Vaccine

The present invention is associated with the development of a novel combined immunogenic peptide vaccine against PCSK9 derived from a combination of two different PCSK9 epitopes linked to an immunogenic carrier. The vaccine is established for the prevention and/or treatment of health disorders, caused by the hyperlipidemia, hypercholesterolemia and atherosclerosis.

Hyperlipidemia, hypercholesterolemia, hypertension and atherosclerosis are cardiovascular disorders considered as leading factors for the worldwide lethality. Together with factors such obesity, diabetes, smoking and lack of physical activity major factors for the development of cardiovascular alterations are genetic disorders such as autosomal dominant hypercholesterolemia (ADH). ADH is considered as an important factor for the development of cardiovascular disorders and is manifested by impaired cholesterol metabolism and increased levels of low density lipoprotein cholesterol, which subsequently leads to the formation of premature coronary artery disease (CAD).

It is known that three major genetic alterations could cause the development of ADH. The classical form of ADH is caused by mutations in the low density lipoprotein receptor (hereafter called LDLR). In addition, mutations in the apolipoprotein B-100 (apoB-100) and more specifically in its ligand-binding domain disrupt the binding of the ApoB-100 to LDLR, which subsequently leads to impaired cholesterol metabolism. Finally, the third and most recently discovered element which by genetic alterations could be involved in the development of the ADH is the proprotein convertase subtilisin/kexin type 9 (hereafter called PCSK9).

PCSK9, also known as neural apoptosis-regulated convertase 1 (NARC-1), is a proteinase K-like subtilase identified as the ninth member of the secretory subtilase family. The PCSK9 protein is synthesized as a ~72kDa proprotein, which undergoes

autocatalytically cleavage between the prodomain and catalytic domain leading consequently to the generation of the mature protein form. The prodomain (~14kDa) remains bound to the mature protein 63kDa and in this form the mature protein is proceeded towards the secretory pathway.

The role of PCSK9 in the lipid homeostasis is already well known. Not only that the expression of PCSK9 is regulated by the Sterol-Regulatory Element Binding Protein (hereafter called SREBP) in a similar manner to other SREBP-responsive genes involved in lipid homeostasis. But PCSK9 is also involved in the low density lipoprotein cholesterol (hereafter called LDLc) clearance by promoting LDLR internalization and degradation.

In vitro and *in vivo* studies highlighted the essential role of PCSK9 in the low density lipoprotein cholesterol uptake from the blood. On one side PCSK9 adenovirus overexpression significantly increased the levels of circulating LDLc, and on the other side PCSK9-/- mice showed a 2.8 fold increase in the levels of LDLR and reduction of LDLc compared to wild type animals.

The gene is localized at human chromosome 1p33-p34.3 and is expressed in tissues such as liver, kidney, cerebellum and small intestines. Many studies confirmed that “gain of function mutations” are causing decrease in the LDLR levels and a consequent hypercholesterolemia and predisposition to atherosclerosis. “Loss of function mutations” are increasing the levels of LDLR with a consequent decrease in low density lipoprotein cholesterol (LDLc).

Altogether, PCSK9 regulates LDLR levels posttranscriptionally and therefore is an attractive target for the treatment of atherosclerosis.

Meanwhile, numerous different strategies and approaches have been established to inhibit the function of PCSK9.

Application of siRNA against PCSK9 in monkeys (Macaca fascicularis) led to a significant reduction of total cholesterol. Other investigations with monoclonal and polyclonal antibodies against PCSK9 in mice and non-human primates succeeded to up-regulate LDLR with a concomitant decrease in the levels of total cholesterol and LDLc.

The reduction of PCSK9 levels by monoclonal or polyclonal antibody therapy or inactivation of PCSK9 upon small molecule inhibitors and knock out technology did not show any side effects in different animal models. Therefore, all in all PCSK9 is a very attractive target for the treatment of atherosclerosis.

WO 2011/027257 relates to immunogenic fragments derived from PCSK9 which can be used in a vaccine for the treatment, prevention and alleviation of PCSK9-mediated disorders.

In the WO 2009/100297 antagonists of human PCSK9 are disclosed.

WO 2010/057242 relates to vaccines which comprise peptides derived from a fragment of human PCSK9.

An object of the present invention is to provide a peptide based vaccine against PCSK9 that is able to inhibit PCSK9 and abrogate/decrease the interaction of PCSK9 and LDLR. This leads to increased levels of LDLR in liver hepatocytes and subsequent reduction of total cholesterol and LDLc.

