

IMMUNE MODULATION

TECHNICAL FIELD

[0001] The present specification relates generally to the field of prophylactic or therapeutic vaccines. In particular, the specification relates to a vaccine for the treatment of peanut allergies by suppressing the allergic response thereto.

BACKGROUND

[0002] In principle, allergic diseases are disorders of the immune system associated with a dysregulation of the T_H1 and T_H2 lymphocyte subsets [de Vries *et al.* 1999, Parronchi *et al.* 1999, Singh *et al.* 1999]. It has been postulated that with a declining incidence of infectious diseases due to vaccination, the use of antibiotics and other public health practices, a major source of T_H1 immune provocation has been lost, with a consequent increase in the T_H2 bias of immune responses towards environmental allergens [Holgate 1999, Shaheen *et al.* 1996].

[0003] Of the various allergic diseases that affect the general population, peanut-induced anaphylaxis is particularly severe and represents the most common contributor of emergency department admissions for treatment of anaphylactic reactions.

[0004] Allergies to peanut result from an aberrant immune response directed against an otherwise harmless environmental antigen. Peanut allergy and anaphylaxis are centred around a type 2 immune response, characterised by the generation of T_H2 T cells and IgE antibody secreting B cells. By contrast, a types 1 immune response can be characterised by antibodies predominately of IgG (IgG2a isotype in mice), activation of NK cells and phagocytic cells, and the development of cytotoxic T lymphocytes (CTL). Both type 1 and 2 responses are coordinated by helper T cells, which differentiate into several functionally different subsets including T_H1 and T_H2 lymphocytes. These subsets are characterised by their cytokine secretion profile [Mosmann *et al.* 1989], where T_H1 cells produce IFN-gamma and T_H2 cells typically secrete IL-4, IL-5 and IL-13.

[0005] Orally ingested peanut allergens first encounter the gut mucosal immune system. Microfold (M) cells are specialised follicle-associated cells that line the epithelium of the gastrointestinal tract and lie in close proximity to Peyer's patches. They are responsible for the induction of tolerising and/or protective gut-associated immune responses. Sensitization to food allergens occurs when exogenous food antigens are taken

up by M cells, and then presented to macrophages and dendritic cells (DCs) [DeLong *et al.* 2011]. Once internalised by macrophages and DCs, the antigens are endocytosed, then denatured and degraded into peptides of around 12-20 amino acids in length. A small fraction of these small peptide fragments are then transported intracellularly and presented on the cell-surface MHC class II molecules for specific interaction with CD4⁺ T cells. These activated CD4⁺ T cells subsequently expand in number and release T_H2 cytokines. The T_H2 cells, IL-4 and IL-5 promote the differentiation of B cells, which bear allergens bound to surface immunoglobulin (Ig) receptors, into cells that secrete allergen-specific IgE antibodies [Turcanu *et al.* 2010]. These IgE-producing B cells then expand in number and become plasma cells that continuously secrete allergen-specific IgE antibodies. Environmental exposure to peanuts results in binding of peanut allergens to specific IgE-coating on mast cells and basophils. Subsequently, Fc receptor cross-linking provides a potent activation stimulus that results in the degranulation of basophils and mast cells, which rapidly release a variety of preformed proinflammatory and vasoactive compounds such as prostaglandins, leukotrienes, serine proteases, histamine and cytokines into the extracellular fluid to produce an inflammatory response [Sicherer *et al.* 2010], all of which culminate in the clinical manifestation of an acute allergic reaction [Long 2002].

[0006] Local symptoms of peanut allergy include abdominal pain, vomiting, cramping and diarrhea, and are common even in cases of mild peanut allergy. This acute non-life threatening reaction causes a transient increase in intestinal permeability, which subsequently allows systemic distribution of macromolecules, such as whole peanut allergens, exacerbating the allergic response to subsequent exposure to peanut allergens, which can cause life-threatening anaphylactic reactions [Sanderson *et al.* 1993].

[0007] Unlike traditional immunotherapy for allergic reactions to grass pollens, dust mite and bee sting venom, subcutaneous desensitization injections of peanut extracts have unacceptable risk-benefits [Oppenheimer *et al.* 1992]. Therefore, at present, avoiding peanuts is the only available method for prevent further reactions. However, strict avoidance is often an unrealistic strategy for many individuals, particularly in light of accidental exposure to peanuts that often occurs through ingestion of processed foods or foods prepared in the same vicinity of those containing peanuts, *e.g.*, restaurants, schools, food courts and work canteens. Therefore, there remains a need for an effective therapeutic strategy for the treatment and prevention of the peanut allergy.

SUMMARY OF THE INVENTION

[0008] In an aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising (i) at least two peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0009] In an aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising (i) at least two peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0010] In another aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising: (i) at least three peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0011] In another aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising: (i) at least three peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0012] In another aspect of the present invention, there is provided use of a poxvirus vector disclosed herein in, or in the manufacture of a medicament for, the treatment of peanut allergy.

[0013] In another aspect of the present invention, there is provided a method of inducing tolerance to or suppressing an allergic response in a subject or patient, the method comprising administering to the subject or patient an effective amount of the poxvirus

vector disclosed herein for a time and under conditions sufficient to elicit suppression/tolerance.

[0014] In another aspect of the present invention, there is provided a method of vaccinating a subject to induce tolerance to a peanut allergen comprising administering the poxvirus vector disclosed herein.

[0015] In another aspect of the present invention, there is provided a kit comprising the poxvirus vector disclosed herein.

[0016] The above summary is not and should not be seen in any way as an exhaustive of all embodiments of the present invention.

BRIEF DESCRIPTION OF THE FIGURES

[0017] **Figure 1** shows an arrangement of the PHAV Antigen according to an embodiment of the present invention including a proteasome degradation tag and multiple peanut allergens (Figures 1A and B) and the PHAV Antigen according to an embodiment of the present invention without a proteasome degradation tag (Figure 1C).

[0018] **Figure 2** shows the nucleic acid sequence of the UBc.PHAV expression cassette.

[0019] **Figure 3** shows the nucleic acid sequence of the PHAVag construct expression cassette, without the ubiquitin sequence.

[0020] **Figure 4** is a diagrammatic representation of the insertion of the PHAV expression cassettes into the A39R ORF of vaccinia virus Copenhagen strain by homologous recombination.

[0021] **Figure 5** lists the features of the homologous recombination cassette diagrammatically represented in Figure 4.

[0022] **Figure 6** shows the nucleic acid sequence of the UBc.PHAV homologous recombination cassette.

[0023] **Figure 7** shows the nucleic acid sequence of the PHAV homologous recombination cassette.

[0024] **Figure 8** is a diagrammatic representation of the pTC11 (UBc.PHAV) and

pTC12 (PHAV). The plasmids are shown in Figure 8.

[0025] Figure 9 is a diagrammatic representation of the proteasomal degradation pathway in a cell.

[0026] Figure 10 shows the levels of peanut protein-specific serum IgE (Figure 10A) and IgG2a (Figure 10B) antibodies before and after vaccination (17 day post vaccination) with the empty vector (SCV000) or the UBc.PHAV vector (SCV201C); $*=p<0.05$.

[0027] Figure 11 shows the levels of IFN-gamma (IFN-g; a T_H1 cytokine; Figure 11A), IL4 (T_H2 cytokines; Figure 11B) and IL5 (T_H2 cytokines; Figures 11C) secreted by cultured lymphocytes obtained from the spleens of SCV000 and SCV201C vaccinate mice.

DETAILED DESCRIPTION

[0028] Reference to any prior art in this specification is not, and should not be taken as, an acknowledgment or any form of suggestion that this prior art forms part of the common general knowledge in any country.

[0029] Throughout this specification, unless the context requires otherwise, the words “comprise,” “comprises” and “comprising” will be understood to imply the inclusion of a stated step or element or group of steps or elements but not the exclusion of any other step or element or group of steps or elements. Thus, use of the term “comprising” and the like indicates that the listed elements are required or mandatory, but that other elements are optional and may or may not be present. By “consisting of” is meant including, and limited to, whatever follows the phrase “consisting of”. Thus, the phrase “consisting of” indicates that the listed elements are required or mandatory, and that no other elements may be present. By “consisting essentially of” is meant including any elements listed after the phrase, and limited to other elements that do not interfere with or contribute to the activity or action specified in the disclosure for the listed elements. Thus, the phrase “consisting essentially of” indicates that the listed elements are required or mandatory, but that other elements are optional and may or may not be present depending upon whether or not they affect the activity or action of the listed elements.

[0030] As used herein the singular forms “a”, “an” and “the” include plural aspects unless the context clearly dictates otherwise. Thus, for example, reference to “a composition” includes a single composition, as well as two or more compositions;

reference to "an agent" includes one agent, as well as two or more agents; reference to "the invention" includes single and multiple aspects of the invention; and so forth.

[0031] Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which this invention belongs. Any materials and methods similar or equivalent to those described herein can be used to practice or test the present invention.

[0032] The present specification enables a vaccine approach to the development of a therapeutic agent for treating or preventing peanut allergy. In particular, the specification enables an agent capable of providing therapy in the context of the major peanut allergens, *e.g.*, at least one, at least two, at least three, etc, of the most widespread or troublesome peanut allergens.

[0033] The present invention is predicated on the inventors' surprising finding that a DNA vaccine comprising a nucleic acid construct operatively encoding a fusion protein, the fusion protein comprising a peanut allergen (such as ara h 1) linked to a proteasome degradation tag (such as ubiquitin), is capable of inducing an immune response in a subject that is biased towards a T_H1 phenotype, thus resulting in the secretion of peanut allergen-specific IgG antibodies, as opposed to peanut allergen-specific IgE antibodies that would otherwise facilitate an allergic reaction upon exposure to the peanut allergen.

[0034] Accordingly, In an aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising (i) at least two peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0035] In another aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising (i) at least two peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0036] In another aspect of the present invention, there is provided a poxvirus vector

comprising a nucleic acid sequence encoding a fusion protein comprising: (i) at least three peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0037] In another aspect of the present invention, there is provided a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising: (i) at least three peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h10 and ara h 11 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0038] In another aspect of the present invention, there is provided a poxvirus vector which expresses in the cell of a subject a fusion protein comprising: (i) a peanut allergen selected from list consisting of (a) at least two peanut allergens from ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7 or a derivative or part thereof having at least 70% sequence identity thereto, or (b) at least three peanut allergens from ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7, or a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

[0039] In another aspect of the present invention, there is provided a poxvirus vector which expresses in the cell of a subject a fusion protein comprising: (i) a peanut allergen selected from list consisting of (a) at least two peanut allergens from ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7, ara h 8, ara h 9, ara h10 and ara h 11 or a derivative or part thereof having at least 70% sequence identity thereto, or (b) at least three peanut allergens from ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h10 and ara h 11 or a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.

Peanut allergens

[0040] Peanut allergens would be known to persons skilled in the art and include any peptide of the *Arachis hypogaea* species to which a subject may be exposed to through, for

example, contact, inhalation, ingestion, injection, or the like. In an embodiment, the at least two peanut allergens are selected from the group consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7. In another embodiment, the at least two peanut allergens are selected from the group consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11.

[0041] The fusion protein can comprise any two or more peanut allergens ara h 1 to ara h 11. For example, the fusion protein may comprise the following peanut allergens:

- (i) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11;
- (ii) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9 and ara h 10;
- (iii) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8 and ara h 9;
- (iv) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7 and ara h 8;
- (v) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7;
- (vi) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5 and ara h 6;
- (vii) ara h 1, ara h 2, ara h 3, ara h 4 and ara h 5;
- (viii) ara h 1, ara h 2, ara h 3 and ara h 4;
- (ix) ara h 1, ara h 2, ara h 3 and ara h 6;
- (x) ara h 1, ara h 2 and ara h 3;
- (xi) ara h 1 and ara h 2;
- (xii) ara h 1 and ara h 3;
- (xiii) ara h 1 and ara h 4;
- (xiv) ara h 1 and ara h 5;
- (xv) ara h 1 and ara h 6;
- (xvi) ara h 1 and ara h 7;
- (xvii) ara h 1 and ara h 8;
- (xviii) ara h 1 and ara h 9;
- (xix) ara h 1 and ara h 10;
- (xx) ara h 1 and ara h 11;
- (xxi) ara h 2 and ara h 3;
- (xxii) ara h 2 and ara h 4; and so on.

[0042] By employing a proteasome degradation tag (*e.g.*, ubiquitin) as a component of

the fusion protein, the synthesized fusion protein is targeted to proteasomal degradation, resulting in the generation of small peptide fragments, which enter the endoplasmic reticulum (ER) where they are complexed with MHC class I proteins and then transported to the cell surface to be presented to T lymphocytes. As a consequence, there is enhanced presentation of the protein fragments with MHC class I. Thus, it would be understood by persons skilled in the art that, where the nucleic acid sequence encodes a fusion protein comprising two or more peanut allergens, the two or more peanut allergens can appear in the fusion protein in any particular order, as the expressed fusion protein will be subjected to proteasomal degradation.

