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(54) **Title:** NEW PHARMACEUTICAL COMPOSITIONS COMPRISING A THYROID HORMON AND THEIR THERAPEUTIC USE

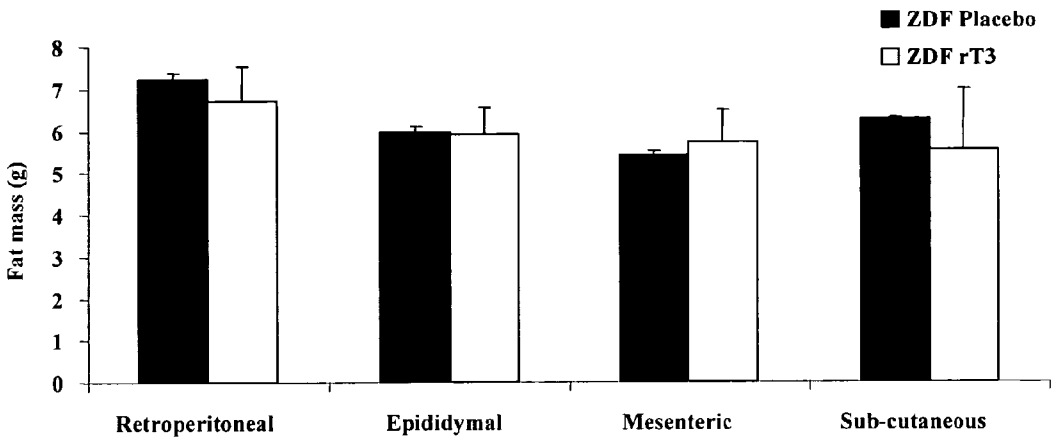

Figure 26

(57) **Abstract:** The present invention relates to a pharmaceutical composition comprising, as active substance, at least one hormone chosen among 3 ',5 ',3 -triiodothyronine (rT3), a rT3 derived hormone, or a precursor of rT3, such as T4 in association with a molecule susceptible to promote the formation of rT3, in association with a pharmaceutically acceptable vehicle.

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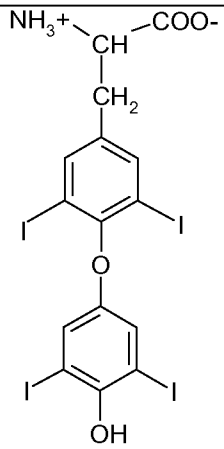
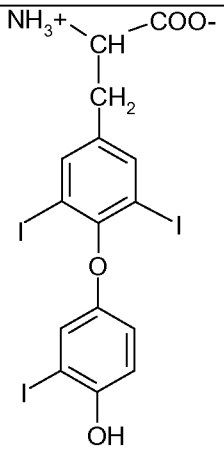
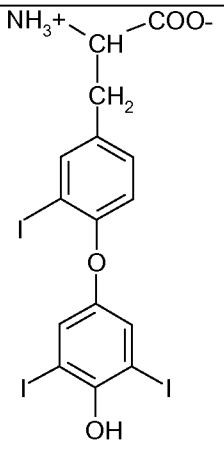
NEW PHARMACEUTICAL COMPOSITIONS COMPRISING A THYROID HORMON AND THEIR THERAPEUTIC USE

The present invention relates to new pharmaceutical compositions comprising a thyroid hormone and their therapeutic use.

Thyroid hormones have been known for a long time. The thyroid hormone family consists in T4 hormone and the derived iodothyronines resulting from successive monodeiodinations of T4. The pathways of the deiodination cascade of T4 have been described by Hulbert A.J. (Biol. Rev., 2000). T4 gives T3 via an outer ring 5'-deiodination or rT3 via an inner ring 5'-deiodination. T3 results in 3,5-T2 via an outer ring 5'-deiodination or 3,3'-T2 via an inner ring 5'-deiodination. rT3 results in 3,3'-T2 via an outer ring 5'-deiodination or 3',5'-T2 via an inner ring 5'-deiodination. 3-T1 is obtained via an inner ring 5'-deiodination from 3,5-T2 or via an outer ring 5'-deiodination from 3,3'-T2. 3'-T1 is obtained via an inner ring 5'-deiodination from 3,3'-T2 or via an outer ring 5'-deiodination from 3',5'-T2.

For information, table 1 indicates the formula of several members of the thyroid hormone family.

 T4	 T3	 rT3

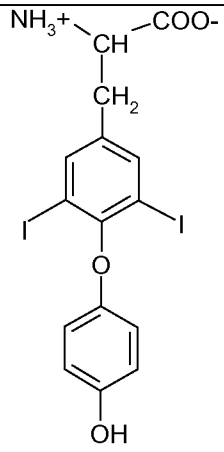
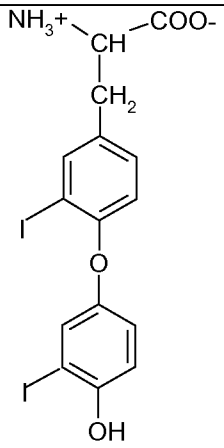
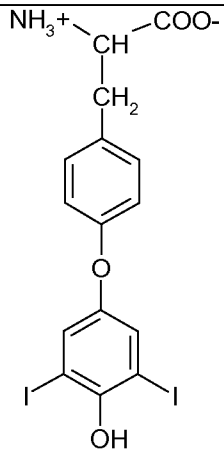
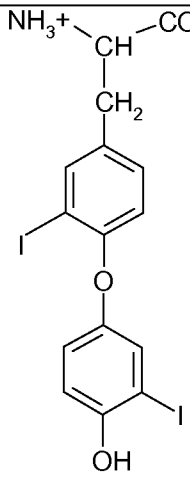
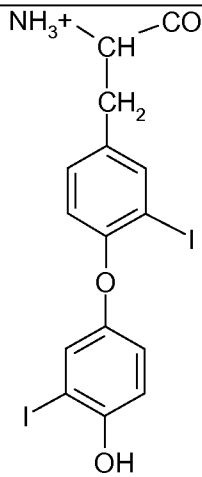
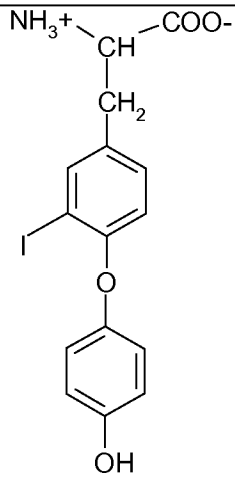
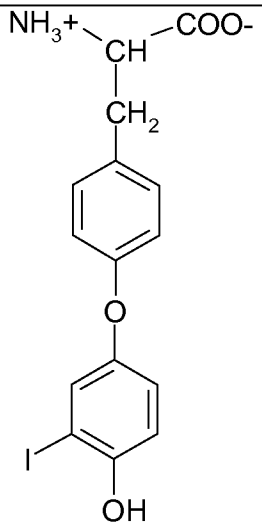
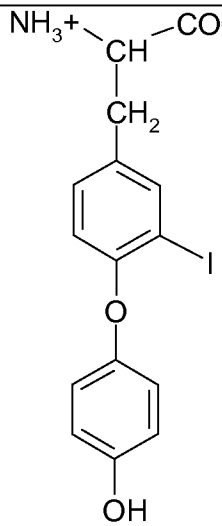
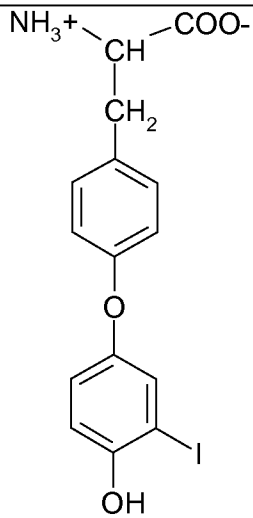
 3,5-T2	 3',3-T2	 3',5'-T2
 5',3-T2	 3',5-T2	 3-T
 3'-T	 5-T	 5'-T

Table 1: Formula of iodothyronine hormones

The known effects of thyroid hormones, particularly of the T3 hormone, result mainly from the binding to two nuclear receptors of the thyroid hormones, TRα-1 and TRβ-1 belonging to the family of nuclear receptors TR-α and TR-β, which are supposed to have different effects. These receptors are thought to be highly specific towards T3, particularly relating to the number of iodine and the spatial arrangement (Bolger et al., J. Biol. Chem., 1980; Koerner et al., J. Biol. Chem., 1975; Dietrich et al., J. Med Chem., 1977) . Since the discovery of the thyroid nuclear receptors, most of scientists have focused on the effects of transcriptional changes of thyroid hormones.

T3 hormone binds very efficiently to the nuclear receptors, whereas the T4 hormone binds less efficiently. The hormones derived from T4 and T3 do not bind to the nuclear receptors (Koerner et al., J. Biol. Chem., 1975; Lazar, Endocrine Rev., 1993; Hulbert, Bio. Rev., 2000; Oppenheimer, Biochimie, 1999; Yen, Physiol. Rev., 2001).

The use of T3 hormone for treating obesity is well known by the man skilled in the art. However, its use has been highly limited because of serious side effects of T3 hormone, particularly cardiac side effects. The treatment of hypothyroidism lies on T3, which can be used directly or produced *in vivo* by the transformation of its very little active precursor, the T4 hormone (Yen, Physiol. Rev., 2001). T3 is known as the real active thyroid hormone.

The effects induced by thyroid hormones, such as T3, via the nuclear receptor pathway are physiologically important effects observed at very low concentrations. These effects are often deleterious when T3 is administered to subjects that do not suffer from hypothyroidism. These effects can be considered as "hyperthyroidic effects" linked to the nuclear receptor pathway.

The international application WO2005/009433 and the corresponding scientific paper (Lanni et al., The FASEB Journal, 2005) have disclosed an effect of the 3,5-T2 on energetic metabolism. More particularly, normal rats receiving a high-fat diet and treated with a daily peritoneal injection of 3,5-T2 gained less weight and had less fat deposit than untreated rats. The 3,5-T2 hormone was thus proposed for the treatment of obesity and related pathologies.

The rT3 hormone is generally considered as an inactive hormone and was thought to represent the inactivation pathway of thyroid hormones (Yen, Physiol. Rev., 2001). Thus, increased rT3 plasmatic concentrations are often found in low T3 syndrome. Recently, cerebral effects of rT3 have been disclosed in the establishment and structuring of astrocytes (Farwell et al. Endocrinology, 2006).

In prior art, it has never been disclosed that thyroid hormones may have effects on insulin and glycemia.

Diabetes is a chronic disease characterized by a hyperglycemia.

Type 1 diabetes results from the destruction of the pancreatic β cells secreting insulin. Treatment of type 1 diabetes particularly consists in the administration of insulin.

Type 2 diabetes is more frequent than type 1 diabetes in the population and is generally associated to obesity. Type 2 diabetes is characterized by two interdependent abnormalities: an insulin-resistance and a reduced production of insulin by response to glycemia.

Treatments of type 2 diabetes particularly consist in using an agonist drug of insulin or an agonist of insulin secretion by the beta cells, in reducing the glycemia and the weight of the diabetic patients.

Obesity is one of the major public health concerns in developed countries as well as in developing countries. The mechanisms involved in obesity are not really understood. Factors involved in obesity are particularly alimentation (fat and sweet diets) and environment conditions (physical activity, social environment, food availability).

More efficient and more appropriate treatments (particularly in term of side effects, comfort of patients such as frequency of use and administering route) are needed against chronic diseases such as diabetes, obesity and dyslipidemia.

One aim of the present invention is to provide new pharmaceutical compositions comprising a thyroid hormone as active substance.

Another aim of the invention is to provide new pharmaceutical compositions for the treatment of metabolic disorders that do not induce hyperthyroidism.

Another aim of the invention is to provide a new therapeutic class of drugs for the treatment of diabetes.

Another aim of the invention is to provide a combination product for a simultaneous, separate or sequential use intended for the treatment of diabetes.

The present invention relates to a pharmaceutical composition comprising, as active substance, at least one hormone chosen among:

- 3',5',3-triiodothyronine (rT3),
- a rT3 derived hormone, such as 3',3-diiodothyronine (3',3-T2), 5',3-diiodothyronine (5',3-T2), 3'-iodothyronine (3'-T), 5'-iodothyronine (5'-T) or 3-iodothyronine (3-T), or

- a precursor of rT3, such as T4 in association with a molecule susceptible to promote the formation of rT3,

in association with a pharmaceutically acceptable vehicle.

Contrary to the teaching of the prior art presenting rT3 as inactive, the Inventors have found that the rT3 hormone can be used as a drug, as well as its derived hormones.

Furthermore, contrary to the effects of other thyroid hormones such as T3, the effects of the hormones according to the invention seem not to involve the nuclear receptor pathway since rT3 is know to have a very little affinity to TH receptors.

The rT3 hormone and the rT3 derived hormones are the physiological forms of thyroid hormones that are inactive for the treatment of hypothyroidism or as hyperthyroidism inducer. Contrary to 3,5-T2, these hormones can not be obtained via T3, which is the active thyroid hormone.

According to the Inventors, rT3, a rT3 derived hormone or a rT3 precursor are shown for the first time to have an energetic activity and to have an effect on glycemia and on insulin sensitivity as well as plasma concentrations.

The Inventors propose that the use of rT3 and its derived hormone is the physiological way to obtain beneficial metabolic effects without inducing hyperthyroidism.

Futhermore, the Inventors propose that rT3 has beneficial effect only on the glycemia of diabetic subjects and has no hypoglycemic effect on non diabetic subjects (see Examples section).

According to the present invention, the term "3',5',3-triiodothyronine" refers to reverse T3 or rT3.

By the expression "rT3 derived hormone", one means any compound that has at least one iodine susceptible to be obtained from rT3, particularly by removing one or several iodines, via natural occurring and / or artificial ways.

By "natural occurring way", it is particularly meant that the rT3 derived hormone is obtained via enzymes such as the iodothyronine deiodinases that remove one or several iodines from rT3. Several biological reactions may be needed to obtain the desired derived hormone.

By the expression "via an artificial way", it is particularly meant that the rT3 derived hormone is obtained via chemical synthesis, biochemical synthesis or recombinant technology.

The preferred rT3 derived hormones are diiodothyronines and iodothyronines. The preferred rT3 derived hormones are 3',3-diiodothyronine, 3',5'-diiodothyronine, 5',3-diiodothyronine, 3'-iodothyronine, 5'-iodothyronine or 3-iodothyronine.

By the expression "a precursor of rT3", one means any compound susceptible to give rT3. The precursor of rT3 may be a natural hormone, a synthesis or recombinant hormone, or a modified hormone.

By the expression "natural hormone", one means a hormone found in a living being, such as an animal or a human being, and which is purified and isolated from said living being.

By the expression "synthesis or recombinant hormone", one means a hormone obtained by chemical or biochemical synthesis or recombinant technology.

By the expression "modified hormone", one means a hormone which is chemically modified to add functional groups. Said functional groups may modify the activity of said hormone or protect said hormone from degradation.

In an advantageous embodiment of the invention, the precursor of rT3 is the T4 hormone, also called "thyroxine".

The rT3 precursor is preferentially used in association with a molecule susceptible to promote the formation of rT3. The use of the precursor of rT3 and said molecule can be simultaneous, separate or sequential.

Particularly, when the T4 hormone is used as rT3 precursor, said molecule susceptible to promote the formation of rT3 is:

- a thyronine deiodinase that allows the preferential formation of the rT3 hormone instead of the T3 hormone, or an agonist of said thyronine deiodinase, or
- an antagonist of a deiodinase that allows the preferential formation of the T3 hormone instead of the rT3 hormone.

The present invention particularly relates to a pharmaceutical composition as defined above, wherein said active substance is rT3.

The present invention particularly relates to a pharmaceutical composition as defined above, in a suitable form for the release of about 0.01 µg/kg/day to about 250 µg/kg/day, particularly about 0.01 µg/kg/day to about 25 µg/kg/day, particularly about 0.1 µg/kg/day to about 15 µg/kg/day of active substance, more particularly about 0.1 µg/kg/day to about 5

μg/kg/day of active substance, most particularly about 0.1 μg/kg/day to 1 μg/kg/day of active substance.

The dosage of active substance particularly depends on the administration route, which is easily determined by the man skilled in the art.

The present invention further relates to pharmaceutical composition as defined above, comprising by dosage unit about 5 μg to about 1.5 g of active substance, particularly about 75 mg to about 750 mg of active substance, to be released in a lapse of time corresponding to the above-mentioned values of the ranges in μg/kg/day or mg/kg/day for a 70kg human.

