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[54] **NUCLEIC ACID VACCINES AGAINST RICKETTSIAL DISEASES AND METHODS OF USE**

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[52] U.S. Cl. **514/44**; 536/23.1; 435/320.1

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[57] **ABSTRACT**

Described are nucleic acid vaccines containing MAP1-related genes to protect animals or humans against rickettsial diseases.

3 Claims, 3 Drawing Sheets

FIG. 1A

C.r. ATGAATTGCAAGAAAATTTTFTA-----TCACAAGTACACTAATATCATTAGTG
E.c. ATGAATTACAAAAAAGTTTCA-----TAACAGCG-ATTGATATCATTAATA
A.m. ATGAATTACAGAGAATTGTTTACAGGGGGCCTG-TCAGCAGCC-ACAGTCTGCGCCTGCT
 ***** ** ** ** * * ** *

C.r. TCATTTT--TACCTGGTGTGTCCTTTTCTGATGTAATACAGGAAGACAGCAACCCAGCAG
E.c. TCCTTCTCTTACCTGGAGTATCATTTTCCGACCCAAGGCAGGTAGTGGTCA---TTAACG
A.m. CCCTACTTGTTAGTGGGGCCGTAGTGGCATCTCCCATGAGTCACGAAGTGGCTTCTGAAG
 * * * * *** * * * * *

C.r. GCAGTGTTTACATTAGCGCAAAATACATGCCAACTGCATCACATTTTGGTAAAATGTCAA
E.c. GTAATTTCTACATCAGTGGAAAAACGATGCCAAGGCTTCGCATTTTGGAGTATTCTCTG
A.m. GGGGAGTAATGGGAGGTAGCTTTTACGTGGGTGCGGCCT-ACAGCCAGCATTTCTTTCT
 * * * * *** * * * * *

C.r. TCAAAGAAGATTCAAAAAATACTCAAACGGTATTTGGTCTAAAAAAGATTGGGATGGCG
E.c. CTAAGGAAGAAAGAAATACAACAGTTGGAGTGTGGACTGAAGCAAAATTTGGGACGGAA
A.m. GTTACCTCGTTCGACATGCGTGAGTCAAGCAAAGAGACCTCA--TACGTTAGAGGCTATG
 * * * * * ** * * * *

C.r. TTAAAACACCATCAGATTCTAGCAATACTAATTCTACAATTTTACTGAAAAGACTATT
E.c. GCGCAATATC--CAACTCCTCCCCAAACGA-----TGTATTCAGTGTCTCAAATTATT
A.m. ACAAGAGCATTGCAACGATTGATGTGAGTGTGCCAGCAAACCTTTCCAAATCTGGCTACA
 * ** * * * ** *

C.r. CTTTCAGATATGAAAACAATCCGTTTTTLAGGTTTTCGCTGGAGCAATTGGGTACTCAATGA
E.c. CATTAAATATGAAAACAACCCGTTTTTLAGGTTTTGCAGGAGCTATTGGTTACTCAATGG
A.m. CTTTTGCCTTCTCTAAAAACTTAATCACGTCTTTCGACGGCGCTGTGGGATATTCTCTGG
 * ** * ** ** * *** * ** * * ** *

FIG. 1C

C.r. GTGGACATTTCCATAGAGTTATAGGTAATGAATTTAAAGATATTGCTACCTTAAAAATAT
E.c. GTGGGCACTTTCATAAGGTAATAGGGAACGAATTTAGAGATATTCCTACTATAATACCTA
A.m. GTGGGTTCTACCACGGGCTATTTGATGAGTCTTACAAGGACATTCCCGCACACAACAGTG
 ***** * ** * * * * * * * ** *** * *

C.r. TTACTTCAAAAACAGGAATATCTAATCCTGGCTTTGCATCAGCAACACTTGATGTTTGTC
E.c. CTGGATCAACACTTGCAGGAAAAGGAAACTACCTGCAATAGTAATACTGGATGTATGCC
A.m. TAAAGTTCTCTGGAGAAGCAAAA-----GCCTCAGTCAAAGCGCATATTGCTG
 * * * * * ** ** * * ** *

C.r. ACTTTGGTATAGAAATTGGAGGAAGGTTTGTATTTTAA---
E.c. ACTTTGGAATAGAAATGGGAGGAAGGTTTAA-----
A.m. ACTACGGCTTTAACCTTGGAGCAAGATTCCTGTTTCAGCTAA
 *** ** * * * ***** ** *

NUCLEIC ACID VACCINES AGAINST RICKETTSIAL DISEASES AND METHODS OF USE

This invention was made with government support under USAID Grant No. LAG-1328-G-00-3030-00. The government has certain rights in this invention.

DESCRIPTION

TECHNICAL FIELD

This invention relates to nucleic acid vaccines for rickettsial diseases of animals, including humans.

BACKGROUND OF THE INVENTION

The rickettsias are a group of small bacteria commonly transmitted by arthropod vectors to man and animals, in which they may cause serious disease. The pathogens causing human rickettsial diseases include the agent of epidemic typhus, *Rickettsia prowazekii*, which has resulted in the deaths of millions of people during wartime and natural disasters. The causative agents of spotted fever, e.g., *Rickettsia rickettsii* and *Rickettsia conorii*, are also included within this group. Recently, new types of human rickettsial disease caused by members of the tribe Ehrlichiae have been described. Over 400 cases of human ehrlichiosis, including some fatalities, caused by *Ehrlichia chaffeensis* have now been reported. Clinical signs of human ehrlichiosis are similar to those of Rocky Mountain spotted fever, including fever, nausea, vomiting, headache, and rash.

