PROCESS FOR PREPARING AN ATTENUATED TETRAVALENT DENGUE VACCINE

Incorporation of Sequence Listing

[0001] The sequence listing that is contained in the file named "60135__146578_ST25.txt", which is 56,450 bytes (measured in operating system MS-Windows), created on August 31, 2015, is filed herewith by electronic submission and incorporated herein by reference in its entirety.

Field of the invention

[0002] The present invention is in the field of biotechnology. The present invention refers to a process for preparing an attenuated tetravalent dengue vaccine. The present invention also refers to an attenuated tetravalent dengue vaccine. The present invention also refers to the use of a composition for reconstituting the vaccine. The present invention also refers to a method for inducing an immune response to serotypes 1, 2, 3 and 4 in a patient. The present invention also refers to a tetravalent dengue vaccine kit.

Background

[0003] Currently, dengue is a disease of major impact on public health in Brazil. It affects half of the world's population living in endemic regions, mainly in Southeast Asia (Pacific region) and America. According to the WHO, in the one recent study it was estimated that there are about 390 million dengue infections per year (95% credible interval 284-528 million), of which 96 million (67-136 million) manifest clinically (with any severity of disease)[1]. In another study about dengue prevalence, it was estimated that 3900 million people, in 128 countries, are at risk of infection with dengue virus [2].

[0004] In Brazil, in the year 2000 the incidence was

200,000 dengue cases and in 2010 there were a million occurrences. In 2015, there were 460,502 reported cases of dengue in Brazil until March. The Southeast region had the highest number of reported cases (304,251 cases, 66.1%) compared to the country, followed by the Midwest (59,855 cases; 13%), Northeast (51,221 cases; 11.1%), North (19,402 cases; 4.2%) and South (25 773 cases, 5.6% [3].

[0005] Dengue fever (DF) and its severe form, dengue hemorrhagic fever (DHF) / dengue shock syndrome (DSS) can be caused by infection with any of the dengue serotypes DEN1, DEN2, DEN3 and DEN4.

[0006] As currently there is no antiviral drug that treats this disease and the mosquito vector (*Aedes aegypti*) control strategies has proven ineffective, the only way to control the advance of dengue is through prevention, with the use of a vaccine against the four types of dengue virus. At the moment, no dengue vaccines have been licensed for human use. Epidemiological studies indicate that primary infection with one dengue serotype usually causes DF, and the chance of a second infection causes DHF is 15-80 times higher than that of primary infection. Therefore, an effective dengue vaccine must be composed of the four serotypes of virus dengue [4]. However, the development of a tetravalent dengue vaccine is very difficult because this product must provide a long-term protection against all dengue virus serotypes [5].

[0007] The patent application US 13/305,639, continuation of application no. 12/398,043, filed on March 4, 2009, now patent no. 8,075,903, which is a continuation of application no. 10/970,640, filed on October 21, 2004, now US patent no. 7,517,531, continuation of application no.

PCT/US03/13279, filed on April 25, 2003, from The Government of the USA, as represented by the Secretary, department of health and human services, is entitled "*Dengue tetravalent vaccine containing a common 30 nucleotide deletion in the 3'-UTR of dengue types 1, 2, 3 and 4, or antigenic chimeric dengue viruses 1, 2, 3 and 4.*" The patent above refers to one product obtained from a process that include a mix of four dengue virus serotypes with a 30 nucleotide deletion or antigenic chimeric dengue virus.

[0008] The patent application US 11/982,488, filed on November 2, 2007, published on May 31, 2012 and granted on August 14, 2012, from Monika Simmons *et al*, entitled "*Induction of an immune response against dengue virus using the prime-boost approach*", describes methods for the induction of an immune response to dengue virus. The method of inducing an immune response against dengue virus comprises administration of a non-replicating immunogen followed by a boost with a tetravalent live attenuated viral vaccine. Another aspect is a method of inducing an immune response against dengue virus using a heterologous prime-boost regimen with the priming immunogen comprising a DNA expression system, an adenovirus expression vector or a Venezuelan equine encephalitis virus replicon system and the boosting immunogen comprising the same without the DNA expression system. Each expression system contains DNA sequences encoding dengue viral proteins. The patent above describes an immune scheme for dengue vaccine. In this scheme the first immunization is used a non-replicating immunogen and after a tetravalent live attenuated dengue vaccine. The object of the present patent application is a process to obtain a live attenuated dengue vaccine.

[0009] The present invention teaches the development of a vaccine against the four types of dengue virus using the attenuated virus strains rDEN1Δ30-1545 (SEQ ID NO:1)and variants thereof; rDEN2/4Δ30(ME)-1495,7163 (SEQ ID NO:2)and variants thereof; rDEN3Δ30/31-7164 (SEQ ID NO:3) and variants thereof; and rDEN4Δ30-7132,7163,8308 (SEQ ID NO:4) and variants thereof. Certain rDEN1Δ30, rDEN2/4Δ30, rDEN3Δ30, and rDEN4Δ30 recombinant attenuated dengue viruses are described in US patent no. 7,517,531, no 7,226,602 and no 8,337,860, which are incorporated herein by reference in their entirety.

[0010] The vaccine of the present invention, called dengue vaccine 1,2,3,4 (attenuated), is presented in lyophilized form in vials with 10 doses. In the development of this vaccine the following process was established: production of Vero cells and dengue virus of serotypes 1, 2, 3 and 4 to obtain the cell and virus banks; production of viral suspensions with cells and virus from these banks; concentration of these suspensions and preparation of bulks; formulation of monovalent and tetravalent vaccines; filling; lyophilization and sealing of the product.

[0011] As may be seen none of the prior art documents discloses or suggests a process for preparing an attenuated tetravalent dengue vaccine that enable dengue vaccine production on a large scale.