As an example, for the treatment of a 70 kg human, the dosage will be:

- about 5 μg to about 150 mg, particularly about 5 μg to about 15 mg, particularly about 50 μg to about 10 mg, particularly about 50 μg to about 3 mg, most particularly about 50 μg to about 500 μg of active substance to achieve an eight day treatment,
- about 20 μg to about 500 mg, particularly about 20 μg to about 50 mg, particularly about 200 μg to about 30 mg, particularly about 200 μg to about 10 mg, most particularly about 200 μg to about 2 mg of active substance to achieve a thirty day treatment,
- about 60 μg to about 1.5 g, particularly about 60 μg to about 150 mg, particularly about 600 μg to about 100 mg, particularly about 600 μg to about 30 mg, most particularly about 600 μg to about 6 mg of active substance to achieve a ninety day treatment.

By the expression "dosage unit", one means the quantity of active substance comprised in one drug unit.

Depending on the administration route and on the formulation of the pharmaceutical composition, the active substance comprised in the dosage unit can be released quickly or continuously over a period of time. The pharmaceutical composition can also be a slow-release drug.

Pharmaceutical compositions of the invention may be administered in a partial dose or a dose one or more times during a 24 hour period. Fractional, double or other multiple doses may be taken simultaneously or at different times during a 24 hour period.

In an advantageous embodiment, the pharmaceutical composition of the invention is administered in a unique dose, which allows a continuous release for a period of time of at least 24h, preferably at least one week, more preferably at least one month, most preferably at least two months, in particular three months.

The present invention also relates to the use of at least one hormone chosen among:

- 3',5',3-triiodothyronine (rT3),
- a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine, or 3-iodothyronine, or
- a precursor of rT3, such as T4, in association with a molecule susceptible to promote the formation of rT3,

for the preparation of a drug intended for the treatment of:

- hyperglycemia, insulin resistance, beta pancreatic cell insufficiency, or related pathologies,
- pathologies wherein the cholesterol and / or triglycerides plasma concentrations are higher than the normal concentrations, or dyslipidemia, or
- pathologies related to overweight or related to an excess of fat deposit.

In an advantageous embodiment, the present invention relates to the use as defined above, for the preparation of a drug intended for the treatment of type 1 and type 2 diabetes, hyperglycemia, insulin resistance, beta pancreatic cell insufficiency, or related pathologies.

The Inventors have shown for the first time that rT3, a rT3 derived hormone or a rT3 precursor are capable of reducing glycemia and insulin plasmatic concentrations.

Hyperglycemia is characterized by fasting glucose concentrations higher that 1.1g/l (or 110 mg/dl or 5.5 mmol/l), particularly higher than 1.20 g/L. The use of rT3, a rT3 derived hormone or a rT3 precursor allows reducing glycemia to normal concentrations.

By the expression "normal concentrations of glucose", one means glucose plasmatic concentration comprised from 4.4 mmol/l to 5.5 mmol/l, "abnormal" blood glucose is defined by fasting plasma glucose >5.55 mmol/l and diabetes by fasting plasma glucose >6.1 mmol/l (Meggs et al., Diabetes, 2003).

Glycemia is assessed by classical blood tests using the glucose oxidase method as reference (Yeni-Komshian et al., Diabetes Care, 2000, p171-175; Chew et al., MJA, 2006, p445-449; Wallace et al., Diabetes Care, 2004, p1487-1495).

The use of rT3, a rT3 derived hormone or a rT3 precursor also improves insulin resistance.

Insulin resistance is characterized by insulin plasmatic concentrations higher than 8 mU/l or 60 pmol/l (Wallace et al., Diabetes Care, 2004, p1487-1495).

Insulin resistance is the condition in which normal amounts of insulin are inadequate to produce a normal response from fat, muscle and liver cells, *i.e.* a resistance to the physiological action of insulin.

It is defined as the lowest quartile of measures of insulin sensitivity (e.g. insulin stimulated glucose uptake during euglycaemic clamp) or highest quartile of fasting insulin or homeostasis model assessment (HOMA) insulin resistance index in the population studied (Alberti et al. "Definition, diagnosis and classification of diabetes mellitus and its complications. Part 1: Diagnosis and classification of diabetes mellitus, provisional report of a WHO consultation", Diabetic Med, 1998, p539-553; Wallace et al., Diabetes Care, 2004, p1487-1495).

The use of the above-mentioned active substances allows reducing insulin plasmatic concentrations to normal concentrations, increasing the sensitivity to insulin and improving the metabolism of glucose and lipids.

By the expression "normal concentrations of insulin", one means insulin plasmatic concentration comprised from 5 to 8 mU/l (36 to 60 pmol/l).

Insulin concentration is assessed by classical blood tests (RIA assay with human antibody; Yeni-Komshian et al., Diabetes Care, 2000, p171-175; Chew et al., MJA, 2006, p445-449; Wallace et al., Diabetes Care, 2004, p1487-1495).

Sensitivity to insulin can be assessed by the HOMA (Homeostasis Model Assessment) method (Wallace et al., Diabetes Care, 2004, p1487-1495, see Figure 2 on page 1489).

Surprisingly, the use of the above-mentioned active substances seems to improve pancreatic β cells survival, and thus the regeneration of said insulin secreting cells.

The regeneration of said cells is evaluated through the measurement of insulin concentration (RIA assay with human antibody; Yeni-Komshian et al., Diabetes Care, 2000, p171-175; Chew et al., MJA, 2006, p445-449; Wallace et al., Diabetes Care, 2004, p1487-1495).

Results obtained on ZDF rats show that treatment with rT3 induced decreasing glucose concentration and increasing plasmatic insulin concentration.

In Goto-Kakizaki (GK) rats, a genetic model of type 2 diabetes, there is a restriction of the β cell mass as early as fetal age, which is maintained in the adult animal. The restriction of the β cell mass can be considered as a crucial event in the sequence leading to overt diabetes in this model. In the GK model, the regeneration of β cells occurs with a lower efficiency as compared to non-diabetic Wistar rats. This defect in the GK rats is both the result of genetic predisposition contributing to an altered β cells neogenesis potential and environment factors, such as chronic hyperglycemia, leading to a reduced β cell proliferative capacity specific to the adult animals. These results are described in Movassat et al., Diabetologia, 1997, p916-925 and in Plachot et al., Histochem Cell Biol., 2001, p131-139, the entire contents of which are incorporated herein by reference.

Assuming that a chronic hyperglycemia induced a destruction of pancreatic β cells and thus a decreased secretion of insulin, restored normal insulin concentrations could mean that the β cells are regenerated.

The β cells functional mass can be correlated to the level of insulin secretion through the HOMA method. On animal models, the man skilled in the art can envision the direct evaluation of pancreas mass.

According to another embodiment, the present invention relates to the use as defined above, for the preparation of a drug intended for the treatment of pathologies wherein the cholesterol and / or triglyceride plasmatic concentrations are higher than the normal concentrations, or dyslipidemia, or pathologies related to overweight or related to an excess of fat deposit.

A cholesterol concentration higher than the normal concentrations means a plasmatic concentration higher than 2.5 g/l.

A triglyceride concentration higher than the normal concentrations means a plasmatic concentration higher than 2 g/l.

Dyslipidemia is characterized by a triglyceride concentration higher than 1.7 mmol/l and/or a HDL-cholesterol level lower than 1 mmol/l (men) or 1.3 mmol/l (women) (Chew, MJA, 2006, p445-449, see table entitled “Clinical definitions of the metabolic syndrome”).

An excess of fat deposit is characterized by a body mass index: (weight, kg / height^2, m^2) higher than 25 kg/m^2 and obesity is characterized by a body mass index higher than 30 kg/m^2.

The invention further relates to the use as define above, for the preparation of a drug intended for the treatment of pathologies chosen among diabetes, particularly type 1 or 2 diabetes, beta pancreatic cell insufficiency, obesity, overweight or related pathologies, hypercholesterolemia, hypertriglyceridemia, dyslipidemia, alcoholic and non alcoholic hepatic steatosis, atherosclerosis, hepatopathies associated to a dysmetabolism, cholecystopathies, deposit of subcutaneous fat, particularly cellulite or vasomotor rhinitis.

In an advantageous embodiment, the invention related to the uses as defined above, wherein said hormone is rT3.

The present invention particularly relates to a pharmaceutical composition as defined above, wherein said pharmaceutically acceptable vehicle refers to pharmaceutically acceptable solid or liquid, diluting or encapsulating, filling or carrying agents, which are usually employed in pharmaceutical industry for making pharmaceutical compositions.

The present invention relates to a pharmaceutical composition as defined above, suitable for an administration via an oral, intravenous, intramuscular, subcutaneous, transcutaneous, nasal, intraperitoneal, sublingual, or rectal route.

In the oral route, drugs are administered orally, particularly under the shape of tablets, coated tablets, pills, syrup or elixirs, dragees, troches, lozenges, aqueous or oily suspensions, liquid solutions, dispersible powders or granules, emulsions, hard or soft capsules.

In the intravenous route or systemic route, the drug can be administered in the bloodstream by a single injection or via a continuous infusion, eventually via a pump.

In the cutaneous route, drugs are applied to the skin. The formulation may be an ointment, a cream, a lotion, a solution, a powder or a gel.

In the subcutaneous route, the drug can be injected directly into fatty tissue just beneath the skin or the drug can be included in capsules that are inserted under the skin.

In the transcutaneous route, the drug passes through the skin to the bloodstream without injection. Particularly, the drug is comprised in a patch applied on the skin.

Concerning patches formulation, the drug can be mixed with a chemical, such as alcohol, to enhance skin penetration.

The dosage forms include immediate release, extended release, pulse release, variable release, controlled release, timed release, sustained release, delayed release, long acting, and combinations thereof.

The dosage forms include, without limitation, tablets, multi-layer tablets, bi-layer tablets, chewable tablets, quick dissolve tablets, effervescent tablets, syrup, suspensions, emulsions, capsules, soft gelatin capsules, hard gelatin capsules, lozenges, chewable lozenges, beads, powders, granules, particles, microparticles, dispersible granules, cachets, creams, topicals, patches, implants, injectables (including subcutaneous, intramuscular, intravenous, and intradermal), infusions.

In an advantageous embodiment of the invention, the pharmaceutical composition is suitable for a transcutaneous, particularly by means of patches.

In an advantageous embodiment, the administration of the pharmaceutical composition avoids partially that the drug passes through liver, which is susceptible of an important degradation of the hormones.

In another advantageous embodiment of the invention, the pharmaceutical composition is suitable for a subcutaneous administration, particularly by means of a capsule injected beneath the skin.

The present invention also relates to a pharmaceutical composition as defined above, wherein said pharmaceutically acceptable vehicle allows a continuous, preferably constant, release, of said active substance, the active substance being chosen among:

- 3',5',3-triiodothyronine (rT3),
- a rT3 derived hormone, such as 3',3-diiodothyronine (3',3-T2), 5',3-diiodothyronine (5',3-T2), 3'-iodothyronine (3'-T), 5'-iodothyronine (5'-T) or 3-iodothyronine (3-T), or
- a precursor of rT3, such as T4 in association with a molecule susceptible to promote the formation of rT3.

The continuous, preferably constant, release of the active substance allows obtaining:

- increased effects on metabolic disorders as compared to results obtained *via* another administration mode, or

- newly observed effects on metabolic disorders on animal models on which there were previously no positive results.

By the expression "continuous release", one means a continuous release of the drug over at least 24 hours, preferably at least one month, most preferably at least two months, in particular three months. Also, a continuous release in the invention can correspond to a discontinuous release. Indeed one release can be separated by a short time interval from another release, such that the concentration of drug remains substantially constant in blood, or at a sufficient efficient amount in blood, between two releases. This short time interval is for example comprised from 10 s to 3 hours, preferably from 1 minute to 2 hours, more preferably from 5 minutes to 1 hour.

By the expression "constant release", one means a continuous release of the drug over at least 24 hours, preferably at least one month, most preferably at least two months, in particular three months, the quantity of released drug/ time unit being essentially constant.

A continuous and constant release is for example achieved by using patches or capsules injected under the skin. Also, an electric syringe, or an electric pump, continuously releasing the hormone, and placed under the skin, can also be used. The syringe or pump can also be placed in the peritoneal cavity.

Also, the continuous and constant release can be provided by controlled-release (CR) formulation of the drug.

Controlled release formulations allow a slow release of a drug over time, such that the concentration of the drug remains substantially constant in blood, or at a sufficiently efficient amount in blood.

Controlled release drugs are for instance formulated such that the active ingredient is embedded in a matrix of insoluble substance (e.g. some acrylics, chitin, PEG (polyethylen glycol)…), or of a slowly degradable substance. To be liberated, the drug has to find its way out through the holes in the matrix. In some controlled released formulations, the matrix swells up to form a gel, and the drug has to dissolve in matrix to be diffused in the outer surface of the matrix.

In another embodiment, rT3, the rT3 derived hormone and the rT3 precursor of the invention are used in a simultaneous, separate or sequential combination with another thyroid hormone, such as 3,5-T2 or 3',5-T2.

The present invention also relates to a product comprising:

- at least one hormone chosen among 3',5',3-triiodothyronine (rT3), a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine, or 3-iodothyronine, or a rT3 precursor, such as T4 in association with a molecule susceptible to promote the formation of rT3,
- at least one active substance activating the pancreatic secretion of insulin, particularly chosen among antidiabetic oral drugs, or susceptible of slowing the digestive absorption of glucose,

as a combination product for a simultaneous, separate or sequential use intended for the treatment of diabetes.

The present invention also relates to nutraceutics or food compositions comprising at least one hormone chosen among:

- 3',5',3-triiodothyronine (rT3),
- a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine or 3-iodothyronine, or
- a precursor of rT3, such as T4 in association with a molecule susceptible to promote the formation of rT3.

The present invention also relates to a method for improving meat quality, in particular pork meat quality, by controlling the ratio between the weight of adipose tissues and lean tissues, in particular by:

- lowering the weight of adipose tissues in animals as compared to the weight of adipose tissues of animals fed with a normal diet, and
- maintaining or increasing the weight of lean tissues as compared to the weight of lean tissues of animals fed with a normal diet,

by the administration of nutraceutics or food compositions comprising at least one hormone chosen among:

- 3',5',3-triiodothyronine (rT3),
- a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine or 3-iodothyronine, or
- a precursor of rT3, such as T4 in association with a molecule susceptible to promote the formation of rT3.

DRAWINGS

In the following figures, asterisk or star (*) represents either significant results with a p-value<0.05, or a specific indicated p-value.

High dose of hormones correspond to 25 µg/100 g of body weight (BW), low doses correspond to 2.5 µg/100 g of body weight and ultra low doses correspond to 0.25 µg/100 g of body weight.

Figures 1A and 1B

Growth rate of Wistar rats treated wit a high dosage of rT3 or 3,3'-T2 (25 µg/100 g of body weight (BW))

Figures 1A and 1B represent the weight of the rats (in grams) relative to time (in days) for a period of 21 days. The weight of the rats treated with thyroid hormones is shown on the curve with white rectangles and the weight of those treated with placebo is represented with black diamonds.

Figure 1A: the rats were treated with rT3.

Figure 1B: the rats were treated with 3,3'-T2.

Figures 2A and 2B

Food intake of Wistar rats treated with a high dosage of rT3 or 3,3'-T2 (25 µg/100 g BW)

Figures 2A, 2B and 2C represent the food intake in grams / day of the rats relative to time (in days) for a period of 21 days. The food intake of the rats treated with thyroid hormones is shown on the curve with white rectangles and the food intake of those treated with placebo is represented with black diamonds.

Figure 2A: the rats were treated with rT3.

Figure 2B: the rats were treated with 3,3'-T2.

Figures 3A and 3B

Energy expenditure of Wistar rats treated with a high dosage rT3 or 3,3'-T2 (25 µg/100 g BW)

Figures 3Aand 3B represent the energy expenditure (EE) in Kcal / day/$kg^{0,75}$ of the rats relative to time (in minutes). The energy expenditure of the rats treated with thyroid hormones is shown on the curve with white triangles (Figure 3A), white diamonds (Figure 3B), and the energy expenditure of those treated with placebo is represented with black circles.

The horizontal black line indicates a period where the rats are in the dark.

Figure 3A: the rats were treated with rT3.

Figure 3B: the rats were treated with 3,3'-T2.

Figures 4A and 4B

Respiratory quotient (RQ) of Wistar rats treated with a high dosage of rT3 or 3,3'-T2 (25 µg/100 g BW).

Figures 4A and 4B represent the respiratory quotient of the rats relative to time (in minutes). The respiratory quotient of the rats treated with thyroid hormones is shown on the curve with white triangles (Figure 4A), white diamonds (Figure 4B), and the respiratory quotient of those treated with placebo is represented with black circles.

The horizontal black line indicates a period where the rats are in the dark.

Figure 4A: the rats were treated with rT3.

Figure 4B: the rats were treated with 3,3'-T2.

Figures 5A, 5B and 5C

Weight and relative weight of adipose tissues, skeletal muscles and brown adipose tissue of Wistar rats treated with a high dosage of rT3 (250 µg/kg BW).

The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

The asterisk corresponds to a p-value <0.01.

