(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 October 2009 (15.10.2009)

PCT

(10) International Publication Number
WO 2009/125986 A2

(51) International Patent Classification:
C12N 15/10 (2006.01) *C12N 15/63* (2006.01)
C07H 21/04 (2006.01)

(21) International Application Number:
PCT/KR2009/001831

(22) International Filing Date:
9 April 2009 (09.04.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/043,605 9 April 2008 (09.04.2008) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

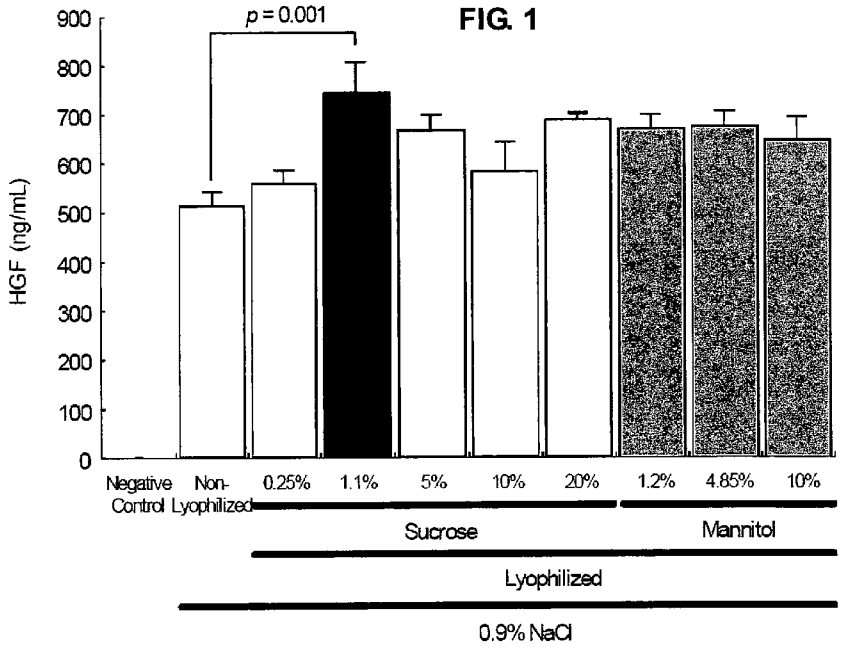
Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

— *with sequence listing part of description (Rule 5.2(a))*

(54) **Title**: LYOPHILIZED DNA FORMULATIONS FOR ENHANCED EXPRESSION OF PLASMID DNA

FIG. 1



(57) **Abstract**: There is provided a DNA formulation lyophilized from a composition comprising a plasmid DNA, a salt and a carbohydrate, wherein said plasmid DNA comprises an HGF gene, or variant thereof.

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LYOPHILIZED DNA FORMULATIONS FOR ENHANCED EXPRESSION OF PLASMID DNA

FIELD OF THE INVENTION

The present invention relates to a DNA formulation lyophilized from a composition comprising a plasmid DNA, a salt and a carbohydrate, wherein said plasmid DNA comprises an HGF gene, or variant thereof.

BACKGROUND OF THE INVENTION

Lyophilization is often a preferred formulation for therapeutic materials because the long-term stability of many materials increases in the lyophilized state. However, for plasmid DNA, lyophilized formulations are not the formulations of choice. In most clinical trials using naked (non-complexed plasmid) DNA as a delivery vector, the preferred formulation has been a liquid formulation.

While lyophilized plasmid DNA may be a preferred form of storage, lyophilized formulations for plasmid DNA have been considered to cause a reduction in gene expression efficiency. Lyophilization causes the removal of the hydration sphere around a molecule. For DNA, it appears that there are approximately 20 water molecules per nucleotide pair bound most tightly to DNA that do not form an ice-like structure upon low-temperature cooling. Upon DNA dehydration over hygroscopic salts at 0% relative humidity, only five or six water molecules remain. Thus, lyophilization may increase the stability of DNA under long-term

storage, but may also cause some damage upon the initial lyophilization process, potentially through changes in the DNA secondary structure or the concentration of reactive elements such as contaminating metals. Therefore, a potential mechanism for loss of gene expression efficiency of lyophilized plasmid DNA may be through a gross structural change to the plasmid.

In Poxon *et al*, *Pharmaceutical Development and Technology* 5:115-122 (2000), the authors demonstrated that lyophilization of a plasmid DNA (pRL-CMV) resulted in a statistically significant loss of transfection efficiency. A biofunctionality assay, measuring transfection activity, demonstrated a loss of more than 75% of plasmid DNA activity after lyophilization as compared to control plasmid that remained in solution. While Poxon *et al* used carbohydrates to ameliorate the *in vitro* decreased transfection activity of a non-therapeutic plasmid, pRL-CMV expressing Renilla luciferase, stored in EDTA buffer, Poxon *et al* did not address the use of lyophilized naked DNA formulations *in vivo* for disease treatment or prevention.

Therefore, there is a need in the art for a stable lyophilized formulation that will not affect gene expression efficiency. The present invention provides for a lyophilized formulation for plasmid DNA that not only preserves the biological activity of the expressed gene but, in certain instances, is able to enhance biological activity.

SUMMARY OF THE INVENTION

The present invention is directed to a lyophilized DNA formulation. In one aspect of the invention, a DNA formulation, prior to lyophilization, comprises a plasmid DNA, salt and a carbohydrate; and where the plasmid DNA comprises an HGF gene, or variant thereof. In

another aspect of the invention, the DNA formulation is lyophilized. In another aspect of the invention, the lyophilized DNA formulation is reconstituted.

In one embodiment, the carbohydrate of the DNA formulation of the present invention is a mono-, oligo-, or polysaccharide such as sucrose, glucose, lactose, trehalose, arabinose, pentose, ribose, xylose, galactose, hexose, idose, mannose, talose, heptose, fructose, gluconic acid, sorbitol, mannitol, methyl α-glucopyranoside, maltose, isoascorbic acid, ascorbic acid, lactone, sorbose, glucaric acid, erythrose, threose, allose, altrose, gulose, erythrulose, ribulose, xylulose, psicose, tagatose, glucuronic acid, galacturonic acid, mannuronic acid, glucosamine, galactosamine, neuraminic acid, arabinans, fructans, fucans, galactans, galacturonans, glucans, mannans, xylans, levan, fucoidan, carrageenan, galactocarolose, pectins, pectic acids, amylose, pullulan, glycogen, amylopectin, cellulose, dextran, cyclodextrin, pustulan, chitin, agarose, keratin, chondroitin, dermatan, hyaluronic acid, alginic acid, xantham gum, or starch.

In certain embodiments of the invention, the carbohydrate is sucrose or mannitol.

In another embodiment, the carbohydrate of the DNA formulation of the present invention is in an amount selected from the group consisting of between about 0.05% to about 30%, between about 0.1% to about 15%, between about 0.2% to about 10%, between about 0.5% and 5%, between about 0.75% and 3%, between about 0.8% and 2%, and between about 0.8% and 1.5%. In particular embodiments, the carbohydrate is sucrose or mannitol. In certain other embodiments, the carbohydrate of the DNA formulation is in an amount of about 1.1%.

In another enbodiment, the salt of the DNA formulation is selected from the group consisting of NaCl or KCl. In further embodiments, the salt of the DNA formulation is in an amount selected from the group consisting of between about 0.01% and 10%, between about 0.1% and 5%, between about 0.1% and 4%, between about 0.5% and 2%, between about

0.8% and 1.5%, between about 0.8% and 1.2% w/v. In certain embodiments, the salt of the DNA formulation is in an amount of about 0.9% w/v.

In another embodiment, the plasmid DNA of the invention comprises an HGF gene, or variant thereof. In certain embodiments, the HGF gene is a mammalian HGF gene or variant thereof. In further embodiments, the HGF gene is a human HGF gene or variant thereof. In certain aspects of the invention, the HGF gene is a hybrid HGF gene, *e.g.*, a hybrid HGF gene comprising HGF cDNA and an inherent or foreign intron or fragment thereof, *e.g.*, an inherent intron 4 or fragment thereof of the human HGF gene. In particular embodiments, the hybrid HGF gene comprises HGF-X2 (SEQ ID NO: 13), HGF-X3 (SEQ ID NO: 14), HGF-X6 (SEQ ID NO: 8), HGF-X7 (SEQ ID NO: 9) or HGF-X8 (SEQ ID NO: 10). In further embodiments, the plasmid DNA comprising a hybrid HGF gene is selected from the group consisting of: pCK-HGF-X2, pCK-HGF-X3, pCK-HGF-X6, pCK-HGF-X7, pCK-HGF-X8, pCP-HGF-X2, pCP-HGF-X3, pCP-HGF-X6, pCP-HGF-X7 and pCP-HGF-X8, where the HGF-X2, HGF-X3, HGF-X6, HGF-X7 and HGF-X8 correspond to SEQ ID NOs: 13-14 and 8-10, respectively.

The lyophilized DNA formulations maintain or enhance the expression of the plasmid DNA. In certain aspects, the lyophilized DNA formulation provides enhanced biological activity of the expressed protein. In certain other aspects of the invention, the enhanced expression of the plasmid DNA or the enhanced biological activity of the expressed protein is due to the presence of the carbohydrate in the formulation. In certain embodiments, this carbohydrate is sucrose or mannitol.

The invention also provides for a reconstituted lyophilized plasmid DNA formulation. In certain embodiments, the lyophilized DNA is reconstituted in a pharmaceutically

acceptable solution. In further embodiments, the pharmaceutically acceptable solution is selected from the group consisting of water, PBS, TE, Tris buffer and normal saline.

In another embodiment, the plasmid DNA of the reconstituted lyophilized formulation is at a final concentration of about 1 ng/mL, about 5 ng/mL, about 10 ng/mL, about 50 ng/mL, about 100 ng/mL, about 250 ng/mL, about 500 ng/mL, about 1 μg/mL, about 5 μg/mL, about 10 μg/mL, about 50 μg/mL, about 100 μg/mL, about 200 μg/mL, about 300 μg/mL, about 400 μg/mL, about 500 μg/mL, about 600 μg/mL, about 700 μg/mL, about 800 μg/mL, about 900 μg/mL, about about 1 mg/mL, about 2 mg/mL, about 2.5 mg/mL, about 3 mg/mL, about 3.5 mg/mL, about 4 mg/mL, about 4.5 mg/mL, about 5 mg/mL, about 5.5 mg/mL, about 6 mg/mL, about 7 mg/mL, about 8 mg/mL, about 9 mg/mL, about 10 mg/mL, about 20 mg/mL, or about 30 mg/mL. In another embodiment, the final concentration of the plasmid DNA of the reconstituted lyophilized formulation is from about 1 ng/mL to about 30 mg/mL. In certain aspects, the final concentration of the plasmid DNA of the reconstituted lyophilized formulation is from about 100 μg/mL to about 2.5 mg/mL. In further aspects, the final concentration of the plasmid DNA of the reconstituted lyophilized formulation is from about 500 μg/mL to about 1 mg/mL.

The present invention is also directed to a method of treating or preventing ischemic or liver disease in a subject, comprising administering a composition reconstituted from a lyophilized hepatocyte growth factor (HGF) DNA formulation, where the DNA formulation comprises a plasmid DNA, salt and a carbohydrate; and where the plasmid DNA comprises an HGF gene, or variant thereof. In certain aspects, the composition reconstituted from a lyophilized HGF DNA formulation is administered by direct injection.

