Abstract:

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The present invention provides compositions and methods for treating cancer in a subject by eliciting an immune response against a MIC polypeptide.
Vaccine Compositions and Methods for Restoring NKG2D Pathway Function Against Cancers

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to, and the benefit of U.S.S.N. 61/953,064 filed on March 14, 2014, the contents of which are incorporated herein by reference in their entirety.

GOVERNMENT SUPPORT

This invention was made with Government support under Grant No. NCI 1R01CA173750-01, awarded by the National Institutes of Health. The Government has certain rights in the invention.

TECHNICAL FIELD

This invention relates to methods and compositions for inducing an anti-cancer immune response in a human subject.

BACKGROUND

MICA is a ligand for NKG2D, a C-type lectin-like, type II transmembrane receptor expressed on most human NK cells, γδ T cells, and CD8+ T cells. Upon ligation, NKG2D signals through the adaptor protein DAP10 to evoke perforin dependent cytolysis and to provide co-stimulation. In humans, the NKG2D ligands include MHC class I chain-related protein A (MICA), the closely related MICB, UL-16 binding proteins (ULBP) 1-4, and RAE-1G.

While NKG2D ligands are not usually found on healthy tissues, various forms of cellular stress, including DNA damage, may upregulate ligand expression, resulting in their frequent detection in multiple solid and hematologic malignancies, including melanoma. NKG2D activation through ligand positive transformed cells contributes to extrinsic tumor immunity, since NKG2D deficient mice manifest enhanced tumor susceptibility. But in many cancer patients NKG2D-mediated tumor immunity is

Soluble NKG2D ligands may also stimulate the expansion of regulatory NKG2D+CD4+Foxp3- T cells that may antagonize anti-tumor cytotoxicity through Fas ligand, IL-10, and TGF-β.

MICA is a NKG2D ligand shed from tumor cells, i.e., released from the cell surface into the surrounding medium, and sera from a subset of cancer patients contains elevated levels of the soluble form (sMICA). MIC (the term "MIC" referring to MICA and MICB) shedding is accomplished in part through interactions with the protein disulfide isomerase ERp5, which cleaves a disulfide bond in the MIC a3 domain, rendering it susceptible to proteolysis by ADAM-10/17 and MMP14. Methods of treating cancer by administering anti-MIC antibodies or antigen-binding peptide fragments have been described. For example, US 8,182,809 describes such methods utilizing a purified antibody or a polypeptide comprising an antigen-binding fragment thereof that specifically binds to the amino acid sequence NGTYQT located in the a3 ectodomain of the MIC polypeptide, such that the interaction of the MIC polypeptide and ERp5 is inhibited and the shedding of MIC is inhibited. And US 7,959,916 describes methods of inhibiting the shedding of MIC polypeptides from cancer cells using anti-MIC a3 domain antibodies. Tumor-derived soluble MIC polypeptides, either MICA or MICB, or both, have also been suggested as biomarkers for diagnosis and prognosis of cancer and anti-
MICA or anti-MICB antibodies as therapeutic agents for the treatment of cancer and autoimmune diseases. For example, US 7,771,718 describes methods of relieving MIC-induced suppression of NKG2D in lymphocytes using anti-MIC antibodies to bind soluble MIC polypeptides.

In practice, methods of treating cancer or other diseases with therapeutic antibodies is relatively expensive because of the need to produce large quantities of such antibodies of sufficient purity for infusion to patients. In view of the complexity of large-scale antibody production and the specialized requirements for antibody infusion protocols, alternative methods are needed to target MIC polypeptides in a more efficient and cost-effective manner. The present invention provides a solution to this problem by providing vaccines for the induction of anti-MIC antibodies in a subject.

Tumor vaccines are typically composed of tumor antigens and immunostimulatory molecules (e.g. cytokines or TLR ligands) that work together to induce antigen-specific cytotoxic T cells (CTLs) that recognize and lyse tumor cells. At this time, almost all vaccines contain either shared tumor antigens or whole tumor cell preparations (Gilboa, 1999). The shared tumor antigens are immunogenic proteins with selective expression in tumors across many individuals and are commonly delivered to patients as synthetic peptides or recombinant proteins (Boon et al, 2006). In contrast, whole tumor cell preparations are delivered to patients as autologous irradiated cells, cell lysates, cell fusions, heat-shock protein preparations or total mRNA (Parmiani et al., 2007). Since whole tumor cells are isolated from the patient, the cells express patient-specific tumor antigens as well as shared tumor antigens. Finally, there is a third class of tumor antigens that has rarely been used in vaccines due to technical difficulties in identifying them (Sensi et al. 2006). This class consists of proteins with tumor-specific mutations that result in altered amino acid sequences. Such mutated proteins have the potential to: (a) uniquely mark a tumor (relative to non-tumor cells) for recognition and destruction by the immune system (Lennerz et al., 2005); (b) avoid central and sometimes peripheral T cell tolerance, and thus be recognized by more effective, high avidity T cells receptors (Gotter et al, 2004).
SUMMARY

The present invention provides compositions and methods for treating cancer in a subject by eliciting an immune response against a MIC polypeptide. The term "MIC" as used herein refers to MICA and/or MICB. In one embodiment, the invention provides a vaccine composition for treating cancer, the composition comprising, as an immunogenic component, an effective amount of a peptide comprising or consisting of one or more of SEQ ID NOs 1-23, the effective amount being an amount effective to elicit an immune response against a MIC polypeptide, or the cancer. In another embodiment, the vaccine composition comprises as an immunogenic component, an effective amount of a peptide comprising or consisting of one or more of SEQ ID NOs 5-7, one or more of SEQ ID NOs 8-10, or one or more of SEQ ID NOs 5-13. In another embodiment, the vaccine composition comprises as an immunogenic component, an effective amount of a peptide comprising or consisting of one or more of SEQ ID NOs 14-23, one or more of SEQ ID NOs 15-23, one or more of SEQ ID NOs 18-23, or one or more of SEQ ID NOs 21-23.

In one embodiment, the vaccine composition is effective to elicit an \textit{in vitro} immune response against a MIC polypeptide. In another embodiment, the vaccine composition is effective to elicit an \textit{in vivo} immune response against a MIC polypeptide. In one embodiment, the immune response is directed against a MIC polypeptide that is not attached to a cell, also referred to as a soluble MIC polypeptide. The soluble MIC may be in either a monomeric or multimeric form. In another embodiment, the immune response is directed against a cancer cell expressing a MIC polypeptide. The cancer cell may be \textit{in vitro} or \textit{in vivo}. In one embodiment, the vaccine composition is effective to elicit an immune response against a cancer cell expressing a MIC polypeptide. The cancer cell may be \textit{in vitro} or \textit{in vivo}.

In one embodiment, the MIC polypeptide is a MICA or MICB polypeptide, or a fusion protein containing the a 3 domains of MICA and MICB.

Any cancer cell expressing MIC can be treated using the compositions and methods of the invention. In one embodiment, the cancer is selected from the group
consisting of prostate cancer, multiple myeloma, glioblastoma multiforme, and melanoma. In one embodiment, the cancer is melanoma.

In one embodiment, the peptide comprises or consists of one or more of SEQ ID NOs 8-13, or a peptide having 90% or 95% amino acid sequence identity to any one of the same. In one embodiment, the peptide comprises or consists of one or more of SEQ ID NOs 15-23, or a peptide having 90% or 95% amino acid sequence identity to any one of the same.

In one embodiment, the vaccine composition comprises a plurality of peptides selected from two or more of SEQ ID NOs 5-10, or a peptide having 95% amino acid sequence identity to any of the same; or from two or more of SEQ ID NOs 8-13, or a peptide having 90% amino acid sequence identity to any of the same. In one embodiment, the vaccine composition comprises a plurality of peptides selected from two or more of SEQ ID NOs 15-20, or a peptide having 95% amino acid sequence identity to any of the same; or from two or more of SEQ ID NOs 21-23, or a peptide having 90% amino acid sequence identity to any of the same.

In one embodiment, the peptide is conjugated to a carrier protein. In one embodiment, the carrier protein is selected from tetanus toxin and diphtheria toxin.

In one embodiment, the vaccine composition comprises a viral capsid protein engineered to display the at least one peptide or plurality of peptides on its surface. In one embodiment, the viral capsid protein is a hepatitis B capsid protein.

In one embodiment, the vaccine composition is in the form of a polymer scaffold comprising the at least one peptide or a plurality of peptides. In one embodiment, the polymer scaffold is a porous, poly-lactide-co-glycolide (PLG) polymer scaffold. In one embodiment, the polymer scaffold further comprises one or both of a GM-CSF protein and a Toll-like receptor agonist. In one embodiment, the polymer scaffold further comprises autologous tumor cell lysates of a subject to be treated for cancer with the composition.

The present invention also provides methods of treating cancer in a subject by administering to a subject a vaccine composition described herein. In one embodiment, a vaccine composition of the invention is administered as part of a therapeutic regimen. In
one embodiment, the therapeutic regimen further comprises one or more of radiation
therapy, immunotherapy, chemotherapy, or targeted therapy. In one embodiment, the
methods comprise administering at least two, preferably three separate vaccine
compositions of the invention as part of a prime-boost strategy, each vaccine composition
having a different immunogen from the others.

Other features and advantages of the invention will be apparent from the
following detailed description and figures, and from the claims.

DESCRIPTION OF DRAWINGS

Figure 1 | Mapping of epitopes on MICA* 100 reference structure. Epitope
mapping was performed using overlapping peptide arrays. Each peptide was a 20 amino
acid linear sequence with a 10 amino acid offset for each peptide.

Figures 2A and 2B | Epitope conservation among common MICA and MICB
alleles.

Figures. 3A and 3B | Design of chimeric protein with properly placed epitopes for
MIC antibodies. The epitopes of MICA Abs 28 and 29 (highlighted in blue and red) were
placed into an unrelated protein with a similar Ig domain structure, human CMV protein
UL18. Comparison of the structures of MICA a3 (A) and the chimeric protein (B)
demonstrates conservation of the epitopes for MICA antibodies 28 and 29.

Figure 3C | The sequence of the chimeric protein is aligned with MICA and UL18
sequences (C). Residues of UL18 that bind to human LIR were mutated (indicated in
white). Residues 206 and 210 of MICA are polymorphic (G/S and W/R, respectively).

Figures 4A and 4B | Design of disulfide-stabilized mini-MICA for display of
MICA epitopes. A mini-MICA protein was designed to focus B cell responses on critical
parts of the protein. A disulfide bond (green) was introduced to stabilize the
conformation of the MICAAb29 epitope. The beta strand connecting Ab28 and Ab29
epitope was deleted to reduce protein flexibility and improve solubility. Note that the N
and C termini of the Mini-MICA protein are in close vicinity, which enables display on
the surface of the hepatitis B core capsid. Blue - Ab28 epitope, Red - Ab29 epitope.
Figure 4C | The sequence of mini-MICA is aligned with MICA.