This object is achieved by a vaccine comprising a multiplicity (more than one, at least two) of fragments of Proprotein convertase subtilisin/kexin type 9 (PCSK9), wherein a first fragment of said at least two fragments comprises at least 8 consecutive amino acid residues of amino acid residues 150 to 170 and a second fragment of said at least two fragments comprises at least 8 consecutive amino acid residues of amino acid residues 205 to 225 of PCSK9 (SEQ ID No. 9).

It turned surprisingly out that a vaccine comprising at least two different peptidic fragments of PCSK9 as defined above is able to increase the amount of LDL receptors much more efficiently compared to a vaccine comprising only one fragment of PCSK9. The administration of the vaccine of the present invention leads, for instance, to an increase in the levels of low density lipoprotein receptor in liver hepatocytes *in vivo*. As a consequence thereof, the mean values of LDLc and total cholesterol in blood plasma upon administration of vaccines decrease significantly. Therefore, the administration of a vaccine according to the present invention allows treating or preventing diseases caused by hyperlipidemia, hypercholesterolemia and/or atherosclerosis with a much higher efficiency and accuracy compared to the administration of the single peptides. In a preferred embodiment of the present invention all PCSK9 fragments of the vaccine of the present invention are derived from the PCSK9 fragments consisting of amino acid residues 150 to 170 and 205 to 225 of SEQ ID No. 9.

The peptidic fragments used in the vaccine of the present invention comprise at least 8, preferably at least 9, more preferably at least 10, consecutive amino acid residues of amino acid residues 150 to 170, preferably of amino acid residues 153 to 165, and 205 to 225, preferably of amino acid residues 209 to 222, of PCSK9 (SEQ ID No. 9).

SEQ ID No. 9 (PCSK9 amino acid sequence):

MGTVSSRRSW WPLPLLLLLL LLLGPAGARA QEDEDGDYEE LVLALRSEED
GLAEAPEHGT TATFHRCAKD PWRLPGTYVV VLKEETHLSQ SERTARRLQA
QAARRGYLTK ILHVFHGLLP GFLVKMSGDL LELALKLPHV DYIEEDSSVF
AQSIPWNLER ITPPRYRADE YQPPDGGSLV EVYLLDTSIQ SDHREIEGRV
MVTDFENVPE EDGTRFHRQA SKCDSHGTHL AGVVSGRDAG VAKGASMRSL
RVLNCQGKGT VSGTLIGLEF IRKSQLVQPV GPLVVLLPLA GGYSRVLNAA
CQRLARAGVV LVTAAGNFRD DACLYSPASA PEVITVGATN AQDQPVTLGT
LGTNFGRCVD LFAPGEDIIG ASSDCSTCFV SQSGTSQAAA HVAGIAAMML
SAEPELTLAE LRQRLIHFSA KDVINEAWFP EDQRVLTPNL VAALPPSTHG

AGWQLFCRTV WSAHSGPTRM ATAVARCAPD EELLSCSSFS RSGKRRGERM
EAQGGKLVCR AHNAFGGEGV YAIARCCLLP QANCSVHTAP PAEASMGTRV
HCHQQGHVLT GCSSHWEVED LGTHKPPVLR PRGQPNQCVG HREASIHASC
CHAPGLECKV KEHGIPAPQE QVTVACEEGW TLTGCSALPG TSHVLGAYAV
DNTCVVRSRD VSTTGSTSEG AVTAVAICCR SRHLAQASQE LQ

The fragments derived from PCSK9 comprise or consist of preferably 8 to 20, more preferably 10 to 15, amino acid residues. According to a particularly preferred embodiment of the present invention the peptides derived from amino acid residues 150 to 170 of PCSK9 comprise 8 to 15, preferably 10 to 13, amino acid residues. The peptides derived from amino acid residues 205 to 225 of PCSK9 comprise 8 to 16, preferably 10 to 14, amino acid residues.

The vaccine of the present invention is a combination of at least 2, preferably at least 3, more preferably at least 4, even more preferably at least 5, peptides derived from amino acid residues 150 to 170 and 205 to 225 of PCSK9 (SEQ ID No. 9). This combination comprises at least two sequences with different epitope origin.

The peptides of the present invention can be chemically synthesized by methods which are well known in the art. Of course it is also possible to produce the peptides of the present invention using recombinant methods. The peptides can be produced in microorganisms such as bacteria, yeast or fungi, in eukaryotic cells such as mammalian or insect cells, or in a recombinant virus vector such as adenovirus, poxvirus, herpes virus, Simliki forest virus, baculovirus, bacteriophage, sindbis virus or Sendai virus. Suitable bacteria for producing the peptides include E. coli, B. subtilis or any other bacterium that is capable of expressing such peptides. Suitable yeast cells for expressing the peptides of the present invention include Saccharomyces cerevisiae, Schizosaccharomyces pombe, Candida, Pichia pastoris or any other yeast capable of expressing peptides.