[0043] It would be understood by persons skilled in the art that the choice of peanut allergen or allergens is likely to depend on the particular therapeutic and/or prophylactic application. For example, where the vaccine is to be used to induce tolerance in a subject who is allergic to peanut allergen Ara h1, then the fusion protein would desirably comprise ara h 1; where the vaccine is to be used to induce tolerance in a subject who is allergic to peanut allergen ara h 2, then the fusion protein would desirably comprise ara h 2; where the vaccine is to be used to induce tolerance in a subject who is allergic to peanut allergens ara h 1 and ara h 2, then the fusion protein would desirably comprise ara h 1 and ara h 2; and so on.

[0044] In an embodiment, the peanut allergen is selected from the group including: arah 1, Clone P41B (GenBank Accession number L34402 or Swiss-Prot: P43238.1); ara h 1 Clone P17 (GenBank Accession number L38853); ara h 2 cDNA (GenBank Accession number L7797 or UniProtKB/TrEMBL: Q8GV20); ara h 3 cDNA (GenBank Accession number AF093541 or ACH91862); ara h 4 cDNA (GenBank Accession number AF086821); ara h 5 cDNA (GenBank Accession number AF059616); ara h 6 cDNA (GenBank Accession number AF092846 or UniProtKB/TrEMBL: Q647G9), ara h 7 cDNA (GenBank Accession number AF091737), ara h 8 (GenBank Accession number AY328088, EF436550), ara h 9 (GenBank Accession number EU159429, EU161278), ara h 10 (AY722694, AY722695) and ara h 11 (DQ097716).

[0045] In an embodiment, the fusion protein comprises at least four peanut allergens, more preferably at least four of the most common peanut allergens affecting individuals who are allergic to peanuts. In an embodiment, the fusion protein comprises peanut allergens ara h 1, ara h 2, ara h 3 and ara h 6.

[0046] As used herein, the term "peanut allergen", including specific examples such as ara h 1, ara h 2, *etc.*, is to be understood as also including a homologue or variant thereof. The term "homologue", as used herein with reference to homologs of nucleic acid sequences or polypeptides described herein (including, for example, any one of SEQ ID NOs: 1-12), should be understood to include, for example, orthologs, paralogs, mutants and variants of nucleic acids or polypeptides described herein. In some embodiments, the homologue comprises a nucleic acid or an amino acid sequence which comprises at least 70% sequence identity, at least 75% sequence identity, at least 80% sequence identity, at least 85% sequence identity, at least 90% sequence identity, at least 95% sequence identity, at least 96% sequence identity, at least 97% sequence identity, at least 98% sequence identity, or at least 99% sequence identity to the nucleic acid or amino acid sequence described herein.

[0047] Thus, in an embodiment, ara h 1 has an amino acid sequence of SEQ ID NO: 4 or an amino acid sequence having at least 70% identity thereto, ara h 2 comprises the amino acid sequence of SEQ ID NO:6 or an amino acid sequence having at least 70% identity thereto, ara h 3 comprises the amino acid sequence of SEQ ID NO:8 or an amino acid sequence having at least 70% identity thereto, and ara h 6 comprises the amino acid sequence of SEQ ID NO:10 or an amino acid sequence having at least 70% identity thereto.

[0048] In another embodiment, ara h 1 is encoded by the nucleic acid sequence of SEQ ID NO:3 or a nucleic acid sequence having at least 70% identity thereto, ara h 2 is encoded by the nucleic acid sequence of SEQ ID NO:5 or a nucleic acid sequence having at least 70% identity thereto, ara h 3 is encoded by the nucleic acid sequence of SEQ ID NO:7 or a nucleic acid sequence having at least 70% identity thereto and ara h 6 is encoded by the nucleic acid sequence of SEQ ID NO:9 or a nucleic acid sequence having at least 70% identity thereto.

[0049] The term "sequence identity" as used herein refers to the extent that sequences are identical on a nucleotide-by-nucleotide basis or an amino acid-by-amino acid basis over a window of comparison. Thus, a "percentage of sequence identity" is calculated by comparing two optimally aligned sequences over the window of comparison, determining the number of positions at which the identical nucleic acid base (*e.g.*, A, T, C, G, I) or the identical amino acid residue (*e.g.*, Ala, Pro, Ser, Thr, Gly, Val, Leu, Ile, Phe, Tyr, Trp, Lys,

Arg, His, Asp, Glu, Asn, Gln, Cys and Met) occurs in both sequences to yield the number of matched positions, dividing the number of matched positions by the total number of positions in the window of comparison (*i.e.*, the window size), and multiplying the result by 100 to yield the percentage of sequence identity. For the purposes of the present invention, “sequence identity” will be understood to mean the “match percentage” calculated by an appropriate method. For example, sequence identity analysis may be carried out using the DNASIS computer program (Version 2.5 for windows; available from Hitachi Software engineering Co., Ltd., South San Francisco, California, USA) using standard defaults as used in the reference manual accompanying the software. The sequence identity of the encompassed peanut allergen amino acid or nucleotide sequence is, in some embodiments, increased to at least 75%, or at least 80%, or at least 85%, or at least 90% or at least 95% or at least 98% sequence identity.

[0050] In some embodiments, the term “allergen” may also include a fragment of any one of the foregoing peptides. As such, the nucleic acid may comprise a nucleotide that encodes a fragment of one of the aforementioned peanut allergens.

[0051] In some embodiments, the peanut allergen includes a modified peanut allergen whereby repeat sequences of 8 or more bases are removed from a native peanut allergen sequence. In some embodiments, the fusion protein includes 2 or more peanut allergens. In some embodiments the fusion protein includes two or more peanut allergens, at least one of which is selected from the group consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11. In some embodiments, the fusion protein includes ara h 1, ara h 2, ara h 3 and ara h 6, or homologues thereof.

[0052] In some embodiments, to facilitate expression of a single fusion protein, the nucleic acid is devoid of stop codons between two sequences encoding peanut allergens.

Proteasome degradation tag

[0053] The present inventors have surprisingly found that employing a proteasome degradation tag (such as ubiquitin) as a component of the fusion protein is able to overcome the apparent toxic and/or inhibitory effect that a non-ubiquitinated peanut allergen peptide construct has on recombinant expression. The use of a proteasome degradation tag targets the expressed fusion peptide to proteasomal degradation. As a result of ubiquitin-targeted proteasomal degradation, small peptide fragments of the fusion

peptide (*e.g.* peptides of about 8-12 amino acids in length) enter the endoplasmic reticulum (ER) where they are complexed with MHC class I proteins and subsequently transported to the cell surface to be presented to T lymphocytes. As a result, there is enhanced presentation of the fusion peptide fragments with MHC class I, resulting in a greater T_H1 immune response to peanut allergens. Thus, the proteasome degradation tag unexpectedly prevents the intact peanut allergen peptide construct from inhibiting recombinant expression in a host cell and biases the immune response towards a T_H1 phenotype.

[0054] The proteasome degradation tag may be any tag that targets the fusion protein for proteasomal degradation. In some embodiments, the proteasome degradation tag may include a ubiquitin molecule or a ubiquitin binding domain. In an embodiment, the proteasome degradation tag is a ubiquitin monomer, an illustrative example of which is ubiquitin C. In some embodiments, the ubiquitin monomer comprises the amino acid sequence of SEQ ID NO:2 or an amino acid sequence having at least 70% nucleotide sequence identity thereto.

[0055] In some embodiments, the C-terminal of the ubiquitin monomer is an alanine residue.

[0056] In another embodiment, the ubiquitin monomer is encoded by the nucleotide sequence of SEQ ID NO: 1 or a nucleotide sequence having at least 70% nucleotide sequence identity thereto.

[0057] The sequence encoding the proteasome degradation tag may be placed before or after the sequence encoding the at least one peanut allergen (*i.e.* the protein degradation tag may be C-terminal or N-terminal fusion protein).

[0058] Ubiquitin molecules may be derived from any suitable species. For a vaccine intended for human treatment, the ubiquitin molecule may be a human ubiquitin molecule or a ubiquitin molecule from another animal species that may have been codon optimised for expression in human cells. In some embodiments, the ubiquitin molecule may be a ubiquitin C monomer. Once expressed, the ubiquitin molecule may attract and bind to other ubiquitin molecules to form a polyubiquitin chain on the fusion protein. The ubiquitin molecule and/or the polyubiquitin chain may direct the fusion protein for proteasomal degradation.

[0059] In some embodiments, the nucleic acid construct operably encodes multiple ubiquitin molecules or one or more sequences encoding a truncated or modified ubiquitin molecule. If multiple ubiquitin molecules are encoded, one or more start and stop codons may be removed to allow translation of the entire fusion protein.

[0060] In some embodiments, a truncated ubiquitin molecule may involve exclusion of the lysine closest to the C-terminal of the native ubiquitin molecule. In some embodiments, a modified ubiquitin molecule may have one or more lysines of the native sequence removed or replaced (e.g. with arginine) from the sequence. In some embodiments, the ubiquitin molecule may only have a single lysine.

[0061] In some embodiments, the C-terminal of the ubiquitin molecule may be modified. For example, the C-terminal glycine of the native molecule may be replaced with alanine. Replacing the glycine with alanine or another amino acid, may prevent protease cleavage of the proteasome degradation tag from the allergen. Replacement of the glycine with alanine may also allow for the formation of a covalent bond between the proteasome degradation tag and the allergen. This covalent bond may be resistant to protease cleavage.

[0062] In some embodiments the proteasome degradation tag may include a ubiquitin binding domain. The protein degradation tag may be a member of the UbL (ubiquitin-like)-UBA (ubiquitin-associated) domain-containing protein family. In this regard, the expressed fusion protein may attract binding of ubiquitin molecules to the binding domain, leading to proteasomal degradation of the fusion protein.

Fusion protein

[0063] In some embodiments, the nucleic acid sequence encodes a fusion protein that has been optimized for expression in a subject. For example, the sequence for a peanut allergen fusion protein can be optimized for expression in a human cell. Similarly, in some embodiments, the proteasome degradation tag is optimized for expression in a subject and/or may be a proteasome degradation tag cloned from the same species as the desired subject. In some embodiments, codon optimization involves replacing a codon with a different codon that encodes the same amino acid but is more efficiently or accurately translated in a target species (e.g. in humans).

[0064] In some embodiments, optimisation of a sequence for expression in a subject

also includes the removal of repeat sequences. For example, in some embodiments, repeat sequences of 8 or more bases are removed from the peanut allergen sequence. This may be particularly important if the sequence is constructed synthetically by back translation. Synthetic sequences generally lack the benefit of codon optimization through evolution. Therefore, disrupting randomly occurring destabilizing repeat sequences within the sequence by changing nucleotide bases without changing the amino acid sequence may improve expression of the sequence.

[0065] In some embodiments, the proteasome degradation tag is encoded by a nucleic acid sequence according to SEQ ID NO: 1 or a homologue thereof. In some embodiments, the peanut allergens of the fusion protein are encoded by a nucleic acid sequence according to SEQ ID NO: 3, SEQ ID NO: 5, SEQ ID NO: 7, and/or SEQ ID NO: 9, or a homologue of any one of the foregoing.

[0066] In some embodiments, the proteasome degradation tag comprises an amino acid sequence according to SEQ ID NO: 2. In some embodiments, the peanut allergens of the fusion protein comprise an amino acid sequence according to SEQ ID NO: 4, SEQ ID NO: 6, SEQ ID NO: 8, and/or SEQ ID NO: 10.

[0067] As conformational epitopes are not required for MHC-1 presentation and in some respects unwanted in order to prevent allergen-specific IgE antibody binding, the allergens expressed as part of the fusion protein are not required to be in their native structural form. This can allow for fusion proteins including multiple peanut allergens to be used and provides flexibility in the design of the fusion protein.

[0068] Accordingly, in some embodiments, the nucleic acid construct operably encodes 2 or more peanut allergens. For example, the fusion protein may encode 2, 3, 4, 5, 6, 7, 8, 9, 10 or more peanut allergens. For some nucleic acids, at least one of the allergens may be selected from the following peanut allergens or homologues thereof: ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 or ara h 11. In an illustrative example, the nucleic acid construct operably encodes ara h 1, ara h 2, ara h 3 and ara h 6, or homologues thereof. For example, the nucleic acid construct may include a nucleic acid sequence according to SEQ ID NO: 11 or may encode a protein with an amino acid sequence according to SEQ ID NO: 12.

[0069] Each allergen may be fused to its own proteasome degradation tag and may be

operably connected to its own promoter (*e.g.* multiple fusion proteins may be expressed). Alternatively, the sequences for the proteasome degradation tag and the allergens may be arranged to allow for expression of a fusion protein including a proteasome degradation tag and the multiple allergens. This latter approach can prevent differential expression of the different allergens and/or prevent intramolecular recombination if multiple expression cassettes are used with identical promoters.

[0070] To allow translation of a fusion protein with 2 or more allergens, the nucleic acid may be devoid of stop codons between two sequences encoding peanut allergens. In some embodiments, the nucleic acid sequence may be devoid of stop codons between any of the sequences encoding peanut allergens and/or may be devoid of stop codons between the sequence encoding the proteasome degradation tag and a sequence encoding an allergen.

