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(72) Inventeurs/Inventors:
ESCHER, ALAN P., US;
LIU, JINGXUE, US

(73) Propriétaire/Owner:
LOMA LINDA UNIVERSITY, US

(74) Agent: GOWLING LAFLEUR HENDERSON LLP

(54) Titre : PROCEDE DE PREVENTION OU DE TRAITEMENT DU DIABETE

(54) Title: METHOD OF PREVENTING OR TREATING TYPE 1 DIABETES BY GENE THERAPY WITH A SECRETED FORM OF GLUTAMIC ACID DECARBOXYLASE.

(57) **Abrégé/Abstract:**

A method for preventing, delaying the onset of or treating diabetes in a patient comprising selecting a patient who is susceptible to developing diabetes, who is developing diabetes or who is diabetic and administering to the patient one or more than one dose of a pharmaceutical agent comprising a polynucleotide encoding a secreted exogenous protein, such as a secreted form of human glutamic acid decarboxylase.

Abstract

A method for preventing, delaying the onset of or treating diabetes in a patient comprising selecting a patient who is susceptible to developing diabetes, who is developing diabetes or who is diabetic and administering to the patient one or more than one dose of a pharmaceutical agent comprising a polynucleotide encoding a secreted exogenous protein, such as a secreted form of human glutamic acid decarboxylase.

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**METHOD OF PREVENTING OR TREATING TYPE I DIABETES BY GENE
THERAPY WITH A SECRETED FORM OF GLUTAMIC ACID
DECARBOXYLASE**

This invention was made with United States Government support under Cooperative Agreement Number DAMD17-97-2-7016 with the National Medical Technology Testbed, Inc., United States Department of the Army. The United States Government has certain rights in this invention.

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BACKGROUND

Diabetes is a major cause of morbidity and mortality in the United States and throughout the world. Diabetes is a metabolic disease characterized by the inability to metabolize glucose and generally divided into two types. Of the two types, type 1 diabetes usually results from autoimmune destruction of beta cells in the pancreas during adolescence which leads to insufficient insulin production.

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Research into the causes and treatments for type 1 diabetes frequently involve the use of nonhuman animals. The non-obese diabetic (NOD) mouse is one animal model system generally accepted for studying type 1 diabetes as NOD mice develop a form of diabetes that parallels type 1 diabetes in humans, including sharing common susceptibility factors such as major histocompatibility complex molecules. Studies of NOD mice and humans have indicated that two proteins synthesized by pancreatic beta cells play determining roles as autoantigens responsible for the onset of diabetes. The two proteins are the hormone insulin, a secreted protein, and the enzyme glutamic acid decarboxylase (GAD), an intracellular protein found as either soluble GAD67, or membrane-bound GAD65 in beta cells. The importance of these two autoantigens for diabetes onset in NOD mice is indicated by the finding that most pathogenic CD8+ T cells recognize a single insulin epitope, and that mice with beta cell-specific reduced expression of *gad65/67* genes do not develop diabetes. In

humans, the presence of anti-insulin and anti-GAD autoantibodies has been used to predict the onset of diabetes. There remains, however, a need for a method of preventing diabetes in humans.

SUMMARY

5 According to the present invention, there is provided a method for preventing, delaying the onset of or treating diabetes in a patient. The method comprises, first, selecting a patient who is susceptible to developing diabetes, who is developing diabetes or who is diabetic. Next, the patient is administered one or more than one dose of a pharmaceutical agent comprising a polynucleotide encoding a secreted exogenous protein.

10 In a preferred embodiment, selecting the patient comprises identifying in the patient the presence of anti-insulin or anti-GAD autoantibodies, or identifying in the patient the presence of increasing hyperglycemia, or identifying in the patient the presence of glycosuria, or identifying in the patient the presence of a genetic predisposition to diabetes. In a particularly preferred embodiment, the one or more than one dose is a plurality of doses. In
15 another particularly preferred embodiment, administering to the patient one or more than one dose comprises injecting the patient intramuscularly with the one or more than one dose. In another preferred embodiment, the method comprises, after administering, monitoring the patient for the development diabetes.