Corresponding means and methods are well known in the art. Also methods for isolating and purifying recombinantly produced peptides are well known in the art and include e.g. gel filtration, affinity chromatography, ion exchange chromatography etc..

To facilitate isolation of the peptides of the present invention, fusion polypeptides may be made wherein the peptides are translationally fused (covalently linked) to a heterologous polypeptide which enables isolation by affinity chromatography. Typical heterologous polypeptides are His-Tag (e.g. His_6; 6 histidine residues), GST-Tag (Glutathione-S-transferase) etc. The fusion polypeptide facilitates not only the purification of the peptides but can also prevent the degradation of the peptides during the purification steps. If it is desired to remove the heterologous polypeptide after purification the fusion polypeptide may comprise a cleavage site at the junction between the peptide and the heterologous polypeptide. The cleavage site may consist of an amino acid sequence that is cleaved with an enzyme specific for the amino acid sequence at the site (e.g. proteases).

According to the present invention at least one fragment is derived from amino acid residues 150 to 170 and at least one fragment is derived from amino acid residues 205 to 225 of PCSK9 (SEQ ID No. 9).

The vaccine of the present invention comprises PCSK9 fragments of different parts of the PCSK9 protein. Therefore, it is particularly preferred that at least one fragment is derived from one specific PCSK9 fragment, whereas at least one fragment is derived from another specific PCSK9 fragment.

According to another preferred embodiment of the present invention the at least two fragments of PCSK9 are selected from the group consisting of peptides having amino acid sequence SIPWNLERITPPR (SEQ ID No. 2), PEEDGTRFHRQASK (SEQ ID No. 3), PEEDGTRFHRQA (SEQ ID No. 4), EEDGTRFHRQASK (SEQ ID No.

5), EEDGTRFHRQAS (SEQ ID No. 6), SIPWNLERITP (SEQ ID No. 7) and SIPWNLERIT (SEQ ID No. 8).

The at least two fragments of PCSK9 may also consist of or comprise an amino acid sequence selected from the group consisting of FAQSIPWNLERITPPRYRAD (SEQ ID No. 10), FAQSIPWNLERITPPRYRA (SEQ ID No. 11), FAQSIPWNLERITPPRYR (SEQ ID No. 12), FAQSIPWNLERITPPRY (SEQ ID No. 13), FAQSIPWNLERITPPR (SEQ ID No. 14), FAQSIPWNLERITPP (SEQ ID No. 15), AQSIPWNLERITPPRYRAD (SEQ ID No. 16), QSIPWNLERITPPRYRAD (SEQ ID No. 17), SIPWNLERITPPRYRAD (SEQ ID No. 18), AQSIPWNLERITPPRYRA (SEQ ID No. 19), QSIPWNLERITPPRYRA (SEQ ID No. 20), SIPWNLERITPPRYRA (SEQ ID No. 21), AQSIPWNLERITPPRYR (SEQ ID No. 22), QSIPWNLERITPPRYR (SEQ ID No. 23), SIPWNLERITPPRYR (SEQ ID No. 24), QSIPWNLERITPPRY (SEQ ID No. 25), SIPWNLERITPPRY (SEQ ID No. 26), AQSIPWNLERITPPR (SEQ ID No. 27), QSIPWNLERITPPR (SEQ ID No. 28), SIPWNLERITPP (SEQ ID No. 29), ENVPEEDGTRFHRQASKCDS (SEQ ID No. 30), ENVPEEDGTRFHRQASKCD (SEQ ID No. 31), ENVPEEDGTRFHRQASKC (SEQ ID No. 32), ENVPEEDGTRFHRQASK (SEQ ID No. 33), NVPEEDGTRFHRQASKCDS (SEQ ID No. 34), VPEEDGTRFHRQASKCDS (SEQ ID No. 35), PEEDGTRFHRQASKCDS (SEQ ID No. 36), NVPEEDGTRFHRQASKCD (SEQ ID No. 37), VPEEDGTRFHRQASKCD (SEQ ID No. 38), PEEDGTRFHRQASKCD (SEQ ID No. 39), NVPEEDGTRFHRQASKC (SEQ ID No. 40), VPEEDGTRFHRQASKC (SEQ ID No. 41), PEEDGTRFHRQASKC (SEQ ID No. 42), NVPEEDGTRFHRQASK (SEQ ID No. 43), VPEEDGTRFHRQASK (SEQ ID No. 44), PEEDGTRFHRQAS (SEQ ID No. 45).