Heartwater is another infectious disease caused by a rickettsial pathogen, namely *Cowdria ruminantium*, and is transmitted by ticks of the genus *Amblyomma*. The disease occurs throughout most of Africa and has an estimated endemic area of about 5 million square miles. In endemic areas, heartwater is a latent infection in indigenous breeds of cattle that have been subjected to centuries of natural selection. The problems occur where the disease contacts susceptible or naive cattle and other ruminants. Heartwater has been confirmed to be on the island of Guadeloupe in the Caribbean and is spreading through the Caribbean Islands. The tick vectors responsible for spreading this disease are already present on the American mainland and threaten the livestock industry in North and South America.

In acute cases of heartwater, animals exhibit a sudden rise in temperature, signs of anorexia, cessation of rumination, and nervous symptoms including staggering, muscle twitching, and convulsions. Death usually occurs during these convulsions. Peracute cases of the disease occur where the animal collapses and dies in convulsions having shown no preliminary symptoms. Mortality is high in susceptible animals. Angora sheep infected with the disease have a 90% mortality rate while susceptible cattle strains have up to a 60% mortality rate.

If detected early, tetracycline or chloramphenicol treatment are effective against rickettsial infections, but symptoms are similar to numerous other infections and there are no satisfactory diagnostic tests (Helmick, C., K. Bernard, L. D'Angelo [1984] *J. Infect. Dis.* 150:480).

Animals which have recovered from heartwater are resistant to further homologous, and in some cases heterologous, strain challenge. It has similarly been found that persons recovering from a rickettsial infection may develop a solid and lasting immunity. Individuals recovered from natural infections are often immune to multiple isolates and even species. For example, guinea pigs immunized with a recom-

binant *R. conorii* protein were partially protected even against *R. rickettsii* (Vishwanath, S., G. McDonald, N. Watkins [1990] *Infect. Immun.* 58:646). It is known that there is structural variation in rickettsial antigens between different geographical isolates. Thus, a functional recombinant vaccine against multiple isolates would need to contain multiple epitopes, e.g., protective T and B cell epitopes, shared between isolates. It is believed that serum antibodies do not play a significant role in the mechanism of immunity against rickettsia (Uilenberg, G. [1983] *Advances in Vet. Sci. and Comp. Med.* 27:427-480; Du Plessis, Plessis, J. L. [1970] *Onderstepoort J. Vet. Res.* 37(3):147-150).

Vaccines based on inactivated or attenuated rickettsiae have been developed against certain rickettsial diseases, for example against *R. prowazekii* and *R. rickettsii*. However, these vaccines have major problems or disadvantages, including undesirable toxic reactions, difficulty in standardization, and expense (Woodward, T. [1981] "Rickettsial diseases: certain unsettled problems in their historical perspective," In *Rickettsia and Rickettsial Diseases*, W. Burgdorfer and R. Anacker, eds., Academic Press, New York, pp. 17-40).

A vaccine currently used in the control of heartwater is composed of live infected sheep blood. This vaccine also has several disadvantages. First, expertise is required for the intravenous inoculation techniques required to administer this vaccine. Second, vaccinated animals may experience shock and so require daily monitoring for a period after vaccination. There is a possibility of death due to shock throughout this monitoring period, and the drugs needed to treat any shock induced by vaccination are costly. Third, blood-borne parasites may be present in the blood vaccine and be transmitted to the vaccinees. Finally, the blood vaccine requires a cold chain to preserve the vaccine.

Clearly, a safer, more effective vaccine that is easily administered would be particularly advantageous. For these reasons, and with the advent of new methods in biotechnology, investigators have concentrated recently on the development of new types of vaccines, including recombinant vaccines. However, recombinant vaccine antigens must be carefully selected and presented to the immune system such that shared epitopes are recognized. These factors have contributed to the search for effective vaccines.

A protective vaccine against rickettsiae that elicits a complete immune response can be advantageous. A few antigens which potentially can be useful as vaccines have now been identified and sequenced for various pathogenic rickettsia. The genes encoding the antigens and that can be employed to recombinantly produce those antigen have also been identified and sequenced. Certain protective antigens identified for *R. rickettsii*, *R. conorii*, and *R. prowazekii* (e.g. rOmpA and rOmpB) are large (>100 kDa), dependent on retention of native conformation for protective efficacy, but are often degraded when produced in recombinant systems. This presents technical and quality-control problems if purified recombinant proteins are to be included in a vaccine. The mode of presentation of a recombinant antigen to the immune system can also be an important factor in the immune response.

Nucleic acid vaccination has been shown to induce protective immune responses in non-viral systems and in diverse animal species (Special Conference Issue, WHO meeting on nucleic acid vaccines [1994] *Vaccine* 12:1491). Nucleic acid vaccination has induced cytotoxic lymphocyte (CTL), T-helper 1, and antibody responses, and has been shown to be protective against disease (Ulmer, J., J. Donnelly,

S. Parker et al. [1993] *Science* 259:1745). For example, direct intramuscular injection of mice with DNA encoding the influenza nucleoprotein caused the production of high titer antibodies, nucleoprotein-specific CTLs, and protection against viral challenge. Immunization of mice with plasmid DNA encoding the *Plasmodium yoelii* circumsporozoite protein induced high antibody titers against malaria sporozoites and CTLs, and protection against challenge infection (Sedegah, M., R. Hedstrom, P. Hobart, S. Hoffman [1994] *Proc. Natl. Acad. Sci. USA* 91:9866). Cattle immunized with plasmids encoding bovine herpesvirus 1 (BHV-1) glycoprotein IV developed neutralizing antibody and were partially protected (Cox, G., T. Zamb, L. Babiuk [1993] *J. Virol* 67:5664). However, it has been a question in the field of immunization whether the recently discovered technology of nucleic acid vaccines can provide improved protection against an antigenic drift variant. Moreover, it has not heretofore been recognized or suggested that nucleic acid vaccines may be successful to protect against rickettsial disease or that a major surface protein conserved in rickettsia was protective against disease.