The present invention is further directed to a method of making a lyophilized HGF DNA formulation comprising: (a) preparing a DNA formulation comprising a plasmid DNA,

a salt and a carbohydrate, where the plasmid DNA comprises an HGF gene, or variant thereof; and (b) lyophilizing the DNA formulation.

The steps for lyophilization may include subjecting a DNA formulation of the invention to the process of being frozen at subzero temperatures (*e.g.*, -10°C to -50°C), and then subjected to one or more drying cycles which comprises gradually heating the DNA formulation to a temperature of about 20°C to less than or equal to about 30°C, wherein the lyophilization occurs over a period of about 50 to about 100 hours. In a further aspect of the invention, the method for lyophilization comprises: (a) forming an aqueous DNA formulation comprising a plasmid DNA, a salt and a carbohydrate, where the plasmid DNA comprises an HGF gene, or variant thereof; (b) cooling the DNA formulation solution to a temperature of about -10°C to about -50°C, until frozen; (c) drying the DNA formulation by heating to a temperature of about 20°C to about 30°C; and (d) recovering a lyophilized DNA formulation composition having a water content of from about 0.1 weight percent to about 5 weight percent based on the total weight of the recovered DNA formulation.

In certain embodiments, the DNA formulation is lyophilized under conditions comprising (a) about 30 hours to about 50 hours at a temperature greater than or equal to about -50°C and less than about 0°C, and (b) about 20 hours to about 50 hours at a temperature greater than or equal to about 0°C to less than or equal to about 30°C, progressively, wherein the lowest (a) temperature is about -50°C to about -30°C and the highest (b) temperature is between about 20°C to about 30°C. In one aspect, the DNA formulation is lyophilized under conditions of -50°C for 4 hours, -40°C for 12 hours, -30°C for 6 hours, -20°C for 6 hours, -10°C for 6 hours, 0°C for 6 hours, 10°C for 6 hours and 30°C for 24 hours, progressively. In another aspect, the DNA formulation is lyophilized under conditions of 5°C for 1 minute, -50°C for 2 hours, -40°C for 6 hours, -35°C for 3 hours, -30

°C for 6 hours, -25°C for 3 hours, -20°C for 3 hours, -15°C for 3 hours, -10°C for 6 hours, -5 °C for 3 hours, 0°C for 6 hours, and 30°C for 17 hours, progressively. In another aspect, the DNA formulation is lyophilized under conditions of 5°C for 1 minute, -10°C for 1 minute, -20°C for 1 minute, -30°C for 1 minute, -50°C for 1 minute, -50°C for 2 hours, -45°C for 6 hours, -40°C for 3 hours, -35°C for 6 hours, -30°C for 3 hours, -25°C for 6 hours, -20°C for 3 hours, -15°C for 6 hours, -10°C for 3 hours, -5°C for 6 hours, 0°C for 12 hours, 10°C for 3 hours, 20°C for 6 hours, and 30°C for 29 hours, progressively.

The invention is further directed to a lyophilized nucleic acid formulation or a reconstituted lyophilized nucleic acid formulation, as set forth above, where the nucleic acid is an RNA that encodes for HGF, or variant thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects and features of the present invention will become apparent from the following description of the invention, when taken in conjunction with the accompanying drawings, in which:

Fig. 1 depicts a bar graph comparing *in vitro* HGF expression among various formulations. HGF expression levels were measured using ELISA in culture supernatants isolated from 293T cells transfected with a lyophilized plasmid DNA pCK-HGF-X7 formulated in 0.9 % NaCl at a final DNA concentration of 0.5 mg/mL, with sucrose at 0.25% (lane 3), 1.1% (lane 4), 5% (lane 5), 10% (lane 6) or 20% (lane 7) or with mannitol at 1.2% (lane 8), 4.85% (lane 9) or 10% (lane 10). Control reactions with a negative control (lane 1) and non-lyophilized DNA (lane 2) were used as comparison.

Fig. 2 depicts a bar graph comparing *in vivo* HGF expression between non-lyophilized and lyophilized pCK-HGF-X7. Mice were injected with 100 μg of non-lyophilized pCK-

HGF-X7 containing 0.9% NaCl (NL-HGF-X7) or pCK-HGF-X7 lyophilized with 1.1% Sucrose and 0.9% NaCl (L-HGF-X7) into the tibialis cranialis. HGF expression levels were measured using ELISA in muscle tissue lysates after sacrificing the mice at day 7. HGF expression levels are shown for negative control (lane 1), non-lyophilized pCK-HGF-X7 containing 0.9% NaCl (NL-HGF-X7; lane 2), and pCK-HGF-X7 lyophilized with 1.1 % sucrose and 0.9 % NaCl (L-HGF-X7; lane 3).

Fig. 3 shows a schematic diagram of the experimental procedure using the porcine ischemic heart disease model. NL-HGF-X7 corresponds to non-lyophilized pCK-HGF-X7 containing 0.9% NaCl. L-HGF-X7 corresponds to pCK-HGF-X7 lyophilized with 1.1 % sucrose and 0.9 % NaCl.

Fig. 4 depicts a bar graph showing the effect of non-lyophilized and lyophilized pCK-HGF-X7 on myocardial perfusion. The percent improvement of myocardial perfusion as compared to baseline is shown when the porcine ischemic heart disease model is utilized. Results are shown for pigs injected with plasmid alone (pCK; lane 1), non-lyophilized pCK-HGF-X7 containing 0.9% NaCl (NL-HGF-X7; lane 2), and pCK-HGF-X7 lyophilized with 1.1 % sucrose and 0.9 % NaCl (L-HGF-X7; lane 3).

Fig. 5 depicts a bar graph showing the effect of non-lyophilized and lyophilized pCK-HGF-X7 on wall thickening. The percent improvement on wall thickening in the injected ischemic border area of the left ventricle as compared to baseline is shown when the porcine ischemic heart disease model is utilized. Results are shown for pigs injected with plasmid alone (pCK; lane 1), non-lyophilized pCK-HGF-X7 containing 0.9% NaCl (NL-HGF-X7; lane 2), and pCK-HGF-X7 lyophilized with 1.1 % sucrose and 0.9 % NaCl (L-HGF-X7; lane 3).

DETAILED DESCRIPTION OF THE INVENTION

Definitions

The term "DNA" or "nucleic acid" or "nucleic acid fragment" refers to any one or more nucleic acid segments, e.g., DNA or RNA fragments, present in a polynucleotide or construct. A nucleic acid or fragment thereof may be provided in linear (e.g., mRNA) or circular (e.g., plasmid) form as well as double-stranded or single-stranded forms. By "isolated" nucleic acid or polynucleotide is intended a nucleic acid molecule, DNA or RNA, which has been removed from its native environment. For example, a recombinant polynucleotide contained in a vector is considered isolated for the purposes of the present invention. Further examples of an isolated polynucleotide include recombinant polynucleotides maintained in heterologous host cells or purified (partially or substantially) polynucleotides in solution. Isolated RNA molecules include in vivo or in vitro RNA transcripts of the polynucleotides of the present invention. Isolated polynucleotides or nucleic acids according to the present invention further include such molecules produced synthetically.

As used herein, a "coding region" is a portion of nucleic acid which consists of codons translated into amino acids. Although a "stop codon" (TAG, TGA, or TAA) is not translated into an amino acid, it may be considered to be part of a coding region, but any flanking sequences, for example promoters, ribosome binding sites, transcriptional terminators, and the like, are not part of a coding region. Two or more nucleic acids or nucleic acid fragments of the present invention can be present in a single polynucleotide construct, e.g., on a single plasmid, or in separate polynucleotide constructs, e.g., on separate (different) plasmids. Furthermore, any nucleic acid or nucleic acid fragment may encode a single HGF polypeptide or fragment, derivative, or variant thereof, e.g., or may encode more than one polypeptide,

e.g., a nucleic acid may encode two or more polypeptides. In addition, a nucleic acid may include a regulatory element such as a promoter, ribosome binding site, or a transcription terminator, or may encode heterologous coding regions fused to the HGF coding region, e.g., specialized elements or motifs, such as a secretory signal peptide or a heterologous functional domain.

In the case of DNA, a polynucleotide comprising a nucleic acid which encodes a polypeptide normally also comprises a promoter and/or other transcription or translation control elements operably associated with the polypeptide-encoding nucleic acid fragment. An operable association is when a nucleic acid fragment encoding a gene product, e.g., a polypeptide, is associated with one or more regulatory sequences in such a way as to place expression of the gene product under the influence or control of the regulatory sequence(s).

A DNA polynucleotide of the present invention may be a circular or linearized plasmid or vector, or other linear DNA which may also be non-infectious and nonintegrating (i.e., does not integrate into the genome of vertebrate cells). A linearized plasmid is a plasmid that was previously circular but has been linearized, for example, by digestion with a restriction endonuclease. As used herein, the terms plasmid and vector can be used interchangeably.

The term "lyophilized DNA" refers to any DNA that is prepared in dry form by rapid freezing and dehydration, in the frozen state under high vacuum. "Lyophilizing" or "lyophilization" refers to a process of freezing and drying a solution. Lyophilized DNA is often made ready for use by addition of sterile distilled water.

A “vector” refers to any vehicle for the cloning of and/or transfer of a nucleic acid into a host cell. A vector may be a replicon to which another DNA segment may be attached so as to bring about the replication of the attached segment. A "replicon" refers to any genetic

element (e.g., plasmid, phage, cosmid, chromosome, virus) that functions as an autonomous unit of DNA replication in vivo, i.e., capable of replication under its own control. The term "vector" includes vehicles for introducing the nucleic acid into a cell *in vitro*, *ex vivo* or *in vivo*. A large number of vectors known in the art may be used to manipulate nucleic acids, incorporate response elements and promoters into genes, etc. Possible vectors include, for example, plasmids such as pBR322 or pUC plasmid derivatives, or the Bluescript vector. For example, the insertion of the DNA fragments corresponding to response elements and promoters into a suitable vector can be accomplished by ligating the appropriate DNA fragments into a chosen vector that has complementary cohesive termini. Alternatively, the ends of the DNA molecules may be enzymatically modified or any site may be produced by ligating nucleotide sequences (linkers) into the DNA termini. Such vectors may be engineered to contain selectable marker genes that provide for the selection of cells. Such markers allow identification and/or selection of host cells that express the proteins encoded by the marker.

Additional vectors include lipoplexes (cationic liposome-DNA complex), polyplexes (cationic polymer-DNA complex), and protein-DNA complexes. In addition to a nucleic acid, a vector may also comprise one or more regulatory regions, and/or selectable markers useful in selecting, measuring, and monitoring nucleic acid transfer results (transfer to which tissues, duration of expression, etc.).

The term "plasmid" refers to an extra-chromosomal element often carrying a gene that is not part of the central metabolism of the cell, and usually in the form of circular double-stranded DNA molecules. Such elements may be autonomously replicating sequences, genome integrating sequences, phage or nucleotide sequences, linear, circular, or supercoiled, of a single- or double-stranded DNA or RNA, derived from any source, in which a number of

nucleotide sequences have been joined or recombined into a unique construction which is capable of introducing a promoter fragment and DNA sequence for a selected gene product along with appropriate 3' untranslated sequence into a cell. As used herein, the term "plasmid" refers to a construct made up of genetic material (i.e., nucleic acids). Typically a plasmid contains an origin of replication which is functional in bacterial host cells, *e.g.*, *Escherichia coli*, and selectable markers for detecting bacterial host cells comprising the plasmid.