BRIEF SUMMARY OF INVENTION

[0012] In order to solve the problems above mentioned, the present disclosure will provide significant advantages over existing processes for preparing tetravalent dengue vaccines. Initially, certain embodiments of the present invention use Vero cell strains with lower passage

(passage 123), which allows a high number of subcultures of this cell line, that is, a high yield. Moreover, Master and Working Vero cell banks were prepared with cells maintained in serum-free culture medium, were subcultured with a non-animal trypsin, and were stabilized with 5% DMSO. The use of a serum-free medium leads to higher reproducibility, not to mention that the use of non-animal trypsin in the subcultures of maintenance and amplification of Vero cells makes the process safer and free from the possibility of contamination of the final product with porcine circovirus. Moreover, Vero cells can be grown in 225 cm^2 TC-flasks (Tissue Culture Flasks) or Nunc™ Cell Factory System™, with 10-tray layers (Thermo Fisher Scientific Inc. Pittsburgh, PA, USA; area of culture of about 6,320 cm^2), which allows a high production of cells/TC-flask of up to about $2x10^9$ cells/CFS. The additional replication of dengue virus in Vero cells, from which Working Virus Seed banks were prepared, increased the process' productivity. The final volume of viral suspension obtained in one production cycle with CFS is 14 L (a high volume). In certain embodiments of the present invention, up to about seven harvests can be obtained in a single production cycle of the virus. Dengue virus suspensions are harvested from the infected cells by removing of the media containing virus from the culture, replacing the removed media with fresh media, incubating the infected cells with the new media, and harvesting the media that contains virus after incubation, which also increases the productivity of the processes provided herein. The present disclosure also teaches the optimal time for harvesting supernatants of viral suspensions through studies of dengue virus replication curves of the serotypes 1, 2, 3 and 4 in Vero cells grown in

TC-flasks and Cell Factory System™, which allows the increase in the number of harvestings. In certain embodiments, the tetravalent vaccine of the present disclosure is prepared with monovalent vaccines containing different titers of virus dengue according with each serotype (5.7±0.2, 5.6±0.2, 6.1±0.2 and 5.8±0.2 Log_{10} PFU/ml for DENV1, DENV2, DENV3, and DENV4, respectively) which allows a higher homogeneity of viral particles of each serotype in the tetravalent vaccine. Finally, the steps of filling and lyophilization of the claimed process provide a vaccine that is stable for 1 year at 2-8°C.

[0013] In summary, the process for preparing an attenuated tetravalent dengue vaccine of the present application presents high yield and is very reproducible. The vaccine, product of said process, is highly stable and without contaminants of animal origin (serum and trypsin), generally used in the manufacturing of vaccines. Said characteristics allow the production of dengue vaccine on a large scale. In addition, the dengue vaccine of the present disclosure has been tested in humans in Brazil since November 2013 (phase II clinical trials). Preliminary data of this study demonstrated that this product is safe and immunogenic.

[0014] In one aspect, the present invention refers to process for preparing an attenuated tetravalent dengue vaccine characterized by the fact that it comprises any subset or all of the following steps: adapting Vero cells to growth in serum-free medium and using a trypsin non-animal origin to obtain the cells subcultures; amplifying Vero cells in 225 cm^2 TC-flasks and later in Cell Factory System™ (CFS); producing the Vero Cell Master Cell Bank (MCB) and Working Cell Bank (WCB) and the Seed Bank and Working Seed Bank with

dengue's virus serotypes 1, 2, 3 and 4; infecting the Vero cells in 225 cm^2 TC-flasks or CFS from working cell bank with dengue's virus serotypes 1, 2, 3 and 4 from working seed virus banks; incubating the TC-flasks or Cell Factory System™ contained the Vero cells/virus dengue suspension at 36.5°C (± 1°C) for 10 to 20 days; harvesting the supernatants, filtering (membrane of 0.2µm of porosity) and storing at -80°C (± 5°C); preparing bulks of dengue virus serotypes 1, 2, 3 and 4; formulating the monovalent vaccines with these bulks; formulating tetravalent vaccine with four monovalent vaccines; filling; lyophilizing; sealing; labeling and storing the product at 2-8°C.

[0015] In certain embodiments the Vero cell line used is ATCC CCL-81.4 (cGMPVero, *Kidney African Green Monkey - Cercopithecus aeothiops*). In a further embodiment the dengue virus strains used are rDEN1Δ30-1545; rDEN2/4Δ30(ME)-1495,7163; rDEN3Δ30/31-7164 and rDEN4Δ30-7132,7163,8308 from the United States National Institutes of Health (NIH). In a further embodiment the MOI of dengue virus strains for each dengue serotype can be about: 0.01 to 0.03 for DENV 1 and 4, 0.02 to 0.04 for DENV 2 and 0.05 to 0.08 for DENV3. In a further embodiment the monovalent vaccines are mixed in the same ratio of volume to obtain the tetravalent dengue vaccine serotypes 1,2,3,4 (attenuated). In a further embodiment the parameters used in the freeze drying (lyophilization) process are: freezing (-30 to -50°C), vacuum (20 to 100µbar), primary drying from -30 to -50°C (36 to 42h) and -5 to -10°C (18 to 24h) secondary drying 25 to 29°C (8 to 15h).

[0016] In another aspect, the invention refers to an attenuated tetravalent dengue vaccine produced by the process as described above.

[0017] In another aspect, the invention refers to the use of a composition comprising sodium phosphate monobasic dihydrate 0.2 M, sodium phosphate dibasic heptahydrate, 0.2 M and WFI (*i.e.*, water for injection) water for reconstituting the vaccine produced by the process as described above. In an embodiment it used 5 mL of said composition to reconstitute the dried vaccine.

[0018] In another aspect, the invention refers to a method for inducing an immune response to virus dengue serotypes 1, 2, 3 and 4 in a subject by administering the vaccine as cited above to the subject. In certain embodiments, the subject is a human.