In a particularly preferred embodiment, the exogenous protein is a secreted *Renilla*
20 luciferase comprising a sequence according to SEQ ID NO:1 or according to SEQ ID NO:3.

FIGURES

These and other features, aspects and advantages of the present invention will become better understood with regard to the following description, appended claims, and the accompanying figure where:

25 Figure 1 is graph showing the percent on non-diabetic, cyclophosphamide treated NOD mice given versus time where the NOD mice were injected with plasmid DNA encoding full-length human GAD65 (filled boxes); SGAD55, a secreted form of human GAD65 (open boxes); SRUC3, a secreted form of the *Renilla reniformis* luciferase (open circles); or no injections of plasmid DNA (filled circles).

DESCRIPTION

According to one embodiment of the present invention, there is provided a method for delaying the onset of type 1 diabetes or preventing type 1 diabetes in a human or animal.

The method comprises selecting a patient who is susceptible to developing diabetes or who is developing diabetes and administering to the patient one or more than one dose of a pharmaceutical agent. The pharmaceutical agent can comprise a polynucleotide encoding a secreted *Renilla* luciferase or can comprise, a polynucleotide encoding a secreted form of glutamic acid decarboxylase.

The present invention resulted from an investigation of cyclophosphamide-accelerated diabetes in non-obese diabetic (NOD) mice that were administered plasmid DNA encoding either intracellular human GAD, a secreted form of human GAD or a secreted form of *Renilla reniformis* luciferase. In summary, four-week old animals were injected with plasmid DNA encoding either intracellular human GAD, a secreted form of human GAD or a secreted form of *Renilla reniformis* luciferase. Animals injected with plasmid DNA encoding secreted GAD demonstrated a significant reduction in the incidence of diabetes. Animals injected with plasmid DNA encoding *Renilla reniformis* luciferase demonstrated a significant delay in the onset of diabetes. However, animals injected with plasmid DNA encoding intracellular GAD did not demonstrate either a significant reduction in the incidence of diabetes or a significant delay in the onset of diabetes, even though previous studies showed that injecting plasmid DNA encoding human GAD65 or a secreted GAD prevented islets inflammation (insulitis) in the pancreas of NOD mice. The present invention will now be disclosed in detail.

First, plasmids designated pND2-SRUC3, pND2-GAD65 and pND2-SGAD55 were constructed as disclosed in Liu, J. et al. (1999). Intramuscular injection of plasmid DNA encoding intracellular or secreted glutamic acid decarboxylase causes decreased insulitis in the non-obese diabetic mouse. *Gene Ther. Mol. Biol.* 3, 197-206. The cDNAs carried by the plasmids were respectively; *sruc3*, SEQ ID NO:1, encoding a secreted form of the soft coral *Renilla reniformis* luciferase; *gad65*, SEQ ID NO:2, encoding full-length human GAD65 protein; and *sgad55*, SEQ ID NO:3, a modified *gad65* cDNA encoding a secreted truncated form of human GAD65, SEQ ID NO:2, that had an 88 amino acid amino-terminal region deletion removing a palmitoylation sequence and a Golgi targeting signal that prevents

secretion of full-length GAD65 protein, leaving residues 265-1758 of SEQ ID NO:2. The deleted sequence was replaced with a human IL-2 sequence encoding a signal peptide, which was cleaved intracellularly before secretion. This truncated GAD65 protein (GAD55) contained all known epitopes recognized by antibodies from patients suffering from type 1 diabetes. Each cDNA was placed under transcriptional control of the cytomegalovirus promoter in plasmid pND2. In addition, each plasmid carried a Col-E1 origin of replication and a gene encoding ampicillin resistance for amplification of plasmid DNA in the bacterium *Escherichia coli*.