Plasmids of the present invention may include genetic elements as described herein arranged such that an inserted coding sequence can be transcribed and translated in eukaryotic cells. In certain embodiments described herein, a plasmid is a closed circular DNA molecule.

The term "expression" refers to the biological production of a product encoded by a coding sequence. In most cases a DNA sequence, including the coding sequence, is transcribed to form a messenger-RNA (mRNA). The messenger-RNA is then translated to form a polypeptide product which has a relevant biological activity. Also, the process of expression may involve further processing steps to the RNA product of transcription, such as splicing to remove introns, and/or post-translational processing of a polypeptide product.

The term "expression vector" refers to a vector, plasmid or vehicle designed to enable the expression of an inserted nucleic acid sequence following transformation into the host. The cloned gene, i.e., the inserted nucleic acid sequence, *e.g.*, a HGF gene or variant thereof, is usually placed under the control of control elements such as a promoter, a minimal promoter, an enhancer, or the like. Initiation control regions or promoters, which are useful to drive expression of a nucleic acid in the desired host cell are numerous and familiar to those skilled in the art. Virtually any promoter capable of driving expression of these genes can be used in an expression vector, including but not limited to, viral promoters, bacterial promoters,

animal promoters, mammalian promoters, synthetic promoters, constitutive promoters, tissue specific promoters, pathogenesis or disease related promoters, developmental specific promoters, inducible promoters, light regulated promoters; including, but are not limited to, the SV40 early (SV40) promoter region, the promoter contained in the 3' long terminal repeat (LTR) of Rous sarcoma virus (RSV), the E1A or major late promoter (MLP) of adenoviruses (Ad), the human cytomegalovirus (HCMV) immediate early promoter, the herpes simplex virus (HSV) thymidine kinase (TK) promoter, the baculovirus IE1 promoter, the elongation factor 1 alpha (EF1) promoter, the glyceraldehyde-3-phosphate dehydrogenase (GAPDH) promoter, the phosphoglycerate kinase (PGK) promoter, the ubiquitin C (Ubc) promoter, the albumin promoter, the regulatory sequences of the mouse metallothionein-L promoter and transcriptional control regions, the ubiquitous promoters (HPRT, vimentin, β-actin, tubulin and the like), the promoters of the intermediate filaments (desmin, neurofilaments, keratin, GFAP, and the like), the promoters of therapeutic genes (of the MDR, CFTR or factor VIII type, and the like), pathogenesis or disease related-promoters, and promoters that exhibit tissue specificity and have been utilized in transgenic animals, such as the elastase I gene control region which is active in pancreatic acinar cells; insulin gene control region active in pancreatic beta cells, immunoglobulin gene control region active in lymphoid cells, mouse mammary tumor virus control region active in testicular, breast, lymphoid and mast cells; albumin gene, Apo AI and Apo AII control regions active in liver, alpha-fetoprotein gene control region active in liver, alpha 1-antitrypsin gene control region active in the liver, beta-globin gene control region active in myeloid cells, myelin basic protein gene control region active in oligodendrocyte cells in the brain, myosin light chain-2 gene control region active in skeletal muscle, and gonadotropic releasing hormone gene control region active in the hypothalamus, pyruvate kinase promoter, villin promoter, promoter of the fatty acid binding

intestinal protein, promoter of the smooth muscle cell β-actin, and the like. In addition, these expression sequences may be modified by addition of enhancer or regulatory sequences and the like. Non-limiting examples of expression vectors of the invention include pCK (Lee *et al., Biochem. Biophys. Res. Commun. 272*:230 (2000); WO 2000/040737) and pCP (pCDNA3.1, Invitrogen, USA).

A "construct" as used herein generally denotes a composition that does not occur in nature. A construct can be produced by synthetic technologies, *e.g.*, recombinant DNA preparation and expression or chemical synthetic techniques for nucleic or amino acids. A construct can also be produced by the addition or affiliation of one material with another such that the result is not found in nature in that form.

A "gene" refers to a polynucleotide comprising nucleotides that encode a functional molecule, including functional molecules produced by transcription only (e.g., a bioactive RNA species) or by transcription and translation (e.g., a polypeptide). The term "gene" encompasses cDNA and genomic DNA nucleic acids. "Gene" also refers to a nucleic acid fragment that expresses a specific RNA, protein or polypeptide, including regulatory sequences preceding (5' non-coding sequences) and following (3' non-coding sequences) the coding sequence. "Native gene" refers to a gene as found in nature with its own regulatory sequences. "Chimeric gene" refers to any gene that is not a native gene, comprising regulatory and/or coding sequences that are not found together in nature. Accordingly, a chimeric gene may comprise regulatory sequences and coding sequences that are derived from different sources, or regulatory sequences and coding sequences derived from the same source, but arranged in a manner different than that found in nature. A chimeric gene may comprise coding sequences derived from different sources and/or regulatory sequences derived from different sources. "Endogenous gene" refers to a native gene in its natural

location in the genome of an organism. A "foreign" gene or "heterologous" gene refers to a gene not normally found in the host organism, but that is introduced into the host organism by gene transfer. Foreign genes can comprise native genes inserted into a non-native organism, or chimeric genes. A "transgene" is a gene that has been introduced into the cell by a gene transfer procedure.

"Heterologous DNA" refers to DNA not naturally located in the cell, or in a chromosomal site of the cell. The heterologous DNA may include a gene foreign to the cell.

The phrases "isolated" or "biologically pure" refer to material that is substantially or essentially free from components which normally accompany the material as it is found in its native state. Thus, isolated peptides in accordance with the invention preferably do not contain materials normally associated with the peptides in their in situ environment.

Lyophilized DNA formulations

The DNA formulation of the invention, prior to lyophilization, is formulated with certain excipients, including a carbohydrate and a salt.

As described herein, the stability of a lyophilized formulation of DNA to be utilized as a diagnostic or therapeutic agent can be increased by formulating the DNA prior to lyophilization with an aqueous solution comprising a stabilizing amount of carbohydrate.

A carbohydrate of the DNA formulation of the invention is a mono-, oligo-, or polysaccharide, such as sucrose, glucose, lactose, trehalose, arabinose, pentose, ribose, xylose, galactose, hexose, idose, mannose, talose, heptose, fructose, gluconic acid, sorbitol, mannitol, methyl α-glucopyranoside, maltose, isoascorbic acid, ascorbic acid, lactone, sorbose, glucaric acid, erythrose, threose, allose, altrose, gulose, erythrulose, ribulose, xylulose, psicose, tagatose, glucuronic acid, galacturonic acid, mannuronic acid, glucosamine, galactosamine,

neuraminic acid, arabinans, fructans, fucans, galactans, galacturonans, glucans, mannans, xylans, levan, fucoidan, carrageenan, galactocarolose, pectins, pectic acids, amylose, pullulan, glycogen, amylopectin, cellulose, dextran, cyclodextrin, pustulan, chitin, agarose, keratin, chondroitin, dermatan, hyaluronic acid, alginic acid, xantham gum, or starch.

In one aspect, the carbohydrate is mannitol or sucrose.

The carbohydrate solution prior to lyophilization can correspond to carbohydrate in water alone, or a buffer can be included. Examples of such buffers include PBS, HEPES, TRIS or TRIS/EDTA. Typically the carbohydrate solution is combined with the DNA to a final concentration of about 0.05% to about 30% sucrose, typically 0.1% to about 15% sucrose, such as 0.2% to about 5%, 10% or 15% sucrose, preferably between about 0.5% to 10% sucrose, 1% to 5% sucrose, 1% to 3% sucrose, and most preferably about 1.1 % sucrose.

A salt of the DNA formulation of the invention is NaCl or KCl. In certain aspects, the salt is NaCl. In further aspects, the salt of the DNA formulation is in an amount selected from the group consisting of between about 0.001% to about 10%, between about 0.1% and 5%, between about 0.1% and 4%, between about 0.5% and 2%, between about 0.8% and 1.5%, between about 0.8% and 1.2% w/v. In certain embodiments, the salt of the DNA formulation is in an amount of about 0.9% w/v.

In the DNA formulation of the invention, the final concentration of DNA is from about 1 ng/mL to about 30 mg/mL of plasmid. For example, a formulation of the present invention may have a final concentration of about 1 ng/mL, about 5 ng/mL, about 10 ng/mL, about 50 ng/mL, about 100 ng/mL, about 200 ng/mL, about 500 ng/mL, about 1 μg/mL, about 5 μg/mL, about 10 μg/mL, about 50 μg/mL, about 100 μg/mL, about 200 μg/mL, about 400 μg/mL, about 500 μg/mL, about 600 μg/mL, about 800 μg/mL, about 1 mg/mL, about 2 mg/mL, about 2.5 mg/mL, about 3 mg/mL, about 3.5 mg/mL, about 4 mg/mL, about 4.5

mg/mL, about 5 mg/mL, about 5.5 mg/mL, about 6 mg/mL, about 7 mg/mL, about 8 mg/mL, about 9 mg/mL, about 10 mg/mL, about 20 mg/mL, or about 30 mg mg/mL of a plasmid. In certain embodiments of the invention, the final concentration of the DNA is from about 100 μg/mL to about 2.5 mg/mL. In particular embodiments of the invention, the final concentration of the DNA is from about 0.5 mg/mL to 1 mg/mL.

The DNA formulation of the invention is lyophilized under standard conditions known in the art. A method for lyophilization of the DNA formulation of the invention may comprise (a) loading a container, *e.g.*, a vial, with a DNA formulation, *e.g.*, a DNA formulation comprising a plasmid DNA, a salt and a carbohydrate, where the plasmid DNA comprises an HGF gene, or variant thereof, into a lyophilizer, wherein the lyophilizer has a starting temperature of about 5°C to about -50°C; (b) cooling the DNA formulation to subzero temperatures (*e.g.*, -10°C to -50°C); and (c) substantially drying the DNA formulation. The conditions for lyophilization, *e.g.*, temperature and duration, of the DNA formulation of the invention can be adjusted by a person of ordinary skill in the art taking into consideration factors that effect lyophilization parameters, *e.g.*, the type of lyophilization machine used, the amount of DNA used, and the size of the container used.

The container holding the lyophilized DNA formulation may then be sealed and stored for an extended period of time at various temperatures (*e.g.*, room temperature to about -180°C, preferably about 2-8°C to about -80°C, more preferably about -20°C to about -80°C, and most preferably about -20°C). In certain aspects, the lyophilized DNA formulations are preferably stable within a range of from about 2-8°C to about -80°C for a period of at least 6 months without losing significant activity. Stable storage plasmid DNA formulation can also correspond to storage of plasmid DNA in a stable form for long periods of time before use as such for research or plasmid-based therapy. Storage time may be as long as several months, 1

year, 5 years, 10 years, 15 years, or up to 20 years. Preferably the preparation is stable for a period of at least about 3 years.

HGF Plasmid DNA

The present invention provides for a lyophilized DNA formulation, where the DNA formulation, prior to lyophilization, comprises a plasmid DNA, and the plasmid DNA comprises an HGF gene, or variant thereof.