Figures 5A-5D are a series of graphs that depict the therapeutic activity of human anti-MICA antibodies. Figure 5A is a graph that indicates that the AML Ab2 improved survival of SCID mice implanted with human U937 tumor cells (3x10⁶ Ab per week). The amount of days elapsed is indicated on the x-axis, and the percent survival is indicated on the y-axis. Figure 5B is a graph that depicts that antibody treatment significantly reduced sMICA concentration in the serum of treated mice as measured by ELISA. Treatment duration is indicated on the x-axis, and the concentration of sMICA in the serum is indicated on the y-axis. Figures 5C and 5D indicate that following one week of treatment, MICA antibodies reduced sMICA in tumor homogenate (normalized to tumor mass; see Figure 5C) and increased MICA expression on the surface of tumor cells, as assayed by flow cytometry (see Figure 5D). The x-axis in Figure 5C indicates experimental conditions, and the y-axis indicates concentration of sMICA in tumor homogenate. The x-axis in Figure 5D indicates experimental condition, and the y-axis indicates mean fluorescence intensity (MFI).

Figures 6A-6F are a series of graphs that indicate human antibodies enhance NK cell accumulation and function in tumors. For these data, SCID mice bearing U937 tumors were treated for one week with MICAmAbs (3x10⁶) and NK cell function was assessed. Figures 6A, 6B, and 6C demonstrate that Antibody treatment increased surface levels of NKG2D (see Figure 6A) and NKp46 (see Figure 6B) by tumor infiltrating CD45⁺NK1.1⁺ NK cells and induced NK cell accumulation in tumors (see Figure 6C, normalized to 1x10⁵ CD45⁺ cells). Figures 6D and 6E demonstrate that treatment increased IFNγ (see Figure 6D) and perforin (see Figure 6E) expression by tumor infiltrating CD45⁺NK.1⁺ NK cells. Figure 6F depicts that all three human MICA antibodies enhanced ex vivo killing of ⁵¹Cr labeled YAC-1 cells by splenocytes.

**DETAILED DESCRIPTION**

The present invention provides compositions and methods for treating cancer in a subject by eliciting an immune response against MIC polypeptides. The terms "elicit," "stimulate," and "induce" are used interchangeably to denote the generation of a de novo
immune response in a subject or to denote the enhancement of the strength or persistence of an existing immune response. The compositions of the invention contain, as an immunogenic component (also referred to herein as "immunogen"), at least one MIC peptide which comprises or consists of the full-length alpha 3 domain of MICA [SEQ ID NO: 1] or MICB [SEQ ID NO: 14]. In certain embodiments, the MIC peptide is an epitope selected from the group consisting of SEQ ID NOs 2-13 or SEQ ID NOs: 15-23.

In the context of the invention, an epitope is a portion of an antigenic molecule capable of eliciting an immune response to the molecule, preferably a cytotoxic T cell response or an antibody-secreting B cell mediated response, or which can be bound by an antibody. The minimal epitopes represented by SEQ ID NOs: 11-13 and 21-23 were identified by the inventors as the antibody-binding epitopes for the CM33322 Ab4, CM33322 Ab28, and CM33322 Ab29, which are described in U.S. Provisional Application Nos. 61/792,034 and 61/913,198 and in US Application No. 14/025,573. These antibodies were isolated from cancer patients responsive to immunotherapy. These antibodies enhance the activity of NK cells and CD8 T cells against cancer cells by inhibiting cleavage of MIC proteins from cancer cells. The antibodies bind to the α3 domain of MIC proteins and have strong anti-tumor activity in relevant animal models. These clinical immunological studies evidence that induction of antibodies against the α3 domain of MIC proteins restores anti-tumor immune function against cancers. In accordance with the present invention, the epitopes recognized by these antibodies can be used as the immunogenic component of a cancer vaccine to stimulate antibody production against the MIC α3 domain. An important element of this invention is that antibodies are produced against the MIC α3 domain, but not against the α1-α2 domains of MIC, given that the NKG2D receptor on NK cells and CD8 T cells binds to the α1-α2 domains. Accordingly, the invention provides the epitopes of the MICA and B proteins that are important for an effective anti-MIC immune response in humans and methods and compositions relating to the use of same as the immunogenic components of a cancer vaccine.
Table 1: Location of antibody binding epitopes within the amino acid sequence of MICA*001 reference sequence (SEQ ID NO:1). Epitopes are in bold and underlined.

<table>
<thead>
<tr>
<th>Antibody</th>
<th>Sequence</th>
</tr>
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| CM33322 Ab4 (SEQ ID NO:1) | HSLRYNLTVLSWDGSVQSGFLAEVHLDGQPFLRYPDRCRAKPKQGQWAEDVLGNKTWDRETRDLTGNGKDLRMTLAHIKDQKEGLLSQGVEIRVCEIHEDNSTRSSQHFYYMDELFLSQNVEETEEWTVPQSSRAQTLMVRNFLKEDAMTKTHYHAMHADCLQERLYLESSVVLRLRTVPPMVNVTTRASESEGNTVTCRASSFYPRNITLTWRQDGVSLSHDTPQQWGDVLPDNGTYQTWVATARICQGEEQRFCTCYMEHSNHRSHPVPSGKLQLQSHWQTFFHVSAYAAAAAFIVIIIFYRCCKKKTSAAEGPPELVSQQLQHPVGTSDHRDATQLGFPQLMSALGSTGSTE 
| CM33322 Ab28 (SEQ ID NO:1) | HSLRYNLTVLSWDGSVQSGFLAEVHLDGQPFLRYPDRCRAKPKQGQWAEDVLGNKTWDRETRDLTGNGKDLRMTLAHIKDQKEGLLSQGVEIRVCEIHEDNSTRSSQHFYYMDELFLSQNVEETEEWTVPQSSRAQTLMVRNFLKEDAMTKTHYHAMHADCLQERLYLESSVVLRLRTVPPMVNVTTRASESEGNTVTCRASSFYPRNITLTWRQDGVSLSHDTPQQWGDVLPDNGTYQTWVATARICQGEEQRFCTCYMEHSNHRSHPVPSGKLQLQSHWQTFFHVSAYAAAAAFIVIIIFYRCCKKKTSAAEGPPELVSQQLQHPVGTSDHRDATQLGFPQLMSALGSTGSTE 
| CM33322 Ab29 (SEQ ID NO:1) | HSLRYNLTVLSWDGSVQSGFLAEVHLDGQPFLRYPDRCRAKPKQGQWAEDVLGNKTWDRETRDLTGNGKDLRMTLAHIKDQKEGLLSQGVEIRVCEIHEDNSTRSSQHFYYMDELFLSQNVEETEEWTVPQSSRAQTLMVRNFLKEDAMTKTHYHAMHADCLQERLYLESSVVLRLRTVPPMVNVTTRASESEGNTVTCRASSFYPRNITLTWRQDGVSLSHDTPQQWGDVLPDNGTYQTWVATARICQGEEQRFCTCYMEHSNHRSHPVPSGKLQLQSHWQTFFHVSAYAAAAAFIVIIIFYRCCKKKTSAAEGPPELVSQQLQHPVGTSDHRDATQLGFPQLMSALGSTGSTE |
Table 2: MICA epitopes recognized by human antibodies from patients responding to cancer immunotherapy (epitopes are underlined)

| CM33322 Ab4 | SEQ ID NO: 2 | LRRTVPPMVNVTRSEASEGNITVTCRASSFYPRNITLTWRQDGVSLSHDTQQWDVLPDNGNYQTWVATRICQGEEQRFTCYMEHSGNHSTHPVPS |
| CM33322 Ab28 | SEQ ID NO: 3 | LRRTVPPMVNVTRSEASEGNITVTCRASSFYPRNITLTWRQDGVSLSHDTQQWDVLPDNGNYQTWVATRICQGEEQRFTCYMEHSGNHSTHPVPS |
| CM33322 Ab29 | SEQ ID NO: 4 | LRRTVPPMVNVTRSEASEGNITVTCRASSFYPRNITLTWRQDGVSLSHDTQQWGDVLPDNGNYQTWVATRICQGEEQRFTCYMEHSGNHSTHPVPS |

Table 3: MICA Epitopes with short flanking sequences

| CM33322 Ab4 | SEQ ID NO: 5 | YLESSVVLRRTVPPMVNVTRSEASEGNITV |
| CM33322 Ab4 | SEQ ID NO: 6 | VVLRTVPPMVNVTRSEASE |
| CM33322 Ab28 | SEQ ID NO: 7 | SEASEGNITVTCRASSFYPRNITLTWRQDG |
| CM33322 Ab28 | SEQ ID NO: 8 | GNITVTCRASSFYPRNITLT |
| CM33322 Ab29 | SEQ ID NO: 9 | VSLSHDTQQWGDVLPDNGNYQTWVATRICQGEEQRFTCY |
| CM33322 Ab29 | SEQ ID NO: 10 | DTQQWGDVLPDNGNYQTWVATRICQGEEQ |
Table 4: Minimal MICA epitopes

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<th>CM3322 Ab4</th>
<th>SEQ ID NO: 11</th>
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<tr>
<td>CM3322 Ab29</td>
<td>SEQ ID NO: 13</td>
<td>GDVLPDNGTYQTWVATRIC</td>
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Table 5: MICB epitopes recognized by human antibodies from patients responding to cancer immunotherapy (epitopes are underlined) in MICB reference sequence (SEQ ID NO: 14)

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<th>PHSLRYNLMVLSQDGSVQSGFLAEGHLDDQPFRLRYDRQK</th>
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<td>HIKDKQGLHSLQEIRVCEIHEDSSTRGSRHYYDGEFLSL</td>
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<td>QNLETQESTVPQSSRAQTLAMNVTNFKWEDAMKTKTHYR</td>
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<td>AMQADCLQLQRYLKSGVAIRRTVPPMVNTCSEVSEGNI</td>
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<td>TVTCRASSFYPRNITLWTQRQDGVSLSHTQQWGDVLPDG</td>
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<td>GTYQTWVATRIRIQGEEQRFTCYMEHSNHGTHPVGSKA</td>
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<td>LVLQSQRTDFPYSAMPCFVIIIICVPCCKKKTSAEGLPE</td>
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<td>LVSLQVLDQHPVGTGDHRDAAQLGFOQPLMSATGSTGSTE</td>
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<td></td>
<td></td>
<td>GA</td>
</tr>
<tr>
<td>CM33322 Ab28</td>
<td>SEQ ID NO: 14</td>
<td>PHSLRYNLMVLSQDGSVQSGFLAEGHLDGQPFLRYDRQK RRAKPQQGWAEDVLGAKTWDTETEDLTENGQDLRRRLT HIKDQKGGLHSLQIEIRVCEIHEDSSTRGSRHFYYDGELFLS QNLETQESTVPQSSRAQTLMNVTNFKEAMDRTKTHYR AMQADCLQKILQRYLKSGVAIIRTVPPMVNVTCSEVSEGNI TVTCRASSFYPRNITLTWRODGVSLIHTOOWGDLVPDG GTYQTWVATIRQGEEQRFTCYMEHSGNHGTHVPVSNGA LVLQSQRDFPYSAAAMPCFVIIIILCVPCCKKTSAAEGPE LVSLQVLDQHPVGTGDHRDAAQLGQLQPLMSATNGSTGSTE GA</td>
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<tr>
<td>CM33322 Ab29</td>
<td>SEQ ID NO: 14</td>
<td>PHSLRYNLMVLSQDGSVQSGFLAEGHLDGQPFLRYDRQK RRAKPQQGWAEDVLGAKTWDTETEDLTENGQDLRRRLT HIKDQKGGLHSLQIEIRVCEIHEDSSTRGSRHFYYDGELFLS QNLETQESTVPQSSRAQTLMNVTNFKEAMDRTKTHYR AMQADCLQKILQRYLKSGVAIIRTVPPMVNVTCSEVSEGNI TVTCRASSFYPRNITLTWRODGVSLIHTOOWGDLVPDG NGTYOTWVATIRIQGEEQRFTCYMEHSGNHGTHVPVSNGA ALVLQSQRDFPYSAAAMPCFVIIIILCVPCCKKTSAAEGPE ELVSLQVLDQHPVGTGDHRDAAQLGQLQPLMSATNGSTGSTE GA</td>
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Table 6: MICB Epitopes with short flanking sequences