[0071] To drive translation, the sequence encoding the first part of the fusion protein may include a start codon at the 5' end of the sequence. Start codons may be absent from the sequence encoding the rest of the fusion protein. In this regard, expression of allergens that are not fused to the proteasome degradation tag may be minimized or prevented. This can minimize or prevent intact peanut allergens from being secreted from the cell or presented on the surface of the cell, which could otherwise stimulate a T_H2 immune response against the allergen.

[0072] In an embodiment, the fusion protein comprises the amino acid sequence of SEQ ID NO: 12 or an amino acid sequence having at least 70% identity thereto.

[0073] In another embodiment, the fusion protein is encoded by the nucleic acid sequence of SEQ ID NO: 11 or a nucleic acid sequence having at least 70% identity thereto.

[0074] In some embodiments, and in order to facilitate expression of the fusion protein as an intact protein and reduce differential expression of each allergen, the vector comprises a transcription control sequence (such as a promoter) and single start codon to facilitate expression of the intact fusion protein.

[0075] In some aspects, the present invention provides a nucleic acid cassette for desensitizing or inducing tolerance in a subject to a peanut allergen, the cassette including: i) the vaccine as described herein and ii) a terminal restriction enzyme linker at each end of

the sequence of the cassette. In some embodiments, at least one terminal restriction enzyme linker includes a Pac1 restriction enzyme recognition/cleavage sequence. In some embodiments the cassette is a viral vector cassette.

[0076] The nucleic acid construct may advantageously include a transcriptional control sequence operably connected to the nucleic acid sequence encoding the fusion protein.

[0077] The term “transcriptional control sequence” is to be understood to include any nucleic acid sequence which effects the transcription of an operably connected nucleic acid. Suitable transcriptional control sequences would be known to persons skilled in the art. Illustrative examples include a leader, polyadenylation sequence, promoter, enhancer or upstream activating sequence, and transcription terminator. Typically, a transcriptional control sequence at least includes a promoter. The term “promoter” as used herein, describes any nucleic acid which confers, activates or enhances expression of a nucleic acid molecule in a cell.

[0078] In some embodiments, at least one transcriptional control sequence is operably connected to the nucleic acid encoding the fusion protein. For the purposes of the present invention, a transcriptional control sequence is regarded as “operably connected” to a given gene or nucleotide sequence when the transcriptional control sequence is able to promote, inhibit or otherwise modulate the transcription of the gene or other nucleotide sequence.

[0079] A promoter may regulate the expression of an operably connected nucleotide sequence constitutively, or differentially, with respect to the cell, tissue, organ or developmental stage at which expression occurs, in response to external stimuli such as physiological stresses, pathogens, or metal ions, amongst others, or in response to one or more transcriptional activators. As such, the promoter used in accordance with the vaccine and/or methods of the present invention may include, for example, a constitutive promoter, an inducible promoter, a tissue-specific promoter or an activatable promoter. The present invention contemplates the use of any promoter which would be active in a cell of interest.

[0080] “Tissue specific promoters” include promoters which are preferentially or specifically expressed in one or more specific cells, tissues or organs in an organism and/or one or more developmental stages of the organism. It should be understood that a tissue specific promoter also be constitutive or inducible.

[0081] The promoter may also be a promoter that is activatable by one or more transcriptional activators, referred to herein as an “activatable promoter”. For example, the activatable promoter may comprise a minimal promoter operably connected to an Upstream Activating Sequence (UAS), which comprises, *inter alia*, a DNA binding site for one or more transcriptional activators.

[0082] As referred to herein the term “minimal promoter” should be understood to include any promoter that incorporates at least a RNA polymerase binding site and, optionally a TATA box and transcription initiation site and/or one or more CAAT boxes.

[0083] As set out above, the activatable promoter may comprise a minimal promoter fused to an Upstream Activating Sequence (UAS). The UAS may be any sequence that can bind a transcriptional activator to activate the minimal promoter. Exemplary transcriptional activators include, for example: yeast derived transcription activators such as Gal4, Pdr1, Gcn4 and Ace1; the viral derived transcription activator, VP16; Hap1 (Hach *et al.*, *J Biol Chem* 278: 248-254, 2000); Gaf1 (Hoe *et al.*, *Gene* 215(2): 319-328, 1998); E2F (Albani *et al.*, *J Biol Chem* 275: 19258-19267, 2000); HAND2 (Dai and Cserjesi, *J Biol Chem* 277: 12604-12612, 2002); NRF-1 and EWG (Herzig *et al.*, *J Cell Sci* 113: 4263-4273, 2000); P/CAF (Itoh *et al.*, *Nucl Acids Res* 28: 4291 - 4298, 2000); MafA (Kataoka *et al.*, *J Biol Chem* 277: 49903-49910, 2002); human activating transcription factor 4 (Liang and Hai, *J Biol Chem* 272: 24088 - 24095, 1997); Bcl10 (Liu *et al.*, *Biochem Biophys Res Comm* 320(1): 1-6, 2004); CREB-H (Omori *et al.*, *Nucl Acids Res* 29: 2154 - 2162, 2001); ARR1 and ARR2 (Sakai *et al.*, *Plant J* 24(6): 703-711, 2000); Fos (Szuts and Bienz, *Proc Natl Acad Sci USA* 97: 5351-5356, 2000); HSF4 (Tanabe *et al.*, *J Biol Chem* 274: 27845 - 27856, 1999); MAML1 (Wu *et al.*, *Nat Genet* 26: 484-489, 2000).

[0084] The transcriptional control sequence may also include a terminator. The term “terminator” refers to a DNA sequence at the end of a transcriptional unit which signals termination of transcription. Terminators are 3'-non-translated DNA sequences generally containing a polyadenylation signal, which facilitate the addition of polyadenylate sequences to the 3'-end of a primary transcript. As with promoter sequences, the terminator may be any terminator sequence which is operable in the cells, tissues or organs in which it is intended to be used. In some embodiments, the nucleic acid sequence may include a viral early transcriptional stop sequence 3' of the sequence encoding the fusion protein.

Vectors

[0085] In an embodiment, the nucleic acid construct is operably incorporated in a vector.

[0086] In some embodiments, the vector may be an expression vector adapted for expression in a eukaryotic cell. As used herein, a "vector" may be any of a number of nucleic acids into which a desired sequence may be inserted. Vectors include, but are not limited to, plasmids, phagemids and virus genomes. In some embodiments, the expression vector is also able to be replicated in a host cell (*e.g.* a bacterial cell), and may also further comprise one or more endonuclease restriction sites at which the vector may be cut in a determinable fashion and into which a desired DNA sequence may be ligated such that the recombinant vector retains its ability to replicate in the host cell. In the case of plasmids, replication of the desired sequence may occur many times as the plasmid increases in copy number within the host bacterium or just a single time per host before the host reproduces by mitosis. In the case of phage, replication may occur actively during a lytic phase or passively during a lysogenic phase.

[0087] Expression vectors may contain transcriptional control sequences to drive expression of inserted nucleic acids in target cells (*e.g.* in a human cell). Transcriptional control sequences include those described above and include, for example, promoters.

[0088] Vectors may further contain one or more selectable marker sequences suitable for use in the identification of cells which have or have not been transformed or transfected with the vector. Markers include, for example, genes encoding proteins which increase or decrease either resistance or sensitivity to antibiotics or other compounds, genes which encode enzymes whose activities are detectable by standard assays known in the art (*e.g.*, β -galactosidase, luciferase), and genes which visibly affect the phenotype of transformed or transfected cells, hosts, colonies or plaques (*e.g.*, various fluorescent proteins such as green fluorescent protein, GFP). Some vectors may be capable of autonomous replication, also referred to as episomal vectors. Alternatively vectors may be adapted to insert into a chromosome, so called integrating vectors. The vector may be provided with transcription control sequences (promoter sequences) which mediate cell/tissue specific expression. These promoter sequences may be cell/tissue specific, inducible or constitutive.

[0089] In some embodiments, the vector may be a viral vector. Suitable viral vectors

would be known to persons skilled in the art. Illustrative examples of viral vectors include a retroviral vector, a lentiviral vector, an adenoviral vector, an adeno-associated viral vector, or a poxvirus viral vector. Poxviral vectors may include, for example, an avipox viral vector (*e.g.* fowlpox or canary pox). In some embodiments, the poxvirus viral vector may be a replication restricted viral vector including, for example, Modified Vaccinia Ankara (MVA) virus, an avipox virus or a crippled vaccinia virus. Use of viral vectors may be beneficial in further biasing a T_H1 response against cells expressing the degraded peanut allergen peptide fragments on MHC Class I molecules as the viral vector itself may promote IL-12 receptor expression on the cells. Furthermore, the activation of immune cells by viral vectors may initiate a complex network of cell-cell interactions and cytokine production cascades that result in the overall enhancement of T_H1 immune functions in an antigen-dependant manner.

[0090] In an embodiment, the viral vector is a poxvirus viral vector.

[0091] In some embodiments, the nucleic acid sequence includes a viral early transcriptional stop sequence 3' of the sequence encoding the fusion protein.

[0092] To facilitate cloning, the nucleic acid construct may be included in a nucleic acid cassette (*i.e.*, an expression cassette). Accordingly, in some embodiments, the present invention provides a nucleic acid cassette for desensitizing a subject to a peanut allergen, the cassette including: the nucleic acid construct operably encoding the fusion protein as described herein and a terminal restriction enzyme linker at each end of the sequence of the cassette.

[0093] The term "nucleic acid cassette" as used herein is intended to mean a nucleic acid sequence designed to introduce a nucleic acid molecule (*e.g.*, the nucleic acid construct as described herein) into a vector or genome.

[0094] The cassette will typically include a terminal restriction enzyme linker at each end of the sequence of the cassette. The terminal restriction enzyme linkers at each end may be the same or different terminal restriction enzyme linkers. In some embodiments, having the same terminal restriction enzyme linkers at each end can be advantageous if replication of the cassette in bacterial cells is desired (and the cassette includes an origin of replication) as the cassette may be circularized by digesting the cassette with the appropriate restriction enzyme and ligating the ends together. Similarly, a circular cassette

may be linearised by digesting the cassette with a single restriction enzyme.

[0095] In some embodiments, the terminal restriction enzyme linkers may include rare restriction enzyme recognition/cleavage sequences, such that unintended digestion of the nucleic acid or the vector or genome into which the cassette is to be introduced does not occur. In some embodiments, the terminal restriction enzyme linkers include a Pac1 restriction enzyme recognition/cleavage sequence.

[0096] The cassette may be cloned into a mammalian expression vector, a bacterial expression or cloning vector, an insect expression vector, a plant expression vector or a viral vector. Accordingly, the cassette may be a mammalian vector cassette, a bacterial vector cassette, an insect vector cassette, a plant vector cassette or a viral vector cassette.

Treatment and prevention of peanut allergy

[0097] The present inventors have surprisingly found that the vaccine of the present invention produces a biased anti-peanut protein T_H1 immune response, which will dominate over an existing allergen-specific T_H2 immune response and, in doing so, will desensitize an individual to subsequent exposure to the peanut allergen. Furthermore, expression of T_H1 cytokines (*e.g.* IFN γ , IL-12, TGF- β , IL2, *etc.*) can reduce the expression of T_H2 cytokines (*e.g.* IL-3, IL-4, IL-5, IL6, IL10, *etc.*), biasing the immune response against the allergen towards a T_H1 immune response, the result of which is the inhibition or amelioration of the activation and/or recruitment of IgE antibody producing B cells, mast cells and eosinophils, thereby reducing or preventing an allergic reaction to subsequent allergen exposure (*e.g.*, anaphylactic reactions). Accordingly, the vaccine of the present invention is suitable for use in the treatment of a peanut allergy in a subject.

[0098] The present inventors have also surprisingly found that the vaccine of the present invention produces a biased T_H1 immune response to peanut allergen that is independent of a pre-existing peanut allergy. Accordingly, the vaccine of the present invention is suitable for use in the prevention of a peanut allergy in a subject who may be at risk thereof.

[0099] Thus, in another aspect, there is provided use of the poxvirus vector disclosed herein in, or in the manufacture of a medicament for, inducing tolerance in a subject to a peanut allergen.

[0100] In an embodiment, the poxvirus vector disclosed herein is used as a

prophylactic to prevent or ameliorate peanut allergy in a subject at risk of developing a peanut allergy (*i.e.* tolerance may be induced in a subject at risk of developing allergy to a peanut allergen). Subjects at risk of developing a peanut allergy may include people already suffering from an allergy such as hayfever, asthma or other food allergies or people that have a family history of allergies.

[0101] In another aspect, there is provided a method of inducing tolerance in a subject to a peanut allergen, the method comprising administering to a subject in need thereof an effective amount of the poxvirus vector disclosed herein for a time and under conditions sufficient to elicit suppression and/or tolerance, for example, by inducing a peanut allergen-specific T_H1 response in the subject.

[0102] The terms "allergic reaction", "allergy", "allergic disorder" and the like, as used herein, are to be understood as meaning an immune disorder in which the immune system is hypersensitive to otherwise harmless environmental substances. These environmental substances that cause allergies are called "allergens." Common allergies include seasonal rhinoconjunctivitis (*e.g.*, allergies to grasses and pollen such as ragweed, timothy grass), allergies to pet dander such as cat dander or dog dander, food allergies such as peanut, dairy and wheat allergies, venom anaphylaxis, and asthma. An allergic disorder is typically characterised by the production of IgE.