[0019] In another aspect, the invention refers to a tetravalent dengue vaccine kit that comprises the lyophilized tetravalent vaccine as cited above, a reconstitution composition comprising sodium phosphate monobasic dihydrate 0.2 M, sodium phosphate dibasic heptahydrate, 0.2 M and WFI water.

[0020] In certain embodiments, processes for preparing an attenuated tetravalent dengue vaccine comprising:(i) amplifying Vero cells in culture to produce Master and Working banks of Vero cells, wherein the Vero cells are adapted for growth in serum-free medium, are grown in serum-free medium, and are sub-cultured with trypsin of non-animal origin of this cell in 225 cm2 Tissue Culture (TC)-flasks and later in a Cell Factory System™ (CFS);(ii) infecting Vero cells from the Master or Working bank with dengue virus serotypes 1, 2, 3 and 4 from a Seed or Working bank of each virus, wherein the Vero cells are independently infected with dengue virus serotypes 1, 2, 3, and 4 in separate cultures with serum free medium; (iii) incubating

the 225 cm2 TC-flasks or Cell Factory System™ (CFS) containing the Vero cells infected with each dengue virus at 36.5°C (± 1°C) for 10 to 20 days;(iv) harvesting the supernatants of each culture; (v) filtering each dengue virus suspension from step (iv) through a membrane with 0.2µm of porosity and storing the filtered dengue virus at -80°C (± 5°C);(vi) preparing dengue virus bulks of the serotypes 1, 2, 3 and 4; (vii) formulating monovalent vaccines; (viii) formulating tetravalent vaccine by mixing the monovalent vaccines; (ix) filling vials with the tetravalent vaccine; (x) lyophilizing the tetravalent vaccine in the vials; (xi) sealing the lyophilized tetravalent vaccine in the vials; and (xii) storing the lyophilized and sealed product at 2-8°C, thereby preparing an attenuated tetravalent dengue vaccine are provided.

[0021] In certain embodiments, a process for preparing an attenuated tetravalent dengue vaccine comprising:(i) amplifying Vero cells in culture to produce Master and Working banks of Vero cells, wherein the Vero cells are adapted for growth in serum-free medium, are grown in serum-free medium, and are sub-cultured with trypsin of non-animal origin;(ii) infecting Vero cells from the Master or Working bank with dengue virus serotypes 1, 2, 3 and 4 from a Seed or Working bank of each virus, wherein the Vero cells are independently infected with dengue virus serotypes 1, 2, 3, and 4 in separate cultures with serum free medium; (iii) incubating the Vero cells infected with each dengue virus at 36.5°C (± 1°C) for 10 to 20 days in a tissue culture flask or Cell Factory System™;(iv) harvesting the supernatants of each culture; (v) filtering each dengue virus suspension from step (iv) through a membrane with 0.2µm of

porosity and storing the filtered dengue virus at -80°C (± 5°C);(vi) preparing dengue virus bulks of the serotypes 1, 2, 3 and 4; (vii) formulating monovalent vaccines; and (viii) formulating tetravalent vaccine by mixing the monovalent vaccines is provided.

[0022] In certain embodiments, an attenuated tetravalent dengue vaccine that is produced by any of the aforementioned processes is provided.

[0023] In certain embodiments, a process for preparing a tetravalent dengue vaccine for administration to a subject that comprises the step of reconstituting the sealed and lyophilized tetravalent dengue vaccine produced by any of the aforementioned methods in a composition comprising 0.2M sodium phosphate monobasic dihydrate, 0.2M sodium phosphate dibasic heptahydrate, and water is provided.

[0024] Also provided are methods for inducing an immune response to virus dengue serotypes 1, 2, 3 and 4 in a subject that comprise administering the aforementioned vaccine to the subject.

[0025] Also provided are tetravalent dengue vaccine kits that comprise the aforementioned vaccine, a reconstitution composition comprising 0.2M sodium phosphate monobasic dihydrate, 0.2M sodium phosphate dibasic heptahydrate and water.

[0026] In certain embodiments of any of the aforementioned processes, vaccines, methods, or kits, the dengue virus strains used are rDEN1Δ30-1545 (SEQ ID NO:1)or a variant thereof; rDEN2/4Δ30(ME)-1495,7163 (SEQ ID NO:2) or a variant thereof; rDEN3Δ30/31-7164 (SEQ ID NO:3)or a variant thereof, and rDEN4Δ30-7132,7163,8308 (SEQ ID NO:4)or a

variant thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The purpose of the disclosure, together with further advantages thereof, can be better understood by reference to the accompanying drawing and the following descriptions:

[0028] FIG. 1 is a summary of the disclosure, describing all the steps of the process for preparing an attenuated tetravalent dengue vaccine.

DESCRIPTION

[0029] Although the present invention may be susceptible to different embodiments, certain embodiments are shown in the drawings and following detailed discussion, with the understanding that the present disclosure can be considered an exemplification of the principles of the invention and is not intended to limit the scope of invention to that which is illustrated and disclosed in this description.