| CM33322 Ab4 | SEQ ID NO: 15 | YLKSGVAIRRTVPPMVNVTCSEVSEGNITV |
| CM33322 Ab4 | SEQ ID NO: 16 | VAIRRTVPPMVNVTCSEVSE |
| CM33322 Ab28 | SEQ ID NO: 17 | SEVSEGNITVTCRASSFYPRNITLTWRODG |
The invention provides a vaccine composition suitable for administration to a human comprising, as an immunogenic component, at least one MIC peptide. In one embodiment, the at least one MIC peptide comprises or consists of the full-length alpha 3 domain of MICA or MICB, which domain corresponds to amino acids 181 to 274 of the reference sequence, [SEQ ID NO: 1]. In another embodiment, the at least one peptide comprises or consists of a peptide epitope of a MIC peptide selected from the group consisting of any one of SEQ ID NOs: 2-13, or SEQ ID NOs: 15-23. In one embodiment, the at least one peptide consists of a peptide epitope selected from the group consisting of SEQ ID NOs: 11-13 or SEQ ID NOs: 21-23 and one or more flanking amino acids. In this context, the term "flanking amino acids" refers to the amino acids adjacent to the peptide epitope sequence in the full-length reference sequence [SEQ ID NO: 1 for MICA or SEQ ID NOs: 14 for MICB]. In certain embodiments, the at least one peptide epitope comprises 2, 4, 6, 8, or 10 flanking amino acids on either its N- or C-terminal end, or both. In one embodiment, the at least one peptide consists of a peptide epitope selected

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<th>CM33322</th>
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<td>NTOQWGDLPGNNTYWTWVATRIROGEO</td>
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Table 7: Minimal MICB epitopes

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<td>CM33322</td>
<td>SEQ ID NO: 23</td>
<td>GDVLPGNNTYWTWVATRIR</td>
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</table>
from the group consisting of SEQ ID NOs: 11-13 or SEQ ID NOs: 21-23 and one or more flanking amino acids such that the peptide consists of about 25 to 30 amino acids, or a length suitable for efficient induction of an antibody response to MIC proteins.

In one embodiment, the vaccine composition comprises, as its immunogenic component, at least two peptide epitopes of a MIC peptide selected from the group consisting of SEQ ID NOs: 2-13 or SEQ ID NOs: 15-23. In one embodiment, the vaccine composition comprises, as its immunogenic component, at least two peptide epitopes of a MIC peptide selected from the group consisting of SEQ ID NOs: 2-4 or SEQ ID NOs: 15-23. In one embodiment, the vaccine composition comprises, as its immunogenic component, at least two peptide epitopes of a MIC peptide selected from the group consisting of SEQ ID NOs: 5-10. In one embodiment, the vaccine composition comprises, as its immunogenic component, at least two peptide epitopes of a MIC peptide selected from the group consisting of SEQ ID NOs: 11-13 or SEQ ID NOs: 21-23.

In one embodiment, the vaccine composition comprises, as its immunogenic component, one or more peptide epitopes of a MIC peptide selected from the group consisting of SEQ ID NOs: 2-13 or SEQ ID NOs: 15-23 wherein the peptide epitopes are in the form of a linear sequence. In one embodiment, the peptide epitopes are in the form of a structurally constrained loop. In one embodiment, the peptides retain their native secondary structure, for example in the form of one or more loops. In one embodiment, the loop is created using either a disulfide bond or a chemical linker. Preferably, the loop is adapted to mimic the three-dimensional conformation of the MIC epitope on the human protein.

In another embodiment, the vaccine composition comprises a nucleic acid encoding one or more of the peptides of SEQ ID NOs: 2-13 or SEQ ID NOs: 15-23. The nucleic acid may be in the form of an expression vector, for example a plasmid or a viral vector, or the nucleic acid may be packaged into nanoparticles. In one embodiment, the nucleic acid is delivered to a subject by injection. In one embodiment, the nucleic acid is injected as purified DNA or in form of nanoparticles. In one embodiment, modified immune cells which have been modified to express the nucleic acid are injected. In one
embodiment, the immune cells are modified via transfection or infection in vitro with a vector comprising the nucleic acid.

In one embodiment, the vaccine composition comprises, as its immunogenic component, a plurality of peptides, the plurality of peptides comprising or consisting of two or more peptides selected from the group consisting of SEQ ID NOs: 2-13 or SEQ ID NOs: 15-23. In one embodiment, the plurality of peptides comprises or consists of at least two peptides selected from the group consisting of SEQ ID NOs: 2-4 or SEQ ID NOs: 15-23. In one embodiment, the plurality of peptides comprises or consists of at least two selected from the group consisting of SEQ ID NOs: 5-10. In one embodiment, the plurality of peptides comprises or consists of at least two selected from the group consisting of SEQ ID NOs: 11-13 or SEQ ID NOs: 21-23.

In one embodiment, the at least one peptide or the plurality of peptides is conjugated to a second peptide containing an MHC-II epitope. Preferably, the amino acid sequence of the second peptide consists of 25 amino acids or less, or 15 amino acids or less. In specific embodiments, the second peptide consists of 9-12 amino acids, 10-18 amino acids, or 8-18 amino acids. Preferably, the second peptide contains a T cell epitope or a B cell epitope. In one embodiment, the T cell epitope is a T helper cell epitope effective to enhance B cell differentiation into antibody-producing plasma cells or a cytotoxic T cell epitope. In one embodiment, the epitopes are overlapping epitopes for different MHC alleles or epitopes presented by many MHC allotypes. In another embodiment, the epitopes are peptides presented by different MHC alleles.

The peptides which form or are incorporated into the vaccine compositions of the invention are preferably purified from contaminating chemical precursors, if chemically synthesized, or substantially free of cellular material from the cell or tissue source from which they are derived. In a specific embodiment, the peptides are 60%, preferably 65%, 70%, 75%, 80%, 85%, 90%, 95%, or 99% free of contaminating chemical precursors, proteins, lipids or nucleic acids. In a preferred embodiment, the peptides are substantially free of contaminating virus. Preferably, each composition for administering to a subject is at least 95%, at least 97%, or at least 99% free of contaminating virus.
In one embodiment, the at least one peptide or the plurality of peptides of a vaccine composition of the invention comprises or consists of one or more peptides that is at least 90%, at least 95%, at least 98%>, or at least 99% identical to a peptide selected from the group consisting of any one of SEQ ID NOs: 2-13, SEQ ID NOs: 5-10, SEQ ID NOs: 11-13, SEQ ID NOs: 15-20, and SEQ ID NOs: 21-23.

In one embodiment, the at least one peptide or the plurality of peptides comprises or consists of one or more peptides that is at least 90%, at least 95%, at least 98%, or at least 99% similar to a peptide selected from the group consisting of any one of SEQ ID NOs: 2-13 or SEQ ID NOs: 15-23. In this context, the term "similar" refers to amino acid sequence similarity which is defined according to the number of conservative and non-conservative amino acid changes in a query sequence relative to a reference sequence. Conservative and non-conservative amino acid changes are known in the art. See, for example, W. R. Taylor, The Classification of Amino Acid Conservation, J. Theor. Biol. 1986 119:205-218, and D. Bordo and P. Argos, Suggestions for "Safe" Residue Substitutions in Site-Directed Mutagensis, 1991 J. Mol. Biol. 217:721-729. Generally, a conservative amino acid change refers to a substitution of one amino acid for another amino acid having substantially similar chemical properties, specifically with reference to the amino acid side chains. A non-conservative change refers to a substitution of one amino acid for another amino acid having substantially different chemical properties. Generally, conservative substitutions are those recognized in the art as being unlikely to affect the overall structure or biological function of the polypeptide, while non-conservative changes are recognized as more likely to affect structure and function.

Non-limiting examples of a conservative amino change include substitution of amino acids within the following groups: aliphatic, aromatic, polar, nonpolar, acidic, basic, phosphorylatable hydrophobic, hydrophilic, small nonpolar, small polar, large nonpolar, and large polar. Non-limiting examples of non-conservative amino acid changes include substitutions of amino acids between the foregoing groups.

In one embodiment, a conservative amino acid change is a substitution in which the substitution matrix for the pair of residues has a positive value. Examples of amino acids include substitution of cysteine for serine, cysteine for threonine, serine for cysteine, threonine for serine, asparagine for glutamine, glutamic acid for aspartic acid, valine for leucine or isoleucine, leucine for valine or isoleucine, and isoleucine for valine or leucine. Examples of non-conservative substituitions of amino acids include substitution of cysteine for a threonine, serine for cysteine, threonine for serine, asparagine for glutamine, glutamic acid for aspartic acid, valine for leucine or isoleucine, leucine for valine or isoleucine, and isoleucine for valine or leucine.
acid substitution matrices are known in the art, for example the BLOSUM50 matrix or
the PAM250 matrix (see W. A. Pearson, Rapid and Sensitive Sequence Comparison with 
Press, San Diego). For further examples of scoring matrices and a comparison between 
them see M. S. Johnson and J. P. Overington, 1993, A Structural Basis for Sequence 

In a preferred embodiment, a conservative amino acid change is a substitution of 
one amino acid for another amino acid within the same chemical group wherein the 
groups are selected from neutral and polar amino acids (Ser, Thr, Pro, Ala, Gly, Asn, 
Gin), negatively charged and polar amino acids (Asp, Glu), positively charged and polar 
amino acids (His, Arg, Lys), nonpolar amino acids lacking a ring structure (Met, Ile, Leu, 
Val), nonpolar amino acids having a ring structure (Phe, Tyr, Trp), and Cysteine. 