Figure 5A: the upper panel gives the weight (g) of different adipose tissues (retroperitoneal, epididymal, mesenteric and subcutaneous fat) and the lower panel gives the relative weight (g/100 g BW) of these adipose tissues.

Figure 5B: the left panel gives the weight (mg) of skeletal muscles (soleus and plantaris muscles) and the right panel gives the relative weight (mg/100 g BW) of these muscles.

Figure 5C: the left panel gives the weight (g) of interscapular brown adipose tissue and the right panel gives the relative weight (g/100 g BW) of this tissue.

Figures 6A, 6 B and 6C

Weight and relative weight of adipose tissues, skeletal muscles and brown adipose tissue of Wistar rats treated with a high dosage of 3,3'-T2 (250 µg/kg BW).

The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

The asterisk corresponds to a p-value <0.01.

Figure 6A: the upper panel gives the weight (g) of different adipose tissues (retroperitoneal, epididymal, mesenteric and subcutaneous fat) and the lower panel gives the relative weight (g/100 g BW) of these adipose tissues.

Figure 6B: the left panel gives the weight (g) of skeletal muscles (soleus and plantaris muscles) and the right panel gives the relative weight (mg/100 g BW) of these muscles.

Figure 6C: the left panel gives the weight (g) of interscapular brown adipose tissue and the right panel gives the relative weight (g/ 100g BW) of this tissue.

Figures 7A, 7B, 7C and 7D

Rate of liver mitochondrial oxygen consumption (JO_2 in nmol of O_2 / min / mg of protein) of animals treated with a 250 µg/kg BW/day of rT3 or 3,3'-T2.

Measurements were performed using mitochondria (1.0 mg of mitochondrial protein/ml) incubated with various substrates:

- GM: glutamate/malate (5 mM/2.5 mM)
- SR: succinate/rotenone (5 mM/5µM),
- GMS : glutamate/malate/ succinate (5 mM/2.5 mM/5mM),
- Palm: palmitoyl carnitine (55µM),
- Octa: octanoyl carnitine (100 µM),
- TMPD/ascorbate (0.5 mM/0.5 mM) and
- TMPD/ascorbate/DNP (0.5 mM/0.5 mM/75 µM) OK

JO_2 was recorded in the presence of the substrate and following the addition of 1mM ADP (adenosine diphosphate) (state 3).

The oligomycin was added to the mitochondrial suspension to determine the non-phosphorylating respiratory rate (state 4).

Oxygen consumption of rats treated with thyroid hormones is shown in white, and oxygen consumption of those treated with placebo in black.

The asterisk corresponds to a p-value <0.01.

Figure 7A: results obtained with rats treated with rT3 at state 4.

Figure 7B: results obtained with rats treated with 3,3'-T2 at state 4.

Figure 7C: results obtained with rats treated with rT3 at state 3.

Figure 7D: results obtained with rats treated with 3,3'-T2 at state 3.

Figures 8A, 8B, 8C and 8D

Rate of muscle mitochondrial oxygen consumption (JO_2 in nmol of O_2 / min / mg of protein) of Wistar rats treated with 250 µg/kg BW/day of rT3 or 3,3'-T2.

All measurements were performed using mitochondria (0.2 mg of mitochondrial protein/ml) incubated with various substrates:

- GM: glutamate/malate (5 mM/2.5 mM)
- SR: succinate/rotenone (5 mM/5µM),
- GMS : glutamate/malate/ succinate (5 mM/2.5 mM/5mM),
- Palm: palmitoyl carnitine (55µM), and
- Octa: octanoyl carnitine (100 µM).

JO_2 was recorded in the presence of the substrate and following the addition of 1mM ADP (state 3).

The oligomycin was added to the mitochondrial suspension to determine the non-phosphorylating respiratory rate (state 4).

Oxygen consumption of rats treated with thyroid hormones is shown in white, and oxygen consumption of those treated with placebo in black.

The asterisk corresponds to a p-value <0.01.

Figure 8A: results obtained with rats treated with rT3 at state 4.

Figure 8B: results obtained with rats treated with 3,3'-T2 at state 4.

Figure 8C: results obtained with rats treated with rT3 at state 3.

Figure 8D: results obtained with rats treated with 3,3'-T2 at state 3.

Figures 9A and 9B

Rate of liver mitochondrial oxygen consumption (JO_2 in nmol of O_2 / min / mg of protein) of Wistar rats treated with a low dosage of rT3 (25µg/kg BW/day).

Oxygen consumption of rats treated with thyroid hormones is shown in white, and oxygen consumption of those treated with placebo in black.

All measurements were performed using mitochondria (1.0 mg of mitochondrial protein/ml) incubated with various substrates:

- GM: glutamate/malate (5 mM/2.5 mM),
- SR: succinate/rotenone (5 mM/5µM),
- GMS : glutamate/malate/ succinate (5 mM/2.5 mM/5mM),
- Palm: palmitoyl carnitine (55µM),
- Octa: octanoyl carnitine (100 µM),
- TMPD/ascorbate (0.5 mM/0.5 mM) and

- TMPD/AsC/DNP: TMPD/ascorbate/DNP (0.5 mM/0.5 mM/75 µM)

The asterisk corresponds to a p-value <0.01.

Figure 9A: JO_2 was recorded in the presence of the substrate and following the addition of 1mM ADP (state 3).

Figure 9B: JO_2 was recorded after the addition of oligomycin to determine the non-phosphorylating respiratory rate (state 4).

Figures 10A, 10B, 10 C, 10D and 10E

Plasma concentrations of glucose, triglycerides, cholesterol, FFA (Free Fatty Acid) and HDL (Heavy Density Lipoprotein) in Wistar rats treated with 250µg/kg BW/day of rT3 or 3,3'-T2. These measurements were done on venous blood of the rats the day of the sacrifice.

The results of the rats treated with rT3 are shown in white, the results of those treated with 3,3'-T2 in grey and the results of those treated with placebo in black.

The asterisk corresponds to a p-value<0.01.

Figure 10A: glucose (mmol/l)

Figure 10B: triglycerides (TG) (g/l)

Figure 10C: cholesterol (g/l)

Figure 10D: FFA (µmol/l)

Figure 10E: HDL (g/l)

Figures 11A, 11B, 11 C, 11D

Mass of Wistar rats at day 0 and day 8 after a treatment with a high dosage of rT3 (25µg/100g BW). The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 11A : continuous and constant administration (subcutaneous pellet)

Figure 11B: daily intra-peritoneal (IP) injection

Figure 11C: daily oral ingestion (per os)

Figure 11D: daily subcutaneous (sc) injection

Figures 12A, 12B, 12 C, 12D

Weight of adipose tissues of Wistar rats treated with a high dosage of rT3 (25 µg/100g BW) after 8 days of treatment. The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 12A : continuous and constant administration (subcutaneous pellet)

Figure 12B: daily intra-peritoneal (IP) injection

Figure 12C: daily oral ingestion (per os)

Figure 12D: daily subcutaneous (sc) injection

Figures 13A, 13B, 13 C, 13D

Weight of brown adipose tissue of Wistar rats treated with a high dosage of rT3 (25 µg/100g BW) after 8 days of treatment. The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 13A : continuous and constant administration (subcutaneous pellet)

Figure 13B: daily intra-peritoneal (IP) injection

Figure 13C: daily oral ingestion (per os)

Figure 13D: daily subcutaneous (sc) injection

Figures 14A, 14B, 14 C, 14D

Weight of skeletal muscles of Wistar rats treated with a high dosage of rT3 (25 µg/100g BW) after 8 days of treatment. The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 14A : continuous and constant administration (subcutaneous pellet)

Figure 14B: daily intra-peritoneal (IP) injection

Figure 14C: daily oral ingestion (per os)

Figure 14D: daily subcutaneous (sc) injection

Figures 15A, 15B, 15 C, 15D

Energy expenditure of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW)

Figures 15A, 15B, 15 C, 15D represent the energy expenditure (EE) in Kcal / day/$kg^{0,75}$ of the rats relative to time (in minutes). The energy expenditure of the rats treated with thyroid hormones is shown on the curve with black squares and the energy expenditure of those treated with placebo is represented with white circles.

Figure 15A : continuous and constant administration (subcutaneous pellet)

Figure 15B: daily intra-peritoneal (IP) injection

Figure 15C: daily oral ingestion (per os)

Figure 15D: daily subcutaneous (sc) injection

Figures 16A, 16B, 16 C, 16D

Respiratory quotient (RQ) of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW).

Figures 16A, 16B, 16 C, 16D represent the respiratory quotient of the rats relative to time (in minutes). The respiratory quotient of the rats treated with thyroid hormones is shown on the curve with black squares, and the respiratory quotient of those treated with placebo is represented with white circles.

Figure 16A : continuous and constant administration (subcutaneous pellet)

Figure 16B: daily intra-peritoneal (IP) injection

Figure 16C: daily oral ingestion (per os)

Figure 16D: daily subcutaneous (sc) injection

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Figure 17:

Blood rT3 dosage. The rT3 concentration is measured for 24 hours in Wistar rats treated with a high dosage of rT3 by intra-peritoneal injection (IP, square), oral ingestion (per os, triangle) or subcutaneous injection (sc, star). Basal rT3 level is measured in animal treated with placebo (lozenge).

Figure 18

Blood glucose concentration of ZDF rats at day 0, and after 8, 16 and 21 days of treatment with a low dose of rT3 (2.5µg/100g BW). Glucose concentration of animals treated with placebo is represented in black and glucose concentration of animals treated with low dose of rT3 is represented in white. Star (*) represents significant differences.

Figure 19

Blood insulin concentration of ZDF rats at day 0, and after 8, 16 and 21 days of treatment with a low dose of rT3 (2.5µg/100g BW). Insulin concentration of animals treated with placebo is represented in black and insulin concentration of animals treated with a low dose of rT3 is represented in white. Star (*) represents significant differences.

Figure 20

Pancreas mass in grams of ZDF rats treated with a low dose of rT3 (2.5µg/100g BW) (White) or treated with placebo (Black) after X days.

Figure 21

Photography of ZDF rats treated for 21 days with placebo (left) or with a low dose of rT3 (right).

Figure 22

Body weight (g) of ZDF rats at day 0, and after 8, 16 and 21 days of treatment with a low dose of rT3 (2.5µg/100g BW). Mass of ZDF rats treated with rT3 is represented by white squares and mass of ZDF rats treated with placebo is represented by black lozenges.

Figure 23

Food intake (g/days) of ZDF rats at day 0, and after 8, 16 and 21 days of treatment with a low dose of rT3 (2.5µg/100g BW). Food intake of ZDF rats treated with rT3 is represented by white squares and food intake of ZDF rats treated with placebo is represented by black lozenges.

Figure 24

Energy expenditure of ZDF rats treated with a low dosage rT3 (2.5 µg/100 g BW)

The energy expenditure of the rats treated with thyroid hormones is shown on the curve with white squares and the energy expenditure of those treated with placebo is represented with black lozenges.

Figure 25

Respiratory quotient (RQ) of ZDF rats treated with a low dosage of rT3 (2.5 µg/100 g BW).

The respiratory quotient of the rats treated with thyroid hormones is shown on the curve with white squares and the respiratory quotient of those treated with placebo is represented with black lozenges.

Figure 26

Weight of adipose tissues of ZDF rats treated with a low dosage of rT3 (2.5 µg/100g BW).

The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 27

Weight of brown adipose tissue of ZDF rats treated with a low dosage of rT3 (2.5 µg/100g BW). The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 28

Weight of skeletal muscles of ZDF rats treated with a low dosage of rT3 (2.5 µg/100g BW). The results of the rats treated with thyroid hormones are shown in white and the results of those treated with placebo in black.

Figure 29

Plasma concentrations FFA (Free Fatty Acid) in ZDF rats treated with 2.5µg/100 g BW of rT3. These measurements were done on venous blood of the rats the day of the sacrifice. The results of the rats treated with rT3 are shown in white and the results of those treated with placebo in black. Star (*) represents significant differences.

Figure 30

Plasma concentrations triglycerides in ZDF rats treated with 2.5µg/100 g BW of rT3. These measurements were done on venous blood of the rats the day of the sacrifice. The results of the rats treated with rT3 are shown in white and the results of those treated with placebo in black.

Figure 31

Plasma concentrations cholesterol in ZDF rats treated with 2.5µg/100 g BW of rT3. These measurements were done on venous blood of the rats the day of the sacrifice. The results of the rats treated with rT3 are shown in white and the results of those treated with placebo in black. Star (*) represents significant differences.

Figure 32

Plasma concentrations HDL (Heavy Density Lipoprotein) in ZDF rats treated with 2.5µg/100 g BW of rT3. These measurements were done on venous blood of the rats the day of the sacrifice. The results of the rats treated with rT3 are shown in white and the results of those treated with placebo in black.

Figure 33

Area under the curve of the glucose concentration 3h after OGTT in n0STZ rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 34

Area under the curve of the insulin concentration 3h after OGTT (Oral Glucose tolerance test) in n0STZ rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 35

Kinetic of glucose concentration in plasma in n0STZ rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 36

Kinetic of Insulin concentration in plasma in n0STZ rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 37

Pancreas mass in n0STZ rats treated with 2.5µg/100 g BW of rT3. . The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black. Star (*) represents significant differences.

Figure 38

Area under the curve of the glucose concentration 3h after OGTT in GK rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 39

Area under the curve of the insulin concentration 3h after OGTT (Oral Glucose tolerance test) in GK rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The

results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 40

Kinetic of glucose concentration in plasma in GK rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 41

Kinetic of Insulin concentration in plasma in GK rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 42

Pancreas mass in GK rats treated with 2.5µg/100 g BW of rT3. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 43

Area under the curve of the glucose concentration 3h after OGTT in Wistar rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 44

Area under the curve of the insulin concentration 3h after OGTT (Oral Glucose tolerance test) in Wistar rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 45

Kinetic of glucose concentration in plasma in Wistar rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 46

Kinetic of Insulin concentration in plasma in Wistar rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 47

Pancreas mass in Wistar rats treated with 2.5µg/100 g BW of rT3. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 48

Growth rate of Wistar rats treated with a high dosage (25 µg/100 g of body weight (BW)) or a low dosage (2.5Mg/100g BW) of rT3. The weight of the rats treated with a high dosage is shown on the curve with white squares, with low dosage with white triangle and the weight of those treated with placebo is represented with black lozenges.

Figure 49

Food intake Wistar rats treated with a high dosage (25 µg/100 g of body weight (BW)) or a low dosage (2.5Mg/100g BW) of rT3. The Food intake of the rats treated with a high dosage is shown on the curve with white squares, with a low dosage with white triangle and the Food intake of those treated with placebo is represented with black lozenges.

Figure 50

Growth rate of Wistar rats treated with an ultra low dosage (0.25 µg/100 g BW) of rT3. The weight of the rats treated with an ultra low dosage is shown on the curve with white squares and the weight of those treated with placebo is represented with black lozenges.

Figure 51

Energy expenditure of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a low dosage (2.5 µg/100 g BW) of rT3. The energy expenditure of the rats treated with high dosage of thyroid hormones is shown on the curve with white squares, the energy expenditure of the rats treated with low dosage of thyroid hormones is shown on the curve with white triangles and the energy expenditure of those treated with placebo is represented with black lozenges.

Figure 52

Energy expenditure of Wistar rats treated with a ultra low dosage (0.25 µg/100 g BW) of rT3. The energy expenditure of the rats treated with high dosage of thyroid hormones is shown on the curve with white squares and the energy expenditure of those treated with placebo is represented with black lozenges.

Figure 53

Respiratory quotient (RQ) of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a low dosage (2.5 µg/100 g BW) of rT3. The respiratory quotient of the rats treated with high dosage of thyroid hormones is shown on the curve with white squares, the respiratory quotient of the rats treated with low dosage of thyroid hormones is shown on the curve with white triangles and the respiratory quotient of those treated with placebo is represented with black lozenges.

Figure 54

Respiratory quotient of Wistar rats treated with a ultra low dosage (0.25 µg/100 g BW) of rT3. The respiratory quotient of the rats treated with high dosage of thyroid hormones is shown on the curve with white squares and the respiratory quotient of those treated with placebo is represented with black lozenges.

Figure 55

Weight of adipose tissues of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a low dosage (2.5 µg/100 g BW) of rT3. The results of the rats treated with high dose of thyroid hormones are shown in white, the results of the rats treated with low dose of thyroid hormones are shown in grey and the results of those treated with placebo in black.

Figure 56

Weight of muscle tissue of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a low dosage (2.5 µg/100 g BW) of rT3. The results of the rats treated with high dose of thyroid hormones are shown in white, the results of the rats treated with low dose of thyroid hormones are shown in grey and the results of those treated with placebo in black.