A process for preparing an attenuated tetravalent dengue vaccine

[0030] In a first embodiment, the present invention refers to a process for preparing an attenuated tetravalent dengue vaccine comprising any subset or all of the following steps: adapting Vero cells to growth in serum-free medium and trypsin of non-animal origin; amplifying Vero cells in culture of this cell in 225 cm^2 TC-flasks and later in Cell Factory System™ (CFS); producing Master and Working banks of Vero cells and Seed and Working banks of dengue's virus serotypes 1, 2, 3 and 4; infecting Vero cells contained in 225 cm^2 TC-flasks or CFS with dengue's virus serotypes 1, 2, 3 and 4 from banks; incubating the 225 cm^2 TC-flasks or CFS

containing the Vero cells/virus suspension infected with dengue virus at 36.5°C (± 1°C) for 10 to 20 days; harvesting the supernatants of these cultures, filtering these dengue virus suspension in membrane with 0.2µm of porosity and storing at -80°C (± 5°C); preparing dengue virus bulks of serotypes 1, 2, 3 and 4; formulating monovalent vaccines with these bulks; formulating tetravalent vaccine mixing the monovalent vaccines; filling, lyophilizing; sealing and storing the product at 2-8°C. In a further embodiment the Vero cell line used is ATCC CCL-81.4 (cGMPVero, *Kidney African Green Monkey - Cercopithecus aeothiops;* available from the ATCC, Manassas, VA, USA). In a further embodiment the dengue virus strains used are rDEN1Δ30-1545 (SEQ ID NO:1) or variants thereof; rDEN2/4Δ30(ME)-1495,7163 (SEQ ID NO:2) or variants thereof; rDEN3Δ30/31-7164 (SEQ ID NO:3) or variants thereof; and rDEN4Δ30-7132,7163,8308 (SEQ ID NO:4) or variants thereof. Variants of the aforementioned dengue virus strains that can be used include but are not limited to: (1) variants of rDEN1Δ30-1545 (SEQ ID NO:1) having a genome with at least 95%, 96%, 97%, 98%, 99%, or 99.5% sequence identity across the entire length of SEQ ID NO:1 and variants with the aforementioned percent sequence identities that encode a viral polyprotein with at least 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the viral polyprotein encoded by SEQ ID NO:1; (2) variants of rDEN2/4Δ30(ME)-1495,7163 (SEQ ID NO:2) having a genome with at least 95%, 96%, 97%, 98%, 99%, or 99.5% sequence identity across the entire length of SEQ ID NO:2 and variants with the aforementioned percent sequence identities that encode a viral polyprotein with at least 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the viral polyprotein encoded

by SEQ ID NO:2; (3) variants of rDEN3Δ30/31-7164 (SEQ ID NO:3) having a genome with at least 95%, 96%, 97%, 98%, 99%, or 99.5% sequence identity across the entire length of SEQ ID NO:3 and variants with the aforementioned percent sequence identities that encode a viral polyprotein with at least 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the viral polyprotein encoded by SEQ ID NO:3; and (4) variants of rDEN4Δ30-7132,7163,8308 (SEQ ID NO:4) having a genome with at least 95%, 96%, 97%, 98%, 99%, or 99.5% sequence identity across the entire length of SEQ ID NO:3 and variants with the aforementioned percent sequence identities that encode a viral polyprotein with at least 95%, 96%, 97%, 98%, 99%, or 100% sequence identity to the viral polyprotein encoded by SEQ ID NO:4.

[0031] rDEN1Δ30 (GenBank access number: AY145123) is a live attenuated virus derived from the DEN1 Western Pacific (WP) wild-type strain by means of a deletion of 30 nucleotides (Δ30) in the 3′ untranslated region (3'UTR). The rDEN1Δ30-1545 strain (SEQ ID NO: 1) used herein encodes a single Lys → Arg mutation at amino acid residue number 484 (A1545G mutation) in the viral polyprotein.

[0032] For the development of the DEN2 virus, the ME region of DEN2 was substituted for the corresponding genes of rDEN4Δ30 to create the vaccine candidate rDEN2/4Δ30(ME). The rDEN2/4Δ30(ME)-1495,7163 strain (SEQ ID NO: 2) used herein encodes a Ser → Phe mutation at amino acid residue number 186 (C1495T mutation) and a Leu → Phe mutation at amino acid residue number 112 (A7163C mutation) in the viral polyprotein.

[0033] rDEN3Δ30/31 is a live attenuated virus derived from rDEN3Δ30 strain. Initially it was constructed

a complete cDNA copy of the strain DEN3 Sleman/78, creating a deletion of 30 nucleotides (Δ30) in the 3'UTR. As from the resulting rDEN3Δ30 virus, an additional deletion of about 31 nucleotides was carried out in the 3'UTR [2]. Therefore, rDEN3Δ30/31 includes the original Δ30 deletion and a non-contiguous 31 nt deletion that removes both the original TL-2 and TL-3 structures. The resultant rDEN3Δ30/31-7164 strain (SEQ ID NO: 3) used herein encodes a Val → Ala mutation at amino acid residue number 115 (T7164C mutation) in the viral polyprotein.

[0034] rDEN4Δ30 is a live attenuated virus derived from the wild-type DEN4 Dominica/81 using recombinant DNA technology. One stem-loop structure, identified as TL2 in the secondary structure of the 3' UTR, was previously removed by deletion of 30 nucleotides from the DEN4 genome (3'd 172-143) and has subsequently been designated as Δ30 mutation. The rDEN4Δ30-7132, 7163, 8308 strain (SEQ ID NO: 4) used herein encodes a Thr → Ile mutation at amino acid residue number 102 (C7132T mutation), a Leu → Phe mutation at amino acid residue number 112 (A7163C mutation) and a Lys → Arg mutation at amino acid residue number 249 (A8308G mutation) in the viral polyprotein.

[0035] In a further embodiment the MOI of dengue virus strains varies for each dengue serotype: 0.01 to 0.03 for DENV 1 and 4, 0.02 to 0.04 for DENV 2 and 0.05 to 0.08 for DENV3. In a further embodiment the monovalent vaccines are mixed in the same ratio of volume to obtain the tetravalent dengue vaccine serotypes 1,2,3,4 (attenuated). In a further embodiment the parameters used in the freeze drying process are: freezing (-30 to -50°C), vacuum (20 to 100µbar), drying from -30 to -50°C (36 to 40h), from -5 to

-10°C (18 to 24h) and 25 to 29°C (8 to 15h).In certain embodiments, the adaptation of Vero cell to serum-free medium was carried out with passage 123; the working cell bank was carried out with passage 134; and, the process for production of dengue virus used Vero cells with passage 138 to 149.