The at least one fragment of PCSK9 has preferably an amino acid sequence selected from the group consisting of SIPWNLERITPPR (SEQ ID No. 2), SIPWNLERITP (SEQ ID No. 7) and SIPWNLERIT (SEQ ID No. 8) and at least one fragment of PCSK9 has an amino acid sequence selected from the group consisting of PEEDGTRFHRQASK (SEQ ID No. 3), PEEDGTRFHRQA (SEQ ID No. 4), EEDGTRFHRQASK (SEQ ID No. 5) and EEDGTRFHRQAS (SEQ ID No. 6).

According to a preferred embodiment of the present invention the vaccine of the present invention comprises SIPWNLERITPPR (SEQ ID No. 2) and PEEDGTRFHRQASK (SEQ ID No. 3), SIPWNLERITPPR (SEQ ID No. 2) and PEEDGTRFHRQA (SEQ ID No. 4), SIPWNLERITPPR (SEQ ID No. 2) and EEDGTRFHRQASK (SEQ ID No. 5), SIPWNLERITPPR (SEQ ID No. 2) and EEDGTRFHRQAS (SEQ ID No. 6), PEEDGTRFHRQASK (SEQ ID No. 3) and SIPWNLERITP (SEQ ID No. 7), PEEDGTRFHRQASK (SEQ ID No. 3) and SIPWNLERIT (SEQ ID No. 8), PEEDGTRFHRQA (SEQ ID No. 4) and SIPWNLERITP (SEQ ID No. 7), PEEDGTRFHRQA (SEQ ID No. 4) and SIPWNLERIT (SEQ ID No. 8), EEDGTRFHRQASK (SEQ ID No. 5) and SIPWNLERITP (SEQ ID No. 7), EEDGTRFHRQASK (SEQ ID No. 5) and SIPWNLERIT (SEQ ID No. 8), EEDGTRFHRQAS (SEQ ID No. 6) and SIPWNLERITP (SEQ ID No. 7) or EEDGTRFHRQAS (SEQ ID No. 6) and SIPWNLERIT (SEQ ID No. 8), whereby a vaccine comprising PEEDGTRFHRQA (SEQ ID No. 4) and SIPWNLERITP (SEQ ID No. 7), EEDGTRFHRQASK (SEQ ID No. 5) and SIPWNLERITP (SEQ ID No. 7), EEDGTRFHRQASK (SEQ ID No. 5) and SIPWNLERIT (SEQ ID No. 8) or EEDGTRFHRQAS (SEQ ID No. 6) and SIPWNLERIT (SEQ ID No. 8) is particularly preferred.

The at least two fragments of PCSK9 preferably comprise a cysteine residue at (bound to) the C- and/or N-terminal end.

The provision of a cysteine residue at the N- and/or C-terminus of a peptide may facilitate its conjugation to a carrier, for instance, and/or may enhance the immunogenicity of the peptide.

According to a preferred embodiment of the present invention the at least two fragments of PCSK9 (i.e. the at least two peptides derived from PCSK9) are coupled, individually or in combination, to a pharmaceutically acceptable carrier, preferably KLH (Keyhole Limpet Hemocyanin).

According to a preferred embodiment of the present invention the at least two fragments of PCSK9 are coupled to a pharmaceutically acceptable carrier, preferably KLH (Keyhole Limpet Hemocyanin), tetanus toxoid, albumin-binding protein,

hepatitis B core antigen, bovine serum albumin, a dendrimer (MAP), peptide linkers (or flanking regions) as well as the adjuvant substances described in Singh et al., Nat. Biotech. 17 (1999), 1075-1081 (in particular those in Table 1 of that document), and O'Hagan et al., Nature Reviews, Drug Discovery 2 (9) (2003), 727-735 (in particular the endogenous immuno-potentiating compounds and delivery systems described therein), or mixtures thereof. The conjugation chemistry (e.g. via heterobifunctional compounds such as GMBS and of course also others as described in "Bioconjugate Techniques", Greg T. Hermanson) in this context can be selected from reactions known to the skilled man in the art. Moreover, the vaccine composition may be formulated with an adjuvant, preferably a low soluble aluminum composition, in particular aluminum hydroxide. Of course, also adjuvants like MF59 aluminum phosphate, calcium phosphate, cytokines (e.g., IL-2, IL-12, GM-CSF), saponins (e.g., QS21), MDP derivatives, CpG oligonucleotides, LPS, MPL, polyphosphazenes, emulsions (e.g., Freund's, SAF), liposomes, lipopeptides, virosomes, iscoms, cochleates, PLG microparticles, poloxamer particles, virus-like particles, heat-labile enterotoxin (LT), cholera toxin (CT), mutant toxins (e.g., LTK63 and LTR72), microparticles and/or polymerized liposomes may be used.