Hepatocyte growth factor (HGF) is a heparin binding glycoprotein also known as scatter factor or hepatopoietin-A. An endogenous gene encoding human HGF is located at chromosome 7q21.1 and comprises 18 exons and 17 introns, having the nucleotide sequence of SEQ ID NO: 1 (Seki T., *et al.*, *Gene 102*:213-219 (1991)). A transcript of about 6 kb is transcribed from the HGF gene, and then, a polypeptide HGF precursor consisting of 728 amino acids (SEQ ID NO: 2) is synthesized therefrom. Simultaneously, a polypeptide of dHGF precursor consisting of 723 amino acids is also synthesized by an alternative splicing of the HGF gene. The biologically inactive precursors may be converted into active forms of disulfide-linked heterodimer by protease in serum. In the heterodimers, the alpha chain having a high molecular weight forms four kringle domains and an N-terminal hairpin loop like a preactivated peptide region of plasminogen. The kringle domains of a triple disulfide-bonded loop structure consisting of about 80 amino acids may play an important role in protein-protein interaction. The low molecular weight beta chain forms an inactive serine protease-like domain. dHGF consisting 723 amino acids is a polypeptide with deletion of five amino acids in the 1st kringle domain of the alpha chain, i.e., F, L, P, S and S.

HGF secreted from mesoderm-derived cells has various biological functions, *e.g.*, 1) inducing epithelial cells into a tubular structure; 2) stimulating vascularization from

endothelial cells in vitro and in vivo; 3) regeneration of liver and kidney, owing to its anti-apoptosis activity; 4) organogenesis of kidney, ovary and testis; 5) controlling osteogenesis; 6) stimulating the growth and differentiation of erythroid hematopoietic precursor cells; and 7) axon sprouting of neurons (Stella, M.C. and Comoglio, P.M., *The International Journal of Biochemistry & Cell Biology 31*:1357-1362 (1999)). Based on these various functions, HGF or a gene encoding HGF or a variant thereof, may be developed as a therapeutic agent for treating ischemic or liver diseases. Actually, *in vivo*, the HGF may exist as either HGF or dHGF, and therefore, the coexpression of HGF and dHGF is important for maximizing the therapeutic effect. A hybrid HGF gene which can simultaneously express HGF and dHGF with a high efficiency for gene therapy is an HGF variant that would be advantageous to utilize in the plasmid DNA formulation of the present invention.

The hybrid HGF gene has been previously described in Intl. Appl. No. WO 03/078568 and U.S. Publ. No. 2005/0079581 A1, the contents of each which are herein incorporated by reference. The hybrid HGF gene is prepared by inserting an inherent or foreign intron between exons 4 and 5 in HGF cDNA. The hybrid HGF gene has a higher expression efficiency than HGF cDNA and simultaneously expresses two heterotypes of HGF and dHGF (deleted variant HGF).

The term "isoform of HGF" refers to any HGF polypeptide having an amino acid sequence that is at least 80% identical (*e.g.*, at least 90% or 95% identical) to a HGF amino acid sequence that is naturally produced in an animal, including all allelic variants. In one embodiment, the term refers to isoforms that are known to have cell proliferation activity. Isoforms of HGF include, without limitation, flHGF, dHGF, NK1, NK2, and NK4, e.g., corresponding to SEQ ID NOs: 2-6, and variants thereof (*e.g.*, NK2 variants, SEQ ID NOs: 11-12).

The term "flHGF" refers to the full length HGF protein of an animal, *e.g.*, a mammal, e.g., amino acids 1-728 (SEQ ID NO: 2) of human HGF.

The term "dHGF" refers to the deleted variant of HGF protein produced by alternative splicing of the HGF gene in an animal, e.g., a mammal, e.g., human HGF consisting of 723 amino acids (SEQ ID NO: 3) with deletion of five amino acids in the 1st kringle domain of the alpha chain (F, L, P, S and S) from the full length HGF sequence.

The term "NK1" refers to an isoform of HGF from an animal, e.g., a mammal, e.g., a human, consisting of the N-terminal hairpin loop and kringle1 domains.

The term "NK2" refers to an isoform of HGF from an animal, e.g., a mammal, e.g., a human, consisting of the N-terminal hairpin loop, kringle1, and kringle2 domains.

The term "NK4" refers to an isoform of HGF from an animal, e.g., a mammal, e.g., a human, consisting of the N-terminal hairpin loop, kringle1, kringle2, kringle3, and kringle4 domains.

The structure and function of HGF has been extensively studied and one of skill in the art is aware of the amino acids in the HGF sequence that are important for retaining substantially all of the biological activity of the protein and that are preferably not changed or only conservatively changed in any sequence variant of HGF. *See, e.g.*, Hartmann *et al.*, *Proc. Natl. Acad. Sci. USA 89*:11574 (1992); Lokker *et al.*, *EMBO J. 11*:2503 (1992), Zhou *et al.*, *Structure 6*:109 (1998), Ultsch *et al.*, *Structure 6*:1383 (1998), Shimizu *et al.*, *Biochem. Biophys. Res. Commun. 189*:1329 (1992), Yoshiyama *et al.*, *Biochem. Biophys. Res. Commun. 175*:660 (1991), each herein incorporated by reference in its entirety. For example, it appears that the N-terminal hairpin loop and kringle1 domains are required for cell proliferation activity. Other amino acids that are not critical to biological activity may be deleted and/or substituted more freely. One of skill in the art can prepare variants of HGF isoforms using

routine mutagenesis techniques, such as those described in the references cited above, and identify variants retaining substantially all of the biological activity of the HGF isoform.

An embodiment of the hybrid HGF gene of the present invention comprising the inherent intron is 7113 bp long and has the nucleotide sequence of SEQ ID NO: 7.

A hybrid HGF gene may comprise a fragment of inherent intron optionally having a small recombinant sequence inserted thereinto between exons 4 and 5 of HGF cDNA. Herein, such a hybrid HGF gene comprising a fragment of inherent intron is designated "HGF-X". Examples of hybrid HGF genes include HGF-X2 (SEQ ID NO: 13), HGF-X3 (SEQ ID NO: 14), HGF-X6 (SEQ ID NO: 8), HGF-X7 (SEQ ID NO: 9) and HGF-X8 (SEQ ID NO: 10).

Administration and Methods of Treatment

As described above, HGF has various biological functions, and based on these various functions, HGF, a gene encoding HGF, or a variant thereof, may be developed as a therapeutic agent for treating ischemic or liver diseases. In the present invention, an HGF DNA formulation is administered after reconstitution of the lyophilized DNA formulation.

The term "reconstituted" or "reconstitution" refers to the restoration to the original form, *e.g.*, by rehydration, of a substance previously altered for preservation and storage, *e.g.*, the restoration to a liquid state of a DNA plasmid formulation that has been previously dried and stored. The lyophilized composition of the present invention may be reconstituted in any aqueous solution which produces a stable, mono-dispersed solution suitable for administration. Such aqueous solutions include, but are not limited to: sterile water, TE, PBS, Tris buffer or normal saline.

The concentration of reconstituted lyophilized DNA in the methods of the current invention is adjusted depending on many factors, including the amount of a formulation to be

delivered, the age and weight of the subject, the delivery method and route and the immunogenicity of the antigen being delivered.

The reconstituted lyophilized DNA formulation of the invention may be administered orally or via parenteral routes such as intravenous, intramuscular, intraendocardial, intramyocardial, intrapericardial, intraventricular, intraarticular, intradermal, intracerebral, intrarenal, intrahepatic, intrasplenic, intralymphatic, subcutaneous, intraabdominal, intratesticular, intraovarian, intrauterine, sternal, intratracheal, intraplueral, intrathoracic, intradural, intraspinal, intramedullary, intramural, intrascorionic and arterial injection or infusion, or topically through rectal, intranasal, inhalational or intraocular administration. In certain embodiments, the method of delivery is intramuscular, intramyocardial, intravenous, intracerebral, or intrarenal.

It should be understood that the typical daily dose of the reconstituted lyophilized DNA formulation of the present invention ought to be determined in light of various relevant factors including the conditions to be treated, the chosen route of administration, the age, sex and body weight of the individual patient, and the severity of the patient's symptom, and can be administrated in a single dose or in divided dose. Therefore, the daily dose should not be construed as a limitation to the scope of the invention in any way.

The term "treat," "treating," or "treatment" of an ischemic or liver disease, as used herein, refers to the administration to a subject of a factor, *e.g.* a HGF, *e.g.*, a hybrid HGF, or variant thereof, in an amount sufficient to result in amelioration of one or more symptoms of the ischemic or liver disease, or prevent advancement of the ischemic or liver disease.

An "ischemic disease" refers to a disease associated with a deficient supply of blood to a body part (as the heart or brain) that is due to obstruction of the inflow of arterial blood (as

by the narrowing of arteries by spasm or disease). Examples of ischemic diseases include coronary artery disease (CAD) and peripheral artery disease (PAD).

The term "liver disease" applies to many diseases and disorders that cause the liver to function improperly or cease functioning. HGF is a major agent promoting hepatocyte proliferation, and acts in concert with transforming growth factor-alpha and heparin-binding epidermal growth factor during liver regeneration. Additionally, HGF ameliorates hepatic injury via anti-apoptotic effects in animal models of fulminant hepatic failure, and attenuates hepatic fibrosis in animals with liver cirrhosis. Consequently, HGF is considered to not only induce liver regeneration, but also to inhibit disease progression and ameliorate hepatic fibrosis in patients suffering from intractable liver diseases. With respect to the treatment of liver disease, the reconstituted lyophilized DNA formulation of the invention may be administered according to the delivery methods as set forth above. In certain embodiments, the method of delivery in the treatment of liver disease will be intravenous, intraarterial, or intrahepatic.

In certain aspects of the invention, the reconstituted HGF DNA formulation can comprise two or more isoforms of HGF. The HGF isoforms may be previously lyophilized separately, or in the same DNA formulation. Both of these lyophilized isoforms, after reconstitution, can be administered separately or at the same time, *i.e.*, co-administered; separate reconstituted plasmid DNA formulations for the two or more isoforms of HGF may be administered or co-administered or a single expression plasmid containing genes for two or more isoforms of HGF and capable of expressing the genes for the two or more isoforms of HGF may be administered. For example, the two isoforms flHGF and dHGF may be administered using two separate plasmids. Alternatively, the two separate plasmids containing genes for flHGF and dHGF may be used for co-administration. Finally, a single

expression plasmid containing genes for both flHGF and dHGF may be administered. In certain aspects of the invention, the flHGF and dHGF on a single expression plasmid is encoded by the same polynucleotide or by separate polynucleotides.

There are a number of approaches to include more than one polynucleotide capable of expressing an HGF isoform on a single plasmid. These include, for example, the use of Internal Ribosome Entry Site (IRES) sequences, dual promoters/expression cassettes, and fusion proteins. The two or more isoforms expressed from the same plasmid or on two separate plasmids, as discussed above, are selected from the group consisting of flHGF, dHGF, NK1, NK2, and NK4 or selected from the group consisting of SEQ ID NOs: 2 to 6. The two or more isoforms can also include additional HGF isoforms known to one of ordinary skill in the art.

In certain aspects of the invention, the plasmid DNA is administered through direct intracellular injection and, more preferably, by the use of a syringe or a catheter. Catheters have been used to introduce recombinant genes *in vivo* (see, e.g., E.G. Nabel, *et al.*, *Proc. Natl. Acad. Sci. USA 89*, 5157 (1992); E.G. Nabel, *et al.*, *Science 249*, 1285 (1990) ; E.G. Nabel, *et al.*, *Science 244*, 1342 (1989) ; E.G. Nabel, *et al.*, *J. Clin. Invest. 91*, 1822 (1993) ; G..Plautz, *et al.*, *Circ. 83*, 578 (1991); E.G. Nabel, *et al.*, *Nature* (1993) (in press)). Utilization of a catheter provides the ability to deliver the plasmid DNA into the cells which are difficult to access by the use of a syringe.