BRIEF SUMMARY OF THE INVENTION

Disclosed and claimed here is a novel vaccine for conferring immunity to rickettsia infection, including *Cowdria ruminantium* causing heartwater. Also disclosed are novel nucleic acid compositions and methods of using those compositions, including to confer immunity in a susceptible host.

The subject invention concerns a nucleic acid, e.g., DNA or mRNA, vaccine containing the major antigenic protein 1 gene (MAP 1) of rickettsial pathogens driven by the human cytomegalovirus (HCMV) enhancer-promoter. In studies immunizing mice by intramuscular injection of a DNA vaccine composition according to the subject invention, up to 75% of the immunized mice seroconverted and reacted with MAP1 in antigen blots. Splenocytes from immunized mice, but not from control mice immunized with vector only, proliferated in response to recombinant MAP1 and rickettsial antigens in in vitro lymphocyte proliferation tests. In experiments testing different DNA vaccine dose regimens, increased survival rates as compared to controls were observed on challenge with rickettsia. Accordingly, the subject invention concerns the discovery that the gene encoding the MAP1 protein can induce protective immunity as a nucleic acid vaccine against rickettsial disease or death resulting therefrom.

BRIEF DESCRIPTION OF THE DRAWING

FIGS. 1A–1C show a comparison of the amino acid sequences from alignment of the three rickettsial proteins, namely, *Cowdria ruminantium* (Cr.), *Ehrlichia chaffeensis* (E.c.), and *Anaplasma marginale* (A.m.). (SEQ ID NOS: 1, 3, and 5.)

BRIEF DESCRIPTION OF THE SEQUENCES

SEQ ID NO. 1 is the coding sequence of the MAP1 gene from *Cowdria ruminantium* (Highway isolate).

SEQ ID NO. 2 is the polypeptide encoded by the polynucleotide of SEQ ID NO. 1.

SEQ ID NO. 3 is the coding sequence of the MAP1 gene from *Ehrlichia chaffeensis*.

SEQ ID NO. 4 is the polypeptide encoded by the polynucleotide of SEQ ID NO. 3.

SEQ ID NO. 5 is the *Anaplasma marginale* MSP4 gene coding sequence.

SEQ ID NO. 6 is the polypeptide encoded by the polynucleotide of SEQ ID NO. 5.

DETAILED DISCLOSURE OF THE INVENTION

The subject invention concerns a novel strategy, termed nucleic acid vaccination, for eliciting an immune response protective against rickettsial disease. The subject invention also concerns novel compositions that can be employed according to this novel strategy for eliciting a protective immune response. According to the subject invention, recombinant plasmid DNA or mRNA encoding an antigen of interest is inoculated directly into the human or animal host where the antigen is expressed and an immune response induced. Advantageously, problems of protein purification, as can be encountered with antigen delivery using live vectors, can be virtually eliminated by employing the compositions or methods according to the subject invention. Unlike live vector delivery, the subject invention can provide a further advantage in that the DNA or RNA does not replicate in the host, but remains episomal with gene expression directed for as long as 19 months post-injection (Wolff, J. A., J. J. Ludike, G. Acsadi, P. Williams, A. Jani [1992] *Hum. Mol. Genet.* 1:363). A complete immune response can be obtained as recombinant antigen is synthesized intracellularly and presented to the host immune system in the context of autologous class I and class II MHC molecules.

As described, the subject invention concerns nucleic acids and compositions comprising those nucleic acids that can be effective in protecting an animal from disease or death caused by rickettsia. For example, a nucleic acid vaccine of the subject invention has been shown to be protective against *Cowdria ruminantium*, the causative agent of heartwater in domestic ruminants. Accordingly, DNA sequences of rickettsial genes, e.g., MAP1 or homologues thereof, can be useful as nucleic acid vaccines against human and animal rickettsial diseases. The MAP1 gene used to obtain this protection is also present in other rickettsiae including *Anaplasma marginale*, *Ehrlichia canis*, and in a causative agent of human ehrlichiosis, *Ehrlichia chaffeensis* (van Vliet, A., F. Jongejan, M. van Kleef, B. van der Zeijst [1994] *Infect. Immun* 62:1451). The MAP1 gene or a MAP1-like gene can also be found in certain *Rickettsia* spp. The MAP1-like gene from *Ehrlichia chaffeensis* has now been cloned and sequenced.

Compositions comprising the subject polynucleotides can include appropriate nucleic acid vaccine vectors (plasmids), which are commercially available (eg., Vical, San Diego, Calif.). In addition, the compositions can include a pharmaceutically acceptable carrier, e.g., saline. The pharmaceutically acceptable carriers are well known in the art and also are commercially available. For example, such acceptable carriers are described in E. W. Martin's *Remington's Pharmaceutical Science*, Mack Publishing Company, Easton, Pa.