In one embodiment, the vaccine composition of the invention comprises as its 
immunogenic component a chimeric protein which consists of two or more MIC peptide 
epitopes independently selected from the group consisting of SEQ ID NOs 2-13 or SEQ 
ID NOs: 15-23 in which the epitopes are linked. In one embodiment, the two or more 
MIC peptide epitopes are the same epitope. In another embodiment, the two or more 
MIC peptide epitopes comprise at least two MIC peptide epitopes that are different. In 
one embodiment, the vaccine composition comprises as its immunogenic component the 
chimeric protein displayed on the surface of a viral capsid, such as a Hepatitis B core 
capsid. 

In one embodiment, the vaccine composition of the invention comprises as its 
immunogenic component a chimeric protein which consists of two or more MIC peptide 
epitopes selected from the group consisting of SEQ ID NOs 2-13 or SEQ ID NOs: 15-23 
placed into an immunoglobulin (Ig) domain having a similar overall immunoglobulin 
fold compared to MICA. In one embodiment, the Ig domain is an Ig domain selected 
from one of the following: UL18 (human CMV), the C-terminal Ig domain of IFN-
alpha/beta binding protein C12R (poxvirus decoy receptor, PDB ID:30Q3), the N-
terminal Ig domain of outer capsid protein from a T4-like bacteriophage (Hoc, PDB ID: 
3SHS), and the human CMV protein US2 (PDB ID: 1IM3).
In one embodiment, the vaccine composition of the invention comprises two separate components adapted to be administered separately, the first component comprising an immunogen consisting of a first MIC peptide which comprises or consists of the full-length alpha 3 domain of MICA [SEQ ID NO: 1] or MICB; the second component comprising an immunogen consisting of one or more MIC peptide epitopes selected from the group consisting of SEQ ID NOs 2-13 or SEQ ID NOs: 15-23. In one embodiment, the vaccine composition comprises a first component comprising an immunogen consisting of a first MIC peptide which comprises or consists of the full-length alpha 3 domain of MICA [SEQ ID NO: 1]; and one or more additional components, each comprising an immunogen consisting of one or more MIC peptide epitopes selected from the group consisting of SEQ ID NOs 2-13 or SEQ ID NOs: 15-23. Preferably, the first component is administered before the second or additional components in a prime-boost fashion according to methods known in the art.

In one embodiment consistent with any of the foregoing embodiments, the vaccine composition of the invention may comprise one or more polynucleotide sequences encoding the MIC epitopes of SEQ ID NOs 1-23. In a further embodiment, the DNA encoding the one or more MIC epitopes is in the form of a nanoparticle comprising the DNA.

**Peptide Variants**

In some instances, amino acid sequences of the peptides disclosed herein can be modified and varied to create peptide variants (e.g., peptides with a defined sequence homology to the peptides disclosed herein), for example, so long as the antigen binding property of the peptide variant is maintained or improved relative to the unmodified peptide (antigen binding properties of any modified peptide can be assessed using the in vitro and/or in vivo assays described herein and/or techniques known in the art).

While peptide variants are generally observed and discussed at the amino acid level, the actual modifications are typically introduced or performed at the nucleic acid level. For example, variants with 80%, 85%, 90%, 95%, 96%, 97%, 98, or 99% amino acid sequence identity to the peptides of the invention can be generated by modifying the
nucleic acids encoding the peptides or portions/fragments thereof, using techniques (e.g., cloning techniques) known in the art.

Amino acid sequence modifications typically fall into one or more of three classes: substitutional, insertional, or deletional modifications. Insertions include amino and/or terminal fusions as well as intra-sequence insertions of single or multiple amino acid residues. Insertions ordinarily will be smaller insertions than those of amino or carboxyl terminal fusions, for example, on the order of one to four residues. Deletions are characterized by the removal of one or more amino acid residues from the protein sequence. Typically, no more than about from 2 to 6 residues are deleted at any one site within the protein molecule. Amino acid substitutions are typically of single residues, but can occur at a number of different locations at once; insertions usually will be on the order of about from 1 to 10 amino acid residues; and deletions will range about from 1 to 30 residues. Deletions or insertions can be made in adjacent pairs, i.e., a deletion of 2 residues or insertion of 2 residues. Substitutions, deletions, insertions or any combination thereof may be combined to arrive at a final construct. The mutations must not place the sequence out of reading frame and preferably will not create complementary regions that could produce secondary mRNA structure. Substitutional modifications are those in which at least one residue has been removed and a different residue inserted in its place. In some instances, substitutions can be conservative amino acid substitutions. In some instances, peptides herein can include one or more conservative amino acid substitutions relative to a peptide of the invention. For example, variants can include 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 20-30, 30-40, or 40-50 conservative amino acid substitutions relative to a peptide shown in Table 1. Alternatively, variants can include 50 or fewer, 40 or fewer, 30 or fewer, 20 or fewer, 10 or fewer, 9 or fewer, 8 or fewer, 7 or fewer, 6 or fewer, 5 or fewer, 4 or fewer, 3 or fewer, or 2 or fewer conservative amino acid substitutions relative to a peptide shown in Table 1. Such substitutions generally are made in accordance with the following Table 2 and are referred to as conservative substitutions. Methods for predicting tolerance to protein modification are known in the art (see, e.g., Guo et al, Proc. Natl. Acad. Sci., USA, 101(25):9205-9210 (2004)).
Table 2: Conservative Amino Acid Substitutions

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Substitutions (others are known in the art)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ala</td>
<td>Ser, Gly, Cys</td>
</tr>
<tr>
<td>Arg</td>
<td>Lys, Gin, His</td>
</tr>
<tr>
<td>Asn</td>
<td>Gin, His, Glu, Asp</td>
</tr>
<tr>
<td>Asp</td>
<td>Glu, Asn, Gin</td>
</tr>
<tr>
<td>Cys</td>
<td>Ser, Met, Thr</td>
</tr>
<tr>
<td>Gin</td>
<td>Asn, Lys, Glu, Asp, Arg</td>
</tr>
<tr>
<td>Glu</td>
<td>Asp, Asn, Gin</td>
</tr>
<tr>
<td>Gly</td>
<td>Pro, Ala, Ser</td>
</tr>
<tr>
<td>His</td>
<td>Asn, Gin, Lys</td>
</tr>
<tr>
<td>Ile</td>
<td>Leu, Val, Met, Ala</td>
</tr>
<tr>
<td>Leu</td>
<td>Ile, Val, Met, Ala</td>
</tr>
<tr>
<td>Lys</td>
<td>Arg, Gin, His</td>
</tr>
<tr>
<td>Met</td>
<td>Leu, Ile, Val, Ala, Phe</td>
</tr>
<tr>
<td>Phe</td>
<td>Met, Leu, Tyr, Trp, His</td>
</tr>
<tr>
<td>Ser</td>
<td>Thr, Cys, Ala</td>
</tr>
<tr>
<td>Thr</td>
<td>Ser, Val, Ala</td>
</tr>
<tr>
<td>Trp</td>
<td>Tyr, Phe</td>
</tr>
<tr>
<td>Tyr</td>
<td>Trp, Phe, His</td>
</tr>
<tr>
<td>Val</td>
<td>Ile, Leu, Met, Ala, Thr</td>
</tr>
</tbody>
</table>

In some instances, substitutions are not conservative. For example, an amino acid in a peptide shown in Table 1 can be replaced with an amino acid that can alter some property or aspect of the peptide. In some instances, non-conservative amino acid substitutions can be made, e.g., to change the structure of a peptide, to change the binding properties of a peptide (e.g., to increase or decrease the affinity of binding of the peptide to an antigen and/or to alter increase or decrease the binding specificity of the peptide to the antigen).
In some instances, peptides and/or peptide variants can include or can be fragments of the peptides shown in Table 1. Such fragments can include, for example, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 50-100, 101-150, fewer amino acids than the CDRs, FRs, and/or AAs shown in Table 1, e.g., so long as the fragments retain at least at portion of the binding properties of the full-length peptide (e.g., at least 50%, 60%, 70%, 80%, 90%, or 100% of the binding properties of the full-length peptide). Truncations can be made at the amino-terminus, the carboxy-terminus, and/or within the peptides herein.

In some instances, the interacting face of a peptide variant can be the same (e.g., substantially the same) as an unmodified peptide, e.g., to alter (e.g., increase or decrease), preserve, or maintain the binding properties of the peptide variant relative to the unmodified peptide. Methods for identifying the interacting face of a peptide are known in the art (Gong et al, BMC: Bioinformatics, 6:1471-2105 (2007); Andrade and Wei et al, Pure and Appl. Chem., 64(11):1777-1781 (1992); Choi et al, Proteins: Structure, Function, and Bioinformatics, 77(1):14-25 (2009); Park et al., BMC: and Bioinformatics, 10:1471-2105 (2009).

Those of skill in the art readily understand how to determine the identity of two polypeptides (e.g., an unmodified peptide and a peptide variant). For example, identity can be calculated after aligning the two sequences so that the identity is at its highest level. Another way of calculating identity can be performed by published algorithms. Optimal alignment of sequences for comparison may be conducted by the local identity algorithm of Smith and Waterman, Adv. Appl. Math, 2:482 (1981), by the identity alignment algorithm of Needleman and Wunsch, J. Mol. Biol. 48:443 (1970), by the search for similarity method of Pearson and Lipman, Proc. Natl. Acad. Sci. USA 85:2444 (1988), by computerized implementations of these algorithms (GAP, BESTFIT, FASTA, and TFASTA in the Wisconsin Genetics Software Package, Genetics Computer Group, 575 Science Dr., Madison, WI), or by inspection.

The same types of identity can be obtained for nucleic acids by, for example, the algorithms disclosed in Zuker, Science 244:48-52 (1989); Jaeger et al, Proc. Natl. Acad.
Sci. USA 86:7706-10 (1989); Jaeger et al, Methods Enzymol. 183:281-306 (1989), which are herein incorporated by reference for at least material related to nucleic acid alignment. It is understood that any of the methods typically can be used and that in certain instances the results of these various methods may differ, but the skilled artisan understands if identity is found with at least one of these methods, the sequences would be said to have the stated identity and to be disclosed herein.

In some instances, as described in more detail under the methods section below, therapeutic compositions disclosed herein can be produced using genetic material (e.g., DNA and/or mRNA) isolated and/or purified from immune cells (e.g., B cells, including memory B cells) obtained using the methods disclosed herein. Once such genetic material has been obtained, methods for using it to produce the therapeutic compositions disclosed herein are known in the art and/or are summarized below.

In some instances, peptides can include a detectable label. As used herein, a "label" refers to a moiety that has at least one element, isotope, or functional group incorporated into the moiety which enables detection of the peptide to which the label is attached. Labels can be directly attached (i.e., via a bond) or can be attached by a linker (e.g., such as, for example, a cyclic or acyclic, branched or unbranched, substituted or unsubstituted alkyne; cyclic or acyclic, branched or unbranched, substituted or unsubstituted alkenylene; cyclic or acyclic, branched or unbranched, substituted or unsubstituted alkynylene; cyclic or acyclic, branched or unbranched, substituted or unsubstituted heteroalkylene; cyclic or acyclic, branched or unbranched, substituted or unsubstituted heteroalkenylene; cyclic or acyclic, branched or unbranched, substituted or unsubstituted heteroalkynylene; substituted or unsubstituted arylene; substituted or unsubstituted heteroarylene; or substituted or unsubstituted acylene, or any combination thereof, which can make up a linker). Labels can be attached to a peptide at any position that does not interfere with the biological activity or characteristic of the inventive polypeptide that is being detected.