The plasmid DNA can be administered through intraarterial or intravenous injection and, more preferably, by the use of a syringe or a catheter. For example, the femoral artery may be used to deliver plasmid DNA to the heart; the portal vein may be used to deliver plasmid DNA to the liver.

Administration of the plasmid DNA of the invention can also be accomplished by gene transfer into target cells, *in situ*, to optimize the subsequent delivery of genes *in vivo*.

The practice of the present invention will employ, unless otherwise indicated, conventional techniques of cell biology, cell culture, molecular biology (including PCR), vaccinology, microbiology, recombinant DNA, and immunology, which are within the skill of the art. Such techniques are explained fully in the literature. *See, for example, Molecular Cloning A Laboratory Manual*, 2nd Ed., Sambrook *et al.*, ed., Cold Spring Harbor Laboratory Press: (1989); DNA Cloning, Volumes I and II (D. N. Glover ed., 1985); Oligonucleotide Synthesis (M. J. Gait ed., 1984); Mullis *et al.* U.S. Pat. No: 4,683,195; Nucleic Acid Hybridization (B. D. Hames & S. J. Higgins eds. 1984); Transcription And Translation (B. D. Hames & S. J. Higgins eds. 1984); Culture Of Animal Cells (R. I. Freshney, Alan R. Liss, Inc., 1987); Immobilized Cells And Enzymes (IRL Press, 1986); B. Perbal, A Practical Guide To Molecular Cloning (1984); the treatise, Methods In Enzymology (Academic Press, Inc., N.Y.); Gene Transfer Vectors For Mammalian Cells (J. H. Miller and M. P. Calos eds., 1987, Cold Spring Harbor Laboratory); Methods In Enzymology, Vols. 154 and 155 (Wu et al. eds.), Immunochemical Methods In Cell And Molecular Biology (Mayer and Walker, eds., Academic Press, London, 1987); and in Ausubel *et al.*, Current Protocols in Molecular Biology, John Wiley and Sons, Baltimore, Maryland (1989). Each of the references cited in this paragraph is incorporated herein by reference in its entirety.

The following Examples are given for the purpose of illustration only, and are not intended to limit the scope of the invention.

Example 1: Preparation of plasmid

The plasmid pCK-HGF-X7 (WO 03/078568) which is designed to express hepatocyte growth factor (HGF) protein was used in the experiment.

E. coli (TOP10, Invitrogen, USA) were transformed with pCK-HGF-X7, and a single colony was isolated. The isolated colony was then cultured in LB media containing 30 μg/mL kanamycin. Plasmid DNA was purified using an EndoFree plasmid Giga kit (Qiagen, USA), and re-suspended in saline containing 0.9% NaCl at a final DNA concentration of 1.0 to 2.0 mg/mL.

Example 2: Lyophilization

Formulations of pCK-HGF-X7 were prepared in saline containing 0.9% NaCl at a final DNA concentration of 0.5 mg/mL or 1 mg/mL, with sucrose (0.25, 1.1, 5, 10 or 20% w/v) or mannitol (1.2, 4.85 or 10% w/v). Table 1A and 1B show the percentage sucrose and mannitol, respectively, and the corresponding carbohydrate/DNA (w/w) ratios for the tested pCK-HGF-X7 formulations.

Table 1A. Percent Sucrose

DNA (mg/ml)	Sucrose (%)	Sucrose (mg/ml))	Sucrose to DNA ratio (w/w)
0.5	0.25	2.5	5
0.5	1.1	11	22
0.5	5	50	100
0.5	10	100	200
0.5	20	200	400
1	0.25	2.5	2.5
1	1.1	11	11
1	5	50	50
1	10	100	100
1	20	200	200

Table 1B. Percent Mannitol

DNA (mg/ml)	Mannitol (%)	Mannitol (mg/ml))	Mannitol to DNA ratio (w/w)
0.5	1.2	12	24
0.5	4.85	48.5	97
0.5	10	100	200
1	1.2	12	12
1	4.85	48.5	48.5
1	10	100	100

The suspended plasmid DNA was then lyophilized with Production-Master Freeze Dryer (C&H Cooling & Heating Systems, Korea). The temperature was lowered to -50°C for 4 hours at 100 mTorr. Then, the temperature was raised to -40°C for 12 hours, -30°C for 6 hours, -20°C for 6 hours, -10°C for 6 hours, 0°C for 6 hours, 10°C for 6 hours and 30°C for 24 hours, progressively, at 28~29 mTorr. The lyophilized plasmid DNA was kept at -20°C until analyzed.

The suspended plasmid DNA was also lyophilized with Production-Master Freeze Dryer (C&H Cooling & Heating Systems, Korea). The temperature was lowered to 5°C for 1 minute, and -50°C for 2 hours at 100 mTorr. Then, the temperature was raised to -40°C for 6 hours, -35°C for 3 hours, -30°C for 6 hours, -25°C for 3 hours, -20°C for 3 hours, -15°C for 3 hours, -10°C for 6 hours, -5°C for 3 hours, 0°C for 6 hours, and 30°C for 17 hours, progressively, at 28~29 mTorr. The lyophilized plasmid DNA was kept at -20°C until analyzed.

The suspended plasmid DNA was also lyophilized with Production-Master Freeze Dryer (C&H Cooling & Heating Systems, Korea). The temperature was lowered to 5°C for 1 minute, -10°C for 1 minute, -20°C for 1 minute, -30°C for 1 minute, and -50°C for 1 minute at 150 mTorr. The temperature was maintained at -50°C for another 2 hours at 150 mTorr. Then, the temperature was raised to -45°C for 6 hours, -40°C for 3 hours, -35°C for 6 hours, -

30°C for 3 hours, -25°C for 6 hours, -20°C for 3 hours, -15°C for 6 hours, -10°C for 3 hours, -5°C for 6 hours, 0°C for 12 hours, 10°C for 3 hours, 20°C for 6 hours, and 30°C for 29 hours, progressively, at 30 mTorr. The lyophilized plasmid DNA was kept at -20°C until analyzed.

The lyophilized formulations prepared above were analyzed for *in vitro* gene expression efficiency according to the methods described in Example 3. The *in vitro* results for these preparations were the same.

Example 3: Effects of lyophilization on *in vitro* gene expression efficiency of plasmid DNA

1. Materials and methods

To assess the effects of the lyophilization on gene expression efficiency of plasmid DNA, the lyophilized plasmid DNA was transfected into 293T cells, and the level of HGF expression was measured. As a control, non-lyophilized plasmid DNA was also transfected.

Four micrograms of pCK-HGF-X7 in various formulations (as noted above in Example 1) were transfected into $1x10^6$ 293T cells using FuGENE6 (Roche Diagnostics, Germany) (n = 5). Before transfection, 1 mg of the lyophilized plasmid DNA was reconstituted with 2 ml of water for injection to the final concentration of 0.5 mg/mL.

Two days after transfection, the culture supernatants were obtained and analyzed for HGF expression using a human HGF ELISA kit (R&D Systems, MN, USA), according to the manufacturer's recommendations. The ELISA results were statistically assessed by Dunnett's multiple comparison test using SPSS program (version 13.0, SPSS. Inc, USA).

2. Results and discussion

The results of HGF gene expression are provided in **Fig. 1**. Contrary to previous reports, lyophilization did not affect the *in vitro* gene expression efficiency of plasmid DNA. Among various formulations, the HGF level from pCK-HGF-X7 lyophilized with 1.1% sucrose and 0.9% NaCl was significantly higher than that from non-lyophilized pCK-HGF-X7 ($p = 0.001$) (Fig. 1).

These results indicate that the lyophilization formulation containing 1.1% Sucrose and 0.9% NaCl would be more suitable for pCK-HGF-X7 than a non-lyophilized formulation.

Example 4: Comparative analysis of *in vivo* gene expression between non-lyophilized and lyophilized pCK-HGF-X7

1. Materials and methods

Thirteen 5-week old BALB/c mice (males, Charles River) were obtained for each group, and provided with food and water *ad libitum*. The mice were allowed 7 days of rest before being subjected to the experiment.

Mice were injected with 100 μg of non-lyophilized pCK-HGF-X7 containing 0.9% NaCl (NL-HGF-X7) or pCK-HGF-X7 lyophilized with 1.1% sucrose and 0.9% NaCl (L-HGF-X7) into the tibialis cranialis, and were sacrificed at day 7 after treatment. The lyophilized plasmid DNA was reconstituted with water to the final concentration of 0.5 mg/mL before injection. To measure the level of HGF protein expression, the injected muscles were collected, and the muscle tissue was lysed with 500 μL of cell lysis buffer (50 mM NaCl, 0.2% sodium dodecyl sulfate, 0.5% sodium deoxycholate, 2% IGEPAL CA-630, 25 mM Tris-HCl, pH7.4, 1 mM phenylmethylsulfonyl fluoride) for 16 hours at 4℃. The

lysates were centrifuged at 12,000 rpm for 5 minutes, and the supernatants were harvested and analyzed for HGF expression using a human HGF ELISA kit (R&D Systems).

The ELISA results were statistically assessed by one way ANOVA and subsequent Tukey's Test using SPSS program (version 13.0).

2. Results and discussion

An average of 246 ng/mL of HGF protein was produced from the animals administered with pCK-HGF-X7 lyophilized with 1.1% sucrose and 0.9% NaCl (L-HGF-X7), while the animals administered with non-lyophilized pCK-HGF-X7 expressed 76 ng/mL of HGF (**Fig. 2**). This result indicates that pCK-HGF-X7 lyophilized with 1.1% sucrose and 0.9% NaCl can express HGF protein more efficiently than non-lyophilized pCK-HGF-X7 ($p < 0.001$).

Example 5: Comparative analysis of therapeutic effects on porcine ischemic heart disease model between non-lyophilized and lyophilized pCK-HGF-X7

1. Materials and methods

(1) Animals

Eleven Yorkshire pigs (male, 28 to 30 kg, Clinical Research Institute in Seoul National University Hospital) were obtained and provided with food two-times per day and water *ad libitum*. The pigs were allowed 7 days of rest before being subjected to the experiment. The overall experimental plan is shown in **Fig. 3**.

(2) Establishment of the porcine ischemic heart disease model

Xylazine (2 mg/kg), ketamine (20 mg/kg), and atropine (0.05 mg/kg) were injected intramuscularly into each pig. Twenty minutes later, a 22-gauge Medicut sheath was inserted into the superficial femoral artery for continuous monitoring of the blood pressure. Thiopental sodium (10 mg/kg) was injected intravenously, and endotracheal intubation was performed via the orotracheal route. Anesthesia was maintained by inhalation of enflurane. During the operation, positive pressure ventilation and an oxygen fraction of 30% ~ 40% were maintained. Electrocardiograms, oxygen saturation and arterial blood pressure were monitored continuously.

Left thoracotomy was then performed. After opening the pericardium followed by exploration of the left anterior descending coronary artery (LAD), 2% lidocaine (1 mg/kg) was injected intravenously and the distal one third of the LAD was ligated for 3 minutes, leaving the second diagonal branch as much as possible. Reperfusion (ischemic preconditioning) was performed for 5 minutes using 5-0 polypropylene sutures buttressed with a small piece of Nelaton (4 Fr). After this single ischemic preconditioning, the distal LAD was ligated and ST-segment depression or elevation on the monitored electrocardiogram was confirmed. Additional lidocaine (1 mg/kg) was injected intravenously 15 minutes after the ligation, and the pericardium and thoracotomy wounds were closed. A single 28 Fr chest tube connected to wall suction was removed immediately after enough spontaneous respiration returned, followed by the removal of the endotracheal tube.