Figure 57

Weight of brown adipose tissue of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a low dosage (2.5 µg/100 g BW) of rT3. The results of the rats treated with high dose of thyroid hormones are shown in white, the results of the rats treated with low dose of thyroid hormones are shown in grey and the results of those treated with placebo in black.

Figure 58 A and 58B

Rate of mitochondrial oxygen consumption (JO_2 in nmol of O_2 / min / mg of protein) of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a low dosage (2.5 µg/100 g BW) of rT3. Oxygen consumption of rats treated with thyroid hormones at high dose is shown in white, at low dose is shown in grey and oxygen consumption of those treated with placebo in black. All measurements were performed using mitochondria (1.0 mg of mitochondrial protein/ml) incubated with various substrates:

- GM: glutamate/malate (5 mM/2.5 mM),
- SR: succinate/rotenone (5 mM/5µM),
- GMS : glutamate/malate/ succinate (5 mM/2.5 mM/5mM),
- Palm: palmitoyl carnitine (55µM),
- Octa: octanoyl carnitine (100 µM),
- TMPD/ascorbate (0.5 mM/0.5 mM) and
- TMPD/AsC/DNP: TMPD/ascorbate/DNP (0.5 mM/0.5 mM/75 µM)

The asterisk corresponds to a p-value <0.01.

Fig 58A: JO_2 was recorded in the presence of the substrate and following the addition of 1mM ADP (state 3).

Figure 58B: JO_2 was recorded after the addition of oligomycin to determine the non-phosphorylating respiratory rate (state 4).

Figure 59

Activity of the GPdH enzyme. Activity of the mitochondrial glycerol 3 phosphate dehydrogenase was assessed in mitochondria from liver extracted from placebo (black) 25µg/A, 100g rT3 (white) or 2.5µg/100g (grey).

Figure 60A, 60B, 60C and 60D

Plasma concentrations triglycerides, cholesterol, FFA (Free Fatty Acid) and HDL (Heavy Density Lipoprotein) in Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), or a

low dosage (2.5 µg/100 g BW) of rT3.These measurements were done on venous blood of the rats the day of the sacrifice (i.e. after 21 days of treatment).

The results of the rats treated with high rT3 are shown in white, with low rT3 are shown in grey and those treated with placebo in black.

The asterisk corresponds to a p-value<0.01.

Figure 60A: FFA (µmol/l)

Figure 60B: triglycerides (TG) (g/l)

Figure 60C: cholesterol (g/l)

Figure 60D: HDL (g/l)

Figure 61

Body weight of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3. Results from rats treated with subcutaneous pellet are shown in white, results from rats treated with subcutaneous pump are shown in light grey, results from rats treated with intra-peritoneal pump are shown in grey and results from those treated with placebo are shown in black.

Figure 62

Fat mass of different adipose tissues (retroperitoneal, epididymal, mesenteric and subcutaneous fat) of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3. Results from rats treated with subcutaneous pellet are shown in white, results from rats treated with subcutaneous pump are shown in light grey, results from rats treated with intra-peritoneal pump are shown in grey and results from those treated with placebo are shown in black.

Figure 63

Brown adipose tissue mass of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3. Results from rats treated with subcutaneous pellet are shown in white, results from rats treated with subcutaneous pump are shown in light grey, results from rats treated with intra-peritoneal pump are shown in grey and results from those treated with placebo are shown in black.

Figure 64

mGPdH activity of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3. Results from rats treated with subcutaneous pellet are shown in white, results from rats treated with

subcutaneous pump are shown in light grey, results from rats treated with intra-peritoneal pump are shown in grey and results from those treated with placebo are shown in black.

Figure 65

EE of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3. Results from rats treated with subcutaneous pellet are shown in white, results from rats treated with subcutaneous pump are shown in light grey, results from rats treated with intra-peritoneal pump are shown in grey and results from those treated with placebo are shown in black.

Figure 66

RQ of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3. Results from rats treated with subcutaneous pellet are shown in white, results from rats treated with subcutaneous pump are shown in light grey, results from rats treated with intra-peritoneal pump are shown in grey and results from those treated with placebo are shown in black.

Figure 67

Body weight of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Results from rats treated with PTU-IOP are shown in white triangles, results from rats treated with PTU-IOP and rT3 are shown in white squares and results from those treated with placebo are shown in black squares.

Figure 68

Food intake of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Results from rats treated with PTU-IOP are shown in white triangles, results from rats treated with PTU-IOP and rT3 are shown in white squares and results from those treated with placebo are shown in black squares.

Figure 69

Energy expenditure of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Results from rats treated with PTU-IOP are shown in white triangles, results from rats treated with PTU-IOP and rT3 are shown in white squares and results from those treated with placebo are shown in black squares.

Figure 70

Respiratory quotient of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Results from rats treated with PTU-IOP are shown in white triangles, results from rats treated with PTU-IOP and rT3 are shown in white squares and results from those treated with placebo are shown in black squares.

Figure 71

Rate of mitochondrial oxygen consumption (JO_2 in nmol of O_2 / min / mg of protein) of Wistar rats treated with a high dosage of rT3 (25 µg/100 g BW), and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Oxygen consumption of rats treated with PTU+IOP is shown in grey, treated with PTU+IOP and rT3 is shown in white and oxygen consumption of those treated with placebo in black. All measurements were performed using mitochondria (1.0 mg of mitochondrial protein/ml) incubated with various substrates:

- GM: glutamate/malate (5 mM/2.5 mM),
- SR: succinate/rotenone (5 mM/5µM),
- GMS : glutamate/malate/ succinate (5 mM/2.5 mM/5mM),
- Palm: palmitoyl carnitine (55µM),
- Octa: octanoyl carnitine (100 µM),
- TMPD/ascorbate (0.5 mM/0.5 mM) and
- TMPD/AsC/DNP: TMPD/ascorbate/DNP (0.5 mM/0.5 mM/75 µM)

JO_2 was recorded in the presence of the substrate and following the addition of 1mM ADP (state 3).

Figure 72

mGPdH activity of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Activity of rats treated with PTU+IOP is shown in grey, treated with PTU+IOP and rT3 is shown in white and activity of those treated with placebo in black.

Figure 73

Brown adipose tissue mass of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). Mass of brown

adipose tissue of rats treated with PTU+IOP is shown in grey, treated with PTU+IOP and rT3 is shown in white and mass of brown adipose tissue of those treated with placebo in black.

Figure 74

Plasma concentration of T4 hormone of Wistar rats treated with a low dosage (2.5 µg/100 g BW) of rT3 and treated or not with PTU (Propylthiouracil) and IOP (iopanoïc acid). T4 concentration of rats treated with PTU+IOP is shown in dark grey, treated with PTU+IOP and rT3 is shown in white and T4 of those treated with placebo in grey.

Figure 75

Area under the curve of the glucose concentration 3h after OGTT in Wistar rats after 8 weeks of feeding with a high-fat high-sucrose diet and treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 76

Area under the curve of the insulin concentration 3h after OGTT (Oral Glucose tolerance test) in Wistar rats after 8 weeks of feeding with a high-fat high sucrose diet and treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

Figure 77

Kinetic of glucose concentration in plasma in Wistar rats after 8 weeks of feeding with a high-fat high sucrose diet and rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 78

Kinetic of Insulin concentration in plasma in Wistar rats after 8 weeks of feeding with a high-fat high sucrose diet and rats treated with 2.5µg/100 g BW of rT3. Rats were fed with 2g/kg of glucose. The results of the rats treated with rT3 are shown with white triangles and the results of those treated with placebo with black lozenges.

Figure 79

Hepatic lipogenesis during day and night in Wistar rats treated with 2.5µg/100 g BW of rT3. The results of the rats treated with rT3 are shown in grey and the results of those treated with placebo in black.

EXAMPLES

Example 1: Use of the rT3 hormone or of a rT3 derived hormone for the treatment of obesity and dyslipidemia

1. Material and Methods

Animal handling

Adult male rat bred in the animal room facilities of Laboratory of Fundamental and Applied Bioenergetics (Wistar strain) or purchased from Charles-River Laboratories, Domaine des oncins, L'ARBRESLE France [(genetically obese normoglycemic (Zucker or Fa/Fa) or diabetic (ZDF)] were caged individually in stainless steel hanging cages and maintained in a 22°C, 50 ± 10% relative humidity and 12h:12h light:dark environment. All animals were fed *ad libitum* with a standard rat chow (Safe A04, Villemoisson, France) and tap water. Body mass and food intake were recorded twice/thrice a week and fresh food was provided at the same time to ensure minimal disturbance to the animals' food behavior.

Pellet implant

Eight-week old rats (300g±10g) were anesthetized by simultaneous intraperitoneal injection of diazepam 4 mg/kg and ketamine 100 mg/kg. In order to maintain body temperature during the surgery (10 min), animals were placed on a warm blanket. After interscapular shaving, a small incision of 0.5 cm of the skin allows the subcutaneous implantation of a small pellet (containing rT3 or 3',3-T2) with a 10-gauge precision trochar. The pellets, manufactured by Innovative Research of America (Sarasota, Florida, USA) are constituted of a biodegradable matrix that effectively and continuously release the active product in the animal.

3,3',5 triiodo-thyronine (reverseT3) or 3-3'diiodothyronine (3-3' T2) were used at different doses (5, 0.5, or 0.1mg/pellet) were implanted in order to provide a continuous and constant drug delivery over 60 days (which represents 25µg, 2.5 µg or 0.5 µg/day /100g BW).

Indirect calorimetry

Energy expenditure as well as the nature of substrate oxidized (carbohydrates or lipids) were investigated by indirect calorimetry. This principle is based on the determinations of CO_2 release (VCO_2) and O_2 consumption (VO_2) by each animal. It assumes that O_2 is entirely involved in substrate oxidation in the respiratory chain (leading to water production) while CO_2 release is related to substrate decarboxylation (in the Krebs' cycle). These measurements allow assessing energy expenditure (EE) and respiratory quotient (VO_2/VCO_2, RQ). EE represent the absolute energy dissipation during rest and activity. RQ is a relative measurement indicating the ratio of carbohydrate versus lipid involved in oxidative pathway. A ratio of 1.0 indicates exclusive carbohydrate oxidation while a ratio of 0.7 indicates exclusive lipid oxidation. Each value between these two extreme values indicates the relative proportion of each substrate (of note protein oxidation was not evaluated). As an example, RQ approaches 0.7 during fasting, indicating lipid oxidation, conversely after feeding RQ increases close to 1 indicating carbohydrate oxidation resulting from food intake and blood insulin rise. Likewise, animals fed high-carbohydrate diets have higher RQs than those fed high-fat diets.

The indirect calorimetry system (Panlab, Barcelona, Spain) consists of cages, pumps, flow controllers, valves, and analyzers. It is computer-controlled in order to sequentially measure O_2 and CO_2 concentrations as well as air flow in four separate cages allowing four simultaneous determinations. Rats are isolated in one of the four metabolic chambers, and room air is used as a reference to monitor ambient O_2 and CO_2 concentrations periodically.

At predefined intervals, the computer sends a signal to store differential CO_2 and O_2 concentrations, flow rate, allowing computing VCO_2, VO_2, RQ, and EE (Weir equation) with data acquisition hardware (Metabolism, Panlab, Barcelona, Spain).

Body composition, blood and tissue sampling

At the end of the experimental period, animals were sacrificed by decapitation, in order to avoid the well-known effects of general anesthetics on mitochondrial metabolism. Blood samples were immediately collected and plasma was frozen for subsequent determination of serum metabolites and hormones. Liver, muscles and fat depots were quickly excised and weighed. Liver median lobe was rapidly freeze-clamped. Muscles (plantaris, soleus and gastrocnemius) were frozen in isopentane precooled in liquid nitrogen. Mesenteric fat consisted of adipose tissue surrounding the gastro-intestinal tract from the gastro-oesophageal sphincter to the end of the rectum with special care taken in distinguishing and removing the pancreas. Retroperitoneal fat pad was taken as the distinct depot behind each kidney along the

lumbar muscles. Epididymal fat consisted of adipose tissue on top of the epididymis. For subcutaneous depot measurement, a rectangular piece of skin was taken on the right side of each animal from the median line of the abdomen between the spine and the right hip to the first rib. Interscapular brown adipose tissue was removed and dissected free from adjacent muscles and white adipose tissue. The heart ventricles, the right kidney and the spleen were also excised, weighed and frozen.

Mitochondrial isolation

The major part of the liver and the red part of each quadriceps were rinsed, and chopped into isolation medium (250 mM sucrose, 20 mM Tris-HCl and 1 mM EGTA-Tris, pH 7.4). Nuclei and cell debris were removed by centrifugation at 800 g for 10 min. Mitochondria were then isolated from the supernatant by spinning twice at 8,000 g for 10 minutes. The mitochondrial pellet was resuspended in 0.5 ml of isolation buffer and kept on ice. Mitochondrial protein was measured by the bicinchoninic acid method (Pierce, Rockford, Illinois). The final mitochondrial suspensions were maintained on ice and were used for measurements of oxygen consumption rate.

Mitochondrial oxygen consumption

The rate of mitochondrial oxygen consumption (JO_2) was measured at 30°C in an incubation chamber with a Clark-type O_2 electrode filled with 2 ml of incubation medium (125 mM KCl, 10 mM Pi-Tris, 20mM Tris-HCl, 0.1 mM EGTA, pH 7.2). All measurements were performed using mitochondria (1.0 or 0.2 mg mitochondrial protein/ml for liver and skeletal muscle) incubated either with various substrates: glutamate/malate (5 mM/2.5 mM) and succinate (5 mM), alone or in combination, palmitoyl carnitine (55µM) and octanoyl carnitine (100 µM). For each substrate, JO_2 was recorded in the presence of the substrate alone (State 2) and following the addition of 1mM ADP (state 3). Oligomycin (1.25µg/mg protein) was added to the mitochondrial suspension to determine the non-phosphorylating respiratory rate (state 4). The incubation medium was constantly stirred with a built-in electromagnetic stirrer and bar flea. The efficiency of the mitochondrial oxidative phosphorylation was assessed by the state 3/state 4 ratio which measures the degree of control imposed on oxidation by phosphorylation (respiratory control ratio, RCR).

Oxidative phosphorylation efficiency

ATP/O ratios with 5 mM glutamate/2.5 mM malate/5 mM succinate or octanoyl-carnitine (100 µM) as respiratory substrates were determined from the ATP synthesis rate (J_{ATP}) versus respiratory rate JO_2 with an ADP regenerating system based on hexokinase (EC 2.7.1.1) plus glucose. J_{ATP} and JO_2 were measured as described above in a medium containing 125 mM KCl, 1 mM EGTA, 5 mM Tris-Pi, 20 mM Tris-HCl, 0.1% fat free BSA (pH 7.2). J_{ATP} was determined from glucose 6-phosphate formation in presence of 20 mM glucose, 1 mM $MgCl_2$, and 125 µM ATP. JO_2 and J_{ATP} were modulated by addition of increasing concentrations of hexokinase (*Nogueira et al, J Bioenerg Biomemb., 34: 55-66, 2002*).

Enzymatic activities

Measurement of the specific activity of the respiratory-chain complex I, II and IV was performed spectrophotometrically. A total of 8-10 µg of mitochondrial proteins were required to determine the activity of complex I and II, and 4 µg were used for complex IV. Enzyme activity was expressed as nmoles of reduced or oxidized substrate per min and per mg of mitochondrial protein.

Measurement of complex I (rotenone-sensitive NADH-ubiquinone oxidoreductase, EC 1.6.99.3): The assay was performed using decylubiquinone (100 µM) as electron acceptor and NADH (200 µM) as a donor, in a 10 mM KH_2PO_4/K_2HPO_4 buffer (pH 7.5) containing BSA (3.75 mg/ml), and in the presence of KCN (2 mM) and antimycin A (7.5 µM). The oxidation of NADH was then measured at 340nm before and after the addition of rotenone (4 µM), allowing the calculation of the rotenone-sensitive specific activity of complex I.

Measurement of complex II (succinate-ubiquinone reductase, EC 1.3.99.1): Succinate-ubiquinone oxidoreductase activity was quantified by measuring the decrease in UV absorbance due to the reduction of DCPIP (100 µM) at 600 nm. The measurement was performed in a medium containing 50 mM KH_2PO_4/K_2HPO_4 (pH 7.5) in the presence of decylubiquinone (100 µM), rotenone (2 µM) and KCN (2 mM).

Measurement of complex IV (cytochrome c oxidase, EC 1.9.3.1): The assay was performed by measuring cytochrome c (100 µM) oxidation at 550nm in a 50 mM KH_2PO_4/K_2HPO_4 buffer (pH 7.0).

Citrate synthase activity was determined by measuring the UV absorbance at 412nm due to the formation of the ion mercaptide in the presence of oxaloacetate dinitrothiobenzoïque acid and acetyl-CoA in a 150 mM Tris buffer pH 8 (Garait et al, Free Rad Biol Med, 2005) .