In a specific embodiment, the subject invention concerns a DNA vaccine (e.g., VCL1010/MAP1) containing the major antigenic protein 1 gene (MAP1) driven by the human cytomegalovirus (HCMV) enhancer-promoter injected intramuscularly into 8–10 week-old female DBA/2 mice after treating them with 50 μ l/muscle of 0.5% bupivacaine 3 days previously. Up to 75% of the VCL1010/MAP1-immunized mice seroconverted and reacted with MAP1 in antigen blots. Splenocytes from immunized mice, but not from control mice immunized with VCL1010 DNA (plasmid vector, Vical, San Diego) proliferated in response to recombinant MAP1 and *C. ruminantium* antigens in in vitro lymphocyte proliferation tests. These proliferating cells

from mice immunized with VCL1010/MAP1 DNA secreted IFN-gamma and IL-2 at concentrations ranging from 610 pg/ml and 152 pg/ml to 1290 pg/ml and 310 pg/ml, respectively. In experiments testing different VCL1010/MAP1 DNA vaccine dose regimens (25–100 µg/dose, 2 or 4 immunizations), survival rates of 23% to 88% (35/92 survivors/total in all VCL1010/MAP1 immunized groups) were observed on challenge with 30LD50 of *C. ruminantium*. Survival rates of 0% to 3% (1/144 survivors/total in all control groups) were recorded for control mice immunized similarly with VCL1010 DNA or saline. Accordingly, the subject invention concerns the discovery that the gene encoding the MAP1 protein can induce protective immunity as a DNA vaccine against rickettsial disease.

The nucleic acid sequences described herein have other uses, as well. For example, the nucleic acids of the subject invention can be useful as probes to identify complementary sequences within other nucleic acid molecules or genomes. Such use of probes can be applied to identify or distinguish infectious strains of organisms in diagnostic procedures or in rickettsial research where identification of particular organisms or strains is needed. As is well known in the art, probes can be made by labeling the nucleic acid sequences of interest according to accepted nucleic acid labeling procedures and techniques. A person of ordinary skill in the art would recognize that variations or fragments of the disclosed sequences which can specifically and selectively hybridize to the DNA of rickettsia can also function as a probe. It is within the ordinary skill of persons in the art, and does not require undue experimentation in view of the description provided herein, to determine whether a segment of the claimed DNA sequences is a fragment or variant which has characteristics of the full sequence, e.g., whether it specifically and selectively hybridizes or can confer protection against rickettsial infection in accordance with the subject invention. In addition, with the benefit of the subject disclosure describing the specific sequences, it is within the ordinary skill of those persons in the art to label hybridizing sequences to produce a probe.

It is also well known in the art that restriction enzymes can be used to obtain functional fragments of the subject DNA sequences. For example, Bal31 exonuclease can be conveniently used for time-controlled limited digestion of DNA (commonly referred to as "erase-a-base" procedures). See, for example, Maniatis et al (1982) *Molecular Cloning: A Laboratory Manual*, Cold Spring Harbor Laboratory, New York. See also Wei et al. (1983) *J. Biol. Chem.* 258:13006-13512.

In addition, the nucleic acid sequences of the subject invention can be used as molecular weight markers in nucleic acid analysis procedures.

Following are examples which illustrate procedures for practicing the invention. These examples should not be construed as limiting. All percentages are by weight and all solvent mixture proportions are by volume unless otherwise noted.

EXAMPLE 1

A nucleic acid vaccine construct was tested in animals for its ability to protect against death caused by infection with the rickettsia *Cowdria ruminantium*. The vaccine construct tested was the MAP1 gene of *C. ruminantium* inserted into plasmid VCL1010 (Vical, San Diego) under control of the human cytomegalovirus promoter-enhancer and intron A. In this study, seven groups containing 10 mice each were injected twice at 2-week intervals with either 100, 75, 50, or

25 µg VCL1010/MAP1 DNA (V/M in Table 1 below), or 100, 50 µg VCL1010 DNA (V in Table 1) or saline (Sal.), respectively. Two weeks after the last injections, 8 mice/group were challenged with 30LD50 of *C. ruminantium* and clinical symptoms and survival monitored. The remaining 2 mice/group were not challenged and were used for lymphocyte proliferation tests and cytokine measurements. The results of the study are summarized in Table 1, below:

TABLE 1

	100 µg V/M	75 µg V/M	50 µg V/M	25 µg V/M	100 µg V	50 µg V	Sal.
Survived	5	7	5	3	0	0	0
Died	3	1	3	5	8	8	8

The VCL1010/MAP1 nucleic acid vaccine increased survival on challenge in all groups, with a total of 20/30 mice surviving compared to 0/24 in the control groups.

This study was repeated with another 6 groups, each containing 33 mice (a total of 198 mice). Three groups received 75 µg VCL1010/MAP1 DNA or VCL1010 DNA or saline (4 injections in all cases). Two weeks after the last injection, 30 mice/group were challenged with 30LD50 of *C. ruminantium* and 3 mice/group were sacrificed for lymphocyte proliferation tests and cytokine measurements. The results of this study are summarized in Table 2, below:

TABLE 2

	V/M 2 inj.	Sal. 2 inj.	V/M 4 inj.	V 4 inj.	Sal. 4 inj.
Survived	7	0	8	0	1
Died*	23	30	22	30	29

*In mice that died in both V/M groups, there was an increase in mean survival time of approximately 4 days compared to the controls ($p < 0.05$).

Again, as summarized in Table 2, the VCL1010/MAP1 DNA vaccine increased the numbers of mice surviving in both immunized groups, although there was no apparent benefit of 2 additional injections. In these two experiments, there were a cumulative total of 35/92 (38%) surviving mice in groups receiving the VCL1010/MAP1 DNA vaccine compared to 1/144 (0.7%) surviving mice in the control groups. In both immunization and challenge trials described above, splenocytes from VCL1010/MAP1 immunized mice, but not from control mice, specifically proliferated to recombinant MAP1 protein and to *C. ruminantium* in lymphocyte proliferation tests. These proliferating splenocytes secreted IL-2 and gamma-interferon at concentrations up to 310 and 1290 pg/ml respectively. These data show that protection against rickettsial infections can be achieved with a DNA vaccine. In addition, these experiments show MAP1-related proteins as vaccine targets.