The plasmid DNA was amplified in *E. coli* strain DH5-a, and isolated using the alkaline-lysis method followed by standard double-round cesium chloride purification. DNA quality and quantity were determined with a U.V. spectrophotometer (A_{260}/A_{280} ratio greater than 1.8), and agarose gel electrophoresis. The plasmid DNA was then dissolved under sterile conditions in phosphate buffer saline (PBS) at a final concentration of 2 $\mu\text{g}/\mu\text{l}$, and stored at -20°C .

The plasmid DNA was administered intramuscularly to female NOD/MrkTac mice (Taconic Laboratories, Germantown, NY US). Each animal was injected into each quadriceps muscle with 200 micrograms/leg at the age of four weeks using disposable tuberculin syringes fitted with 27G needle, and an identical set of injections two days later, for a total of 800 micrograms plasmid DNA/mouse. Three groups of mice received injections of pND-2 plasmid carrying either *sruc3*, SEQ ID NO:1, *gad65*, SEQ ID NO:2, or *sgad55*, SEQ ID NO:3, cDNA. An additional group of mice was left untreated as control. All mice received intra-peritoneal injections of cyclophosphamide (200 mg/kg) at the age of 10 and 12 weeks to accelerate the onset of diabetes. The mice were kept in an animal facility under non-pathogen free conditions, and received injection of DNA under general anaesthesia using 66 mg/kg body weight ketamine (Phoenix Scientific, St Joseph, MO US), 7.5 mg/kg body weight oxylazine (Lloyd Laboratories, Shenandoa, IO US), and 1.5 mg/kg body weight acepromazine maleate (Fermenta Animal Health Co., MO US).

The onset of diabetes in the animals was determined by monitoring for glycosuria twice a week with Clinistix^{*} Reagent Strips for urine analysis (Bayer Corporation, Elkhart, IN US). Once glycosuria was present, a diagnosis of diabetes was confirmed when blood

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glucose levels were greater than 300 mg/deciliter on two consecutive days (using Accu-Chek™ Advantage (Roche Diagnostics Corporation, Indianapolis, IN US). Animals were sacrificed when diagnosed as diabetic, or at the end of the observation period when the animals were 18 weeks old. Statistical analysis of the results were performed using a Kaplan-Meier analysis with a log-rank and Mann-Whitney test to detect differences in prevention and delay of diabetes onset.

Referring now to Figure 1, there is shown a graph depicting the results of administering the DNA given as the percent on non-diabetic, cyclophosphamide treated NOD mice given versus time, where the NOD mice were injected with plasmid DNA encoding full-length human GAD65 (filled boxes); SGAD55, a secreted form of human GAD65 (open boxes); SRUC3, a secreted form of the *Renilla reniformis* luciferase (open circles); or no injections of plasmid DNA (filled circles). As can be seen, the percentage of 18-week old animals that remained non-diabetic after receiving injection of plasmid pND2-SRUC3, pND2-GAD65 or pND2-SGAD55 was 18, 30 and 63, respectively, and 23 percent of untreated animals were free of diabetes at the end of the observation period. A Kaplan Meier plot of diabetes onset, together with statistical analysis, indicated that the mice which received injections of pND2-SGAD55 had a statistically significant reduction in diabetes when compared with untreated control ($P=0.05$, log-rank test). By contrast, mice that received injection of pND2-GAD65 did not show a statistically significant reduction in diabetes when compared with the same controls ($P=0.37$, log rank test). Although groups of untreated mice and mice that received injection of PND2-SRUC3 had a similar percentage of non-diabetic animals at the end of the observation period, injection of pND2-SRUC3 resulted in a significant delay in the onset of diabetes when compared to untreated controls using the Mann-Whitney test ($P=0.01$). Differences between the three groups of treated mice with respect to onset were not found to be statistically significant ($P>0.13$, log rank test).