Mitochondrial glycerol 3-phosphate dehydrogenase (mGPdH) activity was measured on the supernatant of isolated mitochondria after three cycles of freezing-thawing. Forty µg of mitochondria were incubated in a KH_2PO_4/K_2HPO_4 buffer (50 mM, pH 7.5) containing 9.3 µM of antimycin A, 5µM of rotenone and decylubiquinone (50µM). The reduction of 50 µM dichloro-indophénol (DCIP) by mGPDH was measured spectrophotometrically at 600 nm at 37°C and enzymatic activity was expressed as $\mu mol.min^{-1}.mg\ prot^{-1}$.

Cytochromes

Cytochromes content of the mitochondrial respiratory chain was measured in parallel experiments by comparing the spectra of fully oxidized (potassium ferricyanide) *versus* fully reduced (few crystals of sodium dithionite) cytochromes. Knowing the contributions in absorbance of each cytochrome to the major maxima and minima of each of the other cytochromes, a set of 4 simultaneous equations with 4 unknowns can be derived and concentration of each cytochrome can be calculated (*Williams, Arch Biochem Biophys.; 107: 537-43, 1964*).

Hepatocytes Isolation

Wistar rats fasted for 20–24 h were anesthetized with sodium pentobarbital (10 mg/100 g body wt i.p.), and the hepatocytes were isolated according to the method of Berry and Friend (*J. Cell. Biol.* 43: 506-520, 1969) as modified by Groen et al. (*Eur. J. Biochem.* 122: 87-93, 1982). Briefly, the portal vein was cannulated, and a 2-min anterograde perfusion with Ca^{2+}-free Krebs-Ringer bicarbonate buffer (25 ml/min; 37°C, pH = 7.4, continuously gassed with 95% O_2-5% CO_2) was performed to remove blood from the liver. A 10-min retrograde perfusion (25 ml/min) through the posterior vena cava was started with the same perfusion medium. Subsequently, a recirculating perfusion was performed (20 min at 40 ml/min) with 100 ml Krebs-Ringer medium supplemented with 0.25 mg/ml collagenase (type IV, Sigma, St. Louis, MO). The liver was then cut and shaken in the perfusion medium for 2 min under constant gassing (95% O_2-5% CO_2). Finally, the cell suspension was filtered through nylon gauze (pore size, 120 µm), washed twice with Krebs-Ringer bicarbonate buffer containing 1.6 mM Ca^{2+}, and then washed for a third time with the same buffer supplemented with 1% BSA.

Perifusion of hepatocytes

Liver cells were perifused according to the method of van der Meer and Tager (*FEBS Lett.* 67: 36-40, 1976) modified by Groen et al. (*Eur. J. Biochem.* 122: 87-93, 1982).

Hepatocytes (225-250 mg dry mass) were placed in 15-ml perifusion chambers at 37°C and were perifused (5 ml/min) with a continuously gassed (95% O_2-5% CO_2) Krebs-Ringer bicarbonate solution (pH = 7.4) containing 0.2% BSA. The experiments were carried out in duplicate in two perifusion chambers placed in parallel. At the chamber outlet, perifusate O_2 content was monitored with Clark electrodes (Yellow Springs Instruments, Yellow Springs, OH) to assess O_2 uptake of the hepatocyte suspension. After 40 min , when O_2 uptake had reached a steady state, hepatocytes were perifused with increasing amount of glycerol (0.15, 0.30, 0.60, 1.2, 2.4, 4.8, and 9.6 mM), in the presence or not of 0.4 mM octanoate. At the end of each steady state of 20 min, perifusate and cells samples were collected at 2-min intervals for subsequent determination of glucose, lactate, pyruvate, acetoacetate, and 3-hydroxybutyrate concentrations. Samples were stored at 4°C and analyzed within 12 h after the end of the experiment. In addition, 300 µl of the cell suspension were sampled from the chamber for intra- and extracellular fractionation. For this purpose, mitochondrial and cytosolic spaces were separated with the digitonin fractionation method described by Zuurendonk and Tager (*Biochim. Biophys. Acta* 333: 393-399, 1974). Briefly, the cell suspension was placed in a 2.2-ml Eppendorf tube in an isotonic medium containing 2 mM of digitonin (Merck, Lyon, France) at 4°C. After 15 s, the tube was centrifuged for 15 s at 10,000 *g* to precipitate mitochondria through the underlying 800-µl layer of silicon oil (Rhodorsil 640 V 100, Rhône-Poulenc) into 250 µl $HClO_4$ (10% mass/vol) + 25 mM EDTA. The supernatant (700 µl) was immediately removed, deproteinized with $HClO_4$ (5% mass/vol), and neutralized. The intracellular content was then neutralized and kept at -20°C for determination of intracellular metabolites (DHAP and G3P, spectrophotometry) and adenine nucleotides content (HPLC).

Western blot analysis

For mGPdH quantification, polyacrylamide gel electrophoresis and immunoblotting were performed as previously described (23). Briefly, lysed hepatocytes were mixed with 200 µl of buffer containing 40 mM Tris(hydroxymethyl)aminomethane pH 6.8, 1% SDS, 6% glycerol, and 1% b-mercaptoethanol. This mixture was then heated at 100°C for 10 min, and subjected to one -dimensional sodium dodecyl sulfate (SDS)-PAGE with a 5% stacking and 12.5% resolving gels for 12 hours. After electrophoretic separation, proteins were transferred at a constant voltage to PVDF membranes. After protein transfer, the membranes were blocked for 2h, then incubated 2 h with a monoclonal antibody specific for mGPDH (generous gift from Dr. J. Weitzel) and then exposed to the secondary antibody (goat anti-

mouse immunoglobulin G conjugated to horseradish peroxidase, Bio-Rad at a 1:10000 dilution). mGPDH were visualized by the enhanced chemiluminescence detection method (RPN 2106, Amersham). Scanning with a densitometer performed quantification of bands from blots and the data were expressed numerically as integrated optical density arbitrary units.

RNA purification and Reverse Transcription-coupled PCR

Total RNA were extracted from tissue using Tripure RNA Isolation reagent (Roche Diagnostics). Concentration and purity were verified by measuring optimal density at 260 and 280 nm. Their integrity was checked by 1% agarose gel electrophoresis (Eurobio). mRNA concentrations were measured by semi-quantitative reverse transcription polymerase chain reaction (RT-PCR) using β actin as reference. Primer sequences are shown in table 1. For each target mRNA, a RT was performed from 0.1 µg of total RNA with 100 U of M-MLV Reverse Transcriptase (Promega), 5µL of M-MLV RT 5X buffer, 20 U of RNasin Ribonuclease Inhibitor, 12 picomoles of deoxynucleoside triphosphate and 15 picomoles of the specific antisense primer, in a final volume of 25 µL. The reaction consisted in 5 min at 70°C (RNA and antisense primer), then 60 min at 42°C (all mix) followed by 15 min at 70°C. After chilling, 5 µL were used for PCR reaction. The 5 µL of RT medium were added to 45 µL of PCR mix (5 µL 10X REDTaq PCR buffer) containing 6 picomoles of MgCl2, 8 picomoles of deoxynucleoside triphosphate, 2.5 U of REDTad DNA polymerase (Sigma), 15 picomoles of corresponding antisense primers and 22.5 picomoles of sense primers. The PCR conditions were: 2 min at 94 °C followed by 28 cycles, 35 cycles or 18 cycles for UCP3, UCP2 and β actin respectively (1 cycle = 1 min at 94°C, 1 min at 60°C, 1 min at 72°C). PCR was ended by 10 min at 72°C. Products were analysed on 2% agarose gel prestained with ethidium bromide. For quantitation of relative bands intensities, pictures were taken with a Camera DC120 (Kodak) and the ratio of each target to β actine was determined for each sample with Kodak Digital Science 1D 2.0 (Kodak Scientific Imaging System).

2. Results

As shown in Figures 1 (A and B), control (placebo treated) Wistar rat body exhibit a normal growth rate of 150 g over 21 days (*i.e.* a weight gain of about 40%). Treated animals

with either rT3 (Figure 1A) or 3,3'-T2 (Figure 1B) did not show any weight gain, the body mass after 21 days being not significantly different from the initial value.

This indicates a very powerful prevention of normal weight gain in these young adult animals.

As shown in Figures 2 (A and B), the food intake of placebo group was stable over the experimental period around 30 g of food per day. Both groups of treated animals showed similar changes a decrease in food intake immediately after the pellet, containing rT3 (Figure 1A) or 3,3'-T2 (Figure 1B), have been introduced subcutaneously (from day 4 until day 7) then food intake increase showing higher value as compared to those of placebo animals.

Hence the decrease in body weight in both groups of treated animals was associated with an increased food intake.

The energy expenditure (EE) of rats was assessed by indirect calorimetry (see material and method section) and values were analyzed over a period of 24 hours (= 1440 minutes). All groups of animals, treated with placebo (Figures 3A and 3B), rT3 (Figure 3A) or 3,3'-T2 (Figure 3B), exhibited days/nights variations due the classical nocturnal activity and eating behavior of these rodents contrasting with the quiet diurnal period. Both groups of treated rats exhibited a dramatic increase in energy expenditure reaching 25 to 30 of the control values.

This very important result indicates that the metabolic expenses are largely increased by the two treatments both during the nocturnal and the diurnal periods.

The respiratory quotient (RQ) is defined as the ratio between released carbon dioxide to consumed oxygen: VCO_2/VO_2. It is largely accepted that this ratio indicate the origin of oxidized substrates (carbohydrate versus lipids). This value is equal to 1 if carbohydrates represent the exclusive source of energy and 0.7 were lipids represent the unique energetic substrate.

As already shown the EE, RQ also varies between day and night (Figures 4A and 4B). It is higher during the night, when animals are eating and therefore oxidizing more carbohydrates. Conversely during the diurnal period RQ is lower indicating a fasting sate were lipids are the predominant substrates. Regarding rT3 (Figure 4A), it appears that RQ is almost identical to placebo during the day and higher during the night. This would indicate either a higher proportion of carbohydrate or, more likely, a net lipid synthesis from carbohydrate (leading to a RQ value higher than 1) the value presented by these animals being

the sum of substrate oxidation and substrate (lipid synthesis) during the fed state. These changes are quite substantial as compared to placebo. In the 3,3'-T2 group (Figure 4B) the changes during the night were almost the same as those described for rT3 and indicates also most probably a net lipid synthesis during the fed state. However during the diurnal period, or immediately after the dark it seems that the RQ is lower than that of placebo indicating a higher fat oxidation in these fasting animals.

The change in body composition of rats treated with rT3 or placebo are presented both as absolute values (g) or as percentage of total body mass since the two groups of animals did not exhibit the same mass after three weeks (see Figure 1A).

Retroperitoneal, mesenteric and subcutaneous fat masses were significantly lower ($p<0.01$) in rT3 group as compared to placebo, epididymal mass being not different (Figure 5A). This difference was very substantial whatever the data are expressed as absolute or relative values. Interestingly muscle mass was not affected at all (Figure 5B), while brown adipose tissue, a tissue known to be involved in metabolic efficiency and heat production, was significantly increased in rT3 treated animals (Figure 5C).

These results clearly indicate that the decrease in body mass after rT3 treatment is purely due to a loss of fat mass, the lean body mass being not affected.

Similar results are obtained with 3,3'-T2 (Figures 6A and 6B) leading to reach the same conclusion regarding the effect of 3,3'-T2 on fat mass (significantly decreased) and lean body mass (not affected). Interestingly brown adipose tissue was also significantly increased by the treatment.

The effect of both treatments (rT3 or 3,3'-T2) on the efficacy of the coupling between oxidation and phosphorylation at the level of liver mitochondrial respiratory chain were evaluated (Figures 7A and 7B). Respiratory rates of non-phosphorylating mitochondria (*i.e.* in the presence of oligomycin) of the different groups (rT3, Figure 7A and 3,3'-T2, Figure 7B) of treated animals versus placebo were measured. In both cases (rT3 and 3,3'-T2) respiration was much higher as compared to placebo indicating a less efficiency coupling due to the treatments. The different conditions glutamate/malate, succinate-rotenone, glutamate/malate/succinate, palmitoylCoA, octanoylCoA indicate the different substrates provided to the respiratory chain.

Figures 7C and 7D represent the maximal respiratory rate of liver mitochondria achieved in phosphorylating condition (*i.e.* in the presence of ADP) with the various substrate supply (see above Figure 7): TMPD ascorbate investigate complex 4 (cytochrome c oxidase) without or with uncoupling state by DNP. Schematically in all conditions the treatments, either with rT3 (Figure 7C) or 3,3'-T2 (Figure 7B), were responsible for a very significant increased respiratory rate indicating that the treatments increased the maximal respiratory capacity for all substrates, including fatty acids.

Very interestingly completely different results were obtained with muscle mitochondria. Indeed both rT3 and 3,3'-T2 failed to substantially affect both non-phosphorylating (state 4, Figures 8A and 8B) and phosphorylating (state 3, Figures 8C and 8D) states. Actually there were some minor effects leading to a decreased respiration, palmytoyl- and octanoyl-CoA excepted.

Hence this indicated that although both rT3 and 3,3'-T2 exhibit a powerful effect on liver mitochondria leading to the a decreased oxidative phosphorylation efficiency and to an increased maximal respiratory capacity, almost no effect was found on muscle mitochondrial despite the fact that the drug was administered to every tissue (subcutaneous progressive release from the pellet).

Figures 9A and 9B show similar data as presented in the figures 7A and C. However animals were treated with a ten fold lower rT3 dose (25µg/kg instead of 250µg/kg in the figure 7). Essentially similar findings were made although to a lower extent. However the decreased efficiency and the higher maximal respiratory capacity are found to be significant.

Figures 10 show the effect of the two treatments on glucose (Figure 10A), triglycerides (Figure 10B), cholesterol (Figure 10C), free fatty acids (Figure 10D) and HDL (Figure 10E) (rats almost do no have LDL) plasmatic concentrations. Both treatments slightly increased fasting glucose in these normal (non diabetic animals) indicating that none of these treatments was responsible for a potential hypoglycemic effect. Interestingly triglycerides and cholesterol were significantly lower with rT3 and 3,3'-T2 as compared to placebo. Plasma fatty acids were higher as it is observed in animals exhibiting a high rate of lipolysis and fatty acid oxidation as it was already suggested by the data obtained with indirect calorimetry.

In conclusion, the dramatic effect observed in the body mass is completely explained by the decreased fat mass, while the lean body mass (muscle mass) seems not affected. This effect, which is observed despite increased food consumption, is due to an increased energy expenditure, which was substantiated by indirect calorimetry measurement. Since the normal diet of these animals is rather poor in lipid content (4-5%) the increase fat oxidation is achieved at the expense of the fat storage as shown by the strong decrease in fat mass and also probably by a de novo lipogenesis, an expensive pathway, which might explain the higher RQ observed in the fed period. The data concerning the overall increase in energy metabolism (indirect calorimetry) are in very good agreement with the data obtained in liver isolated mitochondria indicating the probably occurrence of energy wasting process at the level of the respiratory chain and ATP synthesis associated with a significant higher maximal respiratory capacity. Most interestingly none of these effects was observed in muscle mitochondria indicating that the wasting process affects more the liver than the muscle mass and concerns lipid oxidation.

Hence in total both rT3 and 3,3'-T2 enhance lipid oxidation and energy expenditure leading to a marked decrease in the mass of adipose tissue only.

Example 2: Comparison of the administration of rT3 hormone on the obesity treatment.

1. Material and Methods

The Material and Methods are those described in Example 1.

Animals

Wistar rats were used in these studies.

Administrations

Wistar rats were treated with rT3 hormone by a daily intraperitoneal injection (IP) (25µg/100g BW), a daily sub-cutaneous injection (SC) (25µg/100g BW), or a per os administration included in the rat food (25µg/100g BW). The continuous and constant administration was performed by using a pellet (25µg/100g BW).

2. Results.

In order to compare the effect of rT3 administration in the rat weight, Wistar rats were treated for 8 days by a pellet diffusing a continuous and constant dose of rT3 (25µg/100g

BW/day), or daily treated by intra-peritoneal or sub-cutaneous injection of rT3 (25µg/100g BW by injection) or by oral administration (25µg/100g BW by ingestion).

As shown in figure 11, only the continuous and constant administration of rT3 reduce the rat body weight (Figure 11 A) after 8 days of treatment, but neither intra-peritoneal injection (Figure 11 B), nor the sub-cutaneous injection (Figure 11 D) and nor the per os administration of the same dosage (Figure 11 C) of rT3 have an influence on the animal mass.

To confirm these data, the individual weight of adipose tissues was measured in the animals treated with the four different rT3 administrations. As previously observed for the global mass, only animals treated with continuous and constant rT3 administration have a significant white fatty tissue mass reduction (Figure 12A), whereas injections (Figures 12B and 12D) or oral administration (Figure 12C) have not effects. The muscular mass (Figure 14 A-D) is unchanged whatever the administration, and the brown adipose tissue mass is significantly enhanced only in rats treated with a continuous and constant dose of rT3 (Figure 13A).