Labels can include: labels that contain isotopic moieties, which may be radioactive or heavy isotopes, including, but not limited to, $^2$H, $^3$H, $^{13}$C, $^{14}$C, $^{15}$N, $^{31}$P, $^{32}$P, $^{35}$S, $^{67}$Ga, $^{99m}$Tc (Tc-99m), $^{111}$In, $^{123}$I, $^{125}$I, $^{169}$Yb, and $^{186}$Re; labels that include immune or...
immunoreactive moieties, which may be antibodies or antigens, which may be bound to enzymes (e.g., such as horseradish peroxidase); labels that are colored, luminescent, phosphorescent, or include fluorescent moieties (e.g., such as the fluorescent label FITC); labels that have one or more photoaffinity moieties; labels that have ligand moieties with one or more known binding partners (such as biotin-streptavidin, FK506-FKBP, etc.).

In some instances, labels can include one or more photoaffinity moieties for the direct elucidation of intermolecular interactions in biological systems. A variety of known photophores can be employed, most relying on photoconversion of diazo compounds, azides, or diazirines to nitrenes or carbenes (see, e.g., Bayley, H., Photogenerated Reagents in Biochemistry and Molecular Biology (1983), Elsevier, Amsterdam, the entire contents of which are incorporated herein by reference). In certain embodiments of the invention, the photoaffinity labels employed are o-, m- and p-azidobenzoysls, substituted with one or more halogen moieties, including, but not limited to 4-azido-2,3,5,6-tetrafluorobenzoic acid.

Labels can also be or can serve as imaging agents. Exemplary imaging agents include, but are not limited to, those used in positron emissions tomography (PET), computer assisted tomography (CAT), single photon emission computerized tomography, x-ray, fluoroscopy, and magnetic resonance imaging (MRI); anti-emetics; and contrast agents. Exemplary diagnostic agents include but are not limited to, fluorescent moieties, luminescent moieties, magnetic moieties; gadolinium chelates (e.g., gadolinium chelates with DTPA, DTPA-BMA, DOTA and HP-D03A), iron chelates, magnesium chelates, manganese chelates, copper chelates, chromium chelates, iodine -based materials useful for CAT and x-ray imaging, and radionuclides. Suitable radionuclides include, but are not limited to, $^{123}$I, $^{125}$I, $^{131}$I, $^{133}$I, $^{135}$I, $^{47}$Sc, $^{72}$As, $^{72}$Se, $^{90}$Y, $^{97}$Ru, $^{100}$Pd, $^{101}$mRh, $^{119}$Sb, $^{128}$Ba, $^{197}$Hg, $^{211}$At, $^{212}$Bi, $^{212}$Pb, $^{109}$Pd, $^{111}$In, $^{67}$Ga, $^{68}$Ga, $^{67}$Cu, $^{75}$Br, $^{77}$Br, $^{99}$mTc, $^{14}$C, $^{13}$N, $^{15}$O, $^{32}$P, $^{33}$P, and $^{18}$F.

Fluorescent and luminescent moieties include, but are not limited to, a variety of different organic or inorganic small molecules commonly referred to as "dyes," "labels," or "indicators." Examples include, but are not limited to, fluorescein, rhodamine, acridine dyes, Alexa dyes, cyanine dyes, etc. Fluorescent and luminescent moieties may include a
variety of naturally occurring proteins and derivatives thereof, e.g., genetically engineered variants. For example, fluorescent proteins include green fluorescent protein (GFP), enhanced GFP, red, blue, yellow, cyan, and sapphire fluorescent proteins, reef coral fluorescent protein, etc. Luminescent proteins include luciferase, aequorin and derivatives thereof. Numerous fluorescent and luminescent dyes and proteins are known in the art (see, e.g., U.S. Patent Publication 2004/0067503; Valeur, B., "Molecular Fluorescence: Principles and Applications," John Wiley and Sons, 2002; and Handbook of Fluorescent Probes and Research Products, Molecular Probes, 9th edition, 2002).

Peptides for use in the vaccine compositions of the invention can be made synthetically. In certain embodiments, one or more peptide bonds is replaced, e.g., to increase physiological stability of the peptide, by: a retro-inverso bonds (C(O)-NH); a reduced amide bond (NH-CH₂); a thiomethylene bond (S-CH₂ or CH₂-S); an oxomethylene bond (0-CH₂ or CH₂-O); an ethylene bond (CH₂-CH₂); a thioamide bond (C(S)-NH); a trans-olefin bond (CH=CH); a fluoro substituted trans-olefin bond (CF=CH); a ketomethylene bond (C(O)-CHR) or CHR-C(O) wherein R is H or CH₃; and a fluoro-ketomethylene bond (C(O)-CFR or CFR-C(O) wherein R is H or F or CH₃.

In certain embodiments, the peptides are modified by one or more of acetylation, amidation, biotinylation, cinnamoylation, farnesylation, fluoresceination, formylation, myristoylation, palmitoylation, phosphorylation (Ser, Tyr or Thr), stearoylation, succinylation and sulfurylation.

In one embodiment, the at least one peptide or the plurality of peptides is conjugated to a carrier protein. In one embodiment, the carrier protein is selected from tetanus toxin and diphtheria toxin. In another embodiment, the peptides are modified to extend in-vivo half-life by protecting against peptidase activity, for example as described in US 2009/0175821. In one embodiment, the peptides or modified peptides are further conjugated to polyethylene glycol (PEG), an alkyl group (e.g., C1-C20 straight or branched alkyl groups), a fatty acid radical, and combinations thereof.

In one embodiment, the plurality of peptides retain native secondary structure, for example, as short disulfide-linked loops. In another embodiment, secondary structure in
the form of loops is created using disulfide bonds or by exposing the peptide to a chemical linker or cross-linker.

In one embodiment, the vaccine composition comprises a viral capsid protein engineered to display the at least one peptide or plurality of peptides on its surface. In one embodiment, the viral capsid protein is a hepatitis B capsid protein, for example as described in Proc Natl Acad Sci U S A. 1999 Mar 2;96(5):1915-20.

In one embodiment, the at least one peptide or the plurality of peptides is contained within a micelle or nanoparticle structure. The use of micelles may be advantageous, for example, to retain peptide secondary structure as described in J. Am. Chem. Soc, 1998, 120 (39), pp 9979-9987.

**Scaffold Embodiment**

In one embodiment, the vaccine composition comprises or is in the form of a protein scaffold and the at least one peptide or the plurality of peptides is contained within the scaffold. A particularly preferred scaffold is a porous, poly-lactide-co-glycolide (PLG) polymer scaffold. In one embodiment, the scaffold further comprises one or both of a GM-CSF protein and a Toll-like receptor agonist. In one embodiment, the Toll-like receptor agonist comprises or consists of unmethylated CpG oligonucleotides (a TLR9 agonist). The scaffold may also contain autologous tumor cell lysates, where autologous is with reference to the subject being treated (i.e., lysates of the subject's own tumor cells). In one embodiment, the scaffold is the WDVAX scaffold described in US 2013/0202707, WO 2011/063336, and US 2012/0100182. The scaffold is also described in Nature Materials, published online 11 January 2009 DOI: 10.1038/NMAT2357 and in Science Translation Medicine, Sci Transl Med 1, 8ral9 (2009); DOI: 10.1126/scitranslmed.3000359.

**Additives and adjuvants**

The vaccine compositions of the invention may further comprise one or more pharmaceutically acceptable additives or adjuvants. In one embodiment, the vaccine composition does not comprise an adjuvant. In one embodiment, the one or more adjuvants is selected from the group consisting of an oil-based adjuvant, a CpG DNA
adjuvant, a mineral salt adjuvant, a mineral salt gel adjuvant, a particulate adjuvant, a micro particulate adjuvant, a mucosal adjuvant, and a cytokine.

Adjuvants may comprise any number of delivery systems, for example, mineral salts, surface active agents, synthetic micro particles, oil-in-water emulsions, immunostimulatory complexes, liposomes, virosomes, and virus-like particles. Adjuvants further comprises one or more potentiators of the immune response such as microbial derivatives (e.g., bacterial products, toxins such as cholera toxin and heat labile toxin from E. coli, lipids, lipoproteins, nucleic acids, peptidoglycans, carbohydrates, peptides), cells, cytokines, (e.g., dendritic cells, IL-12, and GM-CSF), hormones, and small molecules. Adjuvants contemplated include, but are not limited to, oil-based adjuvants (e.g., Freund's adjuvant), CpG oligonucleotides (see Klinman 2003 Expert Rev. Vaccines 2:305-15) aluminum salt adjuvants, calcium salt adjuvants, emulsions and surfactant-based formulations (e.g., MF59, AS02, montanide, ISA-51, ISA-720, and QA21). For a review of improvements in vaccine adjuvants, see Pashine et al. 2005, Nature Med. 11(4):S63-S68.

In one embodiment, the adjuvant comprises or consists of one or more toll-like receptor (TLR) agonists. In one embodiment, the TLR agonist is a pathogen associated agonist selected from the group consisting of triacylated lipopeptides (gram positive bacteria), Peptidoglycan (gram positive bacteria), bacterial lipoprotein, lipoteichoic acid, LPS (Porphyromonas gingivalis, Leptospira interrogans), GPI-anchor proteins (Trypanosoma cruzi), neisserial porins, hemagglutinin (MV), phospholipomannan (Candida), LAM (Mycobacteria), ssRNA virus (WNV), dsRNA virus (RSV, MCMV), LPS (Gram-negative bacteria), F-protein (RSV), mannan (Candida), glycoinositolphospholipids (Trypanosoma), envelope proteins (RSV and MMTV), flagellin (Flagellated bacteria), phenol-soluble modulin (Staphylococcus epidermidis), diacylated lipopeptides (Mycoplasma), LTA (Streptococcus), zymosan (Saccharomyces), viral ssRNA (Influenza, VSV, HIV, HCV), ssRNA from RNA virus, dsDNA viruses (HSV, MCMV), hemozoin (Plasmodium), and unmethylated CpG DNA (bacteria and viruses).
In one embodiment, the TLR agonist is a synthetic ligand selected from the group consisting of Pam3Cys, CFA, MALP2, Pam2Cys, FSL-1, Hib-OMPC, Poly I:C; poly A:U, AGP, MPL A, RC-529, MDF2P, CFA, flagellin, MALP-2, Pam2Cys, FSL-1, Guanosine analogs, imidazoquinolines (e.g. Imiquimod, Aldara® R848, esiquimod®), loxoribine, imidazoquinolines, Loxoribine, ssPolyU, 3M-012, and CpG-oligonucleotides.