The peptides of the present invention are preferably bound to the carrier or adjuvant via a linker, which is selected from the group consisting of NHS-poly (ethylene oxide) (PEO) (e.g. NHS-PEO_4-maleimide).

A vaccine which comprises a peptide of the present invention and the pharmaceutically acceptable carrier may be administered by any suitable mode of application, e.g. intradermally (i.d.), intraperitoneally (i.p.), intramuscularly (i.m.), intranasally, orally, subcutaneously (s.c.), etc. and in any suitable delivery device (O'Hagan et al., Nature Reviews, Drug Discovery 2 (9), (2003), 727-735). The compound of the present invention is preferably formulated for intradermal, subcutaneous or intramuscular administration.

Means and methods for obtaining respective formulations are known to the person skilled in the art (see e.g. "Handbook of Pharmaceutical Manufacturing Formulations", Sarfaraz Niazi, CRC Press Inc, 2004).

Thus, the vaccine according to the present invention comprises at least two peptides which are preferably formulated for intradermal, subcutaneous or intramuscular administration.

The at least two peptides/fragments in the vaccine of the present invention are preferably formulated with an adjuvant, preferably aluminum hydroxide.

According to a preferred embodiment of the present invention the vaccine is used in the treatment and/or prevention of disorders caused by hyperlipidemia, hypercholesterolemia and/or atherosclerosis, preferably cardiovascular diseases, stroke or peripheral vascular diseases.

As outlined, the above mentioned peptides and the combinations thereof are able to induce the formation of antibodies which are able to bind specifically PCSK9. The interaction of the antibodies with PCSK9 leads to the increase of low density lipoprotein receptor in liver hepatocytes in vivo and subsequent reduction of the plasma total cholesterol levels.

The disease associated with atherosclerosis is preferably selected from the group consisting of peripheral arterial occlusive disease, coronary heart disease, apoplectic cerebral insultus and stroke.

The terms "diseases associated with hyperlipidemia, hypercholesterolemia and/or atherosclerosis" and "disorders caused by hyperlipidemia, hypercholesterolemia and/or atherosclerosis" refer to diseases which are a consequence of hyperlipidemia, hypercholesterolemia and atherosclerosis.

These diseases include among others peripheral arterial occlusive disease,coronary heart disease and apoplectic cerebral insultus (see e.g. Steinberg, D. J Lipid Res 46(2005):179-190 and Steinberg, D. J Lipid Res 47(2006):1339-1351).

According to a preferred embodiment of the present invention the at least two fragments of PCSK9 are administered to an individual in an amount of 0.1 ng to 10 mg, preferably of 0.5 to 500 µg, more preferably 1 to 100 µg, per immunization. In a preferred embodiment these amounts refer to all fragments of PCSK9 present in the vaccine. In another preferred embodiment these amounts refer to each single fragment present in the vaccine. It is of course possible to provide a vaccine in which the specific fragments of PCSK9 are present in different or equal amounts. However, the peptide of the present invention may alternatively be administered to an individual in an amount of 0.1 ng to 10 mg, preferably 10 ng to 1 mg, in particular 100 ng to 300 µg/kg body weight.

The amount of peptides that may be combined with the carrier materials to produce a single dosage form will vary depending upon the host treated and the particular mode of administration. The dose of the vaccine may vary according to factors such as the disease state, age, sex and weight of the individual, and the ability of antibody to elicit a desired response in the individual. Dosage regime may be adjusted to provide the optimum therapeutic response. For example, several divided doses may be administered daily or the dose may be proportionally reduced as indicated by the exigencies of the therapeutic situation. The dose of the vaccine may also be varied to provide optimum preventative dose response depending upon the circumstances. For instance, the peptides and vaccine of the present invention may be administered to an individual at intervals of several days, one or two weeks or even months or years depending always on the level of antibodies directed to PCSK9.