To confirm the effect on the metabolism of the treated animals, the EE was estimated by indirect calorimetry over a period of 24hours. The figure 15 shows that only rats treated with a continuous and constant dose of rT3 have enhanced metabolic expanses (Figure 15A), whereas the other routes of administration do no modify the metabolism of the treated rats (Figures 15B-D). In the same way, only the RQ of rats treated with a continuous and constant dose of rT3 have a significant difference from the placebo treated animals after 900 min (Figure 16A).

Therefore, all these data demonstrate that only a continuous and constant administration of rT3 is able, after 8 days of treatment, to significantly reduce the body mass of animals, by only affecting the white fat tissues, by inducing an increase of the fatty acid metabolism.

In order to understand why the discontinuous treated failed to give results, the circulating rT3 was measured in animals, for 24 hours, after the injection. The graph in figure 17 shows that intra-peritonealy injected rT3 is rapidly degraded, and after 5 hours is five fold decreased compared to the injected dose. The per os administration never allows to obtain in blood a concentration of rT3 similar with the concentration observed after intra-peritoneal injection. The sub-cutaneous administration appear to be the best route of administration, since the rT3 concentration remains substantially the same as the injected concentration in blood for a longer time, but rT3 is nevertheless quasi completely degraded after 24 hours.

Example 3: Use of the rT3 hormone or of a rT3 derived hormone for the treatment of diabetes

1. Material and Methods

The Material and Methods are those described in Example 1.

Animals

Rats were genetically obese normoglycemic (Zucker or Fa/Fa), 10-11 week-old diabetic rats (ZDF), genetic non-overweight diabetic (type 2 diabetes) rats (Goto-Kakizaki (GK) model), non-overweight diabetic (type 2 diabetes) rats n0STZ model or normal Wistar rats submitted to an 8-week high-fat high sucrose diet (a model of nutritional induction of insulin resistance).

Blood sampling

The day of the study, after a fasted period overnight (18h), blood samplings will be taken in awaked rats from the tail vein.

Blood parameters

The following biochemical parameters were analyzed: glycemia, insulinemia, HbA1c, TG and Cholesterol.

Thyroid Stimulating Hormone (TSH) and thyroxine (T4) were measured by radioimmunoassay with rat standards (RPA 554 Amersham bioscience, RIA FT4-immunotech, for TSH and T4 respectively).

Insulin levels were determined with commercial kits (Linco Research).

Glucose and 3-hydroxybutyrate (3-HB) were measured enzymatically and non esterified fatty acid (NEFA) by colorimetric assay (Wako Chemicals).

Triglycerides and cholesterol were measured by classical routine automate apparatus.

2. Results

ZDF Model : diabetic and fatty rats

ZDF diabetic rats are a good model for studying the anti-diabetic treatments, since these animals develop a major hyperglycaemia during their life due to the combination of moderate

obesity and pancreas degeneracy. To date, treatments are ineffective when the hyperglycaemia is established.

Then ZDF rats were treated with low doses of rT3 for 21 days (2.5μg/100g BW/day) and the glycaemia, insulinaemia were measured after 8, 16 and 21 days.

Figure 18 shows a large reduction of the glycaemia in rats treated with a low dose of rT3 compared to rats treated with placebo. This reduction appears after 8 days and is maintained over 21 days. Correlated to the reduction of glycaemia, the insulin level is maintained in rats treated with rT3, whereas the insulin level progressively decreases from the beginning of the experiment to 21 days after the beginning reflecting the pancreas degeneracy (Figure 19).

Surprisingly, the insulin level in rats treated with rT3 is associated with an increased of the pancreas mass (Figure 20).

These data indicate that rT3 can reverse the installed diabetic disease of ZDF rats, probably by a mechanism involving the β-pancreas cell self renewing. By this way ZDF rats recover their ability to regulate the glycaemia.

ZDF are also fatty animals with hypertriglyceridemia. So the effect of the rT3 treatment was also evaluated.

Figure 21 shows on the one hand that the rats treated with rT3 are slimmer that rats treated with a placebo, and on the other hand that the fat mass is reduced in rT3 treated animals.

Indeed, as shown in figure 22, the animal mass is reduced when they are treated with rT3 hormone; this mass reduction is not associated with a loose of appetite (Figure 23).

Figure 24 shows that the energy expenditure of ZDF rats treated with rT3 is enhanced compared to the placebo-treated ZDF rats. Moreover, RQ is also enhanced in ZDF rats treated with rT3 compared to placebo treated ZDF rats (Figure 25).

Interestingly, even if the global mass of rT3-treated animals is decreased, the white adipose tissue of the ZDF rats seems not to be affected by the rT3 treatment as shown in figure 26. But as previously shown, the increase of the EE is associated with an increase of the brown adipose tissue mass (Figure 27).

Also, muscular mass is not affected by the rT3 treatment (Figure 28).

To better understand the lipid metabolism, lipid profiles of free fatty acid (FFA, Figure 29), triglycerides (Figure 30), cholesterol (Figure 31) and high density lipoprotein (HDL, Figure 32) were analysed.

In rats treated with rT3, FFA are significantly enhanced (Figure 29) whereas triglycerides are significantly reduced (Figure 30) in ZDF blood. These rats being faintly cholesterolemic, the cholesterol level is not influenced by the rT3 treatment.

In conclusion, a low dose of rT3 administered in ZDF rats has a double effect:

- rT3 decreases the total weight of the treated animals, correlated with the enhance energy expenditure and RQ and increase of brown adipose tissue mass, but without significant reduction in white adipose tissue mass. The energy expenditure is enhanced (+50%), and the RQ value means that oxidized substrates is enhanced. This increase in the RQ value is paradoxal since it would indicate a global glucose oxidation. However, because of a low quantity of lipids in the rat alimentation, the organism transforms glucose into lipids (lipogenesis) and the new formed lipids are then degraded (lipolyse). These data are corroborated by the fatty acid profiles. By this way, the organism burns energy to build and degrades reserves, which induces a global decrease of the rat mass. This hypothesis is strongly substantiated by the results show in the figure 79 where hepatic lipogenesis is almost 4-fold increased in Wistar rats treated with rT3.

- rT3 has an influence on the pancreatic cell proliferation which allow the liberation of insulin and then can correct the high glucose blood concentration in ZDF rats. This is the first time that a thyroid hormone is involved in the pancreatic cell proliferation.

n0STZ Model : diabetic rats.

N0STZ rats are diabetic non obese with moderate insulin-resistance, and have received an injection of streptozotocine just after the birth, said product killing pancreatic cells.

The glucose resistance of these animals was tested by an oral glucose tolerance test (OGTT). Animals were fed with 2g/kg BW of glucose and the Glucose concentration and Insulin concentration in blood were measured.

In rats treated with low dose of rT3 (2.5g/100g BW), 3 hours after the OGGT, the area under the curve (AUC) of the glucose concentration is significantly reduced compared to rats treated with placebo (Figure 33). Conversely, the AUC of the insulin concentration at the same time is largely enhanced in rats treated with rT3 compared to those treated with placebo

(Figure 34). These data indicate that rT3 treatment is able to reduce the blood glucose concentration by enhancing the insulin blood concentration.

To confirm these results, kinetic curves of the OGTT were performed for 20 min. The glucose concentration (Figure 35) and insulin concentration (Figure 36) were then measured for this time.

In figure 35, rats treated with rT3 regulate more rapidly the blood glucose concentration, in the 5 first minutes following the OGTT. This control of glucose concentration is correlated with a high increase of the insulin concentration in animal treated with rT3 (Figure 36). The insulin response is absent in n0STZ rats treated with placebo (Figure 36).

Therefore, a rT3 treatment is able to correct the glucose regulation dysfunction. The increase of the insulin level observed in OGTT is associated with an increase of the pancreas mass of rT3 treated animals (Figure 37).

Then, rT3 treatment regulates the pancreas proliferation.

GK Model : diabetic rats.

GK rats are diabetic non obese with moderate insulin-resistance, and have lower pancreatic cells than control rats. The pancreatic cells are also less efficient in the insulin secretion.

The glucose resistance of these animals was tested by an oral glucose tolerance test (OGTT). Animals were fed with 2g/kg BW of glucose and the Glucose concentration and Insulin concentration in blood were measured.

In rats treated with low dose of rT3 (2.5g/100g BW), 3 hours after the OGGT, the area under the curve (AUC) of the glucose concentration is significantly reduced compared to rats treated with placebo (Figure 38). Correlated, the AUC of the insulin concentration at the same time is largely enhanced in rats treated with rT3 compared to those treated with placebo (Figure 39). These data indicate that rT3 treatment is able to reduce the blood glucose concentration by enhancing the insulin blood concentration.

To confirm these results, kinetic curves of the OGTT were performed for 20 min. The glucose concentration (Figure 40) and insulin concentration (Figure 41) were then measured for this time.

In figure 40, rats treated with rT3 regulate more rapidly the blood glucose concentration, in the 5 first minutes following the OGTT. This control of glucose

concentration is correlated with an increase of the insulin concentration in animal treated with rT3 (Figure 41). The insulin response is absent in GK rats treated with placebo (Figure 41).

Therefore, rT3 treatment is able to correct the glucose regulation dysfunction. The increase of the insulin level observed in OGTT is associated with an increase of the pancreas mass of rT3 treated animals (Figure 42).

Then, rT3 treatment regulates the pancreas proliferation.

Wistar Model : non-diabetic rats.

Wistar rats are non-diabetic, non-obese without insulin-resistance, however like in humans, they tend to get slightly obese and insulin resistant with age. However this is supposed to be "physiological".

The glucose resistance of these animals was tested by an oral glucose tolerance test (OGTT). Animals were fed with 2g/kg BW of glucose and the Glucose concentration and Insulin concentration in blood were measured.

In rats treated with low dose of rT3 (2.5g/100g BW), 3 hours after the OGGT, the area under the curve (AUC) of the glucose concentration is slightly reduced, however not significantly when compared to rats treated with placebo (Figure 43 & 45). By contrast, the AUC of the insulin concentration at the same time is significantly lower in rats treated with rT3 compared to those treated with placebo (Figure 44 & 46). These data indicate that rT3 treatment is able to increase insulin sensitivity. Interestingly, a moderate, albeit significant, increase in pancreas mass is noticed in the rT3 group as compared to placebo..

Example 4: Comparison of the doses of rT3 hormone on the obesity treatment.

1. Material and Methods

The Material and Methods are those described in the previous examples.

2. Results

Wistar rats were treated with high dose (25µg/100g BW), with low dose (2.5µg/100g BW) or with ultra low dose (0.25µg/100g BW) of rT3.

Figure 48 shows that the treatment of Wistar rats treated with high or low dose of rT3 reduce the body weight in comparison to rats treated with placebo, without modifying their appetite (Figure 49). Similar data represented in figure 50 show that ultra low doses of rT3 also reduce the body weight of animals.

After 20 days of treatments, ultra low doses of rT3 and high doses of rT3 give similar results.

With respect to the previous data concerning the metabolic influence of rT3, the energy expenditure of Wistar rats treated with high, low and ultra low doses of rT3 was evaluated.

As shown in figure 51, high doses of rT3 significantly enhance the EE of Wistar rats compared to low doses, which are quite similar to the EE of rats treated with placebo. Ultra low doses of rT3 give similar results than low doses (Figure 52).

Concerning the RQ, animals treated with high and low doses of rT3 have an increase in their RQ compared to the placebo (Figure 53) whereas animal treated with ultra low doses of rT3 have a decrease of their RQ compare to the placebo (Figure 54).

Therefore, although the metabolic involvement of high, low and ultra low doses of rT3 are different, all the doses of the thyroid hormone have a significant effect on the body mass of treated animal.

As a consequence, a dosage comprised from 0.25µg/100g BW to 25µg/100g BW can be used for the treatment of obesity.

Figure 55 compare the effect on the white adipose tissue mass of the treatment with high or low dose of rT3. A low dosage of rT3 reduces the fat mass with a lower efficiency that treatment with high dose of rT3. In a similar manner, high dosage of rT3 induces a high increase of the brown adipose tissue, whereas a low dose induces an intermediate increase (Figure 57).

Then, the different dosages of rT3 do not affect the muscle tissues mass (Figure 56).

Figures 58 A & B compare the effect of high (25 µg/100mg) and low (2.5µg/100mg) rT3 on mitochondrial phosphorylating (state 3, figure 58A) and non-phosphorylating (state 4, Figure 58B) respiratory rates. Administration of rT3 was responsible for a dose-dependent increase in the respiratory rates of both state 3 and sate 4 with almost all tested substrates indicating a global effect of the pathway.

Similarly the enzymatic activity of mitochondrial glycerol-3-phosphate dehydrbgenase was significantly increased with both treatments in a dose-dependent manner.

Concerning the lipid profile of Wistar rats treated with high or low doses of rT3, a high dosage stimulates the liberation of FFA (Figure 60A) and the degradation of triglycerides (Figure 60B) with a better efficiency than low dosage.

For Glycerol (Figure 60C) and HDL (Figure 60D), the high and the low dosages exert the same effect on the reduction of theses lipids.

All these data demonstrate that high, low and ultra low dosages of rT3 are suitable for the reduction of the body weight.

Example 5: Comparison of the administration of rT3 hormone on the obesity treatment.

1. Material and Methods

The effect of continuous sub-cutaneous release (sc pellet) was shown to be significantly superior to oral or intraperitonally discontinuous administration of the same dose. However the role of the administration site was further investigated by comparing continuous administration of rT3 by osmotic pump implanted either subcutaneously or intraperitonally with the reference treatment administered by sub-cutaneous pellets. Wistar rats were treated for 21 days with placebo, sub-cutaneous pellet or sub-cutaneous or intraperitoneal osmotic pumps. rT3 was administered continuously (2.5µg/100g).

2. Results

Wistar rats were treated by a continuous and constant administration of low doses of rT3 by 3 different methods of administration:

- a sub-cutaneous pellet,
- an osmotic pump placed under the skin, and
- an osmotic pump placed in the peritoneal cavity.

The results of these three administrations were analyzed after 21 days.

Figure 61 shows that all the methods of administration induce a significant reduction of the body mass of treated animals. No significant difference among the treated groups could be evidenced.

Figure 62 shows that all the methods induce a significant reduction of the white adipose tissue mass. Some minor differences could be noticed among the treated groups, however the overall effect was quite similar.

Figure 63 shows that the brown adipose tissue is more significantly enhanced by pellet and sub-cutanneous pump than intra-peritoneal pump, but all treatments were effective.

Figure 64 shows that the mitochondrial GPdH activity is enhanced by the 3 methods of administration, and more enhanced by the pellet administration. Again all treatments were effective.

Figures 65 and 66 respectively show the energy expenditure and the respiratory quotient of animals treated with the 3 methods of administration.

All the methods give similar results, i.e. an increase of the metabolic activity, associated with the mass reduction.

Therefore all the tested method of administration of a continuous and constant dose of rT3 give satisfying results to be used in the treatment of the obesity. These results indicate that the rate of administration was more important for the efficacy that the site of injection (sc versus ip).

Example 6: Function of the endogenous thyroid hormones in the action of the continuous and constant rT3 treatment.

1. Material and Methods

All the previous examples have demonstrated the effect of rT3 administration for the therapy of obesity, dyslipidemia and diabete.

In order to understand the mode of action of the treatments, Wistar rats were treated with pharmacological products that inhibit the synthesis and deiodination of thyroid hormones PTU and IOP.

Animals (Wistar) were submitted to a treatment by propyl-thiouracile (PTU in the drinking water) and iopanoic acid (IOP one sc-injection weekly) inducing a complete inhibition of all deiodinases (types I, II and III). Such treatment is responsible for the induction of a severe hypothyroid state. In addition this treatment impairs the peripheral metabolism of all thyroid

hormones by deiodination. Some rats were also submitted to a sub-cutaneous administration of rT3 (2.5µg/100g). Three groups were constituted: controls, PTU+IOP and PTU+IOP+rT3 and duration of the experiment was 3 weeks.

2. Results

Figure 67 shows that PTU+IOP treatment induces a large decrease of the animal mass. Moreover, the addition of rT3 enhances the decrease induced by PTU-IOP. It is important to note that with or without rT3, the appetite of the PTU-IOP treated rats remains unchanged (Figure 68).

Then, since PTU and IOP inhibit the endogenous synthesis of thyroid hormones, the data suggest that the rT3 used in the treatment acts without the intervention of the metabolism of the administered hormone (rT3) nor of other endogenous hormones. To confirm these hypotheses, the T4 concentration was assayed in rats treated or not with PTU+IOP. As shown in figure 74, when rats are treated with PTU+IOP, T4 hormone is absent in the plasma of animals.