[0036] In certain embodiments, a stabilizer is used before step (vii) of formulation of monovalent vaccines. Suitable stabilizers for certain embodiments of the present invention include, but are not limited to, trehalose, sucrose, maltose, lactose, galactose, ASO4 (an stabilizer system including a mixture of stable aluminum hydroxide and monophosphoryl lipid A), human serum albumin (HSA), Pluronic® block copolymers F127, F68 (BASF), P85 (BASF) and P123 (BASF), polysaccharide chitosan, and recombinant HSA (rHSA)[8, 9].

An attenuated tetravalent dengue vaccine

[0037] In another embodiment the present invention refers to an attenuated tetravalent dengue vaccine produced by the process as described above.

Use of a composition for reconstituting the dried vaccine

[0038] In another embodiment a composition comprising sodium phosphate monobasic dihydrate 0.2 M, sodium phosphate dibasic heptahydrate, 0.2 M and WFI water is used to reconstitute the vaccine as described above. In a further embodiment 5 mL of the composition is used to reconstitute the dried vaccine.

A method for inducing an immune response to virus dengue serotypes 1, 2, 3 and 4 in a patient

[0039] In another embodiment the present invention refers to a method for inducing an immune response to virus dengue serotypes 1, 2, 3 and 4 in a subject by administering

the vaccine as described above to the subject.

[0040] For prophylactic treatment against Dengue infection, it is intended that the vaccine of the present invention can be administered prior to exposure of an individual to Dengue virus serotypes 1-4 and that the resulting immune response can inhibit or reduce the severity of the Dengue infection.

A tetravalent dengue vaccine kit

[0041] In another embodiment the present invention refers to a tetravalent dengue vaccine kit comprising the vaccine as described above, a reconstitution composition comprising sodium phosphate monobasic dihydrate 0.2 M, sodium phosphate dibasic heptahydrate, 0.2 M and WFI water.

EXAMPLES

Example 1. DESCRIPTION OF PRODUCTION PROCESS

[0042] The process of production of dengue vaccine 1,2,3,4 (attenuated) comprises the following steps:

[0043] STEP 1. Preparation of culture media and solutions used in the process of vaccine's production

[0044] The serum-free culture media for maintenance of Vero cells, preparation of Bulks and formulation of vaccine are prepared as follows:

[0045] VP-SFM AGT or AGT OptiPRO® (GIBCO) serum-free media: flask of powdered culture medium is diluted in WFI water, and thereto is added L-Glutamine so that, at the end, the culture medium present 200mM of this reagent. The medium is sterilized by filtration in membrane of 0.2µm and samples are taken for measurement of pH and Sterility test.

[0046] Leibovitz (L-15) culture media without phenol red: flasks containing the powdered culture medium are diluted in WFI water. Then, the medium is filtered in

membrane of 0.2µm. Samples are taken for sterility, bacterial endotoxin, pH and appearance testing.

[0047] The culture media filtered are packed in polycarbonate flasks and stored at 2-8°C.

[0048] Buffered saline solution with 0.02M Phosphate is composed of sodium chloride, dibasic sodium phosphate, monobasic potassium phosphate, and WFI water. This solution is used for washing the cultures during the amplification cell process and in the dengue virus suspensions concentration.

[0049] STEP 2. Preparation of banks of Master and Working Vero cells

[0050] The Vero cell banks were obtained from adaptation of Vero cell line ATCC CCL-81.4 (*e.g.* cGMPVero, *Kidney African Green Monkey - Cercopithecus aeothiops* p. 123 Batch 7388125) to the culture in serum-free medium and non-animal origin trypsin. This adaptation was carried out by successive subculture of this cell in culture cell 225 cm^2 T-flasks for cell culture using the serum-free medium (VP-SFM AGT ®- GIBCO) and recombinant trypsin (TrypLE Select® - Gibco). After adaptation of the cells that only grow in medium with serum for growth in serum-free medium, cultures grown in serum-free medium are used to prepare the cell banks.

[0051] In the preparation of Master and Working cell banks, adapted Vero cells contained in culture flasks with a confluence of 90 to 100% are detached with trypsin, suspended in medium OptiPRO AGT (Gibco), centrifuged and the pelleted is resuspended in the same medium containing 5% DMSO. The cell suspension is homogenized and distributed into cryotubes containing 4 to $10x10^6$ cells/ml. The cryotubes

are placed in a freezer at 80°C (± 5°C), for 48 hours and then stored in liquid nitrogen. Samples are taken for bank certification through the following quality control tests: Sterility, Karyotyping, Cell Identity, Adventitious Agents in Cells and Animals, Hemadsorbents Virus and Mycoplasmas.

[0052] STEP 3. Amplification of Vero cells used as cellular substrate in the production of Dengue virus

[0053] The cell amplification process includes thawing of a cryotube containing Vero cells from an origin cell (ATCC -CCL81.4) or from master or working cell banks in a water bath at 37°C (± 1°C). After thawing, the suspension of Vero cell is placed in T-flask with serum-free medium and incubated at 36.5°C (±1°C) until the coverage of the cell monolayer is 90 to 100% of the T-flask cultivation area. The flasks are removed from the incubator and the cells are submitted to a new subculture. In this process, the cell monolayer is washed with saline solution buffered with phosphate 0.02M and detached with recombinant trypsin (Tryple Select® - GIBCO). The cells are suspended in serum-free medium and split into TC-flasks containing the same medium. The TC-flasks are incubated again at 36.5°C (± 1°C) until reaching a coverage of 90 to 100% and then further subcultured. Amplification of the cells is initially, made in 225 cm^2 TC-flasks and later in a Cell Factory System™ (CFS) with 10 tray layers.