EXAMPLE 2

The MAP1 protein of *C. ruminantium* has significant similarity to MSP4 of *A. marginale*, and related molecules may also be presenting other rickettsial pathogens. To prove this, we used primers based on regions conserved between *C. ruminantium* and *A. marginale* in PCR to clone a MAP1-like gene from *E. chaffeensis*. The amino acid sequence derived from the cloned *E. chaffeensis* MAP1-like gene, and alignment with the corresponding genes of *C. ruminantium* and *A. marginale* is shown in FIG. 1. We have now identified the regions of MAP1-like genes which are highly conserved between *Ehrlichia*, *Cowdria*, and *Anaplasma* and which can allow cloning of the analogous genes from other rickettsiae.

It should be understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be

suggested to persons skilled in the art and are to be included within the spirit and purview of this application and the scope of the appended claims.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

(iii) NUMBER OF SEQUENCES: 6

(2) INFORMATION FOR SEQ ID NO:1:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 864 base pairs

(B) TYPE: nucleic acid

(C) STRANDEDNESS: single

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(ix) FEATURE:

(A) NAME/KEY: CDS

(B) LOCATION: 1..861

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

ATG AAT TGC AAG AAA ATT TTT ATC ACA AGT ACA CTA ATA TCA TTA GTG	48
Met Asn Cys Lys Lys Ile Phe Ile Thr Ser Thr Leu Ile Ser Leu Val	
1 5 10 15	
TCA TTT TTA CCT GGT GTG TCC TTT TCT GAT GTA ATA CAG GAA GAC AGC	96
Ser Phe Leu Pro Gly Val Ser Phe Ser Asp Val Ile Gln Glu Asp Ser	
20 25 30	
AAC CCA GCA GGC AGT GTT TAC ATT AGC GCA AAA TAC ATG CCA ACT GCA	144
Asn Pro Ala Gly Ser Val Tyr Ile Ser Ala Lys Tyr Met Pro Thr Ala	
35 40 45	
TCA CAT TTT GGT AAA ATG TCA ATC AAA GAA GAT TCA AAA AAT ACT CAA	192
Ser His Phe Gly Lys Met Ser Ile Lys Glu Asp Ser Lys Asn Thr Gln	
50 55 60	
ACG GTA TTT GGT CTA AAA AAA GAT TGG GAT GGC GTT AAA ACA CCA TCA	240
Thr Val Phe Gly Leu Lys Lys Asp Trp Asp Gly Val Lys Thr Pro Ser	
65 70 75 80	
GAT TCT AGC AAT ACT AAT TCT ACA ATT TTT ACT GAA AAA GAC TAT TCT	288
Asp Ser Ser Asn Thr Asn Ser Thr Ile Phe Thr Glu Lys Asp Tyr Ser	
85 90 95	
TTC AGA TAT GAA AAC AAT CCG TTT TTA GGT TTC GCT GGA GCA ATT GGG	336
Phe Arg Tyr Glu Asn Asn Pro Phe Leu Gly Phe Ala Gly Ala Ile Gly	
100 105 110	
TAC TCA ATG AAT GGA CCA AGA ATA GAG TTC GAA GTA TCC TAT GAA ACT	384
Tyr Ser Met Asn Gly Pro Arg Ile Glu Phe Glu Val Ser Tyr Glu Thr	
115 120 125	
TTT GAT GTA AAA AAC CTA GGT GGC AAC TAT AAA AAC AAC GCA CAC ATG	432
Phe Asp Val Lys Asn Leu Gly Gly Asn Tyr Lys Asn Asn Ala His Met	
130 135 140	
TAC TGT GCT TTA GAT ACA GCA GCA CAA AAT AGC ACT AAT GGC GCA GGA	480
Tyr Cys Ala Leu Asp Thr Ala Ala Gln Asn Ser Thr Asn Gly Ala Gly	
145 150 155 160	
TTA ACT ACA TCT GTT ATG GTA AAA AAC GAA AAT TTA ACA AAT ATA TCA	528
Leu Thr Thr Ser Val Met Val Lys Asn Glu Asn Leu Thr Asn Ile Ser	
165 170 175	
TTA ATG TTA AAT GCG TGT TAT GAT ATC ATG CTT GAT GGA ATA CCA GTT	576
Leu Met Leu Asn Ala Cys Tyr Asp Ile Met Leu Asp Gly Ile Pro Val	
180 185 190	
TCT CCA TAT GTA TGT GCA GGT ATT GGC ACT GAC TTA GTG TCA GTA ATT	624
Ser Pro Tyr Val Cys Ala Gly Ile Gly Thr Asp Leu Val Ser Val Ile	