[0103] Allergic diseases result from immune responses against otherwise harmless environmental antigens, characterised by the generation of T_H2 T cells, which produce IL-4 and IL-5 and promote the differentiation of B cells into IgE antibody secreting cells. IgE antibodies bind to high affinity receptors on basophils and mast cells. Allergen exposure leads to binding of allergen molecules by surface IgE and cross linking of the receptors thus causing activation and degranulation of basophils and mast cells. The latter release a variety of preformed proinflammatory and vasoactive compounds such as histamine, prostaglandins, leukotriens and cytokines, leading to inflammatory response. Binding of peanut allergen to the IgE antibodies that are bound to the surface of mast cells and basophils is the initiating event that eventually culminates in an allergic reaction. Preventing allergen binding to mast cell- and/or basophil-bound IgE will prevent the onset of an allergic reaction. The prevention of allergen specific IgE production upon exposure to peanut allergen will induce tolerance to peanut.

[0104] The term "tolerance", as used herein, is taken to mean an inhibition (partial or

complete) of an allergic reaction to peanut allergen exposure. Inhibition may be prevention, retardation, reduction, abrogation or otherwise hindrance of an allergic reaction. Such inhibition may be in magnitude and/or be temporal in nature. In particular contexts, the terms “inhibit” and “prevent”, and variations thereof may be used interchangeably. Tolerance can be assessed by any means known to persons skilled in the art. As an illustrative example, a skin-prick test can be used to measure the subject's response to an allergen or multiple allergens, before and/or after treatment with the poxvirus vector disclosed herein. For example, in a subject who is allergic to peanuts, a skin-prick test using one or more peanut allergens will typically produce an observable localised allergic response characterised by a localised rash, urticaria and/or swelling. Tolerance in the same individual following treatment with the poxvirus vector disclosed herein will typically manifest itself as a reduced localised allergic reaction to the skin-prick test. This reduction can be measured, for example, by the difference in size (*e.g.*, diameter) of the localised allergic reaction before and after treatment.

[0105] In another illustrative example, tolerance is assessed by the prevention, retardation, inhibition, reduction, abrogation or hindrance of the severity of allergic response following accidental exposure to a peanut allergen. For example, where a subject has a history of anaphylactic responses to peanut allergen exposure, tolerance as a result of treatment with the poxvirus vector in accordance with the present invention may be determined by the absence of an anaphylactic reaction following subsequent peanut allergen exposure, even though the subject may show other signs of an allergic reaction, such as a rash.

[0106] In another illustrative example, tolerance is assessed by determining the level of circulating peanut allergen-specific IgE antibodies in a subject. For instance, a subject who has a history of allergic reactions (including anaphylactic responses) to peanut allergen exposure will typically have a higher level of peanut allergen-specific IgE antibodies as compared, for example, to a subject who does not have a peanut allergy. In such individuals, tolerance may be determined by a reduction in the level of circulating peanut allergen-specific IgE antibodies following treatment with the vaccine of the present invention. Alternatively, or in addition, tolerance may be determined by a higher level of circulating peanut allergen-specific IgG antibodies following treatment with the poxvirus vector of the present invention, which is characteristic of a T_H1 immune response and

typically indicative of a tolerant state.

[0107] Alternatively, or in addition, tolerance may be determined by assessing the cytokine profile in a sample obtained from the subject (e.g., a blood sample, including a plasma or serum sample). For example, a higher level of IFN-gamma is indicative of a bias towards an allergen-specific T_H1 response, whereas a higher level of IL-4 and/or IL-5 is indicative of a bias towards an allergen-specific T_H2 response.

[0108] Alternatively, or in addition, tolerance may be determined by obtaining a sample of T lymphocytes from a subject who has been treated with the poxvirus vector in accordance with the present invention, as disclosed herein, and measuring the cytokine profile of the lymphocytes *ex vivo*. For example, a higher level of IFN-gamma production by the T lymphocytes is indicative of a bias towards an allergen-specific T_H1 response, whereas a higher level of IL-4 and/or IL-5 production by the T lymphocytes is indicative of a bias towards an allergen-specific T_H2 response. Methods of measuring the level of peanut allergen-specific IgE and/or IgG antibodies and cytokines that are capable of differentiating between a T_H1 and T_H2 response would be known to persons skilled in the art. Illustrative examples include radioimmunoassays (RIA) and enzyme linked immunosorbent assays (ELISA).

[0109] It would be understood by persons skilled in the art that the poxvirus vector disclosed herein is to be administered in either in a single dose or as part of a series of doses that provides the desired therapeutic or prophylactic effect in a subject in need thereof; namely, the induction of tolerance to a peanut allergen. Undesirable effects, e.g. side effects, may sometimes manifest along with the desired therapeutic and/or prophylactic effect; hence, a practitioner will generally balance the potential benefits against the potential risks in determining an appropriate effective amount. The exact amount of vaccine required will vary from subject to subject, depending on the species, age and general condition of the subject, mode of administration and the like. Thus, it may not be possible to specify an exact effective amount. However, an appropriate effective amount in any individual case may be determined by one of ordinary skill in the art using routine skills or experimentation. One of ordinary skill in the art would be able to determine the required amounts based on such factors as the subject's size and weight, the severity of a subject's symptoms, and the proposed route of administration.

[0110] The term "treatment" refers to any measurable or statistically significant

inhibition or amelioration in at least some subjects in one or more symptoms of peanut allergy.

[0111] In some embodiments, the poxvirus vector disclosed herein is exploited to desensitize a subject with a peanut allergy (*i.e.* a subject who is hypersensitive to one or more peanut allergens) to one or more peanut allergens. The term “desensitizing a subject” as used herein with reference to a peanut allergen is intended to mean that the sensitivity of the subject to the peanut allergen is reduced, ameliorated or eliminated. In this regard, symptoms of a peanut allergy in a subject are partially or completely reduced upon re-exposure to one or more peanut allergens.

[0112] In some embodiments, alternatively, or in addition, the nucleic acid sequence is exploited to induce tolerance in a subject to one or more peanut allergens. Induction of tolerance to the one or more peanut allergens is performed in a subject with a peanut allergy or in a subject who may be at risk of developing a peanut allergy (*i.e.* the nucleic acid may be exploited as part of a prophylactic treatment of peanut allergy).

[0113] While the poxvirus vector disclosed herein is exploited in different ways to desensitize or induce tolerance in a subject to a peanut allergen (as described herein), the general principle by which the poxvirus vector operates is the same. When the fusion peptide is expressed in a cell, it is targeted to proteasomal degradation by virtue of the proteasome degradation tag, which prevents the intact fusion protein from being secreted from the cell.

[0114] In an embodiment, there is provided a method of vaccinating a subject to induce tolerance to a peanut allergen comprising administering the poxvirus vector as disclosed herein. In a particular embodiment, the method is for inducing tolerance against at least two or at least three major peanut allergens.

[0115] The present invention extends to kits comprising the poxvirus vector, as disclosed herein.

[0116] The poxvirus vector of the present invention may be delivered to a cell *in vivo* or *ex vivo* (*e.g.* as naked DNA or in a vector) by methods known in the art. Illustrative examples include viral delivery, microinjection, gene gun, impalefection, hydrostatic pressure, electroporation, sonication, and/or lipofection. The poxvirus vector may also be delivered to a cell as a pharmaceutical composition.

[0117] Liposomes may serve as a carrier for the poxvirus vector. Liposomes are lipid-based vesicles which encapsulate a selected therapeutic agent (*e.g.* a vector) which is then introduced into a patient. The liposome may be manufactured either from pure phospholipid or a mixture of phospholipid and phosphoglyceride. Typically, liposomes can be manufactured with diameters of less than 200 nm, which enables them to be intravenously injected and able to pass through the pulmonary capillary bed. Furthermore, the biochemical nature of liposomes confers permeability across blood vessel membranes to gain access to selected tissues.

[0118] The poxvirus vector may be naked, that is, unassociated with any proteins or other agents which may affect the recipients' immune system. In this case, it is desirable for the poxvirus vector be in a physiologically acceptable solution, such as, but not limited to, sterile saline or sterile buffered saline. Alternatively, the vaccine may be associated with liposomes, such as lecithin liposomes or other liposomes known in the art. Agents which assist in the cellular uptake of nucleic acid molecules, such as, but not limited to, calcium ions, may also be used.

[0119] In the case of non-viral vectors, the amount of nucleic acid to be introduced into a recipient will have a very broad dosage range and may depend, for example, on the strength of the transcriptional and translational promoters used. In addition, the magnitude of the immune response may depend on the level of protein expression and on the immunogenicity of the expressed fusion protein product. An effective dose range may include about 1 ng to 5 mg, about 100 ng to 2.5 mg, about 1 µg to 750 µg, or about 10 µg to 300 µg of the nucleic acid (*e.g.* as part of a poxvirus vector).

[0120] The poxvirus vector may be administered or inoculated, subcutaneously, intramuscularly, intradermally, or by other modes such as intraperitoneal, intravenous, or inhalation, in the presence of adjuvants or other substances that have the capability of promoting DNA uptake or recruiting immune system cells to the site of inoculation. The chosen route of administration will depend on the composition and the disease status of patients. Relevant considerations include the types of immune cells to be activated, the time which the antigen is exposed to the immune system and the immunization schedule. It is also contemplated that booster treatments may be provided.

[0121] As described herein, the poxvirus vector is able to desensitize (*i.e.*, induce

tolerance in) a subject by expression of the fusion protein in a cell. The fusion protein is degraded within the cell and the degraded peanut allergen fragments are expressed on the cell surface in association with MHC Class I molecules. In some embodiments, no intact expressed peanut allergen is exposed to the subject's immune system during the methods of the present invention. This is as a result of the proteasome degradation tag, which drives the intracellular proteasomal degradation of the expressed fusion protein.

[0122] The method of desensitizing or inducing tolerance in a subject to a peanut allergen may involve administering the poxvirus vector, or a pharmaceutical composition including the poxvirus vector to the subject. Accordingly, the present invention provides a method of desensitizing a subject to a peanut allergen, wherein the method includes expressing the fusion protein in a cell of the subject, wherein the proteasome degradation tag of the expressed fusion protein targets the fusion protein for intracellular proteasomal degradation and association of the degraded peptides of the peanut allergen with MHC class I molecules to promote generation of a T_H1 response to the peanut allergen, thus desensitizing or inducing tolerance in the subject to the peanut allergen.

[0123] The present invention also provides a prophylactic treatment method for inducing tolerance to a peanut allergen in a subject, wherein the method includes expressing the fusion protein in a cell of the subject, wherein the proteasome degradation tag of the expressed fusion protein targets the fusion protein for intracellular proteasomal degradation and association of the degraded peptides of the peanut allergen with MHC class I molecules to promote generation of a T_H1 response to the peanut allergen, thus preventing sensitivity of the subject to the peanut allergen.

[0124] While these methods may involve expressing the fusion protein in a cell *in vivo*, other methods may include expressing the fusion protein in a cell *ex vivo*. As such, the present invention also provides a cell expressing the fusion protein. In this regard, the cell may be used for *in vitro* experiments, *in vivo* treatment and/or *ex vivo* treatments.

Subject

[0125] The terms "*subject*," "*individual*" and "*patient*" are used interchangeably herein to refer to any subject to which the present disclosure may be applicable, particularly a vertebrate subject, and even more particularly a mammalian subject. Suitable vertebrate animals that fall within the scope of the invention include, but are not restricted to, any

member of the subphylum Chordata including primates, rodents (*e.g.*, mice rats, guinea pigs), lagomorphs (*e.g.*, rabbits, hares), bovines (*e.g.*, cattle), ovines (*e.g.*, sheep), caprines (*e.g.*, goats), porcines (*e.g.*, pigs), equines (*e.g.*, horses), canines (*e.g.*, dogs), felines (*e.g.*, cats), avians (*e.g.*, chickens, turkeys, ducks, geese, companion birds such as canaries, budgerigars *etc*), marine mammals (*e.g.*, dolphins, whales), reptiles (snakes, frogs, lizards, *etc.*), and fish. In some embodiments, the subject is a primate (*e.g.*, a human, ape, monkey, chimpanzee).

[0126] In a preferred embodiment, the subject is a human. Accordingly, in some embodiments, the nucleic acid sequence encoding the fusion protein is codon optimized for expression in human cells.

Pharmaceutical compositions

[0127] The poxvirus vector according to the present invention may be provided in a form comprising a pharmaceutically or physiologically acceptable carrier and/or diluent.

[0128] Thus, in another aspect, there is provided a pharmaceutical composition for desensitizing or inducing tolerance in a subject to a peanut allergen, the composition comprising the poxvirus vector disclosed herein and a pharmaceutically acceptable carrier.

[0129] Pharmaceutical compositions are conveniently prepared according to conventional pharmaceutical compounding techniques. See, for example, Remington's Pharmaceutical Sciences, 18th Ed., Mack Publishing, Company, Easton, PA, U.S.A., 1990. These compositions may comprise, in addition to one of the active substances, a pharmaceutically acceptable excipient, carrier, buffer, stabilizer or other materials well known in the art. Such materials should be non-toxic and should not interfere with the efficacy of the active ingredient. The carrier may take a wide variety of forms depending on the form of preparation desired for administration, *e.g.* intravenous, oral or parenteral.