[0054] STEP 4. Preparation of Working Dengue Virus Banks DEN1, DEN2, DEN3 and DEN4

[0055] TC-flasks with 225 cm^2 of culture area containing amplified Vero cells are infected with the dengue virus strains rDEN1Δ30-1545 (SEQ ID NO:1); rDEN2/4Δ30(ME)-1495,7163 (SEQ ID NO:2); rDEN3Δ30/31-7164 (SEQ ID NO:3); and

rDEN4Δ30-7132,7163,8308 (SEQ ID NO:4), separately. The MOI (*Multiplicity of Infection*) used for virus infection is different for each serotype: 0.01 to 0.03 for DENV 1 and DENV 4, 0.02 to 0.04 for DENV 2 and 0.05 to 0.08 for DENV3. The infected cultures are incubated at 36.5°C (±1°C). After 8 days of incubation, supernatants of the cultures infected with DEN1Δ30, DEN2/4Δ30(ME)-1495,7163, DEN3Δ30/31-7164 and DEN4Δ30-7132,7163,8308 are separately harvested, filtered through a sterilizing membrane and stored in a freezer at -80°C (±5°C). The culture medium of flasks is replaced, and the flasks are again incubated at 36.5°C (±1°C). This procedure is repeated for three consecutive days to produce at the end four samples of the supernatants. For cultures infected with DEN3, this procedure begins on the 10th day of incubation. Samples of each harvest of the cultures' supernatant are taken for sterility and virus titration tests.

[0056] In the preparation of working banks, harvests approved in sterility tests, with titers higher than $10^{5.0}$ PFU/ml are mixed, distributed into cryotubes with 2 to 4 mL and maintained in liquid nitrogen. The bank is used after being approved in the following tests: Viral Identity, Sterility, Titration, Adventitious Agents in Cells and Animals, Hemadsorbents Virus and Mycoplasmas.

[0057] STEP 5. Production of Dengue Virus serotypes 1, 2, 3 and 4 for dengue vaccine formulation

[0058] After amplification, Vero cells contained in TC-flasks or Cell Factory System™ obtained from the amplification process, as described in step 3, are trypsinized and suspended in serum-free medium (OptiPRO® AGT - GIBCO). The Vero cell suspension obtained is inoculated

with dengue virus strains rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1,495.7163, rDEN3Δ30/31-7164 and rDEN4Δ30-7132,7163,8308, from the banks of dengue virus prepared in step 4 of the process for production of dengue vaccine. For inoculation the different MOIs (*Multiplicity of Infection*) for each serotype are used: 0.01 to 0.03 for DENV 1 and DENV 4, 0.02 to 0.04 for DENV 2 and 0.05 to 0.08 for DENV3. After inoculation, the virus/cell suspension is stirred at 32°C (±1°C) for 30 to 60 minutes and then distributed in 225 cm^2 TC-flasks or CFS with 10 tray layers. Serum-free culture media is added to cultures until it reaches the volume of 100 to 150 mL in the TC-flask and 1,200 to 1,800 ml for CFS. For CFS with different numbers of tray layers, it is calculated that the volume of culture medium to be added by making a rule of three. The cultures are incubated at 36.5°C (± 1°C). On the 8th or 10th day of incubation, 50% to 60% of the medium is removed, and the same volume of serum-free medium is added in the cultures. The cultures are incubated again at 36.5°C (± 1°C). The harvest of the supernatants of infected Vero cell cultures occur from the 10th to the 20th day after inoculation of dengue virus.

[0059] The harvest process includes the removal of the supernatants of the TC-flasks or CFS cultures infected, mixture of the supernatants harvested, a sterilizing filtration of this mixture, distribution of the dengue virus suspension filtered in polypropylene/polycarbonate flasks and storage in a freezer at -80°C (± 5°C). Samples are taken for Sterility and Viral Titration tests. After approbation in the tests, the flasks with the virus dengue suspension are removed from the freezer and forwarded to the concentration process.

[0060] The virus dengue suspension harvested are thawed and concentrated by tangential filtration process using a Pellicon® System (Millipore) with a membrane of 30 to 50 kDa of porosity. Samples are taken for control quality tests: Viral titration and Sterility. The viral concentrate (C1) of rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1495,7163, rDEN3Δ30/31-7164, or rDEN4Δ30-7132,7163,8308 is denominated and stored at -80°C (± 5°C).

[0061] STEP 6. Preparation of dengue virus Bulks

[0062] Dengue virus concentrate C1 (rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1495,7163, rDEN3Δ30/31-7164, or rDEN4Δ30-7132,7163,8308) are removed from the freezer at -80°C (±5°C), thawed and subjected to the following process: the virus concentrate is diluted with Leibovitz medium without phenol red and dilution factor used is 5 to 10 times its initial volume. The concentrate diluted is concentrated again, by tangential filtration (Pellicon system) to a volume 2.5 to 3 times its initial volume. This concentrate is called C2.

[0063] The concentrate C2 is filtered in membrane with 0.2µm of porosity, distributed in tubes/flasks and stored in a freezer at -80°C (±5°C). Samples are taken for quality control tests (Sterility and Bacterial Endotoxin, Mycoplasmas, Adventitious Agents in cells, Hemadsorbents Virus, Identity and Viral titration). After approbation in quality control tests, the Bulk is released to the formulation of monovalent vaccine.

[0064] The dengue virus Bulks lots produced in 2013 and 2014 are in table 1.

Table 1. Bulks of rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1495,7163, rDEN3Δ30/31-7164, and rDEN4Δ30-7132,7163,8308 dengue virus produced in 2013 and 2014.