Formulations

The vaccine compositions of the invention can be formulated using one or more physiologically acceptable carriers or excipients. For example, where a composition is formulated as a liquid, it may comprise sterile saline, a dextrose solution, or a buffered solution, or other pharmaceutically acceptable sterile fluid. In one embodiment, the formulations are for intradermal or subcutaneous administration. In one embodiment, the formulations are for inhalation or insufflation (either through the mouth or the nose). In one embodiment, the formulations are for oral, buccal, parenteral, vaginal, or rectal administration. The term parenteral as used herein includes subcutaneous, intracutaneous, intravenous, intramuscular, intra-articular, intraarterial, intrasynovial, intrasternal, intrathecal, intralesional and intracranial injection or infusion techniques.

Preferably, the vaccine compositions are formulated to provide increased chemical stability of the peptide component during storage and transportation. For example, in one embodiment, the formulation prevents or reduces oligomerization of the peptides. In another example, the formulation prevents or reduces oxidation of the amino acid residues of the peptides. The formulations may be lyophilized or liquid formulations.

In one embodiment, the compositions are formulated for injection. In a preferred embodiment, the compositions are sterile lyophilized formulations, substantially free of contaminating cellular material, chemicals, virus, or toxins. In a particular embodiment, formulations for injection are provided in sterile single dosage containers. The formulations may or may not contain an added preservative. Liquid formulations may take such forms as suspensions, solutions or emulsions in oily or aqueous vehicles, and may contain formulatory agents such as suspending, stabilizing and/or dispersing agents.

In one embodiment, the formulation comprises liposomes.
In one embodiment, a vaccine composition of the invention is formulated with one or more other therapeutic agents used for the treatment of cancer.

The vaccine compositions of the invention are pharmaceutical compositions and can include one or more pharmaceutically acceptable carriers, additives, or vehicles. In one embodiment, the one or more pharmaceutically acceptable carriers, additives, or vehicles is selected from the group consisting of ion exchangers, alumina, aluminum stearate, lecithin, self-emulsifying drug delivery systems (SEDDS) such as d-I-tocopherol polyethylene glycol 1000 succinate, surfactants used in pharmaceutical dosage forms such as Tweens or other similar polymeric delivery matrices, serum proteins, such as human serum albumin, buffer substances such as phosphates, glycine, sorbic acid, potassium sorbate, partial glyceride mixtures of saturated vegetable fatty acids, water, salts or electrolytes, such as protamine sulfate, disodium hydrogen phosphate, potassium hydrogen phosphate, sodium chloride, zinc salts, colloidal silica, magnesium trisilicate, polyvinyl pyrrolidone, cellulose-based substances, polyethylene glycol, sodium carboxymethylcellulose, polyacrylates, waxes, polyethylene-polyoxypropylene-block polymers, polyethylene glycol and wool fat. Cyclodextrins such as 1-, 0-, and K-cyclodextrin, may also be advantageously used to enhance delivery of compounds of the formulae described herein.

The vaccine compositions of the invention may also comprise a pharmaceutically acceptable acid, base or buffer to enhance the stability of the formulated compound or its delivery form.

In one embodiment, a vaccine composition of the invention is in the form of a solution or powder for inhalation and/or nasal administration. Such compositions may be formulated according to techniques known in the art using suitable dispersing or wetting agents (such as, for example, Tween 80) and suspending agents. The sterile injectable preparation may also be a sterile injectable solution or suspension in a non-toxic parenterally acceptable diluent or solvent, for example, as a solution in 1,3-butanediol. Among the acceptable vehicles and solvents that may be employed are mannitol, water, Ringer's solution and isotonic sodium chloride solution. In addition, sterile, fixed oils are conventionally employed as a solvent or suspending medium. For this purpose, any
bland fixed oil may be employed including synthetic mono- or diglycerides. Fatty acids, such as oleic acid and its glyceride derivatives are useful in the preparation of injectables, as are natural pharmaceutically-acceptable oils, such as olive oil or castor oil, especially in their polyoxyethylated versions. These oil solutions or suspensions may also contain a long-chain alcohol diluent or dispersant, or carboxymethyl cellulose or similar dispersing agents which are commonly used in the formulation of pharmaceutically acceptable dosage forms such as emulsions and or suspensions. Other commonly used surfactants such as Tweens or Spans and/or other similar emulsifying agents or bioavailability enhancers which are commonly used in the manufacture of pharmaceutically acceptable solid, liquid, or other dosage forms may also be used for the purposes of formulation.

In one embodiment, a vaccine composition of the invention is in the form of an orally acceptable dosage form including, but not limited to, capsules, tablets, emulsions and aqueous suspensions, dispersions and solutions. In the case of tablets for oral use, carriers which are commonly used include lactose and corn starch. Lubricating agents, such as magnesium stearate, are also typically added. For oral administration in a capsule form, useful diluents include lactose and dried corn starch. When aqueous suspensions and/or emulsions are administered orally, the active ingredient may be suspended or dissolved in an oily phase is combined with emulsifying and/or suspending agents. If desired, certain sweetening and/or flavoring and/or coloring agents may be added.

Methods of Treating and Administration

The vaccine compositions of the present invention are useful for the prophylaxis and treatment of cancer. Accordingly, the present invention provides methods of prophylaxis against cancer in a subject at risk of developing cancer and methods of treating cancer in a subject in need of such treatment. In one embodiment, the cancer is selected from the group consisting of prostate cancer, multiple myeloma, glioblastoma multiforme, and melanoma. In one embodiment, the cancer is melanoma.

In one embodiment, a vaccine composition of the invention is administered to a subject having a cancer associated with overexpression of MICA. In one embodiment, the cancer is selected from the group consisting of melanoma, lung, breast, kidney,
ovarian, prostate, pancreatic, gastric, and colon carcinoma, lymphoma or leukemia. In one embodiment, the cancer is melanoma. In one embodiment, the cancer is a plasma cell malignancy, for example, multiple myeloma (MM) or pre-malignant condition of plasma cells. In some embodiments the subject has been diagnosed as having a cancer or as being predisposed to cancer.

The vaccine compositions of the invention may be administered separately or as part of a therapeutic regimen or combination therapy, as described below. The vaccine compositions of the invention may also be administered singly, or in multiple administrations, for example in a prime-boost strategy. In this context, the term "prime-boost" refers to the use of two different immunogens in succession. The two different immunogens are typically administered successively following a period of time such as 10 to 30 days or 10 to 60 days. In one embodiment, the period of time is from 2 to 4 weeks. Thus, for example, in one embodiment a vaccine composition of the invention is administered at time zero and a second vaccine composition of the invention (comprising a different immunogen) is administered following a period of time, for example from 10 to 30 days, from 10 to 60 days, or from 2 to 4 weeks.

In one embodiment, one or a plurality of different vaccine compositions of the invention is administered to the subject at multiple sites as described in US 8,1 10,196. Preferably, each site drains to a lymph node or group of lymph nodes. In one embodiment, a vaccine composition of the invention is administered to multiple sites draining to two or more lymph nodes selected from the group consisting of the lymph nodes of the head and neck, the axillary lymph nodes, the tracheobronchial lymph nodes, the parietal lymph nodes, the gastric lymph nodes, the ileocolic lymph nodes, and the inguinal and subinguinal lymph nodes. In another embodiment, the sites are selected from the group consisting of the right arm, the left arm, the right thigh, the left thigh, the right shoulder, the left shoulder, the right breast, the left breast, the abdomen, the right buttock, and the left buttock. In one embodiment, the site is or drains to a nonencapsulated cluster of lymphoid tissue selected from the group consisting of the tonsils, the adenoids, the
appendix, and Peyer's patches. In one embodiment, a vaccine composition of the
invention is administered to a site that drains to the spleen.

In one embodiment, each vaccine composition is administered by a route
independently selected from the group consisting of intradermally, subcutaneously,
transdermally, intramuscularly, orally, rectally, vaginally, by inhalation, and a
combination thereof. In one embodiment, at least one composition is injected directly into
an anatomically distinct lymph node, lymph node cluster, or nonencapsulated cluster of
lymphoid tissue.

Any suitable route of administration is encompassed by the methods of the
invention, e.g. intradermal, subcutaneous, intravenous, intramuscular, or mucosal.
Mucosal routes of administration include, but are not limited to, oral, rectal, vaginal, and
nasal administration. In a preferred embodiment, at least one composition is administered
transdermally, intradermally, subcutaneously, orally, rectally, vaginally or by inhalation.
Any route approved by the Food and Drug Administration (FDA) can be used for the
vaccine compositions of the invention. Exemplary methods of administration are
described in the FDA's CDER Data Standards Manual, version number 004 (which is
available at fda.give/cder/dsm/DRG/drg00301.htm).

Preferably, the route of administration is selected to target a composition to a
particular site, for example, by injection directly into a lymph node or a lymph node
cluster, by oral administration to target the lymph nodes of the stomach, by anal
administration to target the lymph nodes of the rectum, by inhalation or aerosol to target
the lymph nodes of the lungs, or by any other suitable route of administration.

Where the methods of the invention comprise administering a vaccine
composition to multiple sites, each composition is preferably administered at
substantially the same time, for example, within one to eight hours or during the same
doctor's visit. In one embodiment, each composition is administered within one to two
hours, within one to three hours, within one to four hours, or within one to five hours.

Where the vaccine composition is in the form of a scaffold, the method of
vaccinating a subject comprises implanting the scaffold composition in the subject,
preferably subcutaneous implantation. In certain embodiments, the method of
vaccinating a subject may comprise implanting or injecting the scaffold vaccine composition in two or more areas of the subject's anatomy.

In one embodiment, the methods of the invention further comprise administering to the subject antigen presenting cells which have been sensitized with at least one MIC peptide selected from the group consisting of SEQ ID NOs: 2-13. In a preferred embodiment, the antigen presenting cells are dendritic cells.

In one embodiment, the method further comprises administering to the subject one or more adjuvants. In one embodiment, the one or more adjuvants is selected from the group consisting of an oil-based adjuvant, a CpG DNA adjuvant, a mineral salt adjuvant, a mineral salt gel adjuvant, a particulate adjuvant, a microparticulate adjuvant, a mucosal adjuvant, and a cytokine. Such adjuvants may either be formulated with the compositions of the invention or administered separately from the compositions, e.g., prior to, concurrently with, or after the compositions are administered to the subject.

The methods disclosed herein can be applied to a wide range of species, e.g., humans, non-human primates (e.g., monkeys), horses, cattle, pigs, sheep, deer, elk, goats, dogs, cats, mustelids, rabbits, guinea pigs, hamsters, rats, and mice.

The terms "treat" or "treating," as used herein, refers to partially or completely alleviating, inhibiting, ameliorating, and/or relieving the disease or condition from which the subject is suffering. In some instances, treatment can result in the continued absence of the disease or condition from which the subject is suffering.

In general, methods include selecting a subject at risk for or with a condition or disease. In some instances, the subject's condition or disease can be treated with a pharmaceutical composition disclosed herein. For example, in some instances, methods include selecting a subject with cancer, e.g., wherein the subject's cancer can be treated by targeting one or both of MICA and/or angiopoetin-2.