All protocols were approved by the Seoul National University Animal Care and Use Committee.

(3) Intramyocardial injection of plasmids

Twenty eight days after the ligation of the coronary artery, re-thoracotomy was performed. Using 27 gauge insulin injection needles, a total dose of 1 mg of pCK-HGF-X7 lyophilized with 1.1% sucrose and 0.9% NaCl (L-HGF-X7, n = 3) or non-lyophilized pCK-HGF-X7 containing 0.9% NaCl (NL-HGF-X7, n = 4) was injected into the anterolateral ischemic border zone which lies between the fibrotic infarction area and the grossly normal myocardium along the course of the second diagonal branch. A total of five sites were injected. Each site was injected with 0.2 mg of plasmid DNA and the interval between injection sites was 1.5 cm. The lyophilized plasmid DNA was reconstituted with water to the final concentration of 1 mg/mL before injection. As a control, the identical amount of non-lyophilized pCK containing 0.9% NaCl (n = 4) was injected into the anterolateral ischemic border zone. The injection points were marked with suture tags using metal rings.

(4) Myocardial single photon emission computed tomography

Twenty six days after the surgical induction of myocardial infarction, ^{99m}Tc- MIBI gated single photon emission computed tomography (SPECT) (Vertex EPIC, ADAC Labs, CA., USA) was performed to set a baseline before plasmid injection. The gated SPECT was repeated 28 days later (on Day 54 after the induction of the myocardial infarction).

A 20-segment model was chosen for a segmental analysis. Six segments corresponding to the cardiac base were excluded from the analysis because this region could be easily influenced by the diaphragmatic attenuation or some artifacts around the heart; also because the heart base was far away from the sites of the distal coronary ligation and plasmid injection.

The SPECT images constructed by electrocardiography gating were analyzed by an auto-quantitation program (AutoQUANT, ADAC Labs, CA., USA), which is believed to eliminate the possible bias by any associated technician's manipulation.

The amount of segmental perfusion was quantified by measuring the uptake of ^{99m}Tc-MIBI and calculated as a percentage of the maximum uptake. When the segmental perfusion thus estimated was less than 70%, it was defined as an underperfused segment and used as the target of plasmid delivery. Segments remaining well perfused even after the coronary ligation were also excluded, as they would probably get no benefit from the therapeutic angiogenesis. Wall thickening in the systolic phase was indicated as a percentage of the end diastolic wall thickness on the gated images.

(5) Statistics

Data are presented as the percent improvement compared to the baseline. All data were analyzed using SPSS (version 13.0). The statistical analysis of the myocardial perfusion and the segmental wall-thickening was performed using paired-samples Student t-test.

2. Results

Within each treatment group, the changes in the segmental perfusion before and after the plasmid DNA injection were compared. The baseline values for the average of segmental perfusion measured on Day 26 after LAD ligation were 39.0 ± 14.6, 43.4 ± 13.4 and 36.9 ± 16.3 % for pCK, NL-HGF-X7 and L-HGF-X7 treatment group, respectively. ^{99m}Tc-MIBI gated SPECT conducted on Day 54 showed that the average values of the segmental perfusion in the pCK and NL-HGF-X7 groups were 37.8 ± 13.9 % and 44.0 ± 14.5 %, respectively, which were not significantly different from the baseline values measured on Day 26 (p =

0.320 for pCK and 0.721 for NL-HGF-X7). In contrast, the average value of the segmental perfusion in the L-HGF-X7 treatment group was 41.2 ± 17.6 %, showing significant increase over the baseline value (p = 0.003). When the magnitude of the percent increase in the segmental perfusion from baseline value was compared between groups, the percent increase of the segmental perfusion in the L-HGF-X7 treatment group was 14.74 % higher than that of pCK treatment group (p = 0.003), while the NL-HGF-X7 treatment group did not show significant difference from the pCK treatment group (p = 0.254) (**Fig. 4**).

In each treatment group, the changes in the segmental wall-thickening before and after the DNA administration were also compared. On Day 26, the average values of the segmental wall-thickening were 24.7 ± 16.5, 33.4 ± 15.9 and 16.5 ± 15.9 % for pCK, NL-HGF-X7 and L-HGF-X7 treated group, respectively, and there were no significant inter-group differences (p = NS). On Day 54, the average value of segmental wall-thickening for pCK, NL-HGF-X7 and L-HGF-X7 treatment group was 27.9 ± 18.4, 43.1 ± 11.8, and 30.2 ± 10.7 %, respectively. When the magnitude of the percent increase in the segmental wall-thickening from baseline value was compared between the treatment groups, the percent increase in the L-HGF-X7 treatment group was 83.54%, which was significantly higher than that of the NL-HGF-X7 group (28.99%) (**Fig. 5**).

These results indicate that the intramyocardial administration of the lyophilized formulation (L-HGF-X7) can more efficiently increase the regional blood flow and wall-thickening in the injected ischemic border area of left ventricle compared to the non-lyophilized formulation (NL-HGF-X7). Without wishing to be bound by theory, this is likely due to angiogenic and antifibrotic activities of expressed HGF-X7.

3. Summary

The segmental perfusion and wall-thickening were significantly increased in the lyophilized pCK-HGF-X7 treated group as compared to those of the non-lyophilized pCK and pCK-HGF-X7 treated groups.

These results demonstrate that the intramyocardial administration of pCK-HGF-X7 lyophilized with 1.1% sucrose and 0.9% NaCl to the affected pigs could efficiently and stably increase the regional perfusion and the wall-thickening in the ischemic myocardium as compared to non-lyophilized pCK-HGF-X7.

While the invention has been described with respect to the above specific embodiments, it should be recognized that various modifications and changes may be made to the invention by those skilled in the art which also fall within the scope of the invention as defined by the appended claims.

WHAT IS CLAIMED IS:

1. A DNA formulation comprising a plasmid DNA, a salt and a carbohydrate, wherein said plasmid DNA comprises an HGF gene, or variant thereof.

2. The DNA formulation of claim 2, wherein said carbohydrate is a mono-, oligo-, or polysaccharide selected from the group consisting of sucrose, glucose, lactose, trehalose, arabinose, pentose, ribose, xylose, galactose, hexose, idose, mannose, talose, heptose, fructose, gluconic acid, sorbitol, mannitol, methyl α-glucopyranoside, maltose, lactone, sorbose, glucaric acid, erythrose, threose, allose, altrose, gulose, erythrulose, ribulose, xylulose, psicose, tagatose, glucuronic acid, galacturonic acid, mannuronic acid, glucosamine, galactosamine, neuraminic acid, arabinans, fructans, fucans, galactans, galacturonans, glucans, mannans, xylans, levan, fucoidan, carrageenan, galactocarolose, pectins, pectic acids, amylose, pullulan, glycogen, amylopectin, cellulose, dextran, pustulan, chitin, agarose, keratin, chondroitin, dermatan, hyaluronic acid, alginic acid, xantham gum, and starch.

3. The DNA formulation of any of claims 1-2, wherein said carbohydrate is in an amount selected from the group consisting of between about 0.05% to about 30%, between about 0.1% to about 15%, between about 0.2% to about 10%, between about 0.5% and 5%, between about 0.75% and 3%, between about 0.8% and 2%, and between about 0.8% and 1.5%.

4. The DNA formulation of any of claims 1-3, wherein said carbohydrate is in an amount of about 0.1% to about 10%.

5. The DNA formulation of claims 3 or 4, wherein said carbohydrate is in an amount of about 1.1%.

6. The DNA formulation of any of claims 1-5, wherein said carbohydrate is selected from the group consisting of sucrose and mannitol.

7. The DNA formulation of any of claims 1-6, wherein said salt is selected from the group consisting of NaCl and KCl.

8. The DNA formulation of any of claims 1-7, wherein said salt is in an amount selected from the group consisting of between about 0.01% and 10%, between about 0.1% and 5%, between about 0.5% and 2%, between about 0.8% and 1.5%, between about 0.8% and 1.2%.

9. The DNA formulation of claim 8, wherein said salt of said DNA formulation is in an amount of about 0.9%.

10. The DNA formulation of any of claims 1-9, wherein said HGF gene or variant thereof is selected from the group consisting of flHGF, dHGF, NK1, NK2, and NK4.

11. The DNA formulation of any of claims 1-9, wherein said plasmid DNA comprises a hybrid HGF gene.

12. The DNA formulation of claim 11, wherein said hybrid HGF gene is selected from the group consisting of HGF-X2, HGF-X3, HGF-X6, HGF-X7, and HGF-X8.

13. The DNA formulation of claim 12, wherein said plasmid DNA is selected from the group consisting of: pCK-HGF-X2, pCK-HGF-X3, pCK-HGF-X6, pCK-HGF-X7, pCK-HGF-X8, pCP-HGF-X2, pCP-HGF-X3, pCP-HGF-X6, pCP-HGF-X7 and pCP-HGF-X8.

14. The DNA formulation of any of claims 1-13, wherein said DNA is at a concentration of from about 1 ng/mL to about 30 mg/mL.

15. The DNA formulation of claim 14, wherein said DNA is at a concentration of about 1 ng/mL, about 5 ng/mL, about 10 ng/mL, about 50 ng/mL, about 100 ng/mL, about 500 ng/mL, about 1 μg/mL, about 5 μg/mL, about 10 μg/mL, about 50 μg/mL, about 100 μg/mL, about 200 μg/mL, about 400 μg/mL, about 500 μg/mL, about 600 μg/mL, about 800 μg/mL, about 1 mg/mL, about 2 mg/mL, about 2.5 mg/mL, about 3 mg/mL, about 3.5 mg/mL, about 4 mg/mL, about 4.5 mg/mL, about 5 mg/mL, about 5.5 mg/mL, about 6 mg/mL, about 7 mg/mL, about 8 mg/mL, about 9 mg/mL, about 10 mg/mL, about 20 mg/mL, or about 30 mg/mL of a plasmid.

16. The DNA formulation of any of claims 14 , wherein said DNA is at a concentration of about 0.1 mg/ml to about 2.5 mg/mL.

17. The DNA formulation of any of claims 1-16, wherein said DNA formulation is lyophilized.

18. The lyophilized DNA formulation of claim 17, wherein the lyophilization of said DNA formulation comprises (a) loading a container with said DNA formulation into a lyophilizer; (b) cooling said DNA formulation to a subzero temperature; and (c) drying said DNA formulation.

19. The lyophilized DNA formulation of claim 17 or 18, wherein said lyophilization occurs under conditions comprising (a) about 30 hours to about 50 hours at a temperature greater than or equal to about -50°C and less than about 0°C, and (b) about 20 hours to about 50 hours at a temperature greater than or equal to about 0°C to less than or equal to about 30

°C, progressively, wherein the lowest (a) temperature is about -50°C to about -40°C and the highest (b) temperature is between about 20°C to about 30°C.

20. The lyophilized DNA formulation of any one of claim 17-19, that is reconstituted in a pharmaceutically acceptable buffer.

21. The lyophilized DNA formulation of claim 20, wherein said pharmaceutically acceptable buffer is selected from the group consisting of water, PBS, TE, Tris buffer and normal saline.

22. A method of treating or preventing ischemic or liver disease in a subject, comprising administering a composition reconstituted from a lyophilized DNA formulation,

wherein said lyophilized DNA formulation comprises a plasmid DNA, salt and a carbohydrate; and

wherein said plasmid DNA comprises an HGF gene, or variant thereof.