-continued

195	200	205	
AAT GCT ACA AAT CCT AAA TTA TCT TAT CAA GGA AAG CTA GGC ATA AGT Asn Ala Thr Asn Pro Lys Leu Ser Tyr Gln Gly Lys Leu Gly Ile Ser 210 215 220			672
TAC TCA ATC AAT TCT GAA GCT TCT ATC TTT ATC GGT GGA CAT TTC CAT Tyr Ser Ile Asn Ser Glu Ala Ser Ile Phe Ile Gly Gly His Phe His 225 230 235 240			720
AGA GTT ATA GGT AAT GAA TTT AAA GAT ATT GCT ACC TTA AAA ATA TTT Arg Val Ile Gly Asn Glu Phe Lys Asp Ile Ala Thr Leu Lys Ile Phe 245 250 255			768
ACT TCA AAA ACA GGA ATA TCT AAT CCT GGC TTT GCA TCA GCA ACA CTT Thr Ser Lys Thr Gly Ile Ser Asn Pro Gly Phe Ala Ser Ala Thr Leu 260 265 270			816
GAT GTT TGT CAC TTT GGT ATA GAA ATT GGA GGA AGG TTT GTA TTT Asp Val Cys His Phe Gly Ile Glu Ile Gly Gly Arg Phe Val Phe 275 280 285			861
TAA			864

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 287 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met Asn Cys Lys Lys Ile Phe Ile Thr Ser Thr Leu Ile Ser Leu Val
1 5 10 15

Ser Phe Leu Pro Gly Val Ser Phe Ser Asp Val Ile Gln Glu Asp Ser
20 25 30

Asn Pro Ala Gly Ser Val Tyr Ile Ser Ala Lys Tyr Met Pro Thr Ala
35 40 45

Ser His Phe Gly Lys Met Ser Ile Lys Glu Asp Ser Lys Asn Thr Gln
50 55 60

Thr Val Phe Gly Leu Lys Lys Asp Trp Asp Gly Val Lys Thr Pro Ser
65 70 75 80

Asp Ser Ser Asn Thr Asn Ser Thr Ile Phe Thr Glu Lys Asp Tyr Ser
85 90 95

Phe Arg Tyr Glu Asn Asn Pro Phe Leu Gly Phe Ala Gly Ala Ile Gly
100 105 110

Tyr Ser Met Asn Gly Pro Arg Ile Glu Phe Glu Val Ser Tyr Glu Thr
115 120 125

Phe Asp Val Lys Asn Leu Gly Gly Asn Tyr Lys Asn Asn Ala His Met
130 135 140

Tyr Cys Ala Leu Asp Thr Ala Ala Gln Asn Ser Thr Asn Gly Ala Gly
145 150 155 160

Leu Thr Thr Ser Val Met Val Lys Asn Glu Asn Leu Thr Asn Ile Ser
165 170 175

Leu Met Leu Asn Ala Cys Tyr Asp Ile Met Leu Asp Gly Ile Pro Val
180 185 190

Ser Pro Tyr Val Cys Ala Gly Ile Gly Thr Asp Leu Val Ser Val Ile
195 200 205

Asn Ala Thr Asn Pro Lys Leu Ser Tyr Gln Gly Lys Leu Gly Ile Ser
210 215 220

Tyr Ser Ile Asn Ser Glu Ala Ser Ile Phe Ile Gly Gly His Phe His

-continued

225	230	235	240
Arg Val Ile Gly Asn Glu Phe Lys Asp Ile Ala Thr Leu Lys Ile Phe	245	250	255
Thr Ser Lys Thr Gly Ile Ser Asn Pro Gly Phe Ala Ser Ala Thr Leu	260	265	270
Asp Val Cys His Phe Gly Ile Glu Ile Gly Gly Arg Phe Val Phe	275	280	285

(2) INFORMATION FOR SEQ ID NO:3:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 842 base pairs
- (B) TYPE: nucleic acid
- (C) STRANDEDNESS: single
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: DNA (genomic)

(ix) FEATURE:

- (A) NAME/KEY: CDS
- (B) LOCATION: 1..840

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:3:

ATG AAT TAC AAA AAA AGT TTC ATA ACA GCG ATT GAT ATC AAT AAT ATC	48		
Met Asn Tyr Lys Lys Ser Phe Ile Thr Ala Ile Asp Ile Ile Asn Ile			
290	295	300	
CTT CTC TTA CCT GGA GTA TCA TTT TCC GAC CCA AGG CAG GTA GTG GTC	96		
Leu Leu Leu Pro Gly Val Ser Phe Ser Asp Pro Arg Gln Val Val Val			
305	310	315	
ATT AAC GGT AAT TTC TAC ATC AGT GGA AAA TAC GAT GCC AAG GCT TCG	144		
Ile Asn Gly Asn Phe Tyr Ile Ser Gly Lys Tyr Asp Ala Lys Ala Ser			
320	325	330	335
CAT TTT GGA GTA TTC TCT GCT AAG GAA GAA AGA AAT ACA ACA GTT GGA	192		
His Phe Gly Val Phe Ser Ala Lys Glu Glu Arg Asn Thr Thr Val Gly			
340	345	350	
GTG TTT GGA CTG AAG CAA AAT TGG GAC GGA AGC GCA ATA TCC AAC TCC	240		
Val Phe Gly Leu Lys Gln Asn Trp Asp Gly Ser Ala Ile Ser Asn Ser			
355	360	365	
TCC CCA AAC GAT GTA TTC ACT GTC TCA AAT TAT TCA TTT AAA TAT GAA	288		
Ser Pro Asn Asp Val Phe Thr Val Ser Asn Tyr Ser Phe Lys Tyr Glu			
370	375	380	
AAC AAC CCG TTT TTA GGT TTT GCA GGA GCT ATT GGT TAC TCA ATG GAT	336		
Asn Asn Pro Phe Leu Gly Phe Ala Gly Ala Ile Gly Tyr Ser Met Asp			
385	390	395	
GGT CCA AGA ATA GAG CTT GAA GTA TCT TAT GAA ACA TTT GAT GTA AAA	384		
Gly Pro Arg Ile Glu Leu Glu Val Ser Tyr Glu Thr Phe Asp Val Lys			
400	405	410	415
AAT CAA GGT AAC AAT TAT AAG AAT GAA GCA CAT AGA TAT TGT GCT CTA	432		
Asn Gln Gly Asn Asn Tyr Lys Asn Glu Ala His Arg Tyr Cys Ala Leu			
420	425	430	
TCC CAT AAC TCA GCA GCA GAC ATG AGT AGT GCA AGT AAT AAT TTT GTC	480		
Ser His Asn Ser Ala Ala Asp Met Ser Ser Ala Ser Asn Asn Phe Val			
435	440	445	
TTT CTA AAA AAT GAA GGA TTA CTT GAC ATA TCA TTT ATG CTG AAC GCA	528		
Phe Leu Lys Asn Glu Gly Leu Asp Ile Ser Phe Met Leu Asn Ala			
450	455	460	
TGC TAT GAC GTA GTA GGC GAA GGC ATA CCT TTT TCT CCT TAT ATA TGC	576		
Cys Tyr Asp Val Val Gly Glu Gly Ile Pro Phe Ser Pro Tyr Ile Cys			
465	470	475	
GCA GGT ATC GGT ACT GAT TTA GTA TCC ATG TTT GAA GCT ACA AAT CCT	624		
Ala Gly Ile Gly Thr Asp Leu Val Ser Met Phe Glu Ala Thr Asn Pro			
480	485	490	495

