogamulizumab treatment in a dose-finding study for this antibody.

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CASE REPORT

A 65-YEAR-OLD JAPANESE woman complained of persistent fatigue and weight loss of 8 kg in 2 weeks. The laboratory findings showed that her white blood cell count was elevated to 16 800/μL, of which abnormal lymphocytes accounted for 18%, and seropositivity for human T-cell leukemia virus type-1 (HTLV-1). Monoclonal integration of HTLV-1 was revealed by Southern blotting of DNA from peripheral blood. She was diagnosed as ATL, chronic type, in April 2004. Since then, she had experienced repeating infectious episodes and systemic lymph node swelling. On April 2005, she began to receive systemic chemotherapy composed of sobuzoxane (400 mg/day), etoposide (25 mg/day) and prednisolone (10 mg/day) p.o. twice a week because of disease progression to acute type which was accompanied by new ATL involvement in her right breast region and right axilla lymphadenopathy. As her disease was refractory to this regimen, she received four cycles of THP-COP regimen (cyclophosphamide, pirarubicin, vincristine and prednisolone) from August 2005 through October 2005 (Fig. 1a). She achieved a partial response and was followed up without subsequent chemotherapy including steroids for 1.4 years, but her disease progressed with markedly increased ATL cells

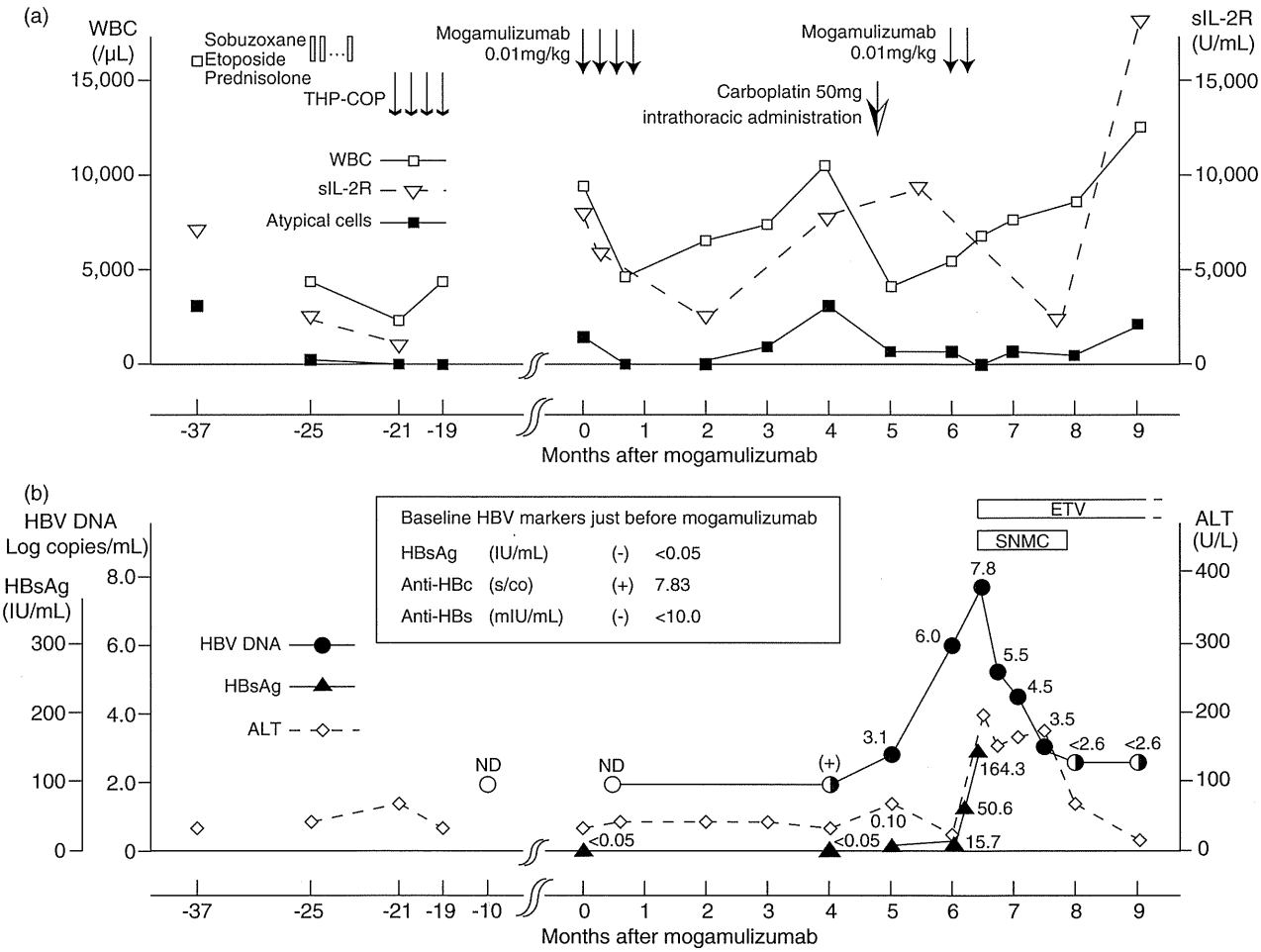

Figure 1 Clinical course and kinetics of HBV markers in a patient with adult T-cell leukemia–lymphoma before and after the anti-CC chemokine receptor 4 monoclonal antibody mogamulizumab treatment. ALT, alanine aminotransferase; anti-HBc, antibody against hepatitis core antigen; anti-HBs, antibody against hepatitis surface antigen; ETV, entecavir; HBsAg, hepatitis B surface antigen; HBV, hepatitis B virus; ND, not detectable; sIL-2R, soluble interleukin-2 receptor; SNMC, Stronger Neo-Minophagen C; THP-COP, cyclophosphamide, pirarubicin, vincristine and prednisolone; WBC, white blood cells.