23. The method of claim 22, wherein said carbohydrate is a mono-, oligo-, or polysaccharide selected from the group consisting of sucrose, glucose, lactose, trehalose, arabinose, pentose, ribose, xylose, galactose, hexose, idose, mannose, talose, heptose, fructose, gluconic acid, sorbitol, mannitol, methyl α-glucopyranoside, maltose, lactone, sorbose, glucaric acid, erythrose, arabinose, allose, altrose, gulose, erythrulose, ribulose, xylulose, psicose, tagatose, glucuronic acid, galacturonic acid, mannuronic acid, glucosamine, galactosamine, neuraminic acid, arabinans, fructans, fucans, galactans, galacturonans, glucans, mannans, xylans, levan, fucoidan, carrageenan, galactocarolose, pectins, pectic acids, amylose, pullulan, glycogen, amylopectin, cellulose, dextran, pustulan, chitin,

agarose, keratin, chondroitin, dermatan, hyaluronic acid, alginic acid, xantham gum, and starch.

24. The method of claim 22 or 23, wherein said carbohydrate is in an amount selected from the group consisting of between about 0.05% to about 30%, between about 0.1% to about 15%, between about 0.2% to about 10%, between about 0.5% and 5%, between about 0.75% and 3%, between about 0.8% and 2%, and between about 0.8% and 1.5%.

25. The method of any of claims 22-24, wherein said carbohydrate is in an amount of about 0.1% to about 10%.

26. The method of claim 25, wherein said carbohydrate is in an amount of about 1.1%.

27. The method of claim 23, wherein said carbohydrate is selected from the group consisting of sucrose and mannitol.

28. The method of any of claims 22-27, wherein said salt is selected from the group consisting of NaCl and KCl.

29. The method of any of claims 22-28, wherein said salt is in an amount selected from the group consisting of between about 0.01% and 10%, 0.1% and 5%, between about 0.1% and 4%, between about 0.5% and 2%, between about 0.8% and 1.5%, and between about 0.8% and 1.2%.

30. The method of claim 29, wherein said salt of said DNA formulation is in an amount of about 0.9%.

31. The method of any of claims 22-30, wherein said HGF gene or variant thereof is selected from the group consisting of flHGF, dHGF, NK1, and NK2.

32. The method of any of claims 22-30, wherein said plasmid DNA comprises a hybrid HGF gene.

33. The method of claim 32, wherein said hybrid HGF gene is selected from the group consisting of HGF-X2, HGF-X3, HGF-X6, HGF-X7, and HGF-X8.

34. The method of claim 33, wherein said plasmid DNA is selected from the group consisting of: pCK-HGF-X2, pCK-HGF-X3, pCK-HGF-X6, pCK-HGF-X7, pCK-HGF-X8, pCP-HGF-X2, pCP-HGF-X3, pCP-HGF-X6, pCP-HGF-X7 and pCP-HGF-X8.

35. The method of any of claims 22-34, wherein said DNA is at a concentration of from about 1 ng/mL to about 30 mg/mL.

36. The method of claim 35, wherein said DNA is at a concentration of about 1 ng/mL, about 5 ng/mL, about 10 ng/mL, about 50 ng/mL, about 100 ng/mL, about 250 ng/mL, about 500 ng/mL, about 1 μg/mL, about 5 μg/mL, about 10 μg/mL, about 50 μg/mL, about 100 μg/mL, about 200 μg/mL, about 400 μg/mL, about 500 μg/mL, about 600 μg/mL, about 800 μg/mL, about 1 mg/mL, about 2 mg/mL, about 2.5 mg/mL, about 3 mg/mL, about 3.5 mg/mL, about 4 mg/mL, about 4.5 mg/mL, about 5 mg/mL, about 5.5 mg/mL, about 6 mg/mL, about 7 mg/mL, about 8 mg/mL, about 9 mg/mL, about 10 mg/mL, about 20 mg/mL, or about 30 mg/mL of a plasmid.

37. The method of claim 35, wherein said DNA is at a concentration of about 0.1 mg/ml to about 2.5 mg/mL.

38. The method of any of claims 22-37, wherein said lyophilized DNA is reconstituted in a pharmaceutically acceptable buffer.

39. The method of claim 38, wherein said pharmaceutically acceptable solution is selected from the group consisting of water, PBS, TE, Tris buffer and normal saline.

40. The method of any of claims 22-39, wherein said reconstituted composition is administered by direct injection.

41. A method of making a lyophilized DNA formulation comprising:

preparing a DNA formulation comprising a plasmid DNA, a salt and a carbohydrate, wherein said plasmid DNA comprises an HGF gene, or variant thereof; and

lyophilizing said DNA formulation, thereby making said lyophilized DNA formulation.

42. The method of claim 41, wherein the lyophilization of said DNA formulation further comprises (a) loading a container with said DNA formulation into a lyophilizer; (b) cooling said DNA formulation to a subzero temperature; and (c) drying said DNA formulation.

43. The method of claim 41 or 42, wherein said DNA formulation is lyophilized under conditions comprising (a) about 30 hours to about 50 hours at a temperature greater than or equal to about -50°C and less than about 0°C, and (b) about 20 hours to about 50 hours at a temperature greater than or equal to about 0°C to less than or equal to about 30°C, progressively, wherein the lowest (a) temperature is about -50°C to about -40°C and the highest (b) temperature is between about 20°C to about 30°C.

44. The lyophilized DNA formulation according to any one of claims 41-43.

FIG. 1

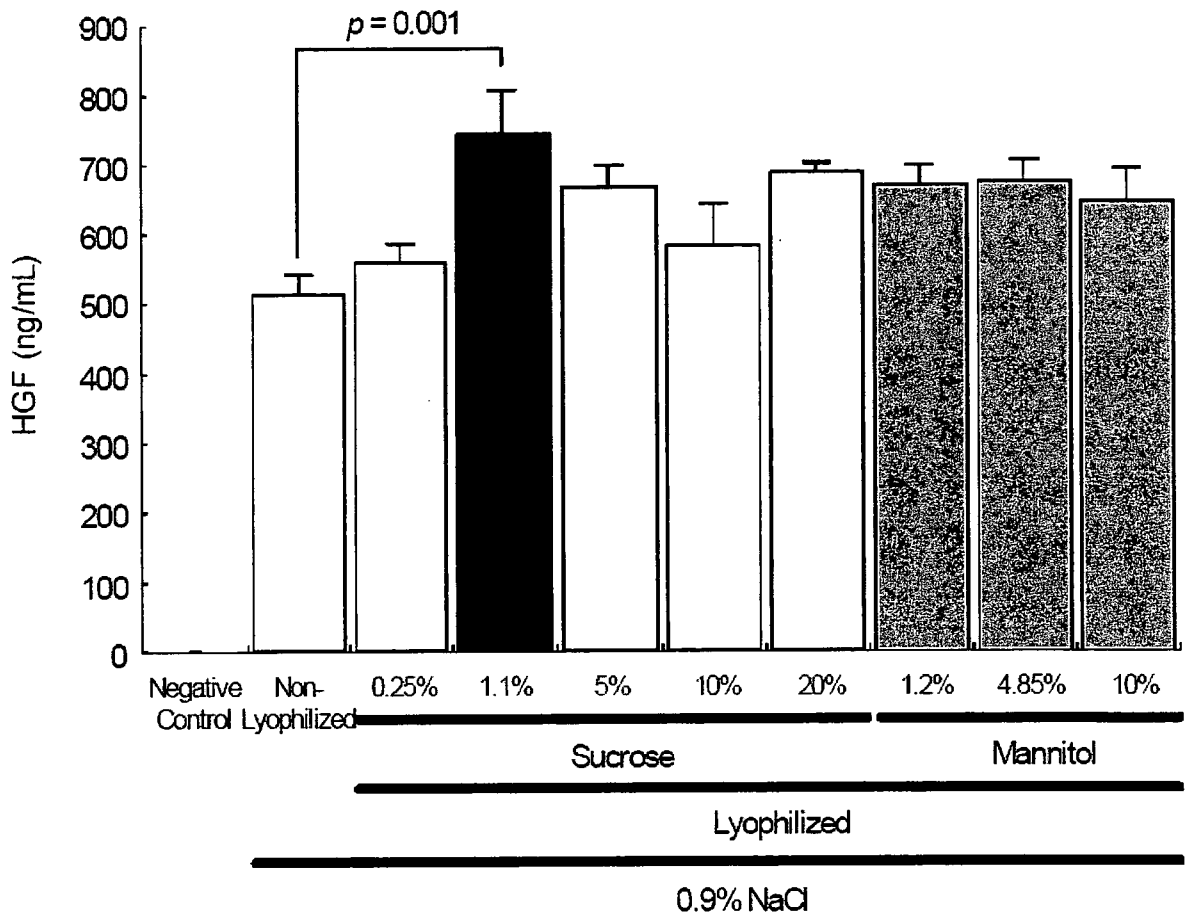

p = 0.001
HGF (ng/mL)
900
800
700
600
500
400
300
200
100
0
Negative Control
Non-Lyophilized
0.25%
1.1%
5%
10%
20%
1.2%
4.85%
10%
Sucrose
Mannitol
Lyophilized
0.9% NaCl