[0130] In some embodiments, the present invention provides a method of desensitizing or inducing tolerance in a subject to a peanut allergen, the method including expressing the fusion peptide as described herein in a cell of the subject, wherein the proteasome degradation tag of the expressed fusion protein targets the fusion protein for intracellular proteasomal degradation and association of the degraded peptides of the peanut allergen with MHC class I molecules to promote generation of a T_H1 response to the peanut allergen, thus desensitizing or inducing tolerance in the subject to the peanut allergen.

[0131] In some embodiments, the present invention provides a prophylactic treatment method for inducing tolerance to a peanut allergen in a subject, the method including expressing the fusion peptide as described herein in a cell of the subject, wherein the proteasome degradation tag of the expressed fusion protein targets the fusion protein for intracellular proteasomal degradation and association of the degraded peptides of the peanut allergen with MHC class I molecules to promote generation of a T_H1 response to the peanut allergen, thus preventing sensitivity of the subject to the peanut allergen.

[0132] The present inventors have surprisingly found that a poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising peanut allergens and a proteasome degradation tag, can, upon vaccination, produce a peanut-specific T_H1 immune response, as measured by the production of peanut allergen-specific IgG2a antibodies and peanut allergen-induced secretion of T_H1 cytokines from lymphocytes. As this poxvirus vector stimulated a peanut allergen-specific T_H1 immune response, it follows that the poxvirus vector disclosed herein can be used to desensitize (*i.e.*, induce tolerance in) subjects who are allergic to peanut allergens.

[0133] The present invention also provides a nucleic acid sequence for desensitizing or inducing tolerance in a subject to a peanut allergen, the nucleic acid including a sequence encoding a fusion protein, the fusion protein including a proteasome degradation tag and a peanut allergen. The nucleic acid may be used as a genetic vaccine.

[0134] As described herein, in some embodiments, the nucleic acid is included in an expression vector (*e.g.*, a viral vector) or pharmaceutical composition which can be administered to a subject to allow expression of the ubiquitinated fusion protein in a cell *in vivo*. Alternatively, the nucleic acid is expressed in an *ex vivo* cell (*e.g.*, an antigen presenting cell) that may then be administered to a subject. Alternatively, or in addition, the transfected cell can be used to stimulate and expand a T_H1 lymphocyte population *ex vivo*, which are then administered to the subject.

[0135] In some embodiments, establishment of T_H1 memory to the presented peptides of the peanut allergen can prevent or reduce T_H2 immune responses against the peanut allergen upon subsequent exposure to a peanut allergen. In some embodiments, T_H1 memory against the peanut allergen is established by the activation and maintenance of peanut allergen specific $CD8^+$ T cells.

Cells

[0136] In another aspect of the present invention, there is provided a cell expressing the fusion protein as described herein, such as a host cell or an antigen presenting cell (*e.g.*, a dendritic cell). The transfected cell expressing the fusion protein can then be used to generate and/or expand a peanut allergen reactive T_H1 lymphocyte population *in vivo* or *ex vivo*. Thus, in an embodiment, the present disclosure enables a method of generating and/or expanding a peanut allergen reactive T_H1 lymphocyte population *ex vivo*, the method comprising culturing the cell (*i.e.*, a transfected cell expressing the fusion protein) as described herein with one or more T lymphocytes. In another embodiment, the present disclosure enables a method of generating and/or expanding a peanut allergen reactive T_H1 lymphocyte population *in vivo*, the method comprising administering a transfected cell as described herein in a subject in need thereof, wherein the administered transfected cell activates naïve T cells in the subject to become peanut allergen-specific T_H1 cells.

[0137] In some embodiments, the present invention provides a method of desensitizing or inducing tolerance in a subject to a peanut allergen, the method comprising: i) collecting lymphocytes from the subject; ii) co-culturing the lymphocytes with cells as described herein (*i.e.*, transfected cells expressing the fusion protein disclosed herein) to generate and/or expand a T_H1 lymphocyte population that recognizes the proteasomally degraded peanut allergen fusion protein associated with MHC Class I molecules on the cells; and iii) administering the T_H1 lymphocytes from (ii) to the subject.

[0138] In some embodiments, the cell may include a prokaryotic cell (*e.g.* a bacterial cell). The prokaryotic cell may be used to replicate the nucleic acid construct (*e.g.* in vector form) and/or in various cloning steps. In some embodiments, the cell may include a eukaryotic cell (*e.g.* a mammalian cell). In this regard, the present invention also includes a cell expressing the nucleic acid construct operably encoding the fusion protein.

[0139] The poxvirus vector as disclosed herein can also be used to activate naïve antigen presenting cells, which can then be reintroduced back into the subject to activate naïve T cells to become peanut allergen- specific T_H1 cells. Thus, in some embodiments, the present invention provides a method of desensitizing or inducing tolerance in a subject to a peanut allergen, the method comprising: i) collecting antigen presenting cells from the subject; ii) co-culturing the antigen presenting cells with the cells as described herein (*i.e.*,

transfected cells expressing the fusion protein disclosed herein) to generate and/or expand a population of activated T_H1 antigen presenting cell population; and iii) administering the activated T_H1 antigen presenting cell from (ii) to the subject to activate T lymphocytes towards an allergen-specific T_H1 phenotype. Suitable naïve antigen presenting cells would be known to persons skilled in the art. Illustrative examples include dendritic cells and fibroblasts.

[0140] The cell type expressing the fusion protein is only limited in that the cell should be a nucleated cell that expresses an MHC Class I molecule. In this regard, the cell may be a cell from a cell line (*e.g.* a CHO cell line, HEK cell line, fibroblast cell line, *etc.*) or a primary cell (*e.g.*, a fibroblast, a dendritic cell). In embodiments whereby the cell is intended as an *ex vivo* autologous treatment, the cell may be cell which may be readily removed from a subject (*e.g.* a cell in blood, lymph, bone marrow) and/or readily cultured from a tissue sample (*e.g.* fibroblast cells). In some embodiments, the cell may be a professional antigen presenting cell (*e.g.* a dendritic cell, macrophage, B-cell, epithelial cell, *etc.*) or may be a non-professional antigen presenting cell (*e.g.* a fibroblast, thymic epithelial cell, thyroid epithelial cell, glial cell, pancreatic beta cell, vascular endothelial cell, *etc.*).

[0141] Expressing the fusion protein in a cell *ex vivo* (*e.g.*, transfecting the cell with the poxvirus vector disclosed herein) can be advantageous in that the number of cells expressing the nucleic acid may be controlled. Furthermore, a wider range of nucleic acid delivery systems are available for cells *ex vivo*. The cells expressing the fusion protein (*i.e.*, the transfected cells) may then be administered to a subject to activate naïve T cells in the subject towards a peanut allergen-specific T_H1 phenotype, which can then desensitize or induce tolerance in the subject to one or more peanut allergens. Alternatively, the cells expressing the fusion protein may be cultured with lymphocytes *ex vivo* to generate peanut allergen reactive T_H1 lymphocytes, which may then be administered to the subject.

[0142] Accordingly, the present invention also provides a method of generating and/or expanding a peanut allergen reactive T_H1 lymphocyte *ex vivo*, wherein the method includes culturing a cell expressing the fusion protein with one or more T lymphocytes. The T lymphocytes may be included in a mixed lymphocyte population or may be isolated T lymphocytes. Mixed lymphocyte populations may be readily obtained from peripheral blood, lymph or bone marrow by methods known in the art. T cells may be isolated from

such mixed lymphocyte populations by methods known in the art including, for example, nylon wool isolation, FACS sorting, magnetic bead separation, *etc.* In some embodiments, particular T lymphocyte subsets may be isolated for culturing with the cell expressing the nucleic acid.

[0143] It would be understood by persons skilled in the art that, where cells are transfected *ex vivo* to express the fusion protein and/or where a population of T_H1 lymphocytes are generated and/or expanded *ex vivo*, as disclosed herein, it is often desirable to use autologous cells (*i.e.*, cells derived from the subject to be treated), thereby avoiding or minimising an immune response that may occur where allogeneic cells (*i.e.*, cells derived from a different subject) are used and administered to the subject.

[0144] *Ex vivo* expansion of peanut allergen reactive T_H1 lymphocyte may be used to generate large numbers of peanut allergen reactive T_H1 lymphocyte, which may then be administered to a subject as a prophylactic or therapeutic treatment of peanut allergy. In some instances, *ex vivo* expansion may accelerate the activation and expansion of peanut allergen reactive T_H1 lymphocytes compared with *in vivo* activation and expansion. Furthermore, *ex vivo* expansion allows control over the number and reactivity of peanut allergen reactive T_H1 lymphocytes that are expanded. In some embodiments, the peanut allergen reactive T_H1 lymphocytes may be autologous to the subject.

[0145] Accordingly, the present invention also provides a method of desensitizing a subject to a peanut allergen, the method including: (i) collecting lymphocytes from the subject; (ii) co-culturing the lymphocytes with cells expressing the fusion protein to generate and/or expand a T_H1 lymphocyte that recognizes proteasomally degraded fusion protein peptide fragments associated with MHC Class I molecules on the cells; and (iii) administering the T_H1 lymphocytes from (ii) to the subject. In some embodiments, the lymphocytes are collected from the subject before administration of the poxvirus vector as disclosed herein.

[0146] In some embodiments, the method may include isolating the lymphocytes from step (ii) prior to administration to the subject. Isolating the lymphocytes from step (ii) may include isolating all lymphocytes from the cells expressing the nucleic acid and/or may include isolating one or more lymphocyte types (*e.g.* all T cells lymphocytes, all T_H1 lymphocytes, *etc.*). Alternatively, the T_H1 lymphocytes from (ii) may be administered to the subject without isolating the lymphocytes from the cells expressing the fusion protein,

in which case the administered cells expressing the fusion protein may continue to activate further T_H1 lymphocytes *in vivo*. Methods for isolating lymphocytes from a subject, methods for isolating T cells and T cell subsets include those methods described above.

[0147] Also enabled herein are methods in which T lymphocytes are obtained, whether isolated or not, from the subject treated in accordance with the present invention, and determining whether the lymphocytes are biased towards a T_H1 phenotype, as disclosed herein (*e.g.*, determining the cytokine expression profile *ex vivo*). This approach has the added advantage of determining whether the administration of the poxvirus vector has induced a T_H1 -biased allergen-specific immune response in the subject. Thus, in some embodiments, the method includes determining whether the lymphocytes isolated from step (ii) are biased towards a T_H1 phenotype prior to their administration to the subject.

[0148] In some embodiments, desensitization or tolerance induction of a subject to a peanut allergen may prevent or reduce hypersensitivity reactions against subsequent exposure of the subject to peanuts. As such, the methods described above may reduce the risk of anaphylactic reactions to peanuts in subjects previously allergic to peanuts upon subsequent exposure of the subject to peanuts and/or reduce the risk of anaphylactic reactions to peanuts in subjects at risk of developing a peanut allergy.

[0149] The present invention is further described by the following non-limiting examples. It is to be understood that the following description is for the purpose of describing particular embodiments only and is not intended to be limiting with respect to the above description.

EXAMPLES

Materials and Methods

[0150] ***Production of a PHAV Antigen:*** A nucleic acid sequence for a fusion protein (PHAV antigen) including a human Ubiquitin C monomer (Ubc) and four peanut allergens was designed as set out below and illustrated in Figure 1A.

[0151] The amino acid sequence for Ubc (NM_021009), ara h 1 (Swiss-Prot entry P43238), ara h 2 (TrEMBL entry Q8GV20), ara h 3 (Genbank Protein ACH91862) and ara h 6 (UniProtKB/TrEMBL entry Q647G9) were obtained from online protein sequence databases. The start codon amino acid Met (M) was removed from ara h 1, ara h 2, ara h 3 and ara h 6 protein sequences before joining the sequences to form one continuous protein

sequence in the order of: Ubc + ara h1+ ara h2+ ara h3 + ara h6. The DNA sequence coding this PHAVag protein was obtained by back translation using a *Homo Sapiens* codon preferred table.

[0152] The PHAVag amino acid sequence was back translated into a nucleotide sequence using Gene Designer (DNA2.0 Inc) and employed a *Homo Sapiens* codon optimisation set at a 10% threshold. Repeat sequences of 8 bases or more were also filtered out. The resulting sequence was further screened for secondary structure formation potential and destabilising elements by DNA2.0 Inc. The final nucleotide sequence of the PHAVag protein sequence was screened for the pox virus early transcriptional motif “TTTTTNT”. However, none were found.

[0153] At the end of the nucleotide sequence coding for the PHAV antigen, a “TAA” stop codon was added. The Pox virus early transcriptional stop sequence TTTTAT was also added immediately after the stop codon. The expression cassette was flanked with Pac I linkers. As Pac I recognition sites were not present within the cassette, this cassette could be cloned into plasmids and excised whole from a plasmid by Pac I restriction endonuclease digestion.

[0154] As shown in Table 1, Ubc, ara h 1, ara h 2, ara h 3 and ara h 6 in the PHAV Antigen had around 75% nucleic acid sequence identity to the native sequences.