and an elevated lactate dehydrogenase value in peripheral blood in March 2007. She was enrolled into a phase 1 study for dose-finding of the anti-CCR4 antibody, mogamulizumab,[9] and received this antibody at 0.01 mg/kg by i.v. infusion once a week for 4 weeks (Fig. 1a, thin arrows). No combination of other anticancer chemotherapy was performed and no steroids were given, except for allergic prophylaxis. She was HBsAg negative at baseline on enrollment in the phase 1 study. Retrospective analysis using preserved samples revealed that she was anti-hepatitis B core positive, anti-hepatitis B surface negative, and HBV DNA was undetectable at baseline, attributed to previously resolved HBV infection (Fig. 1b). After mogamulizumab, ATL cells disappeared immediately from the peripheral blood, the nodal disease partially improved and no severe adverse event was observed. However, at 9 weeks after the end of mogamulizumab, the ATL cells reappeared in the peripheral blood. Furthermore, she received intrathoracic administration of carboplatin for involvement of ATL (right pleural effusion) in August 2007. During the next month, her cervical lymph nodes enlarged rapidly and we decided to re-treat with mogamulizumab because of the previous efficacy and safety of this antibody. After two doses of mogamulizumab, she was hospitalized in emergency due to ALT flare on October 2007 (Fig. 1b, 6.5 months after mogamulizumab). The laboratory findings showed that HBsAg had become positive and her HBV DNA levels increased to 7.8 log copies/mL, suggesting that the liver damage was caused by HBV reactivation. Entecavir (0.5 mg/day) and Stronger Neo-Minophagen C (40 mg/day) were given immediately and hepatitis B improved gradually (with ALT peaking at 205 U/L) for approximately 2 months. Entecavir was effective in controlling hepatitis B, and was continued for 1.5 years without any severe adverse events.

DISCUSSION

THE PRESENTED CASE is the first report of HBV reactivation in a HBsAg negative patient receiving mogamulizumab. We analyzed preserved samples retrospectively and showed that her liver damage was attributable to HBV reactivation. Also, those analyses showed the following important findings regarding the kinetics of HBV DNA during reactivation: First, HBV DNA was undetectable at baseline, before administration of mogamulizumab. Elevated HBV DNA levels were detectable, in which polymerase chain reaction (PCR) signals were only detected 10 weeks prior to the development of hepatitis and 13 weeks after the end of this antibody treatment. HBV DNA levels, measured by PCR-based assay, increased rapidly from 3.1 to 6.0 log copies/mL for 1 month and, finally, up to 7.8 log copies/mL. Second, the elevated HBV DNA levels preceded the detection of HBsAg (Architect Assay; Abbott Laboratories, North Chicago, IL, USA) by 1 month. Third, the patient was infected with HBV genotype C with a point mutation in the precore regions (G1896A) which might have been associated with the rapidly increasing kinetics of HBV DNA levels in this case.

How was the anti-CCR4 antibody mogamulizumab involved in the HBV reactivation? CCR4 is a chemokine receptor expressed on T-helper type 2 and regulatory T cells, and is thought to carry an important role in maintaining the balance of the human immune system.[7–9] It is difficult to demonstrate how mogamulizumab caused HBV reactivation in this case; the reduction of CCR4-expressing cells following this antibody treatment might have been associated with imbalance of antiviral immunity, resulting in the development of hepatitis due to HBV reactivation. Other than mogamulizumab, the intrathoracic administration of carboplatin and the ATL disease progression are considered to be factors potentially influencing HBV reactivation. However, retrospective analysis showed that HBV DNA levels were detectable in the peripheral blood before administration of carboplatin, suggesting that carboplatin is unlikely to have been mainly involved in the HBV reactivation. ATL is often diagnosed with a compromised immune system, and the disease progression might have been associated with reactivation of the virus. Interestingly, the timing of the rapid increase in ATL cells in the peripheral blood coincided with that of HBV replication in this case. However, disease progression of ATL alone is very unlikely to have caused the HBV reactivation because reactivation did not occur during the previous ATL progression.

To prevent hepatitis due to HBV reactivation, what lesson can we learn from this case? HBV reactivation following immunosuppressive therapy may lead to acute liver failure or fulminant hepatitis, and the patients have poor prognosis regardless of intensive antiviral treatment.[11,12] For preventing HBV reactivation in patients with previously resolved HBV infection, monitoring of HBV DNA-guided preemptive antiviral therapy is recommended in some guidelines,[13,14] however, the evidence of optimal interval of HBV DNA monitoring is limited. Most recently, monthly monitoring of HBV DNA was shown to effectively prevent HBV reactivation in patients with previously resolved HBV