In some instances, treatments methods can include a single administration, multiple administrations, and repeating administration as required for the prophylaxis or treatment of the disease or condition from which the subject is suffering. In some instances treatment methods can include assessing a level of disease in the subject prior
to treatment, during treatment, and/or after treatment. In some instances, treatment can continue until a decrease in the level of disease in the subject is detected.

The terms "administer," "administering," or "administration," as used herein refers to implanting, absorbing, ingesting, injecting, or inhaling, the inventive peptide, regardless of form. In some instances, one or more of the peptides disclosed herein can be administered to a subject topically (e.g., nasally) and/or orally. For example, the methods herein include administration of an effective amount of compound or compound composition to achieve the desired or stated effect. Specific dosage and treatment regimens for any particular patient will depend upon a variety of factors, including the activity of the specific compound employed, the age, body weight, general health status, sex, diet, time of administration, rate of excretion, drug combination, the severity and course of the disease, condition or symptoms, the patient's disposition to the disease, condition or symptoms, and the judgment of the treating physician.

Following administration, the subject can be evaluated to detect, assess, or determine their level of disease. In some instances, treatment can continue until a change (e.g., reduction) in the level of disease in the subject is detected.

Upon improvement of a patient's condition (e.g., a change (e.g., decrease) in the level of disease in the subject), a maintenance dose of a compound, composition or combination of this invention may be administered, if necessary. Subsequently, the dosage or frequency of administration, or both, may be reduced, as a function of the symptoms, to a level at which the improved condition is retained. Patients may, however, require intermittent treatment on a long-term basis upon any recurrence of disease symptoms.

In some instances, the disclosure provides methods for detecting immune cells e.g., B cells and/or memory B cells, from a human subject. Such methods can be used, for example, to monitor the levels of immune cells e.g., B cells and/or memory B cells, in a human subject, e.g., following an event. Exemplary events can include, but are not limited to, detection of diseases, infection; administration of a therapeutic composition disclosed herein, administration of a therapeutic agent or treatment regimen,
administration of a vaccine, induction of an immune response. Such methods can be used clinically and/or for research.

Effective Amounts and Dosages

In one embodiment, an effective amount of a vaccine composition of the invention is the amount sufficient to reduce the severity of a cancer in a subject having cancer, or the amount sufficient to reduce or ameliorate the severity of one or more symptoms thereof, the amount sufficient to prevent the progression of the cancer, the amount sufficient to prevent further metastasis of the cancer, the amount sufficient to cause clinical regression of the cancer, or the amount sufficient to enhance or improve the therapeutic effect(s) of another therapy or therapeutic agent administered concurrently with, before, or after a vaccine composition of the invention.

Symptoms of cancer are well-known to those of skill in the art and include, without limitation, unusual mole features, a change in the appearance of a mole, including asymmetry, border, color and/or diameter, a newly pigmented skin area, an abnormal mole, darkened area under nail, breast lumps, nipple changes, breast cysts, breast pain, death, weight loss, weakness, excessive fatigue, difficulty eating, loss of appetite, chronic cough, worsening breathlessness, coughing up blood, blood in the urine, blood in stool, nausea, vomiting, liver metastases, lung metastases, bone metastases, abdominal fullness, bloating, fluid in peritoneal cavity, vaginal bleeding, constipation, abdominal distension, perforation of colon, acute peritonitis (infection, fever, pain), pain, vomiting blood, heavy sweating, fever, high blood pressure, anemia, diarrhea, jaundice, dizziness, chill, muscle spasms, colon metastases, lung metastases, bladder metastases, liver metastases, bone metastases, kidney metastases, and pancreatic metastases, difficulty swallowing, and the like.

In one embodiment, the effective amount of a vaccine composition of the invention is the amount sufficient to produce an antibody secreting B cell or cytotoxic T cell mediated immune response directed against one or more of the peptides of the vaccine compositions of the invention. In one embodiment, the effective amount of a vaccine composition of the invention is the amount sufficient to produce an antibody
secreting B cell or cytotoxic T cell mediated immune response directed against a cancer cell. The ability of the vaccine compositions of the invention to elicit an immune response can be determined using any routine method available to those of skill in the art. In one embodiment, the effective amount of each composition is the amount sufficient to produce a cytotoxic T cell response in the subject as measured, for example, by a mixed lymphocyte T cell assay.

In one embodiment, the effective amount of the vaccine composition administered to the subject, or at a particular site of the subject, is that amount which delivers 1 to 1000 micrograms of the one or more peptides of the composition. In one embodiment, the amount of peptides is 1 to 100 micrograms, 1 to 200 micrograms, 1 to 300 micrograms, 1 to 400 micrograms, 1 to 500 micrograms, 1 to 600 micrograms, 1 to 700 micrograms, 1 to 800 micrograms, or 1 to 900 micrograms. In another embodiment, the amount of peptides is 1 to 10 micrograms, 1 to 20 micrograms, 1 to 30 micrograms, 1 to 40 micrograms, 1 to 50 micrograms, 1 to 60 micrograms, 1 to 70 micrograms, 1 to 80 micrograms, or 1 to 90 micrograms. Preferably, the total amount of peptides administered to a subject does not exceed 5 milligrams, and most preferably the total amount does not exceed 2 milligrams.

**Combination Therapy**

The present invention also provides methods for the treatment or prophylaxis of cancer which comprise administering a vaccine composition of the invention to a subject in need thereof, along with one or more additional therapeutic agents or therapeutic regimens. In one embodiment, a vaccine composition of the invention is administered as part of a therapeutic regimen that includes surgery, a chemotherapeutic agent, or radiation therapy, an immunotherapy, or any combination of the foregoing.

In one embodiment, the therapeutic regimen comprises or further comprises a one or more immunostimulatory agents. In one embodiment, the one or more immunostimulatory agents is selected from the group consisting of an anti-CTLA-4 antibody or peptide, an anti-PD-1 antibody or peptide, an anti-PDL-1 antibody or peptide,
an anti-OX40 (also known as CD134, TNFRSF4, ACT35 and/or TXGP1L) antibody or peptide, an anti-GITR (also known as TNFRSF18, AITR, and/or CD357) antibody or peptide, an anti-LAG-3 antibody or peptide, and/or an anti-TIM-3 antibody or peptide.

In one embodiment, the one or more immunostimulatory agents is selected from an anti-MICA antibody described in WO 2013/049517 or WO 2008/036981. In one embodiment, the one or more immunostimulatory agents is selected from CM33322 Ab4, CM33322 Ab28, and CM33322 Ab29, which are described in U.S. Provisional Application Nos. 61/792,034 and 61/913,198 and in US Application No. 14/025,573.

In one embodiment, the therapeutic regimen comprises or further comprises one or more cytokines. In one embodiment, the vaccine compositions of the invention comprise one or more cytokines. In one embodiment, at least one cytokine is an interleukin or an interferon. In one embodiment, at least one cytokine is an interleukin selected from the group consisting of IL-1.alpha., IL-1.beta., IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-12, IL-13, IL-15, and IL-18. In another embodiment, at least one cytokine is an interferon selected from IFN.alpha., IFN.beta., and IFN.gamma.

In one embodiment, a vaccine composition of the invention is administered as part of a therapeutic regimen that includes administering to the subject at least one chemotherapeutic agent selected from the group consisting of histone deacetylase inhibitors ("HDAC") inhibitors, proteasome inhibitors, alkylating agents, and topoisomerase inhibitors.

In one embodiment, the chemotherapeutic agent is an HDAC inhibitor selected from the group consisting of hydroxamic acid, Vorinostat (Zolinza), suberoylanilide hydroxamic acid (SAHA)(Merck), Trichostatin A (TSA), LAQ824 (Novartis), Panobinostat (LBH589) (Novartis), Belinostat (PXD101)(CuraGen), ITF2357 Italfarmaco SpA (Cinisello), Cyclic tetrapeptide, Depsipeptide (romidepsin, FK228) (Gloucester Pharmaceuticals), Benzamide, Entinostat (SNDX-275/MS-275)(Syndax Pharmaceuticals), MGCD0103 (Celgene), Short-chain aliphatic acids, Valproic acid, Phenyl butyrate, AN-9, pivanex (Titan Pharmaceutical), CHR-3996 (Chroma Therapeutics), and CHR-2845 (Chroma Therapeutics).
In one embodiment, the chemotherapeutic agent is a proteasome inhibitor selected from the group consisting of Bortezomib, (Millennium Pharmaceuticals), NPI-0052 (Nereus Pharmaceuticals), Carfilzomib (PR-171)(Onyx Pharmaceuticals), CEP 18770, and MLN9708.

In one embodiment, the chemotherapeutic agent is an alkylating agent such as mephalan.

In one embodiment, the chemotherapeutic agent is a topoisomerase inhibitor such as Adriamycin (doxorubicin).

In one embodiment, the therapeutic regimen comprises or further comprises one or more of chemotherapy, radiation therapy, cytokines, chemokines and other biologic signaling molecules, tumor specific vaccines, cellular cancer vaccines (e.g., GM-CSF transduced cancer cells), tumor specific monoclonal antibodies, autologous and allogeneic stem cell rescue (e.g., to augment graft versus tumor effects), other therapeutic antibodies, molecular targeted therapies, anti-angiogenic therapy, infectious agents with therapeutic intent (such as tumor localizing bacteria) and gene therapy.

Kits

The invention provides a pharmaceutical pack or kit for carrying out the methods or therapeutic regimens of the invention. In one embodiment, the kit comprises a vaccine composition of the invention in lyophilized form. In one embodiment, the kit comprises a vaccine composition of the invention in the form of a protein scaffold.

In another embodiment, the kit further comprises in one or more additional containers a cytokine or an adjuvant.

The composition in each container may be in the form of a pharmaceutically acceptable solution, e.g., in combination with sterile saline, dextrose solution, or buffered solution, or other pharmaceutically acceptable sterile fluid. Alternatively, the composition may be lyophilized or desiccated; in this instance, the kit optionally further comprises in a separate container a pharmaceutically acceptable solution (e.g., saline, dextrose solution, etc.), preferably sterile, to reconstitute the composition to form a solution for injection purposes.
In another embodiment, the kit further comprises one or more reusable or disposable device(s) for administration (e.g., syringes, needles, dispensing pens), preferably packaged in sterile form, and/or a packaged alcohol pad. Instructions are optionally included for administration of the compositions by a clinician or by the patient. The kit may also comprise other materials, e.g., metal or plastic foil, such as a blister pack.

In some embodiments, the present disclosure provides methods for using any one or more of the vaccine compositions (indicated below as 'X') disclosed herein in the following methods:

Substance X for use as a medicament in the treatment of one or more diseases or conditions disclosed herein (e.g., cancer, referred to in the following examples as 'Y'). Use of substance X for the manufacture of a medicament for the treatment of Y; and substance X for use in the treatment of Y.

In some instances, therapeutic compositions disclosed herein can be formulated for sale in the US, import into the US, and/or export from the US.

Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. Methods and materials are described herein for use in the present invention; other, suitable methods and materials known in the art can also be used. The materials, methods, and examples are illustrative only and not intended to be limiting. All publications, patent applications, patents, sequences, database entries, and other references mentioned herein are incorporated by reference in their entirety. In case of conflict, the present specification, including definitions, will control.

EXAMPLES

The invention is further described in the following examples, which do not limit the scope of the invention described in the claims.
Example 1: Design of Chimeric Protein with Properly Placed Epitopes for MICA Antibodies

Two designs are shown in Figures 3 and 4. In the first design (Figure 3) the two key epitopes recognized by human MICA antibodies were placed into an irrelevant protein (UL18 from human CMV) which has a similar overall immunoglobulin fold. This protein should be especially useful in the context of a booster following primary immunization with the human MICA a3 domain.

In the second design (Figure 4) a minimal protein is created in which the two key epitopes are linked. This protein could be displayed on the surface of a viral capsid, such as Hepatitis B core capsid since N- and C-termini are in close vicinity.

Example 2: Therapeutic activity of human MICA antibodies

Methods

The study design was approved by the institutional animal care and use committee (IACUC, protocol ID 08-049). Six-week-old male SCID (ICR-Prkdc<sup>scid</sup>) mice were obtained from Taconic (Hudson, NY). U937 cells were obtained from the American Type Culture Collection (ATCC, Manassas, VA). For survival experiments, 2×10<sup>6</sup> cells were injected into the peritoneal cavity of naïve mice. Tumors were allowed to grow for ten days prior to randomization of mice into blinded treatment groups. Each treatment group contained ten mice, which is sufficient to discern survival benefits per the laboratory's previous experience. Randomization was based on in vivo imaging of mice, with treatment groups containing mice with similar overall mean signal intensity, indicating similar tumor burden. Treatments were blinded by an outside lab member not performing survival experiments. Investigators administered treatments in syringes labeled "Group A" or "Group B". Study was unblended at the conclusion of each survival experiment. Antibody treatments were given intravenously at a 100µg/dose. Animals received three doses per week for a total of three weeks. Mice were bled weekly for the detection of circulating sMICA. All mice were included in the analysis.
For short-term treatment, 2x10^6 U937 cells were implanted subcutaneously and allowed to establish tumors for ten days. Mice with palpable tumors were then treated for one 1 week (3x 100μg) with fully human antibodies (isotype, AML Ab2, Mel Ab28, or Mel Ab29). Eight days following initial treatment, mice were sacrificed, and tumors and spleens were excised, with tumor mass recorded. Tumors were cut into small pieces in Petri dishes containing 5mL of digestion media containing RPMI media with 2% FBS, 50 U/ml collagenase type IV (Invitrogen), and 10 U/mL DNAse (Roche). Tissues were incubated in digestion medium at 37°C for 2 hours. Tumors were then further dissociated using a gentleMACS Dissociator (Miltenyi Biotech). Supernatant of tumor cell suspension was saved for measurement of local sMICA concentrations. Cell suspensions were filtered through a 70μM strainer and washed three times with PBS. Single cell suspensions were then stained for NK cell analysis with Zombie Yellow (viability dye, BioLegend), NKG2D-APC (CX5), Perforin-PE (eBioOMAK-D), CD45-PacBlue (30-F11), NKp46-PerCP/Cy5.5 (29A1.4), IFNy-BV711 (XMG1.2), NK1.1-BV510 (PK136), CD16-APC/Cy7 (93), and CD49b-FITC (DX5). All antibodies were from BioLegend with the exception of Perforin (eBiosciences). An additional separate aliquot of cells was stained for MICA expression using anti-MICA-PE (clone 6D4, BioLegend).

It is to be understood that while the invention has been described in conjunction with the detailed description thereof, the foregoing description is intended to illustrate and not limit the scope of the invention, which is defined by the scope of the appended claims. Other aspects, advantages, and modifications are within the scope of the following claims.

*Human MICA/B antibodies potently inhibit MICA shedding in the tumor microenvironment*

A mouse model for assessment of the therapeutic efficacy of human MICA antibodies was established. Mice do not have MICA or MICB orthologs, but the mouse NKG2D receptor recognizes human MICA/B. See Liu et al. 2013, JCI 123(10): 4410-4422. We implanted human U937 cells, an AML cell line, in SCID mice that have NK cells but are deficient in T and B cells. This model allowed us to determine the impact of human MICA antibodies on NK cell mediated immunity against human tumor cells, but
CD8 T cell responses could not be evaluated in this model. MICA antibody AML Ab2 was expressed with a murine IgG2a Fc segment to enable appropriate interaction with murine Fc receptors. The patient antibody had the human IgGl isotype, which is functionally similar to mouse IgG2a. Mice were implanted with U937 cells and randomized to blinded treatment groups after ten days. Treatment for a three-week period (3x10(^3/g/week) provided a substantial survival benefit, with 55% survival at day 45 in the treatment group (AML Ab2) compared to 0% in the control group (Istotype). See Figure 5A. Mechanistic studies demonstrated that sMICA became undetectable in sera after only two weeks of antibody treatment, while sMICA levels rose in the control group. See Figure 5B.

We next examined the functional effects of treatment at an early time point using three fully human MICA/B antibodies. Following one week of treatment of SCID mice with subcutaneous tumors, sMICA levels were greatly reduced in mice in AML Ab2, Mel Ab28, and Mel Ab29 treatment groups compared to isotype control. See Figure 5C. Flow cytometric analysis of tumors also revealed significantly increased expression of MICA on the surface of the tumor cells, mirroring in vitro results. See Figure 5D. These results established that human MICA/B antibodies potently inhibit MICA shedding in the tumor microenvironment and thereby increase the density of MICA on tumor cells for recognition by cytotoxic lymphocytes.

**Human MICA/B antibodies thus improve both local and systemic NK cell mediated immunity against tumor cells**

We performed further mechanistic studies on tumor-infiltrating NK cells at the one week time point of treatment. Inhibition of MICA shedding in tumors increased NKG2D surface expression on tumor-infiltrating NK cells. See Figure 6A. Antibody treatment also resulted in >40-fold expansion of tumor-infiltrating NK cells and enhanced expression of the NKp46 receptor. See Figures 6B and 6C. Expanded tumor-infiltrating NK cells produced larger quantities of IFNγ, a cytokine critical for anti-tumor immunity, and expressed higher levels of perforin, a key molecule for cytotoxic function. See Figures 6d and 6e. To determine cytotoxic potential of NK cells in MICA/B antibody treated mice, we assessed killing of YAC-1 cells ex vivo by splenic NK cells. Enhanced
killing was observed across all anti-MICA antibody treated mice relative to isotype treated mice. See Figure 6F. Human MICA/B antibodies thus improve both local and systemic NK cell mediated immunity against tumor cells.
WHAT IS CLAIMED:

1. A vaccine composition for treating cancer, the composition comprising, as an immunogenic component, an effective amount of a peptide comprising or consisting of one or more of SEQ ID NOs: 1-13, the effective amount being an amount effective to elicit an immune response against a MIC polypeptide, or the cancer.

2. The vaccine composition of claim 1, wherein the composition is effective to elicit an in vitro immune response against a MIC polypeptide.

3. The vaccine composition of claim 1, wherein the composition is effective to elicit an in vivo immune response against a MIC polypeptide.

4. The vaccine composition of claim 1, wherein the MIC polypeptide is not attached to a cell.

5. The vaccine composition of claim 1, wherein the composition is effective to elicit an immune response against a cancer cell expressing a MIC polypeptide.

6. The vaccine composition of claim 1, wherein the MIC polypeptide is a MICA or MICB polypeptide.

7. The vaccine composition of claim 1, wherein the cancer expresses MICA and/or MICB proteins.

8. The vaccine composition of claim 1, wherein the cancer is melanoma.

9. The vaccine composition of claim 1, wherein the peptide comprises or consists of one or more of SEQ ID NOs 2-13, or SEQ ID NOs: 15-23, or a peptide having 90% or 95% amino acid sequence identity to any of the same.

10. The vaccine composition of claim 1, wherein the vaccine composition comprises a plurality of peptides selected from two or more of SEQ ID NOs 5-10, or SEQ ID NOs: 15-20 or a peptide having 95% amino acid sequence identity to any of the same; or from two or more of SEQ ID NOs 2-13, or SEQ ID NOs: 21-23 or a peptide having 90%> amino acid sequence identity to any of the same.

11. The vaccine composition of claim 1, wherein the peptide is conjugated to a carrier protein.

12. The vaccine composition of claim 11, wherein the carrier protein is selected from tetanus toxin and diphtheria toxin.
13. The vaccine composition of claim 1, wherein the composition comprises a viral capsid protein engineered to display the at least one peptide or plurality of peptides on its surface.

14. The vaccine composition of claim 13, wherein the viral capsid protein is a hepatitis B capsid protein.

15. The vaccine composition of claim 1, wherein the composition is in the form of a polymer scaffold comprising the at least one peptide or the plurality of peptides.

16. The vaccine composition of claim 15, wherein the polymer scaffold is a porous, poly-lactide-co-glycolide (PLG) polymer scaffold.

17. The vaccine composition of claim 16, wherein the polymer scaffold further comprises one or both of a cytokine and a Toll-like receptor agonist.

18. The vaccine composition of claim 17, wherein the polymer scaffold further comprises autologous tumor cell lysates of a subject to be treated for cancer with the composition.

19. A method of treating cancer in a subject, the method comprising administering to a subject a vaccine composition of claim 1.

20. The method of claim 19, wherein the vaccine composition is administered as part of a therapeutic regimen.

21. The method of claim 20, wherein the therapeutic regimen further comprises one or more of radiation therapy, targeted therapy, immunotherapy, or chemotherapy.

22. The method of claim 19, wherein the vaccine composition is administered as part of a prime-boost strategy and the prime-boost strategy further comprises administering at least one, preferably two additional vaccine compositions of the invention, each vaccine composition having a different immunogen from the others.
Figure 3

(A) Chimeric α3  (B) MICA α3

Blue – Ab28 epitope
Red – Ab29 epitope

C

Mutations to reduce LIR-1 binding (white)

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<tr>
<th>Chimera</th>
<th>Polymorphic residues in MICA009</th>
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<tr>
<td>Chimera</td>
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<td>UL18</td>
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Change to MICA sequence due to clash

<table>
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<th>Polymorphic residues in MICA009</th>
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<tr>
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<tr>
<td>UL18</td>
<td></td>
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</tbody>
</table>
Figure 4

A

B

C

Equivalent segment of native MICA

Blue – Ab28 epitope
Red – Ab29 epitope

Mini-MICA

Micro-MICA
Figure 5: Therapeutic activity of human anti-MICA antibodies

(a) Survival %
- Isotype
- AML Ab2

(b) sMICA in Serum
- Isotype
- AML Ab2

(c) Tumor Surface MICA
- Mel A29
- Mel A26
- AML A29
- Isotype

(d) sMICA in Tumor
- Mel A29
- Mel A26
- AML A29
- Isotype
Figure 6: Human antibodies enhance NK cell accumulation and function in tumors.