Table 1: Sequence comparison of PHAV Antigen components and native sequences

	Nucleotide sequence comparison		Amino acid sequence comparison	
	Number of differences to native sequence/ total length	% identity to native sequence	Number of differences to native sequence/ total length	% identity to native sequence
Ubc	53/228	76.8%	1/76	98.7%
Ara h 1	440/1875	76.5%	0/625	100%
Ara h 2	124/513	75.8%	0/171	100%
Ara h 3	405/1587	74.5%	22/529	95.8%
Ara h 6	103/435	76.3%	0/145	100%

[0155] A summary of the nucleic acid and amino sequences of the PHAV Antigen construct and components thereof is set out in Table 2.

Table 2: Sequence Summary

	Name	Sequence Type
1	Ubc	Nucleic acid
2	Ubc	Amino acid
3	ara h 1	Nucleic acid
4	ara h 1	Amino acid
5	ara h 2	Nucleic acid
6	ara h 2	Amino acid
7	ara h 3	Nucleic acid
8	ara h 3	Amino acid
9	ara h 6	Nucleic acid
10	ara h 6	Amino acid
11	PHAV Antigen	Nucleic acid
12	PHAV Antigen	Amino acid

[0156] *Production of an alternative PHAV Antigen:* A ubiquitinated peanut hypo-allergy vaccine antigen (UBc.PHAVag) was made comprising a PHAV antigen protein sequence made up of a fusion of the following protein coding sequences – ubiquitin C monomer, the peanut allergen ara h 1, peanut allergen ara h 2, peanut allergen ara h 3 and peanut allergen ara h 6.), pox virus early transcriptional stop sequence and finally another Pac 1 linker.

[0157] The ubiquitin C monomer was modified at the C-terminal to replace the terminal Gly (G) residue with Ala (A). The modified ubiquitin C targets the PHAV antigen upon synthesis to the proteasomal degradation pathway in the host cell (see Figure 9). This ensures that no intact protein is presented for antibody production and that the resulting peptide fragments are processed by the MHC class I pathway, triggering a T_H1 immune response to the PHAV antigen.

[0158] The configuration and features of the PHAV expression cassettes are shown diagrammatically in Figure 1B and include Pac I restriction endonuclease linkers at the 5' and 3' ends, as well as a vaccinia early/late promoter at the 5'end.

[0159] The amino acid sequence for UBc, ara h 1, ara h 2, ara h 3 and ara h 6 were obtained from either Swit-Prot or EMBL protein databases. The start codon encoding a Met (M) residue was removed from the ara h 1, ara h 2, ara h 3 and ara h 6 nucleic acid sequences before joining them up to form the continuous nucleic acid sequence encoding the protein sequence UBc+h1+h2+h3+h6, in that order.

[0160] The DNA sequence for coding this UBc.PHAVag was obtained by back translation using a Homo Sapiens codon preferred table. The UBc.PHAVag amino acid sequence was back translated into a nucleotide sequence using Gene Designer (DNA2.0 Inc) and employing Homo Sapiens codon optimisation set at 10% threshold and filtering out repeat sequences of 8 bases or more. The resulting sequence was further screened for secondary structure formation potential and destabilising elements by DNA2.0 Inc. The final nucleotide sequence encoding UBc.PHAVag was screened for pox virus early transcriptional motif "TTTTTNT" – none were found. At the end of the nucleotide sequence coding for UBc.PHAV, "TAA" stop codon was added. The Pox virus early transcriptional stop sequence TTTTAT was also added immediately after the stop codon. The expression cassette was flanked with Pac I linkers and because Pac I recognition sites are not present within the cassette, this cassette can be cloned into plasmids and excised whole from plasmid by Pac I restriction endonuclease digestion. The DNA sequence of the UBc.PHAV expression cassette can be found in Figure 2.

[0161] A peanut hypollergen vaccine antigen was also constructed in which the ubiquitin monomer at the 5' end was omitted. This construct was identical to the UBc.PHAVag construct, as described above, but without the ubiquitin sequence. This construct was referred to as PHAVag and a diagrammatic representation of the configuration and features of PHAVag can be found in Figure 1C and the DNA sequence found in Figure 3.

[0162] Both the UBc.PHAVag and PHAVag expression cassettes were cloned into bacterial plasmids so that these expression cassette could be retrieved after cloning by PacI/Sbf I digestion and gel purification.

[0163] Additional ubiquitinated peanut hypo-allergy vaccine antigens could be made that include the following peanut allergens:

- (i) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11;
- (ii) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9 and ara h 10;
- (iii) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8 and ara h 9;
- (iv) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7 and ara h 8;
- (v) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7;
- (vi) ara h 1, ara h 2, ara h 3, ara h 4, ara h 5 and ara h 6;
- (vii) ara h 1, ara h 2, ara h 3, ara h 4 and ara h 5;
- (viii) ara h 1, ara h 2, ara h 3 and ara h 4;
- (ix) ara h 1, ara h 2 and ara h 3;
- (x) ara h 1 and ara h 2;
- (xi) ara h 1;
- (xii) ara h 2;
- (xiii) ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10, and ara h 11;
- (xiv) ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9 and ara h 10;
- (xv) ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8 and ara h 9;
- (xvi) ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7 and ara h 8;
- (xvii) ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7;
- (xviii) ara h 2, ara h 3, ara h 4, ara h 5 and ara h 6;
- (xix) ara h 2, ara h 3, ara h 4 and ara h 5;
- (xx) ara h 2, ara h 3 and ara h 4;
- (xxi) ara h 2 and ara h 3;
- (xxii) ara h 3;
- (xxiii) ara h 1, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11;
- (xxiv) ara h 1, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9 and ara h 10;
- (xxv) ara h 1, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8 and ara h 9;
- (xxvi) ara h 1, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7 and ara h 8;
- (xxvii) ara h 1, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7;

- (xxviii) ara h 1, ara h 3, ara h 4, ara h 5 and ara h 6;
- (xxix) ara h 1, ara h 3, ara h 4 and ara h 5;
- (xxx) ara h 1, ara h 3 and ara h 4;
- (xxxi) ara h 1 and ara h 3;
- (xxxii) ara h 1, ara h 2, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11;
- (xxxiii) ara h 1, ara h 2, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9 and ara h 10;
- (xxxiv) ara h 1, ara h 2, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8 and ara h 9;
- (xxxv) ara h 1, ara h 2, ara h 4, ara h 5, ara h 6, ara h 7 and ara h 8;
- (xxxvi) ara h 1, ara h 2, ara h 4, ara h 5, ara h 6 and ara h 7;
- (xxxvii) ara h 1, ara h 2, ara h 4, ara h 5 and ara h 6;
- (xxxviii) ara h 1, ara h 3, ara h 4 and ara h 5;
- (xxxix) ara h 1, ara h 2 and ara h 4;
- (xl) ara h 1, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11;
- (xli) ara h 1, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9 and ara h 10;
- (xlii) ara h 1, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8 and ara h 9;
- (xliii) ara h 1, ara h 4, ara h 5, ara h 6, ara h 7 and ara h 8;
- (xliv) ara h 1, ara h 4, ara h 5, ara h 6 and ara h 7;
- (xlv) ara h 1, ara h 4, ara h 5 and ara h 6;
- (xlvi) ara h 1, ara h 4 and ara h 5;
- (xlvii) ara h 1 and ara h 4;
- (xlviii) ara h 4; and so on.

[0164] The amino acid sequences for ara h1, h2, h3, h4, h5, h6, h7, h8, h9, h10 and h11 are readily obtained from either Swit-Prot or EMBL protein databases. The start codon encoding a Met (M) residue and also the stop codon would be removed from the ara h nucleic acid sequences before joining them up to form a continuous nucleic acid sequence encoding a fusion protein of any two or more of the ara h proteins, and in any particular order. However, a start codon would be required at the start of the fusion protein coding sequence and stop codon to terminate expression of the encoded fusion protein.

[0165] *Construction of vaccinia virus homologous recombination plasmid:* The homologous recombination cassette consist of the following element, all of which were synthetically made by GeneArt GmbH of Life Technologies: (i) 500bp left homologous

recombination arm that flanks up-stream of the VACV-A39R ORF of the Copenhagen strain, (ii) EGFP expression cassette under the control of a vaccinia early/late promoter and terminating in the poxvirus early transcription stop sequence (TTTTTNT), (iii) Ecogpt expression cassette under the control of a vaccinia early/late promoter and terminating in the poxvirus early transcription stop sequence (TTTTTNT); (iv) the peanut hypoallergen vaccine antigen expression cassette (UBc.PHAVag or PHAVag) as described above, (v) 500bp right homologous recombination arm that flanks down-stream of the VACV-A39R ORF of the Copenhagen strain. A diagrammatic presentation of these cassettes can be found in Figure 4 and their DNA sequences can be found in Figures 6 and 7.

[0166] Both UBc.PHAV and PHAV homologous recombination cassettes were flanked with Not I restriction enzyme sites and cloned into plasmids to form clones pTC11 (UBc.PHAV) and pTC12 (PHAV). The plasmids are shown in Figure 8. As these cassettes were synthetically made, any TTTTTNT sequences occurring with the protein coding sequences of EGFP and Ecogpt were disrupted with silent mutations without affecting the encoded amino acid sequences.

[0167] *Construction of Vaccinia Virus expressing the peanut hypoallergen vaccine antigens:* The PHAV expression cassettes were inserted into the A39R ORF of vaccinia virus Copenhagen strain by homologous recombination. Figure 4 shows a map illustrating site of the insertion within the A39R ORF. Briefly, this was carried out by infecting BHK21 cells at a low multiplicity of infection (moi) of 0.01 pfu per cell for 45 minutes and then transfecting the cells with either of the Not I linearized pTC11 or pTC12 plasmid vectors. The infected/transfected cells were then harvested once the infection reach near completion. Harvested cells were then sonicated to make viral extracts and these virus extracts were subjected to one round of plaque purification under positive selection with Mycophenolic acid (MPA) in the presence of xanthine, hypoxanthine, aminopterin and thymidine. Plaque purified clones were then sequentially amplified under MPA positive selection to make a seed stock of virus. Recombinant vaccinia virus harbouring the UBc.PHAVag expression cassette was designated as SCV201C and the recombinant virus harbouring the PHAVag expression cassette was designated SCV202C.

[0168] Detailed protocols for making recombinant vaccinia virus using Ecogpt selection method can be found in *Smith 1993*. The method employed to make SCV201C and SCV202C is outlined below.

[0169] ***Homologous recombination:*** For each virus construction, three T25 flasks containing growth medium (RPMI-1640/10% FCS/2mM Glutamax/Pen-Strep) were seeded with BHK21 cells and culture until subconfluent at 37°C/5%CO₂. On the day of infection, two flasks were infected with VACV-COP at an moi 0.01 pfu/cell, where the other flask was not infected (uninfected control). After infecting flask 1 and 2 for 45 min at room temperature, the virus inoculums were removed and the monolayer of cells washed twice with PBS. After washing, 4 ml of Maintenance Medium (MM: RPMI-1640/2% FCS/2mM Glutamax/Pen-Strep) was added to each flask including Flask 3 that had also gone through the same washing step.

[0170] Transfection was carried out using Effectene Transfection reagent (Qiagen, Cat No 301425) and following the manufacturer's instructions. Briefly, 16µL of Enhancer was added to 2µg of linearized pTC11 or pTC12 in 150µL of EC buffer and left to stand for 5 minutes at room temperature after thoroughly mixing. To this 25 µl of Effectene Transfection reagent was added, thoroughly mixed and left to stand at room temperature for 10 minutes. Finally, 1 ml of MM (RPMI-1640/2% FCS/2mM Glutamax/Pen-Strep) was added mixed thoroughly mixed gently together. This transfection mix was then added to flask 1 that had previously been infected with VACV-COP.

[0171] Flask 1 (homologous recombination), Flask 2 (infection only control) and Flask 3 (uninfected control) were incubated overnight at 37°C/5%CO₂ where the following day each flask had a media change with fresh MM containing 25µg/mL mycophenolic acid (MPA), 250µg/mL xanthine and 1^x HAT (Sigma Cat# H0262-10VL) – 5mL per flask and further incubated at 37°C/5%CO₂ until gross CPE can be seen in Flask 1 only. There was little or no sign of gross CPE in Flask 2 as the MPA treatment inhibited VACV-COP spread of infection, and the monolayer looked healthy in Flask 3.

[0172] Cells in Flask 1 were harvested by scraping the cells into the culture medium, then pelleted by low speed centrifugation (500g for 5 minutes at room temperature) followed by resuspending the cell pellet in 1mL of 10 mM Tris-HCl pH8. A viral extract was prepared by multiple freeze and thaw cycles and then stored at -80°C ready for plaque purification phase. The viral constructs were designated SCV201C (UBc.PHAV insertion) and SCV202C (PHAV insertion).

[0173] **Plaque purification process:** The homologous recombination extract was serially diluted and each dilution was used to infect one row of BHK21 cells cultured in a 48 well plate in the presence of MPA. The aim was to dilute the virus down to 1 pfu infection per well and look for wells that contain only 1 fluorescent plaque after approx. 30hr of infection before harvesting.