Figures 69 and 70 show that the EE and RQ are respectively reduced compared to the placebo when animals are treated with PTU+IOP, but is enhanced when rT3 is administered. These data confirm the endogenous-independence of the administered rT3.

Figures 71 and 72 indicate that the severe hypothyroidism induced by PTU+IOP administration was responsible for a decreased state 3 respiratory rate with glutamate/malate (GM), succinate (S) and glutamate/malate/succinate (GMS, Figure 71) and the activity of mGPdH (Figure 72). Treatment with rT3 (2.5µg/100g) either corrected the effect of PTU+IOP (state 3) or stimulates (mGPdH).

Concerning the brown adipose tissue, PTU+IOP treatment enhances the mass of the energetic adipose tissue, but this mass is also enhanced when rats are treated with rT3.

In conclusion, all these data demonstrate that rT3 administration has an effect on body mass and metabolic activity of treated animals without intervention of the endogenous thyroid hormones and without further deiodination of rT3.

Example 7: High fat high sucrose diet.

A clinically relevant situation of a nutritionally-induced insulin resistance is known as a high fat high sucrose diet (HF). Therefore, the effects of rT3 on glucose and insulin response to an OGTT test were investigated. Wistar rats were fed a diet containing 45.5% fat (38% lard and 7.5% soy oil) and 34% carbohydrate (25% as sucrose) for 8 weeks. OGTT was performed as described above.

Figure 75 shows that rT3 (2.5µg/100g) was responsible for a significant lowering of blood glucose expressed as area under the curve (AUC, figure 75) or change over time of plasma concentration (figure 77). In parallel, insulin levels were significantly lower for both AUC (Figure 76) and changes over time (Figure 78).

These results confirm the effect of a treatment with rT3 for increasing insulin sensitivity in a situation where the resistance of insulin is due to an inappropriate diet.

Example 8: De novo hepatic lipogenesis

Taken together, the effects of rT3 show an increased energy expenditure associated to a decrease in body mass no major change in food intake and a decrease in blood glucose and triglyceride levels while free fatty acid are increased. This indicates that fatty acid oxidation is increased (as it is found in isolated mitochondria). However, global assessments of glucose versus fatty acid oxidation via the tool of indirect calorimetry are not univocal since RQ is sometimes increased and sometimes decreased. One hypothesis is that low fat content of rodent chow, in some situations, fatty acids must be first synthesized from carbohydrate, before being oxidized. Indeed this might be especially relevant when fatty acid oxidation is strongly activated, for instance with high dose of rT3.

To confirm this point, the rate of endogenous triglyceride synthesis by using stable isotopes has been assessed.

Figure 79 shows that, rT3 is responsible for a powerful stimulation of endogenous (liver) synthesis of lipids. Interestingly, this effect is maximal during the day, i.e. in a fasting situation in which animals are prone to lipid oxidation and not storage, storage being the physiological goal of endogenous synthesis.

These results confirm that rT3 could be responsible for a simultaneous activation of both lipolysis, lipid oxidation and lipogenesis, resulting in a futile cycling, which may explain the considerable increase in basal energy expenditure.

CLAIMS

1. Pharmaceutical composition comprising, as active substance, at least one hormone chosen among:
   - 3',5',3-triiodothyronine (rT3),
   - a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine or 3-iodothyronine, or
   - a precursor of rT3, such as T4 in association with a molecule susceptible to promote the formation of rT3,

   in association with a pharmaceutically acceptable vehicle.

2. Pharmaceutical composition according to claim 1, wherein said active substance is rT3.

3. Pharmaceutical composition according to any of claims 1 to 2, in a suitable form for the release of about 0.01 µg/kg/day to about 250 µg/kg/day, particularly about 0.01 µg/kg/day to about 25 µg/kg/day, particularly about 0.1 µg/kg/day to about 15 µg/kg/day of active substance, more particularly about 0.1 µg/kg/day to about 5 µg/kg/day of active substance, most particularly about 0.1 µg/kg/day to 1 µg/kg/day of active substance.

4. Pharmaceutical composition according to claim 1 or 3, comprising by dosage unit about 5 µg to about 1.5 g of active substance, particularly about 75 mg to about 750 mg of active substance.

5. Use of at least one hormone chosen among:
   - 3',5',3-triiodothyronine (rT3),
   - a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine, or 3-iodothyronine, or
   - a precursor of rT3, such as T4, in association with a molecule susceptible to promote the formation of rT3,

   for the preparation of a drug intended for the treatment of:
   - hyperglycemia, insulin resistance, beta pancreatic cell insufficiency, or related pathologies,

- pathologies wherein the cholesterol and/or triglycerides plasma concentrations are higher than the normal concentrations, dyslipidemia, or
- pathologies related to overweight or related to an excess of fat deposit.

6. Use according to claim 5, for the preparation of a drug intended for the treatment of pathologies chosen among diabetes, particularly type 1 or 2 diabetes, beta pancreatic cell insufficiency, obesity, overweight or related pathologies, hypercholesterolemia, hypertriglyceridemia, dyslipidemia, alcoholic and non alcoholic hepatic steatosis, atherosclerosis, hepatopathies associated to a dysmetabolism, cholecystopathies, deposit of subcutaneous fat, particularly cellulite or vasomotor rhinitis.

7. Use according to claim 5 or 6, wherein said hormone is rT3.

8. Pharmaceutical composition according any of claims 1 to 4, wherein said pharmaceutically acceptable vehicle refers to pharmaceutically acceptable solid or liquid, diluting or encapsulating, filling or carrying agents, which are usually employed in pharmaceutical industry for making pharmaceutical compositions.

9. Pharmaceutical composition according any of claims 1 to 4 or 8, suitable for an administration via an oral, intravenous, intramuscular, subcutaneous, transcutaneous, nasal, intraperitoneal, sublingual, or rectal route.

10. Pharmaceutical composition according any of claims 1 to 4 or 8 or 9, wherein said pharmaceutically acceptable vehicle allows a continuous, preferably constant, release, of said active substance.

11. Product comprising:

- at least one hormone chosen among 3',5',3-triiodothyronine (rT3), a rT3 derived hormone, such as 3',3-diiodothyronine, 5',3- diiodothyronine, 3'-iodothyronine, 5'-iodothyronine, or 3-iodothyronine, or a rT3 precursor, such as T4 in association with a molecule susceptible to promote the formation of rT3,

- at least one active substance activating the pancreatic secretion of insulin, particularly chosen among, or susceptible of slowing the digestive absorption of glucose,

as a combination product for a simultaneous, separate or sequential use intended for the treatment of diabetes.