Bulks	Lots	Number of flasks	Viral titer $Log_{10}PFU/ml$	Quality Control Tests	
				Bacterial Endotoxin (UE/mL)	Other tests
IB-DEN1Δ30/Vero/M	01/13	18	6.8	<1.25	Approved
	02/13	40	5.8	<1.25	Approved
	01/14	43	6.4	<0.50	Approved
	02/14	16	6.9	<0.73	Approved
	03/14	24	6.1	<0.51	Approved
	04/14	26	6.8	<0.50	Approved
IB-DEN2/4Δ30/Vero/M	01/13	19	5.7	<1.25	Approved
	02/13	32	5.9	<1.25	Approved
	01/14	39	6.4	<0.50	Approved
	02/14	21	7.0	4.43	Approved
	03/14	21	7.0	<0.50	Approved
	04/14	40	6.5	<0.50	Approved
IB-DEN3Δ30/31Vero/M	01/13	17	6.1	<1.25	Approved
	02/13	45	6.1	<1.25	Approved
	02/14	22	6.8	<0.50	Approved
	03/14	23	6.6	<0.50	Approved
IB-DEN4Δ30/Vero/M	01/13	50	5.9	<1.25	Approved
	02/13	35	6.3	<1.25	Approved
	01/14	23	6.9	0.68	Approved
	02/14	19	6.0	<0.50	Approved
	03/14	30	6.8	0.68	Approved

PS. The endotoxin value until 50UE/mL is considered satisfactory, since the final product must be smaller or equal to 10UE/mL.

[0065] STEP 7. Formulations of monovalent vaccines rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1495,7163, rDEN3Δ30/31-7164, and rDEN4Δ30-7132,7163,8308 and dengue vaccine serotypes

1,2,3,4 (attenuated)

[0066] Four dengue monovalent vaccines are formulated, one for each type of dengue virus (rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1495,7163, rDEN3Δ30/31-7164, and rDEN4Δ30-7132,7163,8308). The calculations for formulation consist in determining a dilution factor so that the monovalent vaccines according with each serotype are provided in the following amounts: 5.7±0.2, 5.6±0.2, 6.1±0.2 and 5.8±0.2 Log_{10}PFU/ml for DENV1, DENV2, DENV3, and DENV4, respectively.

[0067] The formula to determine the dilution factor is: antilog of the bulk titer (Log_{10} PFU/ml) divided by the antilog of viral titer (Log_{10} PFU/ml) desired for each type of monovalent. The formulations of rDEN1Δ30-1545, rDEN2/4Δ30(ME)-1495,7163, rDEN3Δ30/31-7164, and rDEN4Δ30-7132,7163,8308 monovalent are made with Leibovitz (L-15) medium without phenol red concentrate twice, i.e., the medium remains with its original components twice concentrated.

[0068] To make the dengue vaccine serotypes 1,2,3,4 (attenuated) formulation, the monovalent 1, 2, 3 and 4 vaccines are mixed in the same ratio of volume. After homogenization of the formulated tetravalent vaccine, the product is subjected to a filtration (membrane with 0.2µm of porosity) and samples are taken to the flowing quality control tests: Sterility, Bacterial Endotoxin, Viral Titration, pH, and Appearance of the product.

[0069] STEP 8. Filling, Lyophilization and Sealing of the tetravalent dengue vaccine.

[0070] After the tetravalent dengue vaccine formulation, the product is used to fill vials with 3 ml of vaccine. Samples of filled vials are taken for quality

control tests (Sterility, Endotoxin Bacterial, Viral Titration, Appearance and pH).

[0071] After the filling of the vials they are transported to the lyophilizer and start the freeze-drying process. In this process, the following parameters are established: freezing (-30 to -50°C), vacuum (20 to 100µbar), drying from -30 to -50°C (36 to 40h), from -5 to -10°C (18 to 24h) and 25 to 29°C (8 to 15h).

[0072] At the end of freeze-drying process, the vials with the lyophilized vaccine are subjected to a sealing process. The final product, dengue vaccine 1,2,3,4 (attenuated), is stored at 2-8°C. Samples of the vaccine lot are tested for Sterility, Bacterial Endotoxin, Viral Titration, Product Appearance before and after reconstitution with the diluent, pH, Residual DNA and Residual Moisture tests.

[0073] The product can be denominated **dengue vaccine serotypes 1,2,3,4 (attenuated)**, when following the Brazilian regulations for designation of vaccines.

[0074] The product can be reconstituted with 5.0 mL of the specific diluent to this vaccine (mixture of sodium phosphates), which corresponds to 10 doses/0.5 mL/vial. Each dose contains $10^{2.7}$ to $10^{3.7}$ PFU/dose of each of dengue virus used in the dengue vaccine 1,2,3,4 (attenuated) formulation. The results of quality control tests obtained from six batches produced in 2014, are shown in table 2.

Table 2. Dengue vaccine serotypes 1,2,3,4 (attenuated) lots produced in 2014.

Lots	Results of quality control tests					
	Viral titer Log_{10}/PFU/dose	Bacterial Endotoxin	PH	Residual DNA	Residual moisture	Sterility Product

	DEN1	DEN2	DEN3	DEN4	(UE/mL)		(pg/dose)	%	appearance
01/14	3.0	3.4	3.0	3.2	<0.500	6.9	32.6	1.33	Approved
02/14	2.7	3.1	2.8	3.2	<0.500	6.9	27.2	2.01	Approved
03/14	3.1	3.2	2.9	3.2	<0.500	6.9	52.6	1.99	Approved
04/14	3.2	3.6	3.1	3.6	0.956	6.9	40.8	0.89	Approved
05/14	3.5	3.6	3.0	3.5	1.030	6.9	31.5	0.52	Approved
06/14	3.4	3.5	3.5	3.4	<0.500	6.9	35.1	0.35	Approved

Values for lot approval: Bacterial endotoxin= 10UE/ml; Viral titration= $10^{2.7}$ to $10^{3.7}$ PFU/dose; **pH=** 6.8 to 7.2; Residual Cellular DNA ≤100pg/dose; Residual moisture ≤3%; Product appearance **before** the reconstitution: slightly yellowish (homogeneous cake (SYHC) and Product appearance after reconstitution: slightly yellowish clear liquid (SYCL).