-continued

AAA ATT TCT TAC CAA GGA AAG TTA GGT TTA AGC TAC TCT ATA AGC CCA	672
Lys Ile Ser Tyr Gln Gly Lys Leu Gly Leu Ser Tyr Ser Ile Ser Pro	
500 505 510	
GAA GCT TCT GTG TTT ATT GGT GGG CAC TTT CAT AAG GTA ATA GGG AAC	720
Glu Ala Ser Val Phe Ile Gly Gly His Phe His Lys Val Ile Gly Asn	
515 520 525	
GAA TTT AGA GAT ATT CCT ACT ATA ATA CCT ACT GGA TCA ACA CTT GCA	768
Glu Phe Arg Asp Ile Pro Thr Ile Ile Pro Thr Gly Ser Thr Leu Ala	
530 535 540	
GGA AAA GGA AAC TAC CCT GCA ATA GTA ATA CTG GAT GTA TGC CAC TTT	816
Gly Lys Gly Asn Tyr Pro Ala Ile Val Ile Leu Asp Val Cys His Phe	
545 550 555	
GGA ATA GAA ATG GGA GGA AGG TTT AA	842
Gly Ile Glu Met Gly Gly Arg Phe	
560 565	

(2) INFORMATION FOR SEQ ID NO:4:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 280 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:4:

Met Asn Tyr Lys Lys Ser Phe Ile Thr Ala Ile Asp Ile Ile Asn Ile	
1 5 10 15	
Leu Leu Leu Pro Gly Val Ser Phe Ser Asp Pro Arg Gln Val Val Val	
20 25 30	
Ile Asn Gly Asn Phe Tyr Ile Ser Gly Lys Tyr Asp Ala Lys Ala Ser	
35 40 45	
His Phe Gly Val Phe Ser Ala Lys Glu Glu Arg Asn Thr Thr Val Gly	
50 55 60	
Val Phe Gly Leu Lys Gln Asn Trp Asp Gly Ser Ala Ile Ser Asn Ser	
65 70 75 80	
Ser Pro Asn Asp Val Phe Thr Val Ser Asn Tyr Ser Phe Lys Tyr Glu	
85 90 95	
Asn Asn Pro Phe Leu Gly Phe Ala Gly Ala Ile Gly Tyr Ser Met Asp	
100 105 110	
Gly Pro Arg Ile Glu Leu Glu Val Ser Tyr Glu Thr Phe Asp Val Lys	
115 120 125	
Asn Gln Gly Asn Asn Tyr Lys Asn Glu Ala His Arg Tyr Cys Ala Leu	
130 135 140	
Ser His Asn Ser Ala Ala Asp Met Ser Ser Ala Ser Asn Asn Phe Val	
145 150 155 160	
Phe Leu Lys Asn Glu Gly Leu Leu Asp Ile Ser Phe Met Leu Asn Ala	
165 170 175	
Cys Tyr Asp Val Val Gly Glu Gly Ile Pro Phe Ser Pro Tyr Ile Cys	
180 185 190	
Ala Gly Ile Gly Thr Asp Leu Val Ser Met Phe Glu Ala Thr Asn Pro	
195 200 205	
Lys Ile Ser Tyr Gln Gly Lys Leu Gly Leu Ser Tyr Ser Ile Ser Pro	
210 215 220	
Glu Ala Ser Val Phe Ile Gly Gly His Phe His Lys Val Ile Gly Asn	
225 230 235 240	
Glu Phe Arg Asp Ile Pro Thr Ile Ile Pro Thr Gly Ser Thr Leu Ala	

-continued

490	495	500	
TTT ACT CCG GAA ATA TCC	TTG GTG GCA GGT GGG	TTC TAC CAC GGG CTA	720
Phe Thr Pro Glu Ile Ser	Leu Val Ala Gly Gly Phe	Tyr His Gly Leu	
505	510	515 520	
TTT GAT GAG TCT TAC AAG	GAC ATT CCC GCA CAC	AAC AGT GTA AAG TTC	768
Phe Asp Glu Ser Tyr Lys	Asp Ile Pro Ala His	Asn Ser Val Lys Phe	
	525	530 535	
TCT GGA GAA GCA AAA GCC	TCA GTC AAA GCG CAT	ATT GCT GAC TAC GGC	816
Ser Gly Glu Ala Lys Ala	Ser Val Lys Ala His	Ile Ala Asp Tyr Gly	
	540	545 550	
TTT AAC CTT GGA GCA AGA	TTC CTG TTC AGC TAA		849
Phe Asn Leu Gly Ala Arg	Phe Leu Phe Ser		
	555	560	