Anti-luciferase and anti-GAD IgG and IgG1 antibody levels in mice sera were determined using ELISA to detect an immune response to luciferase and GAD polypeptides after injection of pND2-SRUC3, pND2-GAD65, and pND2-SGAD55 plasmids as follows. Blood was collected (0.5-1.5 ml) after heart puncture, and sera were obtained from samples after two centrifugations at 3,000 x g for 10 minutes at 4°C, and 10 ml of 1% sodium azide

was added to each sample. Ninety-six well microtiter plates (Dynex Technologies Inc., Chantilly, VA US) were coated overnight at 4°C with 100 µl phosphate buffer saline (PBS) containing 5 mM DTT, 100 mM beta-mercaptoethanol, and 10 mg/ml recombinant human GAD55 protein isolated from *E. coli*, or BSA. After blocking with 0.5% BSA in PBS for 2 hours at 37°C, serially diluted sera were added to wells and allowed to incubate for 2 hours at 37°C. Unbound proteins and antibodies were removed with four washes of PBS + 0.1% Triton x100 for 5 minutes at room temperature after each reaction. Alkaline phosphatase-conjugated Fab-specific anti-mouse IgG monoclonal antibodies (Sigma, St Louis, MO US) were diluted 1:40,000 in blocking buffer, added to wells, and incubated for 2 hours at 37°C. The relative amounts of bound antibodies were determined after addition of 100 µl alkaline phosphatase substrate Lumi-Phos Plus^{*} (Lumigen Inc., Southfield, MI US) to each well. Light emission catalyzed by alkaline phosphatase was measured in a ML3000 Luminometer (Dynex Technologies Inc., Chantilly, VA US) after allowing the reaction to develop for 30 minutes at 37°C.

No increase in anti-luciferase IgG was detected in sera of mice that received injections of pND2-SRUC3 plasmid DNA, when compared with the other three groups of NOD mice and with a control group of untreated CD1 mice. Further, there were no apparent differences in the range of titers of anti-GAD IgG antibodies in sera of mice that received injections of pND2-GAD65 and pND2-SGAD55 plasmids, when compared with untreated controls and with mice that had received injection of plasmid pND2-SRUC3. However, titers of anti-GAD IgG were in generally higher in NOD mice than in CD1 controls, in contrast with titers of anti-luciferase IgG.

Because Th2 cells mediate a process that leads to production of IgG1 antibodies, IgG1 levels were determined and were used as a marker of whether a Th2 type of response was induced. IgG1 antibodies were determined using a corresponding protocol to that above, except that alkaline phosphatase-conjugated IgG1-specific anti-mouse IgG monoclonal antibodies (Zymed Laboratories Inc., South San Francisco, CA US) were used for detection at a dilution of 1:2,000.

No increase in anti-luciferase IgG1 titer was detected in sera of mice that received injections of plasmid pND2-SRUC3, when compared to other groups of NOD mice and with

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CD1 controls. Similarly, there was no increase in anti-GAD IgG1 titer in sera of NOD mice from the group that received injection of plasmid pND2-SRUC3 and the untreated group when compared to CD1 mice. By contrast, however, an increase in anti-GAD IgG1 titer was detected in several non-diabetic mice that received injections of plasmid pND2-SGAD55. In addition, some of the mice that received injection of plasmid pND2-GAD65 also showed increased anti-GAD IgG1 titer, but the increase did not always correlate with an absence of diabetes. None of the animals had titer of anti-luciferase and anti-GAD IgG2a antibodies above background.

These results indicate that insulinitis scores obtained previously, Liu, J. et al., after injection of plasmid DNA encoding SRUC3, which did not decrease insulinitis, and GAD65, which did decrease insulinitis, were not predictive of diabetes prevention. Further, cellular location of human GAD polypeptide encoded by a genetic vaccine affects prevention of CYP-accelerated diabetes in the NOD mouse because injection of plasmid DNA encoding full-length intracellular GAD did not significantly prevent diabetes, while injection of plasmid encoding secreted GAD did decrease diabetes frequency. The decrease was accompanied by an increase in anti-GAD IgG1 titers, implicating the involvement of Th2 lymphocytes. In addition, the finding that both the injection of DNA encoding secreted foreign protein and secreted autoantigen delays the onset of diabetes implies that secretion of exogenous protein alone effects disease onset.