III DILUENT FOR THE RECONSTITUTION OF DENGUE VACCINE 1,2,3,4 (ATTENUATED)

Composition:

For the preparation of 1,000 mL

Solution 1 (sodium phosphate monobasic dihydrate 0.2 M)..... 195mL

Solution 2 (sodium phosphate dibasic heptahydrate, 0.2 M)..... 05mL

WFI water qsp.....1,000mL

[0075] Presentation: vials or ampoules with 5.0 mL

IV STABILITY STUDIES OF DENGUE VACCINE 1,2,3,4 (ATTENUATED)

STABILITY STUDIES at 2-8°C

[0076] The results of the tests carried out in the samples of three batches of dengue vaccine 1,2,3,4 (attenuated) stored at 2-8°C are shown in tables 3 and 4.

Table 3 Results of sterility and physical-chemical tests found in the lots of dengue vaccine 1,2,3,4 (attenuated) stored at 2-8

Vaccine Lots	Months of Storage 2-8°C	Results of Samples			
		Sterility	pH	Appearance before and after reconstitution	Residual moisture (%)
01/10	12	Approved	7.1	SYHC and SYCL	2.91
02/10	12	Approved	7.1	SYHC and SYCL	2.79
01/11	12	Approved	7.1	SYHC and SYCL	2.48

SYHC: slightly yellowish homogeneous dried cake. SYCL: slightly yellowish clear liquid.

III DILUENT FOR THE RECONSTITUTION OF DENGUE VACCINE 1,2,3,4 (ATTENUATED)

Composition:

[0077] The analysis of the results of Table 3 indicates that for up to at least one year of storage the titers of dengue virus serotypes 1, 2, 3 and 4 remained satisfactory. After 18 months of storage at 2-8°C, titers of DENV3 and DENV4 fell below the minimum required ($10^{2.7}$ PFU/dose of vaccine).

Table 4 Results of dengue virus titers components of dengue vaccine 1,2,3,4 (attenuated) stored at 2-8°C.

Vaccine Lots	Serotypes	Dengue virus titers (Log_{10} PFU/dose)					
		Months of Storage at 2-8°C					
		0	3	6	9	12	18
01/10	DEN1	3.1	3.2	3.3	3.3	3.1	3.0
	DEN2	3.1	3.2	3.3	3.3	3.1	3.0
	DEN3	3.2	3.3	3.1	3.1	3.2	2.0
	DEN4	3.3	3.4	3.4	3.4	3.3	2.8
02/10	DEN1	3.1	3.1	3.6	3.3	3.1	3.2
	DEN2	3.2	3.2	3.3	3.3	3.2	3.0

	DEN3	3.2	3.2	3.1	3.1	3.1	2.2
	DEN4	3.2	3.2	3.4	3.4	3.2	2.2
01/11	DEN1	3.1	3.4	3.1	3.1	3.1	3.0
	DEN2	3.2	3.3	3.1	3.0	3.0	3.0
	DEN3	3.2	3.1	3.1	3.1	3.0	2.4
	DEN4	3.1	3.1	3.1	3.0	3.0	1.7

REFERENCES

[1] Bhatt S, Gething PW, Brady OJ, Messina JP, Farlow AW, Moyes CL et.al 2013. The global distribution and burden of dengue. Nature;496:504-507.

[2] Brady OJ, Gething PW, Bhatt S, Messina JP, Brownstein JS, Hoen AG et al. Refining the global spatial limits of dengue virus transmission by evidence-based consensus. PLoS Negl Trop Dis. 2012;6:e1760. doi:10.1371/journal.pntd.0001760.

[3] Ministério da Saúde Brazil. Boletim Epidemiológico. Monitoramento de casos de dengue. Vol. N° 11.2015 in htt//portalsaude.gov.br/index.php/situação.e

[4] Ishikawa, T.; Yamanaka, A.; Konishi E. 2014. A review of successful flavivirus vaccines and the problems with those flaviviruses for which vaccines are not yet available. Vaccine. 32: 1326-1337.

[5] WHO (World Health Organization). Dengue vaccines. In the world wide web internet site "who.int/immunization/research/development/dengue_vaccines/en/" [accessed 30 April 2015].

[6] Durbin AP, Karron RA, Sun W, Vaughn DW, Reynolds MJ, Perreault JR, Thumar B, Men R, Lai CJ, Elkins WR, Chanock RM, Murphy BR, Whitehead SS. Attenuation and immunogenicity in humans of a live dengue virus type-4 vaccine candidate with a 30 nucleotide deletion in its 3'-untranslated region. AM. J. Trop. Med. Hyg. (2001) Nov 65(5):405-13.

[7] Whitehead SS, Falgout B, Hanley KA, Blaney Jr JE Jr, Markoff L, Murphy BR. A live, attenuated dengue virus type 1 vaccine candidate with a 30-nucleotide deletion in the 3' untranslated region is highly attenuated and immunogenic in monkeys. J. Virol. (2003) Jan 77(2): 1653-7.

[8] Wiggan O'Neil, Livengood JA, Silengo SJ, Kinney RM , Osorio JE, Huang CYH, Stinchcomb DT. Novel formulations enhance the thermal stability of live-attenuated flavivirus vaccines. Vaccine 29 (2011) 7456- 7462.

[9] Burke CJ,Hsu T-A, Volkin DB. Formulation, Stability and Delivery of Live Attenuated Vaccines for Human Use. Critical Review in Therapeutic Drug Carrier Systems (1999) 16(1):1-8.

[0078] Having described certain embodiments of the invention, one skilled in the art will appreciate in the appended claims that many modifications and variations of the present invention are possible in light of the above teachings. It is therefore, to be understood that, within the scope of the appended claims and disclosure provided herein, the invention may be practiced otherwise than as specifically described in certain embodiments.