In a preferred embodiment of the present invention the peptide/vaccine is applied between 2 and 10, preferably between 2 and 7, even more preferably up to 5 and most preferably up to 4 times. This number of immunizations may lead to a basic immunisation. In a particularly preferred embodiment the time interval between the subsequent vaccinations is chosen to be between 2 weeks and 5 years, preferably between 1 month and up to 3 years, more preferably between 2 months and 1.5 years. An exemplified vaccination schedule may comprise 3 to 4 initial vaccinations over a period of 6 to 8 weeks and up to 6 months. Thereafter the vaccination may be repeated every two to ten years. The repeated administration of the peptide/vaccine of the present invention may maximize the final effect of a therapeutic vaccination.

The vaccine of the present invention may also comprise antigens derived from other proteins which are also involved in the regulation of the LDL and/or HDL levels within a human body. For instance, the PCSK9 fragments of the present invention may be combined with epitopes derived from human CETP protein.

Typically, the vaccine contains the peptides of the present invention in an amount of 0.5 to 500 µg, preferably 1 to 100 µg and alternatively from 0.1 ng to 10 mg, preferably 10 ng to 1 mg, in particular 100 ng to 100 µg, or, alternatively, e.g. 100 fmol to 10 µmol, preferably 10 pmol to 1 µmol, in particular 100 pmol to 100 nmol. Typically, the vaccine may also contain auxiliary substances, e.g. buffers, stabilizers etc.

According to a preferred embodiment of the present invention relates to the use of two or more peptides. According to the present invention for the manufacture of a vaccine for preventing and/or treating of atherosclerosis and diseases associated with atherosclerosis, wherein the disease associated with atherosclerosis is preferably selected from

the group consisting of peripheral arterial occlusive disease, coronary heart disease, apoplectic cerebral insultus and stroke.

Yet another aspect of the present invention relates to a method for treating an individual suffering or at risk to suffer from atherosclerosis or a disease associated with atherosclerosis in the course of which a peptide or vaccine according to the present invention is administered to said individual.

Next to the vaccine of the present invention, the individual to be treated may receive also other active ingredients known to influence the LDL and/or HDL levels in humans and mammals such as statins, fibrates, nicotinic acid, cholesterol uptake inhibitor (e.g. ezetimibe), ApoA1 Milano, delipidated HDL, plant sterols. It is particularly preferred to administers to an individual the vaccine of the present invention together (i.e. at the same time, consecutively etc.) with statins.

The present invention is further illustrated in the following figures and examples without being restricted thereto.

Fig. 1 shows the amount of low density lipoprotein receptor in liver lysates for peptides with Sequence ID No. 1 (irrelevant peptide control), 4, 5, 6, 7 and 8 and combination A (SEQ ID No. 4 and 7), B (SEQ ID No. 5 and 7), C (SEQ ID No. 5 and 8) and D (SEQ ID No. 6 and 8) compared to control animals.

Fig.2 shows the percent decrease of plasma levels of total cholesterol (n=5 mice per group) for peptides with Sequence ID No. 1 (irrelevant peptide control), 4, 5, 6, 7 and 8 and combination A (SEQ ID No. 4 and 7), B (SEQ ID No. 5 and 7), C (SEQ ID No. 5 and 8) and D (SEQ ID No. 6 and 8).

EXAMPLES:

Materials and Methods

Vaccine:

The peptides were conjugated via the heterobifunctional linker GMBS (4-Maleimidobutyric acid N-hydroxysuccinimide ester) to KLH (Keyhole Limpet Hemocyanin).

15 µg of the peptides were suspended with aluminum hydroxide (end concentration of aluminum hydroxide was 0.2%). As buffer phosphate was used.

Table 1. Sequences used for the vaccine production

	Amino acid sequence	**Sequence Information**
SEQ ID No. 1	**RPETWIPNRSPIL**	irrelevant (control group)
SEQ ID No. 2	**SIPWNLERITPPR**	aa 153-165 of SEQ ID No. 9
SEQ ID No. 3	**PEEDGTRFHRQASK**	aa 209-222 of SEQ ID No. 9
SEQ ID No. 4	**PEEDGTRFHRQA**	aa 209-220 of SEQ ID No. 9
SEQ ID No. 5	**EEDGTRFHRQASK**	aa 210-222 of SEQ ID No. 9
SEQ ID No. 6	**EEDGTRFHRQAS**	aa 210-221 of SEQ ID No. 9
SEQ ID No. 7	**SIPWNLERITP**	aa 153-163 of SEQ ID No. 9
SEQ ID No. 8	**SIPWNLERIT**	aa 153-162 of SEQ ID No. 9
Combination A (SEQ ID No. 4 and 7)	**PEEDGTRFHRQA + SIPWNLERITP**	aa 209-220 + aa 153-163 of SEQ ID No. 9