FIG. 2

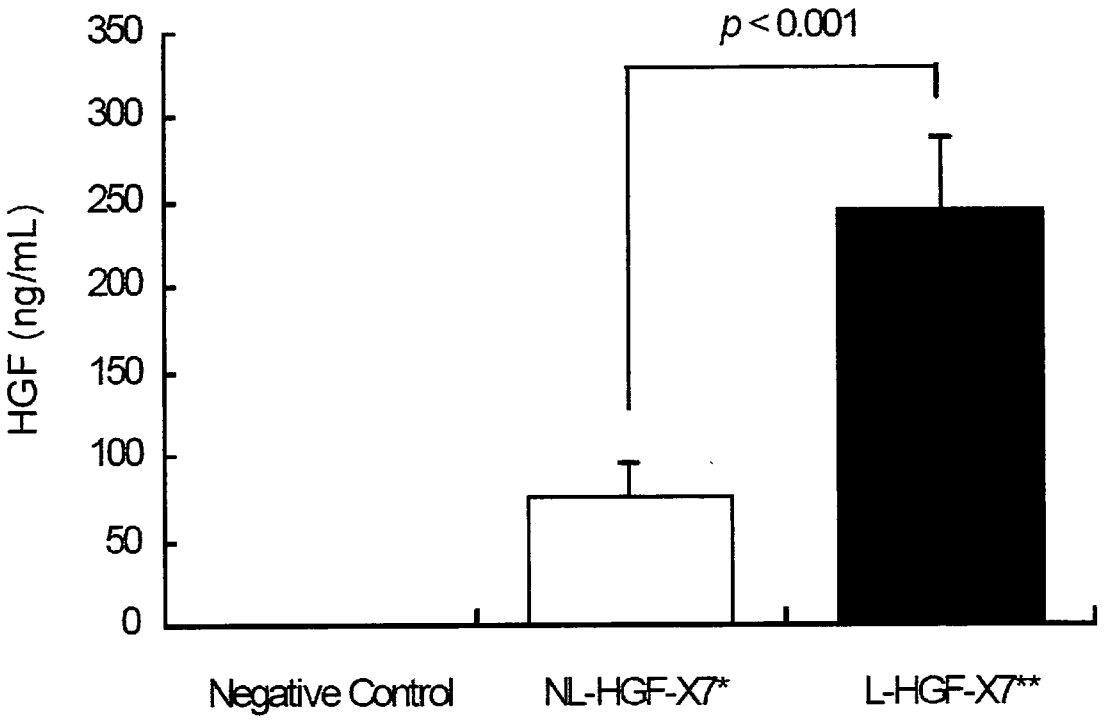
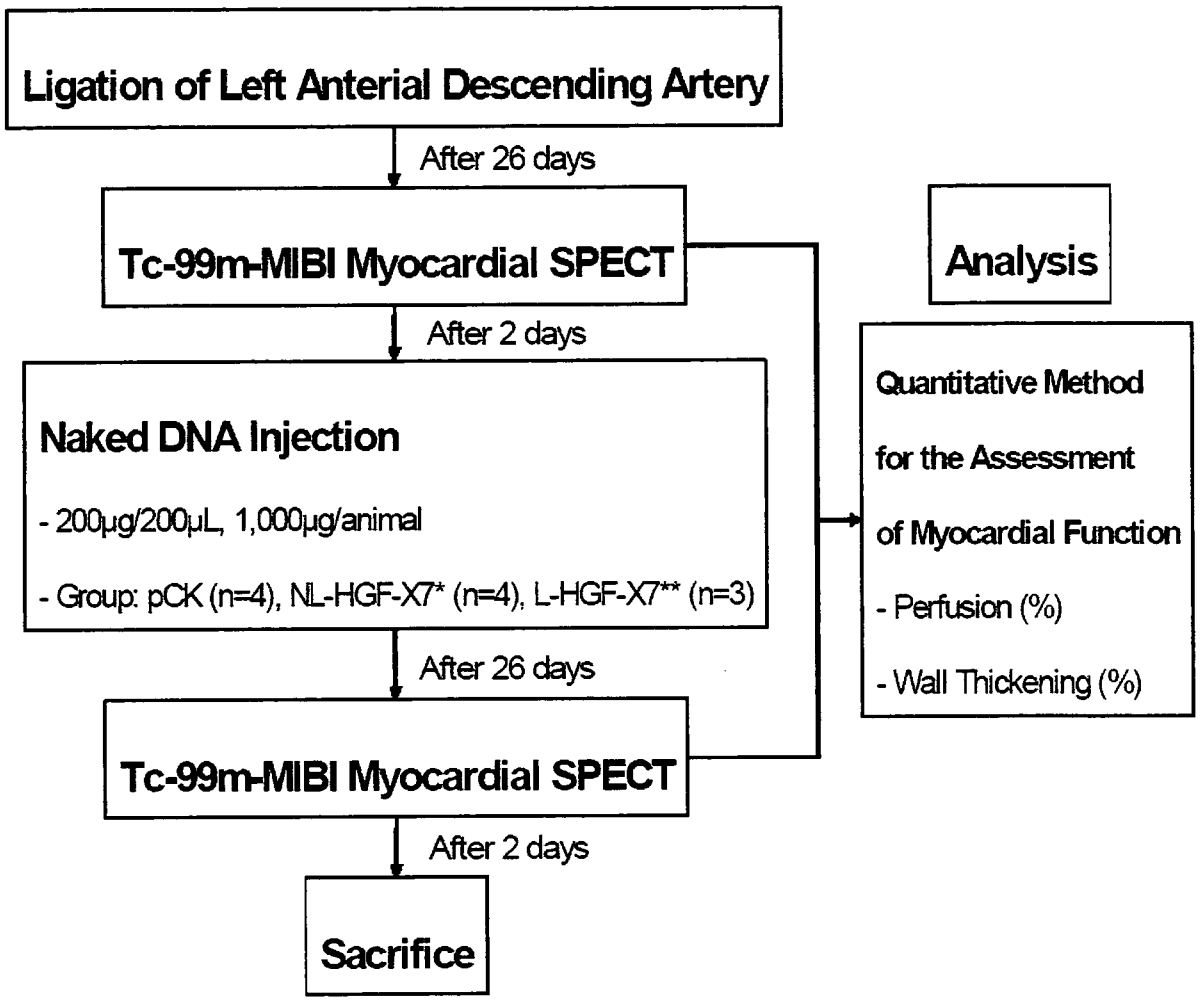

p < 0.001
350
300
250
200
150
100
50
0
HGF (ng/mL)
Negative Control
NL-HGF-X7*
L-HGF-X7**

FIG. 3



* NL-HGF-X7: Non-lyophilized pCK-HGF-X7 containing 0.9% NaCl

** L-HGF-X7: lyophilized pCK-HGF-X7 containing 1.1% Sucrose and 0.9% NaCl

FIG. 4

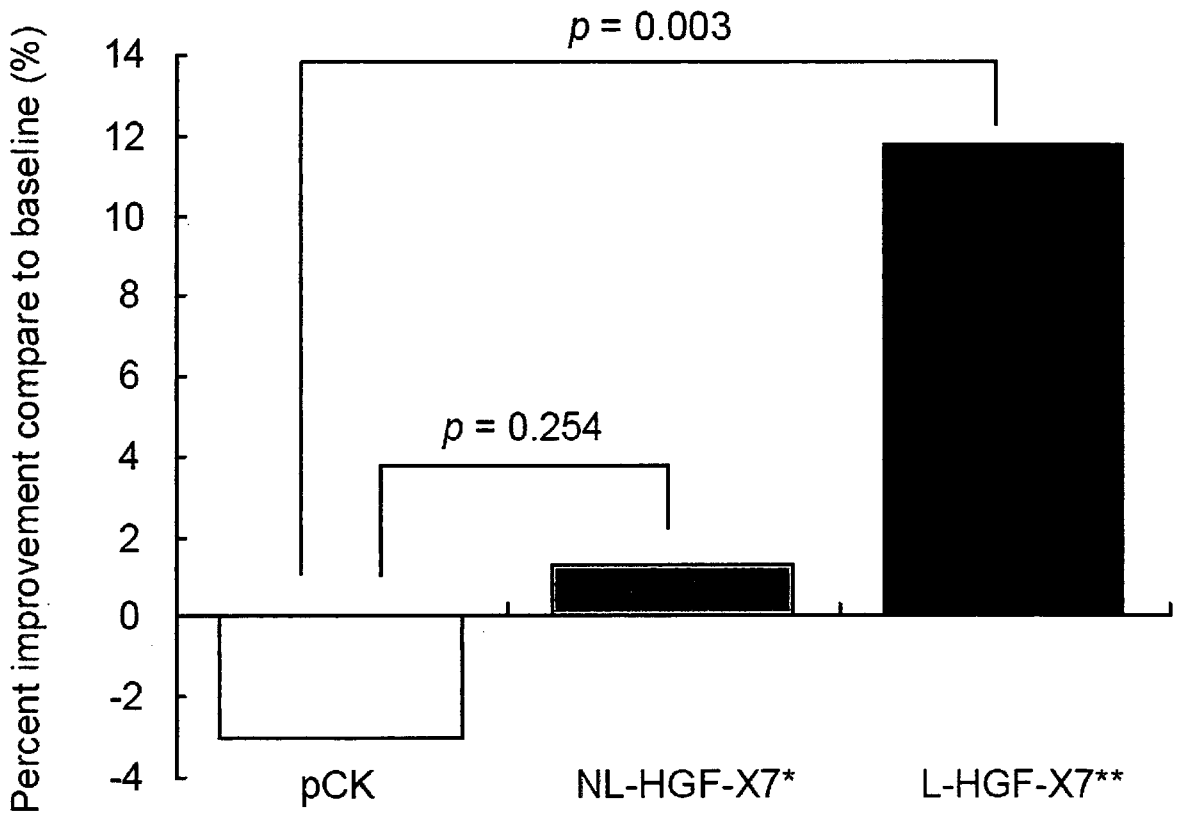
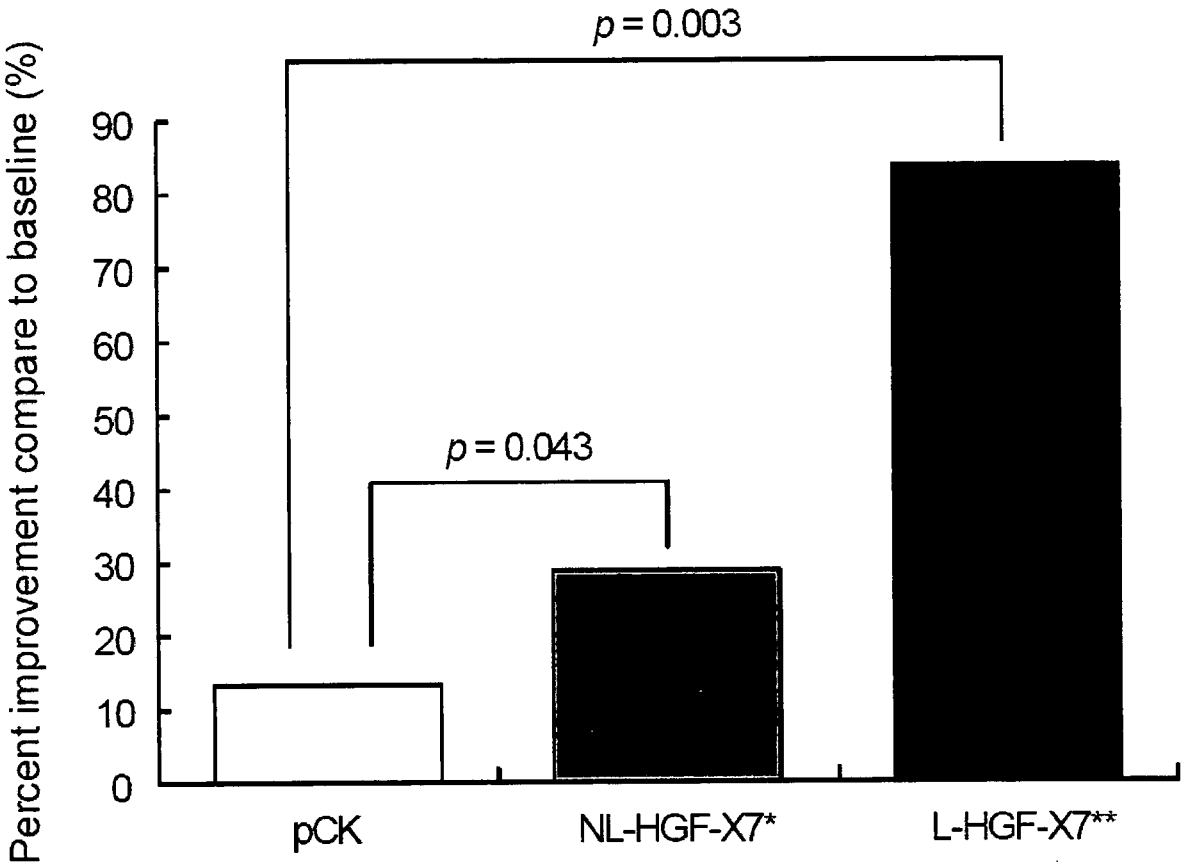

p = 0.003
p = 0.254
Percent improvement compare to baseline (%)
14
12
10
8
6
4
2
0
-2
-4
pCK
NL-HGF-X7*
L-HGF-X7**

FIG. 5


p = 0.003
p = 0.043
Percent improvement compare to baseline (%)
90
80
70
60
50
40
30
20
10
0
pCK
NL-HGF-X7*
L-HGF-X7**