[0174] BHK21 cells were seeded into each well of a 48-well plate and culture to 100% in growth medium (RPMI-1640/10% FBS/2mM Glutamax/pen-strep) at 37°C/5% CO₂. Thereafter the medium was replaced with MM containing 25µg/mL MPA, 250µg/mL xanthine and 1^x HAT (Sigma Cat# H0262-10VL) and incubated further overnight.

[0175] For infection, the homologous recombination extracts (SCV201C and SCV202C) were thawed and briefly sonicated to break up lumps and aggregates. Tenfold serial dilution down to 10⁻⁵ of each viral extract was performed using MM (RPMI/2% FBS/Glutamax/PenStrep) in 1mL volumes. For each dilution, one row of the 48-well plate was seeded with 100uL of diluted virus after removing the growth medium from each well and washed once with PBS. The 48-well plate was left at room temperature for 45 minute for viral adsorption to occur. After viral adsorption, the virus inoculum was carefully removed from each well where residual inoculum was removed by a washing step consisting of 500µL of PBS per well. After washing, 500µL of MM (RPMI/2% FBS/Glutamax/PenStrep) containing 25µg/mL MPA, 250µg/mL xanthine and 1^x HAT (Sigma Cat# H0262-10VL) was added to each well and then incubated at 37°C/CO₂ until fluorescent green foci of infections could be clearly seen under a fluorescent microscope.

[0176] For harvesting, only wells containing a single fluorescent foci at the highest dilution possible was selected. The medium from selected wells were carefully removed and 100µL of 10mM TrisHCl pH8 was added. The plate was freeze-thawed three times and the contents of the selected wells were recovered.

[0177] One selected clone was then further amplified by infecting 1 well of a 6-well plate containing BHK21 cells at 100% confluency that had been pretreated overnight with 25µg/mL MPA, 250µg/mL xanthine and 1^x HAT (Sigma Cat# H0262-10VL), by removing the culture medium from the well and adding 10µL of viral extract diluted to 500µL in PBS. After 45 min at room temperature 2mL of MM containing 25µg/mL MPA, 250µg/mL xanthine and 1^x HAT (Sigma Cat# H0262-10VL) was added to the well and

incubated further at 37°C/5%CO₂ for 3 days until majority of the cells fluoresced green under a fluorescent microscope. The cells within the infected well were scraped into the culture medium and then pelleted at 500g for 5 minutes. The pelleted cells were resuspended in 500µL of 10mM TrisHCl pH8 and briefly sonicated to make a viral extract.

[0178] A portion of this extract was used for further amplification by infecting five T175 flask of BHK21 under MPA selection. The infected cells were recovered and then pelleted at 500g for 5 mins. The pelleted cells for all five flasks were resuspended in 5mL of 10mM TrisHCl pH8 and briefly sonicated to make a viral extract. Insoluble material was then remove by pelleting at 500g for 5 min. The supernatant (viral extract) was then titrated in BHK21 cells using the following procedure outlined below and the presence of the inserted UBc.PHAV within the A39R ORF was confirmed by PCR analysis.

[0179] *Titration:* Titration was carried out using 24-well plate format. Plaques were clearly distinguishable as Crystal violet counter-stained holes in the monolayer (plaques), as seen by the naked eye.

[0180] For each recombinant virus to be titrated, one 24 well plate was seeded with BHK21 cells and cultured to confluency in growth medium (RPMI/10% FBS/Glutamax/Pen Strep). On the day of titration, each viral stock was thawed and sonicated to break up lumps and clumps. Each virus was serially diluted in PBS down to 10⁻⁸. The medium was removed from each well and starting from the 10⁻⁸ dilution, 500µL of each dilution was added to each well of a column in the 24 well plate (4 wells per dilution) and left to incubate at room temperature for 45mins for the virus to adsorb to the cells. After this, the virus inoculum was removed from each well, where each well was then washed once with PBS. After washing, 1mL of MM (RPMI/2% FBS/Glutamax/PenStrep) was added to each well and the plates were incubated at 37°C/5% CO₂ until plaques can be seen in the monolayers. For plaque counter staining, the medium from each well was removed and 500µL of Crystal Violet solution (0.4% w/v in 20% ethanol) was added to each well. Staining was carried out at room temperature for 15-30 min where after the Crystal Violet stain was removed from each well and each well left to air dry before counting plaques. From the dilution that gave rise to 10-30 counts per well, the mean was calculated. This value was then multiplied by the reciprocal of the serial dilution and then further multiplied by 2 (*i.e.*, 2 x 500µL = 1mL) to produce the titre in pfu/mL.

[0181] *Immunogenicity testing of SCV201C in C3H/HeJ mice:* To test the immunogenicity of SCV201C and determine if the ubiquitinated PHAV antigen can induce a peanut protein specific T_H1 immune response 3 groups of C3H/HeJ mice (5 mice per group) were vaccinated with the following: (i) 10⁶pfu of SCV201C administered intraperitoneally (IP), (ii) 10⁶pfu of SCV000 administered intraperitoneally (IP), and (iii) PBS administered intraperitoneally (IP). Blood samples were taken just prior to vaccination (prebleed) and 17 days after vaccination. Spleens for cytokine profiling were harvested 9 weeks after vaccination.

[0182] *Preparation of soluble peanut protein extract:* The method used to extract soluble peanut protein from roasted unsalted peanuts was derived from the procedures described by Sachs et al. (1981) and Burks et al. (1992). Roasted unsalted peanuts were purchased from a local grocery store. The nuts were then pulverized in a blender to a meal and then to a butter paste. Lipids/fats were removed from the peanut butter by the addition of de-fatting reagent hexane. To do this, n-hexane was added to the peanut butter and shaken vigorously to mix. The mixture was transferred to a glass beaker and left to settle into solvent and solid phases. The solvent phase (which contains the extracted lipids/fats) was removed from the solid phase. The solid phase was air dried into a cake. This cake was dissolved in 0.1M NH₄HCO₃ (2mL per gram) at 4°C for 36 hours with stirring to extract soluble proteins. The slurry was centrifuged for 15 min at 10,000g to remove solids. The supernatant was dialyzed against 5mM phosphate buffer (pH7 to pH8) or PBS using 3500 MWCO membrane/tubing. The dialyzed solution was centrifuged at 10,000g for 15min at 4°C to clarify the extract. Total protein concentration in the soluble extract was measured using standard techniques. The resulting soluble protein extract (10mg/ml) was kept at -20°C for storage, and thawed prior to use.

[0183] *Quantification of peanut-specific serum IgE and IgG2a:* Flat-bottom 96-well EIA/RIA ELISA plates (Costar) were coated with 2µg/well purified peanut extract in PBS and incubated at 37°C for 1hr then overnight at 4°C. Plates were washed with 200µl/well PBS three times before blocking with 5% skim milk with PBS and 0.05% Tween (SM+PBS+TW). Non-specific binding was blocked at 37°C for at least one hour before three 200µl/well washes with PBS with 0.05% Tween (PBS+TW). After washing, serum samples were first diluted 1:100 for IgE assays, or 1:500 for IgG1 and IgG2a assays, in SM+PBS+TW. Serum samples were serially diluted across three columns. Various wells

were left without serum as background controls. The plates were incubated at 37°C for one hour.

[0184] Plates were washed five times with 200µl of PBS and secondary antibody (1:500 Goat antimouse IgE HRP conjugate, Alpha Diagnostic; 1:1000 HRP rat anti-mouse IgG2a, BD Biosciences- BD Pharmingen) diluted in SM+PBS+TW was added (100µl/well). The plates were incubated for one hour and then washed five times as above, and 100µl/well of o-Phenylenediaminedihydrochloride (OPD) substrate solution prepared according to manufacturer's directions (SigmaFAST™ OPD, Sigma-Aldrich) was added. Reactions were stopped with 20µl/well 1M HCl when colour had begun to develop in 'blank' wells (ranging from five minutes in IgG1 and IgG2a assays to 45 minutes for IgE assay). Optical densities were measured at 450nm on a plate reader (EL808 Ultra Microplate Reader, Bio-tek Instruments Inc).

[0185] Optical densities for serial dilutions from each respective time point were plotted against dilution factor on a logarithmic scale using GraphPadPrism V5.01 (GraphPad Software, San Diego, CA, USA). The endpoint titre for each time point was determined as the dilution value at which the curve intercepted the calculated cut-off optical density (minimum of three times standard error mean (SEM) of pre-bleed samples but greater than the highest optical density value measured for all pre-bleed samples).

[0186] *Statistical Analyses:* Statistical comparisons were performed using GraphPad Prism V5.01 (GraphPad Software, San Diego, CA, USA). Two-way analysis of variance (ANOVA) with Bonferroni post-testing was used to deduce significant differences among the ELISA results.

Example 1: Ubiquitination of PHAV antigen enabled the successful expression of SCV201C but not SCV202C

[0187] The expression of SCV201C following insertion of the UBc.PHAVag expression cassette into the A39R of vaccinia virus was successful. After homologous recombination and during the plaque purification step, MPA resistant plaques could be clearly identify and amplified in the presence of MPA to produce a seed stock that gave sufficient titres to proceed to the next step of immunogenicity testing in mice.

[0188] By contrast, the expression of SCV202C was difficult to progress beyond the plaque purification step, as no clearly discernable plaques could be found at the high dilution range. Fluorescent infected cells could be detected at the low dilution range and at these dilution only 100% CPE was seen in the infected wells as opposed to discernable plaques. When these wells were harvested and subjected to further amplification in the presence of MPA, very little virus titre was obtained most of which consisted of parental virus as determined by PCR analysis and plaque assays showing the lack of fluorescent plaque in the absence of MPA.

[0189] The expression of PHAVag following infection had an inhibitory or toxic effect on virus propagation, which was overcome with the SCV201C construct. Without being bound by theory or by a particular mode of application, it is postulated that the inhibitory or toxic effect of the synthesized PHAVag was overcome by the use of a proteasome degradation tag such as ubiquitin to target the expressed PHAVag to proteasomal degradation.

[0190] This inhibitory effect of viral propagation by expressing the intact PHAVag was further confirmed because the construction a recombinant vaccinia containing only the Ecogpt and EFGP expression cassettes inserted into the A39R ORF was easily achievable (designated as SCV000).

Example 2: Antigen-specific antibody responses following vaccination

[0191] The results are present in Figure 10 for both peanut protein-specific serum IgE (Figure 10A) and IgG2a (Figure 10B) antibody level before and after vaccination (17 day post vaccination). It can be clearly seen that vaccination with SCV201C produced significant levels of peanut protein-specific IgG2a after 17 day post vaccination. These level were significantly higher than the vector only control (SCV000) and PBS control, demonstrating SCV201C produces a specific anti-peanut protein antibody response. It is to be noted that SCV201C produced a much smaller IgE response as compared to an IgG2a response; that is, an endpoint dilution of 1:2,500 for IgE as compared to an endpoint dilution approaching 1: 1,000,000 for IgG2a. Moreover, the IgE response was not much more above the responses induced by the empty vector (SCV000) or PBS controls.

[0192] These results show that SCV201C produces an IgG2a response to peanut proteins, but very little IgE response, indicating that SCV201C had initiated a peanut-specific T_H1 biased immune response in response to PHAVag.

Example 3: Lymphocyte cytokine profile following SCV201C vaccination in mice

[0193] Spleens were harvested from mice and stored in complete RPMI before being transferred to a 60mm tissue culture dish. Spleens were then cut into three sections and disaggregated into single-cell suspension. The cells were then filtered and washed with 5% RPMI (300g x 5 minutes). Red blood cells were then lysed in 5ml of alkaline lysis buffer for 5 minutes, then diluted to 20ml with 5% RPMI and centrifuged at 200g for 5 minutes. Cells were then resuspended and counted. Meanwhile, 96-well plates with control RPMI, soluble peanut-antigen (100 μ g/ml), and ConA (5 μ g/ml) wells were prepared. Lymphocytes were then add at 400,000 cells/well and incubated at 37C for 96 hours.

[0194] After the 96 hour incubation period, 100 μ l of supernatant from each was collected and frozen at -80°C. T_H1 / T_H2 cytokines were then quantified by flow cytometry according to the manufacturer's instructions (BD Biosciences # 551287). The samples were then run on a BD FACSCanto II flow cytometer. Cytokine concentrations were determined using Soft Flow FCAP Array software. All further analysis was done in Graph Pad 6.0.

[0195] The results presented in Figure 11 clearly show that vaccination with SCV201C produces a biased T_H1 immune response to peanut protein exposure. This is illustrated by the significantly higher level of IFN-gamma (IFN-g; a T_H1 cytokine; Figure 11A) as compared to levels of IL4 and IL5 (T_H2 cytokines; Figures 11B and 11C) secreted by cultured lymphocytes obtained from the spleens of the SCV201C vaccinate mice.

Conclusion

[0196] Vaccination of mice with SCV201C produced a biased anti-peanut protein T_H1 immune response. An allergen-specific T_H1 immune response will dominate over an existing allergen-specific T_H2 immune response and, in doing so, will desensitize an individual to subsequent exposure to the allergen. The studies disclosed herein show that ubiquitinated peanut hypoallergen vaccine antigen (UBc.PHAVag) stimulates an anti-peanut protein-specific T_H1 immune response. Thus, vaccines containing the ubiquitinated

hypoallergen vaccine antigen as herein described can be used to desensitize individuals to peanut allergens and can therefore be used to treat and/or prevent allergic reactions in individuals that are triggered by exposure to peanut allergens.