Combination B (SEQ ID No. 5 and 7)	**EEDGTRFHRQASK + SIPWNLERITP**	aa 210-222 + aa 153-163 of SEQ ID No. 9
Combination C (SEQ ID No. 5 and 8)	**EEDGTRFHRQASK + SIPWNLERIT**	aa 210-222 + aa 153-162 of SEQ ID No. 9
Combination D (SEQ ID No. 6 and 8)	**EEDGTRFHRQAS + SIPWNLERIT**	aa 210-221 + aa 153-162 of SEQ ID No. 9

Animal experiments:

5 Balb/c mice were subcutaneously immunized. Mice had access to food and water ad libitum and were kept under a 12 h light/dark cycle. Age of mice at the beginning of experiments was usually 8 to 10 weeks.

Mice were injected four times in 2 week intervals with 15 µg of net peptide coupled to KLH and adsorbed to Alum as adjuvant in a volume of 1 ml in total via the s.c. route.

Blood was taken approximately 2 weeks after the final injection.

Protein ELISA:

To determine the immunogenicity of the vaccines, 96-well Nunc-Maxisorb plates were coated with recombinant human PCSK9 protein. Unspecific binding was blocked by incubation with blocking buffer (1% BSA in PBS). Appropriate serum dilutions were added to the wells serially diluted 1:2 fold and incubated for approximately 1 hour at 37°C. On every ELISA plate a standard serum was included as internal control. Bound antibodies were detected by incubation with biotinylated goat anti-mouse IgG, followed by horseradish peroxidase coupled to Streptavidin. As substrate ABTS was added and the optical density (OD) at 405 nm was measured in a Microwell plate-reader. As negative control sera from the control group injected with an irrelevant peptide were analyzed. The titers

were defined as the dilution of the serum where 50% of the ODmax in the assay are reached.

Total Cholesterol assay

Total cholesterol was measured with the WAKO LabAssay™ Cholesterol Kit (Wako).

LDLR sandwich ELISA

To determine the levels of low density lipoprotein receptor (LDLR) in murine liver, mice were sacrificed 2 weeks after the last vaccination. Liver tissue was isolated and protein extraction was done according to standard protocols.

96 well Nunc-Maxisorb plates were coated with mouse LDLR affinity purified goat polyclonal anti-LDLR antibody (R&D Systems). Unspecific binding was blocked by incubation with 1% BSA/PBS. Subsequently, the liver lysates were incubated for 3 h at room temperature to capture the murine LDLR. The detection of captured LDLR was done by chicken polyclonal anti-LDLR antibody (Abcam) followed by incubation with a secondary biotinylated goat anti-chicken IgG (Southern Biotech) and by streptavidin-HRP conjugate. Finally, TMB was used as a peroxidase chromogen substrate.

The quantification of low density lipoprotein receptor was done by comparison to a standard calibration curve and was normalized to the total protein concentration of the lysates.

The control group (irrelevant peptide control vaccination) has been set to 100%, and the levels of groups treated with anti-PCSK9 vaccines were compared to this control group.

Example 1. Median protein titers against human PCSK9. (n=5 mice per group).

Sequence ID	Median Protein Titer OD max/2
seq 1 control	0

seq 4	45.000
seq 7	47.000
seq 5	14.000
seq 7	47.000
seq 5	14.000
seq 8	31.000
seq 6	13.000
seq8	31.000

Example 2. Mean values in mg/dL and percentage of decrease of total cholesterol. (n=5 mice per group).

	Sequence ID	Mean Values (mg/dl)	Stdv	% TC decrease compared to control group
	seq 1 control	98	9	
	seq 4	88	12	10
	seq 7	78	4	20
Combination A	seq 4 + 7	71	5	28
	seq 1 control	86	9	
	seq 5	61	7	29
	seq 7	64	5	26
Combination B	seq 5 + 7	51	1	41
	seq 1 control	83	7	
	seq 5	60	8	28
	seq 8	55	3	34
Combination C	seq 5 + 8	47	7	43
	seq 1 control	83	7	
	seq 6	65	4	22
	seq 8	55	3	34
Combination D	seq 6 + 8	48	4	42

Example 3. Amount of low density lipoprotein receptor in mouse liver *in vivo* (n=5 mice per group), compared to the control group.