(2) INFORMATION FOR SEQ ID NO:6:

(i) SEQUENCE CHARACTERISTICS:

- (A) LENGTH: 282 amino acids
- (B) TYPE: amino acid
- (D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:6:

Met	Asn	Tyr	Arg	Glu	Leu	Phe	Thr	Gly	Gly	Leu	Ser	Ala	Ala	Thr	Val
1				5						10				15	
Cys	Ala	Cys	Ser	Leu	Leu	Val	Ser	Gly	Ala	Val	Val	Ala	Ser	Pro	Met
			20					25					30		
Ser	His	Glu	Val	Ala	Ser	Glu	Gly	Gly	Val	Met	Gly	Gly	Ser	Phe	Tyr
		35					40					45			
Val	Gly	Ala	Ala	Tyr	Ser	Pro	Ala	Phe	Pro	Ser	Val	Thr	Ser	Phe	Asp
	50					55					60				
Met	Arg	Glu	Ser	Ser	Lys	Glu	Thr	Ser	Tyr	Val	Arg	Gly	Tyr	Asp	Lys
	65				70					75					80
Ser	Ile	Ala	Thr	Ile	Asp	Val	Ser	Val	Pro	Ala	Asn	Phe	Ser	Lys	Ser
				85					90					95	
Gly	Tyr	Thr	Phe	Ala	Phe	Ser	Lys	Asn	Leu	Ile	Thr	Ser	Phe	Asp	Gly
			100					105					110		
Ala	Val	Gly	Tyr	Ser	Leu	Gly	Gly	Ala	Arg	Val	Glu	Leu	Glu	Ala	Ser
		115					120					125			
Tyr	Arg	Arg	Phe	Ala	Thr	Leu	Ala	Asp	Gly	Gln	Tyr	Ala	Lys	Ser	Gly
	130					135					140				
Ala	Glu	Ser	Leu	Ala	Ala	Ile	Thr	Arg	Asp	Ala	Asn	Ile	Thr	Glu	Thr
	145				150					155					160
Asn	Tyr	Phe	Val	Val	Lys	Ile	Asp	Glu	Ile	Thr	Asn	Thr	Ser	Val	Met
			165					170						175	
Leu	Asn	Gly	Cys	Tyr	Asp	Val	Leu	His	Thr	Asp	Leu	Pro	Val	Ser	Pro
			180					185					190		
Tyr	Val	Cys	Ala	Gly	Ile	Gly	Ala	Ser	Phe	Val	Asp	Ile	Ser	Lys	Gln
		195					200					205			
Val	Thr	Thr	Lys	Leu	Ala	Tyr	Arg	Gly	Lys	Val	Gly	Ile	Ser	Tyr	Gln
	210					215					220				
Phe	Thr	Pro	Glu	Ile	Ser	Leu	Val	Ala	Gly	Gly	Phe	Tyr	His	Gly	Leu
	225				230					235					240
Phe	Asp	Glu	Ser	Tyr	Lys	Asp	Ile	Pro	Ala	His	Asn	Ser	Val	Lys	Phe
			245						250					255	
Ser	Gly	Glu	Ala	Lys	Ala	Ser	Val	Lys	Ala	His	Ile	Ala	Asp	Tyr	Gly

-continued

260	265	270
Phe Asn Leu Gly Ala Arg Phe Leu Phe Ser		
275	280	

We claim:

1. A composition comprising an isolated polynucleotide which encodes a polypeptide having the characteristic of eliciting an immune response protective against disease or death caused by a rickettsial pathogen wherein said polynucleotide has the nucleic acid sequence shown in SEQ ID NO. 1.

10 2. The composition, according to claim 1, wherein said polynucleotide is operably linked to a vector suitable for use in vaccination.

3. The composition, according to claim 1, further comprising a pharmaceutically acceptable carrier.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,025,338
DATED : February 15, 2000
INVENTOR(S) : Anthony F. Barbet, Roman Reddy Ganta, Michael J. Burr ridge,
Suman M. Mahan, Travis C. McGuire, Aceme Nyika, and Fred
Rurangirwa

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

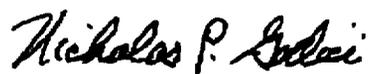
Title Page [75] Inventors: "Anthony F. Barbet, Archer; Roman Reddy Ganta; Michael J. Burr ridge, both of Gainesville, all of Florida; Suman M. Mahan, Harare, Zimbabwe" should read --Anthony F. Barbet, Archer; Roman Reddy Ganta; Michael J. Burr ridge, both of Gainesville, all of Florida; Suman M. Mahan, Harare, Zimbabwe; Travis C. McGuire, Pullman, WA; Aceme Nyika, Harare, Zimbabwe; and Fred R. Rurangirwa, Pullman, WA.--.

Column 2, line 66: "(CIL)" should read --(CTL)--.

Column 4, lines 53-54: "Phannaceutical" should read --Pharmaceutical--.

Signed and Sealed this

First Day of May, 2001



NICHOLAS P. GODICI

Attest:

Attesting Officer

Acting Director of the United States Patent and Trademark Office