[0197] As noted above, the expression of the SCV201C construct was successful following infection, whereas the expression of the non-ubiquitinated SCV202C construct was difficult to progress beyond the plaque purification step. The expression of PHAVag following infection therefore appears to have an inhibitory or toxic effect on virus propagation, which was overcome with the ubiquitinated SCV201C construct. Without being bound by theory or by a particular mode of application, it is postulated that the inhibitory or toxic effect of the synthesized PHAVag was overcome by the use of ubiquitin, targeting the expressed PHAVag to proteasomal degradation. As a result of ubiquitin-targeted proteasomal degradation of PHAVag, the small peptide fragments of PHAVag enter the endoplasmic reticulum (ER) where they are complexed with MHC class I proteins and then transported to the cell surface to be presented to T lymphocytes (see, for example, Figure 9). The consequence of this is that there is enhanced presentation of the PHAVag fragments with MHC class I, resulting in a greater T_H1 immune response to peanut allergens. Thus, the proteasome degradation tag (*e.g.*, ubiquitin) unexpectedly prevents the artificial, intact PHAVag fusion protein from inhibiting virus replication.

[0198] Ara h 1, ara h 2, ara h 3 are the three major peanut allergens that have been shown to cause peanut-specific allergic reactions in susceptible individuals. Ara h 6 has been implicated in childhood susceptibility to peanut allergy (Flinterman *et al.* 2007). Ara h 7 is recognised in 43% peanut allergic individuals, ara h 8 is recognised in 85% peanut allergic individuals, ara h 4 is recognised in 54% peanut allergic individuals and ara h 5 is recognised in 13% peanut allergic individuals.

[0199] The disclosure of every patent, patent application, and publication cited herein is hereby incorporated herein by reference in its entirety.

[0200] Many modifications will be apparent to those skilled in the art without departing from the scope of the present invention.

BIBLIOGRAPHY

- Burks WA, Williams LW, Connaughton C, Cockrell G, O'Brien TJ, Helm RM., 1992. Identification and characterization of a second major peanut allergen, Ara h II, with use of the sera of patients with atopic dermatitis and positive peanut challenge. *J. Allergy Clin. Immunol.*, 90: 962-969.
- DeLong JH, Simpson KH, Wambre E, James EA, Robinson D, Kwok WW. 2011. Ara h 1-reactive T cells in individuals with peanut allergy. *J. Allergy Clin. Immunol.* 127 (5): 1211-1218.e3.
- Dudek T, Knipe DM. 2006. Replication-defective viruses as vaccines and vaccine vectors. *Virology* 344 (1): 230-239.
- Flinterman AE, van Hoffen E, den Hartog Jager CF, Koppelman S, Pasmans SG, Hoekstra MO, Bruijnzeel-Koomen CA, Knulst AC, Knol EF. 2007. Children with peanut allergy recognize predominantly Ara h2 and Ara h6, which remains stable over time. *Clin Exp Allergy*. 37(8):1221-8.
- Heath WR, Carbone FR. 1999. Cytotoxic T lymphocyte activation by cross-priming. *Curr. Opin. Immunol.* 11 (3): 314-318.
- Hartl A, Kiesslich J, Weiss R, Bernhaupt A, Mostböck S, Scheiblhofer S, Ebner C, Ferreira F, Thalhamer J. 1999. Immune responses after immunization with plasmid DNA encoding Bet v 1, the major allergen of birch pollen. *J. Allergy Clin. Immunol.* 103: 107-13.
- Hartl A, Hochreiter R, Stepanoska T, Ferreira F, Thalhamer J. 2004. Characterization of the protective and therapeutic efficiency of a DNA vaccine encoding the major birch pollen allergen Bet v 1a. *Allergy* 59: 65-73.
- Holgate ST. 1999. The epidemic of allergy and asthma. *Nature* 402 (6760 Suppl), B2-B4
- Hsu CH, Chua KY, Tao MH, Lai YL, Wu HD, Huang SK, Hsieh KH. 1996. Immunoprophylaxis of allergen-induced immunoglobulin E synthesis and airway hyperresponsiveness in vivo by genetic immunization. *Nat. Med.* 2 (5): 540-544.
- Jilek S, Barbey C, Spertini F, Cortes B. 2001. Antigen-independent suppression of the allergic immune response to bee venom phospholipase A(2) by DNA vaccination in CBA/J mice. *J. Immunol.* 166: 3612-21.

- Kumaraguru U, Rouse RJ, Nair SK, Bruce BD, Rouse BT. 2000. Involvement of an ATP-dependent peptide chaperone in cross-presentation after DNA immunization. *J. Immunol.* 165 (2): 750-759.
- Leitner WW, Hammerl P, Thalhamer J. 2001. Nucleic acid for treatment of cancer: genetic vaccines and DNA adjuvants. *Curr. Pharm. Des.* 7(16): 1641-1667.
- Long A. 2002. The nuts and bolts of peanut allergy. *N. Engl. J. Med.* 346 (17): 1320-1322.
- Lu Z, Yuan L, Zhou X, SotE, Levitsky HI, Pardoll DM. 2000. CD40-independent pathways of T cell help for priming of CD8(+) cytotoxic T lymphocytes. *J. Exp. Med.* 191 (3): 541-550.
- Mosmann TR, Coffman RL. 1989. TH1 and TH2 cells: different patterns of lymphokine secretion lead to different functional properties. *Annu. Rev. Immunol.* 7: 145-173.
- Oppenheimer JJ, Nelson HS, Bock SA, Christenson F, Leung DY. 1992. Treatment of peanut allergy with rush immunotherapy. *J. Allergy Clin. Immunol.* 90 (2): 256-262.
- Parronchi P, Maggi E, Romagnani S. 1999. Redirecting Th2 responses in allergy. *Curr. Top. Microbiol. Immunol.* 238: 27-56.
- Polo JM, Dubensky TW Jr. 2002. Virus-based vectors for human vaccine applications. *Drug Discov. Today* 7 (13): 719-727.
- Raz E, Tighe H, Sato Y, Corr M, Dudler JA, Roman M, Swain SL, Spiegelberg HL, Carson DA. 1996. Preferential induction of a Th1 immune response and inhibition of specific IgE antibody formation by plasmid DNA immunization. *Proc. Natl. Acad. Sci. USA.* 93 (10): 5141-5145.
- Ridge JP, Di Rosa F, Matzinger P. 1998. A conditioned dendritic cell can be a temporal bridge between a CD4+ T-helper and a T-killer cell. *Nature* 393 (6684): 474-478.
- Rocha CD, Caetano BC, Machado AV, Bruna-Romero O. 2004. Recombinant viruses as tools to induce protective cellular immunity against infectious diseases. *Int. Microbiol.* 7 (2): 83-94.
- Roy K, Mao HQ, Huang SK, Leong KW. 1999. Oral gene delivery with chitosan-DNA nanoparticles generates immunologic protection in a murine model of peanut allergy. *Nat. Med.* 1999; 5: 387-91.

- Sachs MI, Jones RT, Yunginger JW. 1981. Isolation and partial characterization of a major peanut allergen. *J. Allergy Clin. Immunol.*, 67: 27-34.
- Sanderson IR, Walker WA. 1993. Uptake and transport of macromolecules by the intestine: possible role in clinical disorders (an update). *Gastroenterology* 104 (2): 622-639.
- Shaheen SO, Aaby P, Hall AJ, Barker DJ, Heyes CB, Shiell AW, Goudiaby A. 1996. Measles and atopy in Guinea-Bissau. *Lancet* 347 (9018): 1792-1796.
- Sicherer SH, and Leung DY. 2010. Advances in allergic skin disease, anaphylaxis, and hypersensitivity reactions to foods, drugs, and insects in 2009. *J. Allergy Clin. Immunol.* 125 (1), 85-97.
- Singh VK, Mehrotra S, Agarwal SS. 1999. The paradigm of Th1 and Th2 cytokines: its relevance to autoimmunity and allergy. *Immunol. Res.* 20 (2): 147-161.
- Slater JE, Colberg-Poley A. 1997. A DNA vaccine for allergen immunotherapy using the latexallergen Hev b 5. *Arb. Paul Ehrlich Int. Bundesamt Sera ImpfstoffeFrankf. A. M.* 91: 230-235.
- Smith GL. 1993. Expression of genes by vaccinia virus vectors. In *Molecular Virology: A practical approach*. Edited by AJ Dawson and RM Elliott. IRL Press at Oxford University Press, Oxford UK.
- Spiegelberg HL, Orozco EM, Roman M, Raz E. 1997. DNA immunization: a novel approach to allergen-specific immunotherapy. *Allergy* 52 (10): 964-970.
- Srivastava KD, Qu C, Zhang T, Goldfarb J, Sampson HA, Li XM. 2009. Food allergy herbal formula-2 silences peanut-induced anaphylaxis for a prolonged posttreatment period via IFN-gamma-producing CD8⁺ T cells. *J. Allergy Clin. Immunol.* 123 (2), 443-451.
- Toda M, Sato H, Takebe Y, Taniguchi Y, Saito S, Inouye S, Takemori T, Sakaguchi M. 2000. Inhibition of immunoglobulin E response to Japanese cedar pollen allergen (Cry j 1) in mice by DNA immunization: Different outcomes dependent on the plasmid DNA inoculation method. *Immunology* 99: 179-86.
- Turcanu V, Stephens AC, Chan SM, Rance F, Lack G. 2010. IgE-mediated facilitated antigen presentation underlies higher immune responses in peanut allergy. *Allergy* 65 (10), 1274-1281.

deVries JE, Carballido JM, Aversa G. 1999. Receptors and cytokines involved in allergic TH2 cell responses. *J. Allergy Clin. Immunol.* 103 (5 Pt 2), S492-S496.

CLAIMS:

1. A poxvirus vector comprising a nucleic acid sequence encoding a fusion protein comprising (i) at least two peanut allergens selected from the group consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.
2. The poxvirus vector of claim 1, wherein the nucleic acid sequence encodes a fusion protein comprising: (i) at least two peanut allergens selected from list consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7, and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.
3. The poxvirus vector of claim 1, wherein the nucleic acid sequence encodes a fusion protein comprising: (i) at least three peanut allergens selected from the group consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6, ara h 7, ara h 8, ara h 9, ara h 10 and ara h 11 and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.
4. The poxvirus vector of claim 3, wherein the nucleic acid sequence encodes a fusion protein comprising: (i) at least three peanut allergens selected from the group consisting of ara h 1, ara h 2, ara h 3, ara h 4, ara h 5, ara h 6 and ara h 7, and a derivative or part thereof having at least 70% sequence identity thereto, and (ii) a proteasome degradation tag to enhance intracellular degradation of the fusion protein.
5. The poxvirus vector of any one of claims 1 to 4, wherein the vector comprises a promoter and single start codon to facilitate expression of the intact fusion protein.
6. The poxvirus vector of any one of claims 1 to 5, wherein the proteasome degradation tag comprises a ubiquitin monomer.
7. The poxvirus vector of any one of claim 1 to 6, wherein the nucleic acid sequence encodes a fusion protein comprising four peanut allergens which are ara h 1, ara h 2, ara h 3, and ara h 6, or a derivative or part thereof having at least 70% sequence identity thereto.
8. The poxvirus vector of any one of claims 1 to 7, wherein the fusion protein comprises an amino acid sequence set out in SEQ ID NO: 12 or a derivative or part thereof

having at least 70% sequence identity thereto.

9. The poxvirus vector of any one of claims 1 to 7, wherein the poxvirus vector comprises the nucleic acid sequence set out in one of SEQ ID NO: 11 or a derivative or part thereof having at least 70% sequence identity thereto.

10. The poxvirus vector of any one of claims 1 to 7, wherein the ubiquitin monomer comprises a nucleotide sequence set out in one of SEQ ID NO: 1 or a derivative thereof having at least 70% nucleotide sequence identity thereto.

11. The poxvirus vector of any one of claims 1 to 7, wherein the proteasome degradation tag comprises ubiquitin C.

12. The poxvirus vector of any one of claims 1 to 12, wherein the nucleic acid sequence encodes a fusion protein comprising peanut allergens ara h 1, ara h 2, ara h 3 and ara h 6.

13. The poxvirus vector of any one of claims 1 to 12, wherein the poxvirus vector is a vaccinia vector.

14. The poxvirus vector of claim 13, wherein the poxvirus vector is a modified vaccinia vector or an avipox vector.

15. The poxvirus vector of any one of claims 1 to 14, comprising a pharmaceutically or physiologically acceptable carrier and/or diluent.

16. The poxvirus vector of any one of claims 1 to 15, for use in the treatment of a peanut allergy in a subject.

17. Use of a poxvirus vector of any one of claims 1 to 14 in the manufacture of a medicament for the treatment of peanut allergy.

18. The use of claim 17, for inducing tolerance against at least two or at least three major peanut allergens.

19. A kit comprising the poxvirus vector of any one of claim 1 to 15.

20. The poxvirus vector of any one of claims 1 to 15, for use in a human subject.

21. The poxvirus vector of claim 20, wherein the nucleic acid sequence encoding the fusion protein is codon optimized for expression in human cells.