In one embodiment, the present invention is a method of preventing, delaying the onset of or treating diabetes in a patient. The method comprises, first, selecting a patient who is susceptible to developing diabetes, who is developing diabetes or who is diabetic. The selection can be made using standard methods as will be understood by those with skill in the art with reference to this disclosure. For example, the selection can be made by identifying in the patient the presence of anti-insulin or anti-GAD autoantibodies or both anti-insulin and or anti-GAD autoantibodies, the presence of increasing hyperglycemia, the patient the presence of glycosuria, the presence of a genetic predisposition to diabetes or more than one of these.

Next, the patient is administered one or more than one dose of a pharmaceutical agent comprising a polynucleotide encoding a secreted exogenous protein. In a preferred

embodiment, the pharmaceutical agent is administered in a plurality of doses. In another preferred embodiment, the dose is between about 0.001 mg/Kg and about 10 mg/Kg. In another preferred embodiment, the dose is between about 0.01 mg/Kg and about 1 mg/Kg. In another preferred embodiment, the dose is about 0.1 mg/Kg. In another preferred embodiment, the dose is administered weekly between about 2 and about 10 times. In a particularly preferred embodiment, the dose is administered weekly 4 times.

In a particularly preferred embodiment, the secreted exogenous protein is a secreted *Renilla* luciferase comprising a sequence according to SEQ ID NO:1. In another particularly preferred embodiment, is a secreted form of human glutamic acid decarboxylase comprising a sequence according to SEQ ID NO:3. Additionally, the method can comprise, after administering, monitoring the patient for the development diabetes.

EXAMPLE 1

According to the present invention, the onset of diabetes in a patient is delayed or prevented, for example, as follows. First, the patient is selected based on the presence of circulating anti-insulin and anti-GAD autoantibodies. Next, the patient is injected intramuscularly with 0.1 mg/Kg of a pharmaceutical agent comprising a plasmid encoding a secreted form of human glutamic acid decarboxylase. The injection is repeated weekly for 3 weeks while the level of circulating anti-insulin and anti-GAD autoantibodies is monitored. The treatment is ended when the level of circulating anti-insulin and anti-GAD autoantibodies has returned to normal.

Although the present invention has been discussed in considerable detail with reference to certain preferred embodiments, other embodiments are possible. Therefore, the scope of the appended claims should not be limited to the description of preferred embodiments contained in this disclosure.

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CLAIMS:

1. A use of one or more than one dose of a polynucleotide encoding a secreted glutamic acid decarboxylase (SEQ ID NO:3) for preventing, delaying the onset of or treating diabetes in a patient who is susceptible to developing diabetes, who is developing diabetes or who is diabetic.
2. A use of one or more than one dose of a polynucleotide encoding a secreted glutamic acid decarboxylase (SEQ ID NO:3) for the production of a medicament for preventing, delaying the onset of or treating diabetes in a patient who is susceptible to developing diabetes, who is developing diabetes or who is diabetic.
3. The use according to claim 1 or 2 wherein the patient exhibits anti-insulin or anti-glutamic acid decarboxylase autoantibodies or both anti-insulin and anti-glutamic acid decarboxylase autoantibodies.
4. The use according to claim 1 or 2 wherein the patient exhibits hyperglycemia.
5. The use according to claim 1 or 2 wherein the patient exhibits glycosuria.
6. The use according to claim 1 or 2 wherein the patient exhibits a genetic predisposition to diabetes.
7. The use according to any one of claims 1 to 6, wherein the use comprises a plurality of doses.
8. The use according to any one of claims 1 to 7, wherein said use is intramuscular use.
9. The use according to anyone of claims 1 to 8, wherein subsequent to said use, said subject is monitored for the development of diabetes.

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