	Sequence ID	% LDLR	Stdv
	seq 1 control	100	8
	seq 4	130	8
	seq 7	148	12
Combination A	seq 4 +7	212	24
	seq 1 control	100	19
	seq 5	140	6
	seq 7	140	14
Combination B	seq 5 + 7	202	18
	seq 1 control	100	13
	seq 5	135	12
	seq 8	143	17
Combination C	seq 5 + 8	212	21
	seq 1 control	100	22
	seq 6	116	27
	seq 8	125	14
Combination D	seq 6 + 8	187	30

Claims:

1. Vaccine comprising at least two fragments of Proprotein convertase subtilisin/kexin type 9 (PCSK9), wherein a first fragment of said at least two fragments comprises at least 8 consecutive amino acid residues of amino acid residues 150 to 170 and a second fragment of said at least two fragments comprises at least 8 consecutive amino acid residues of amino acid residues 205 to 225 of PCSK9 (SEQ ID No. 9).

2. Vaccine according to claim 1, wherein the at least two fragments are selected from the group consisting of peptides having amino acid sequence SIPWNLERITPPR (SEQ ID No. 2), PEEDGTRFHRQASK (SEQ ID No. 3), PEEDGTRFHRQA (SEQ ID No. 4), EEDGTRFHRQASK (SEQ ID No. 5), EEDGTRFHRQAS (SEQ ID No. 6), SIPWNLERITP (SEQ ID No. 7) and SIPWNLERIT (SEQ ID No. 8).

3. Vaccine according to claim 1 or 2, wherein at least one fragment of PCSK9 has an amino acid sequence selected from the group consisting of SIPWNLERITPPR (SEQ ID No. 2), SIPWNLERITP (SEQ ID No. 7) and SIPWNLERIT (SEQ ID No. 8) and at least one fragment of PCSK9 has an amino acid sequence selected from the group consisting of PEEDGTRFHRQASK (SEQ ID No. 3), PEEDGTRFHRQA (SEQ ID No. 4), EEDGTRFHRQASK (SEQ ID No. 5) and EEDGTRFHRQAS (SEQ ID No. 6).

4. Vaccine according to any one of claims 1 to 3, wherein the vaccine comprises SIPWNLERITPPR (SEQ ID No. 2) and PEEDGTRFHRQASK (SEQ ID No. 3), SIPWNLERITPPR (SEQ ID No. 2) and PEEDGTRFHRQA (SEQ ID No. 4), SIPWNLERITPPR (SEQ ID No. 2) and EEDGTRFHRQASK (SEQ ID No. 5), SIPWNLERITPPR (SEQ ID No. 2) and EEDGTRFHRQAS (SEQ ID No. 6), PEEDGTRFHRQASK (SEQ ID No. 3) and SIPWNLERITP (SEQ ID No. 7), PEEDGTRFHRQASK (SEQ ID No. 3) and SIPWNLERIT (SEQ ID No. 8), PEEDGTRFHRQA (SEQ ID No. 4) and SIPWNLERITP (SEQ ID No. 7), PEEDGTRFHRQA (SEQ ID No. 4) and SIPWNLERIT (SEQ ID No. 8), EEDGTRFHRQASK (SEQ ID No. 5) and SIPWNLERITP (SEQ ID No. 7), EEDGTRFHRQASK (SEQ ID No. 5) and SIPWNLERIT (SEQ ID No. 8), EEDGTRFHRQAS (SEQ ID No. 6) and

SIPWNLERITP (SEQ ID No. 7) or EEDGTRFHRQAS (SEQ ID No. 6) and SIPWNLERIT (SEQ ID No. 8).

5. Vaccine according to any one of claims 1 to 4, characterised in that the at least two fragments of PCSK9 comprise a cysteine residue at the C- and/or N-terminal end.

6. Vaccine according to any one of claims 1 to 5, characterised in that the at least two fragments of PCSK9 are coupled to a pharmaceutically acceptable carrier, preferably KLH (Keyhole limpet hemocyanin).

7. Vaccine according to any one of claims 1 to 6, characterised in that the at least two fragments of PCSK9 are formulated for intradermal, subcutaneous or intramuscular administration.

8. Vaccine according to any one of claims 1 to 7, characterised in that the vaccine comprises at least one adjuvant, preferably aluminum hydroxide.

9. Vaccine according to any one of claims 1 to 8 for use in the treatment and/or prevention of disorders caused by hyperlipidemia, hypercholesterolemia and/or atherosclerosis, preferably cardiovascular diseases, stroke or peripheral vascular diseases.

10. Vaccine according to claim 9, characterised in that the at least two fragments of PCSK9 are administered in an amount of 0.1 ng to 10 mg, preferably 1 µg to 500 µg, per dose to an individual.