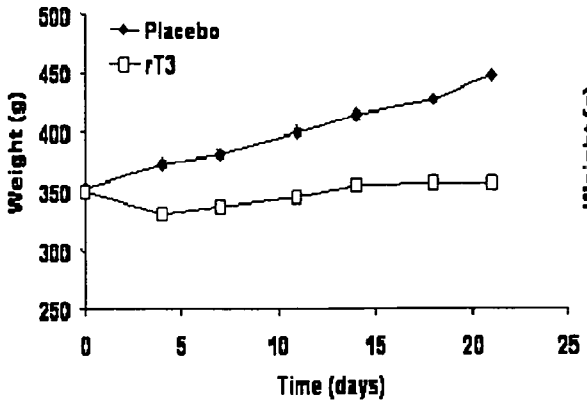


Figure 1A

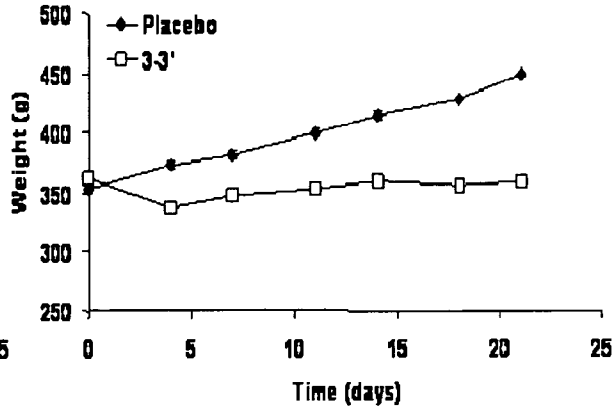


Figure 1B

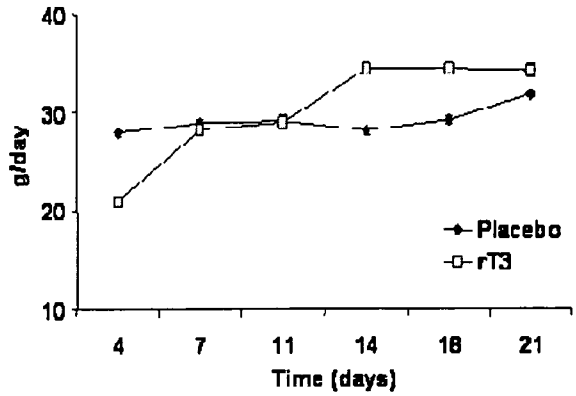


Figure 2A

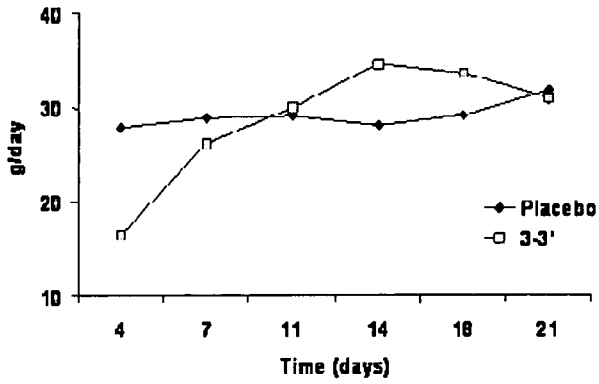


Figure 2B

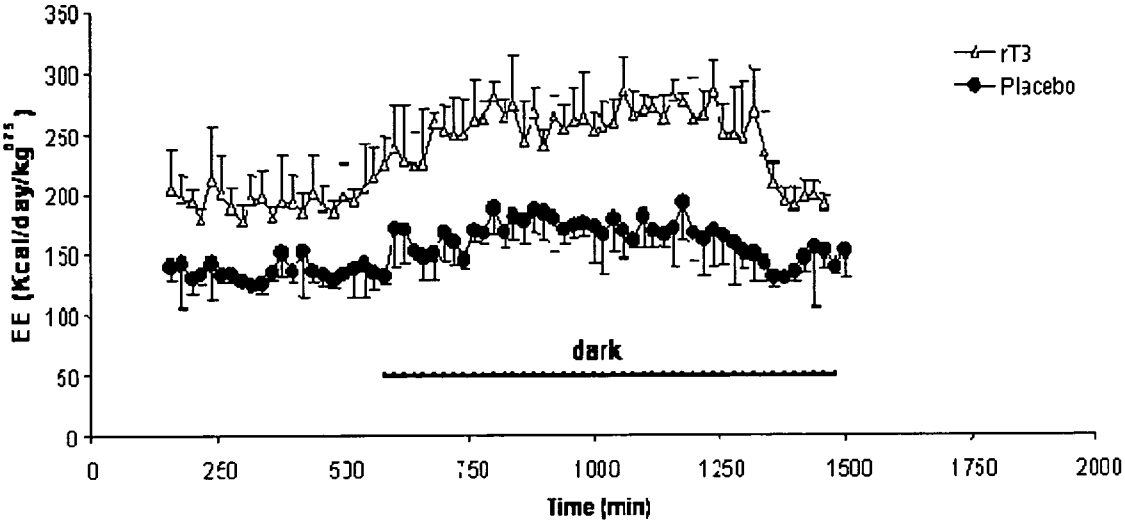


Figure 3A

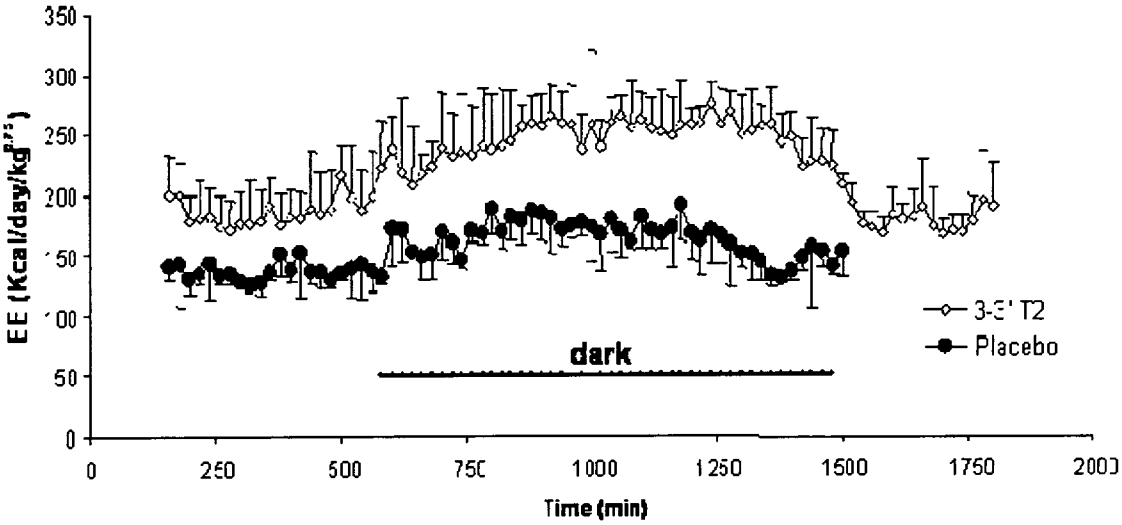


Figure 3B

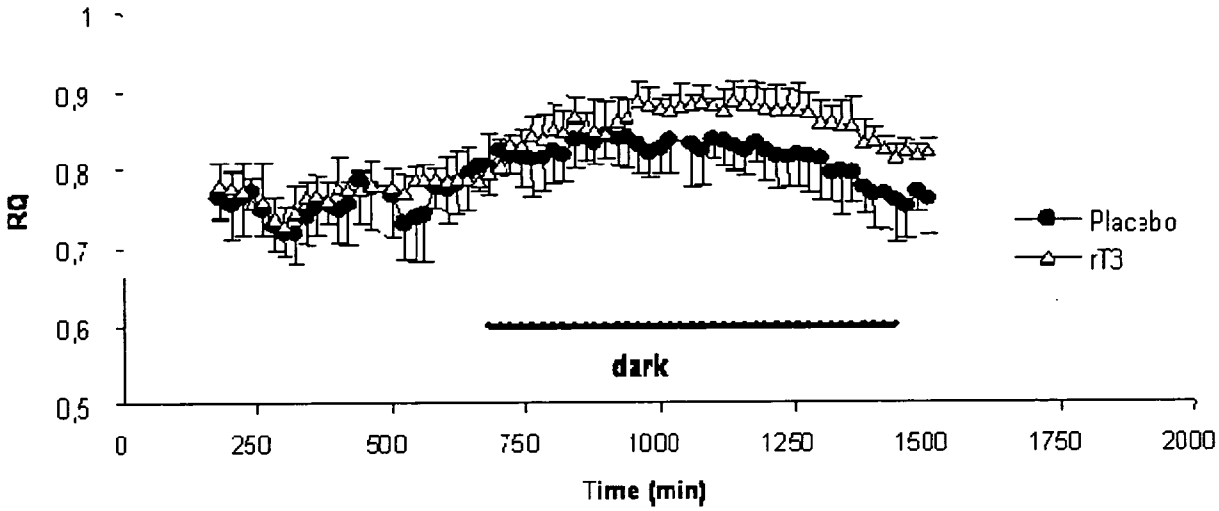


Figure 4A

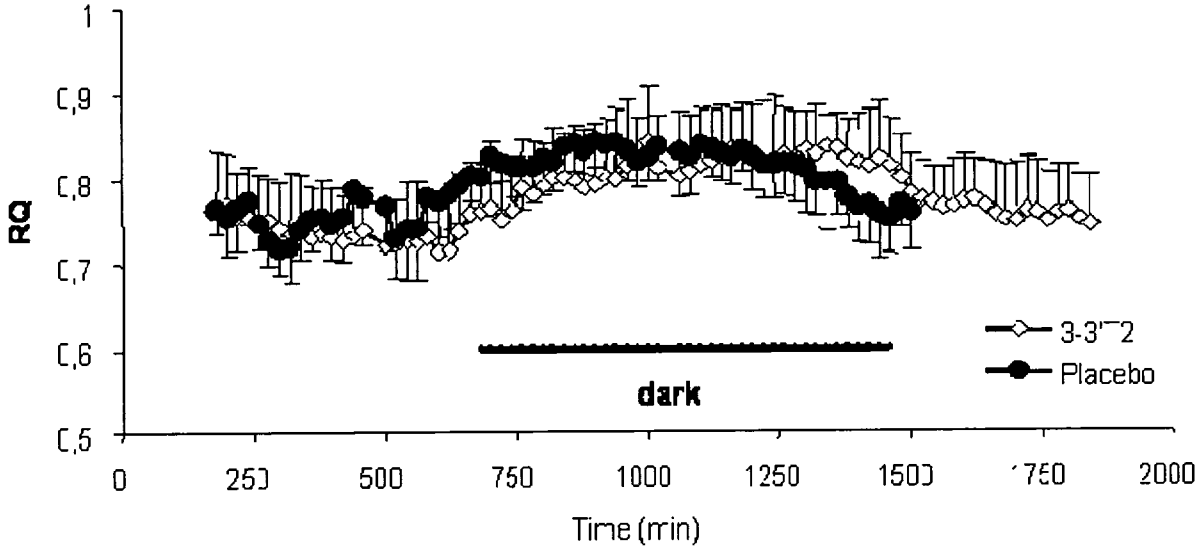


Figure 4B

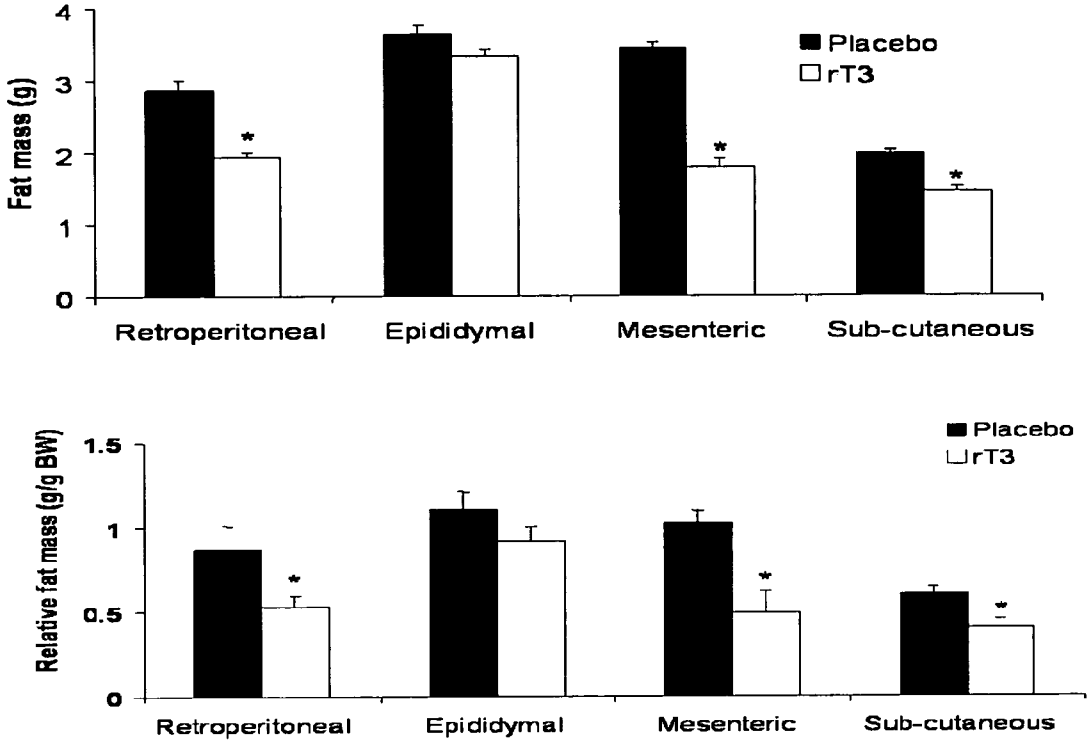


Figure 5A

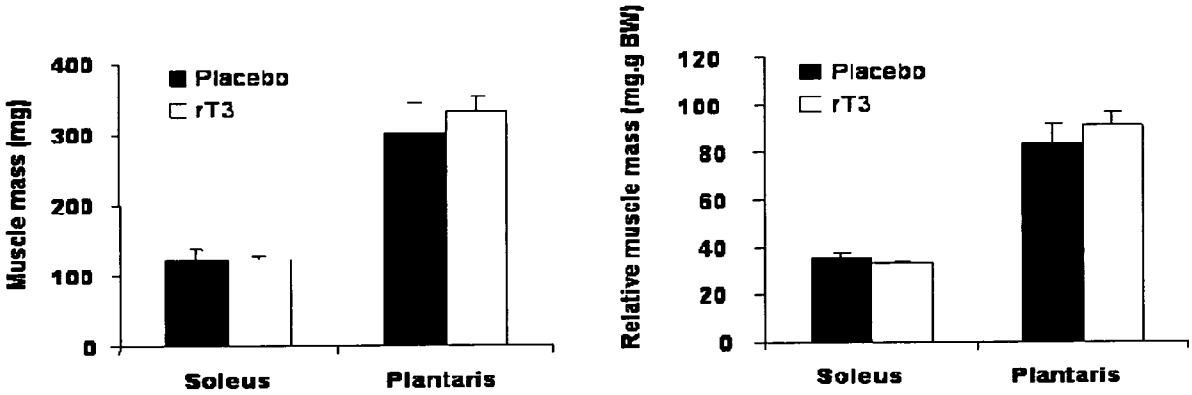


Figure 5B

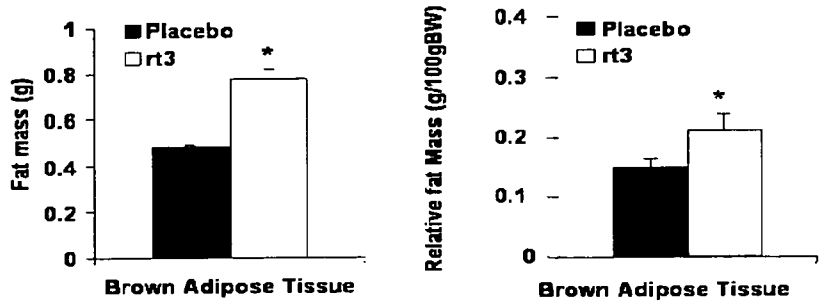


Figure 5C

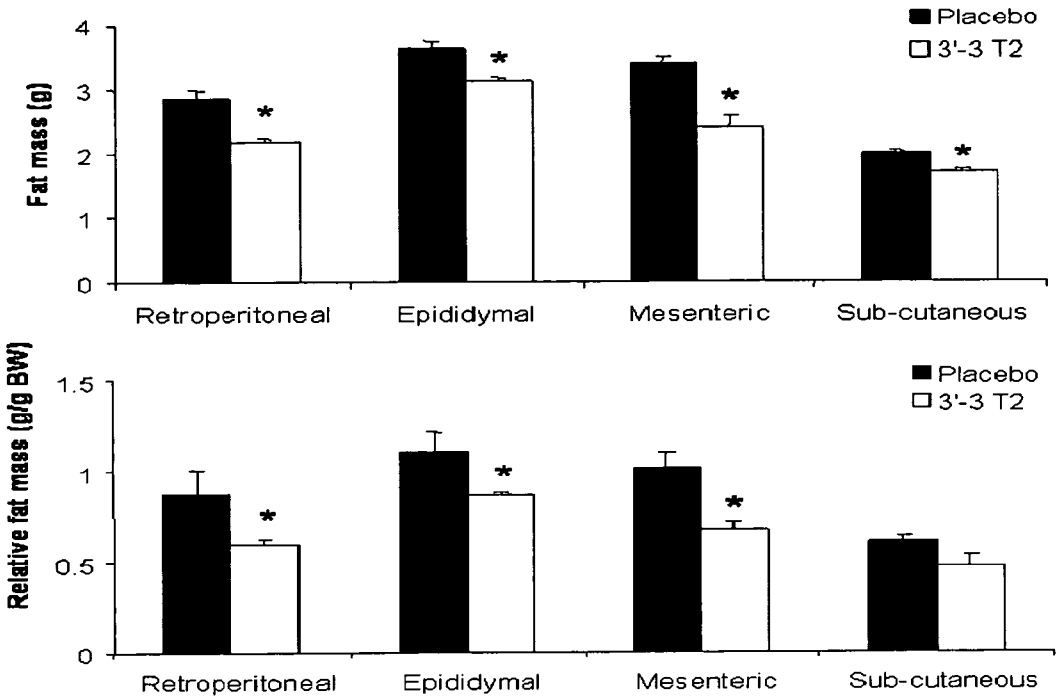


Figure 6A

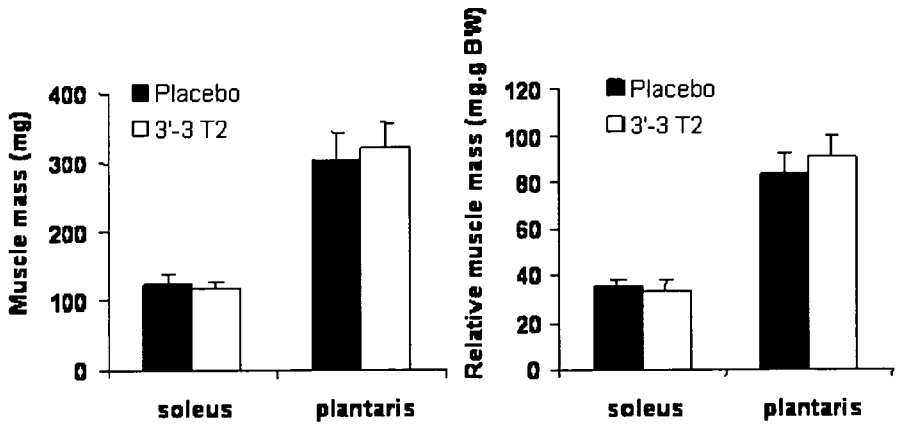


Figure 6B

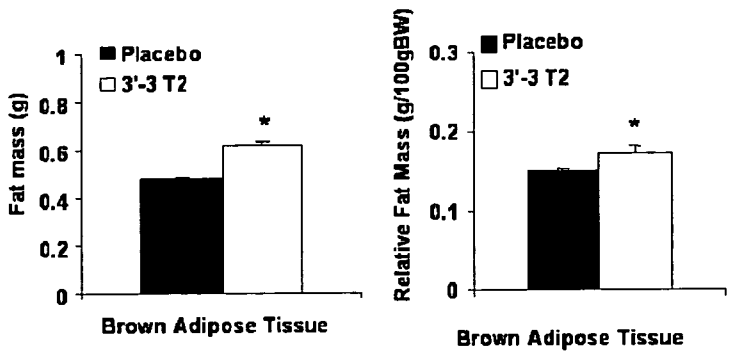


Figure 6C

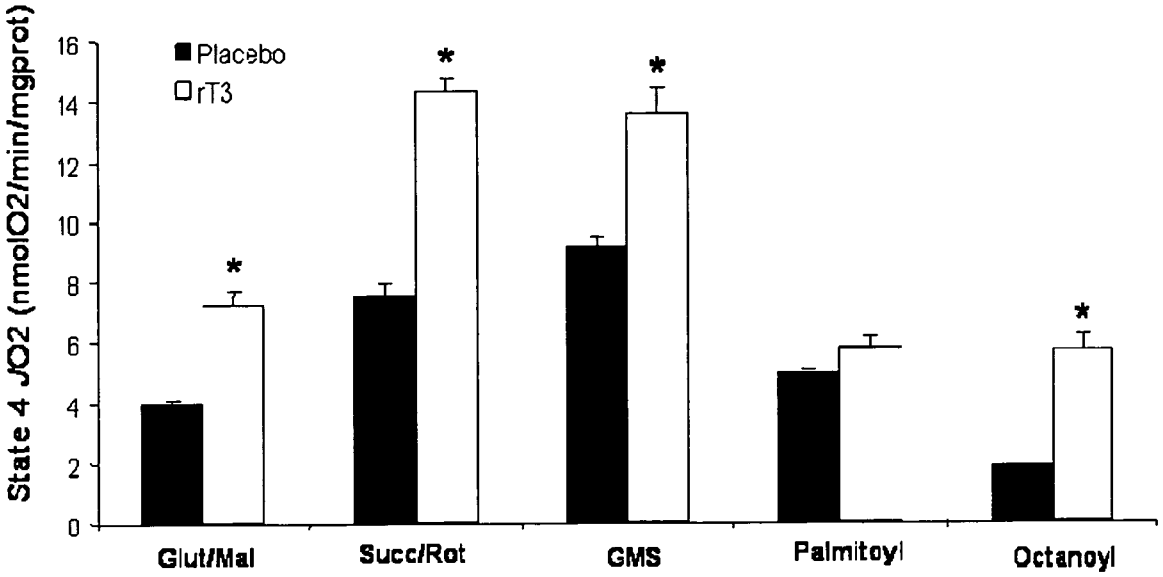


Figure 7A

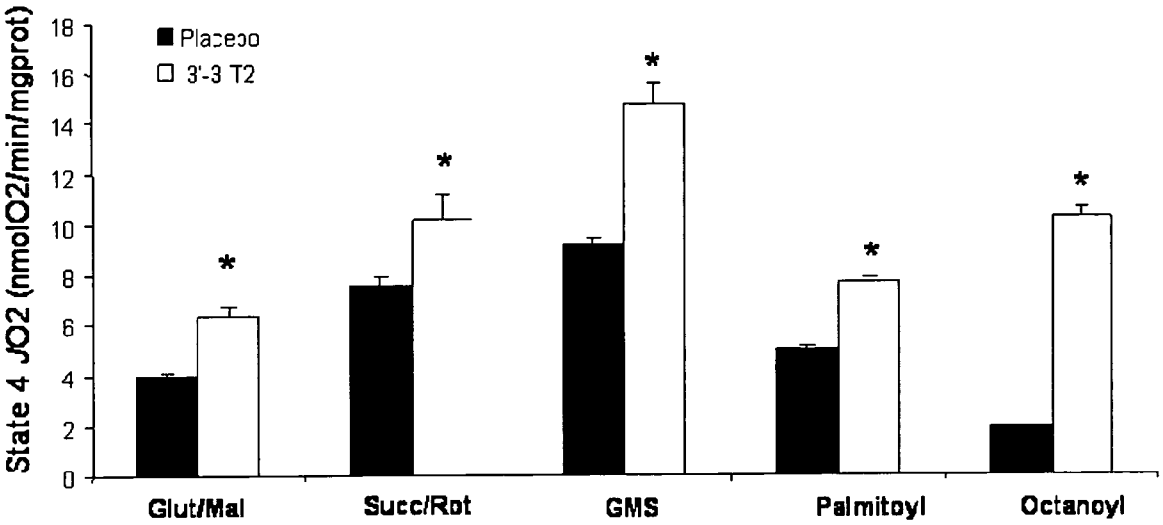


Figure 7B

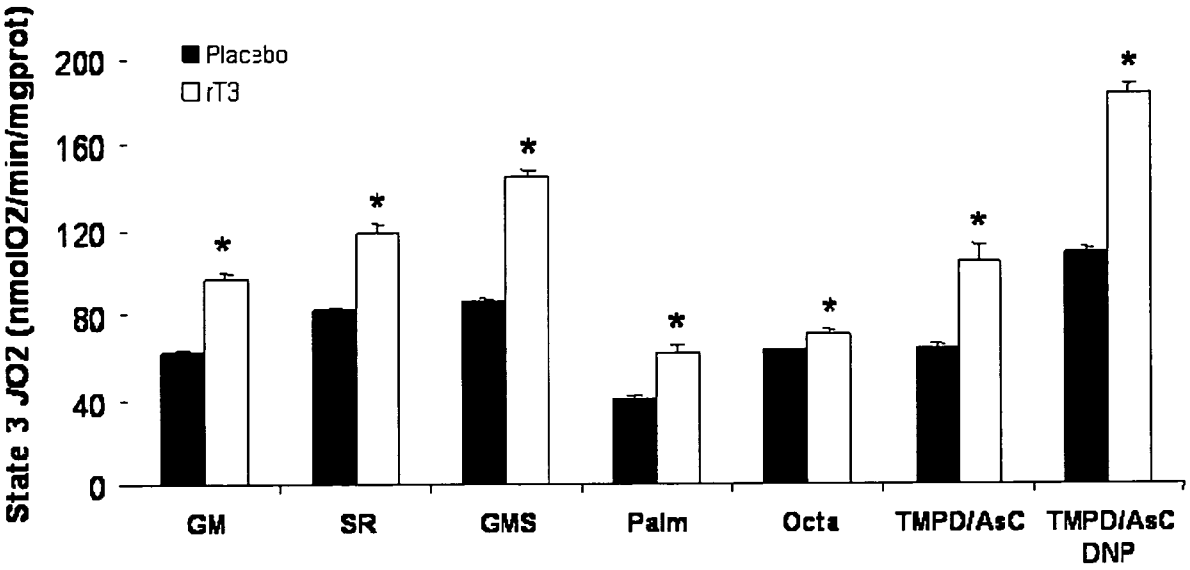


Figure 7C

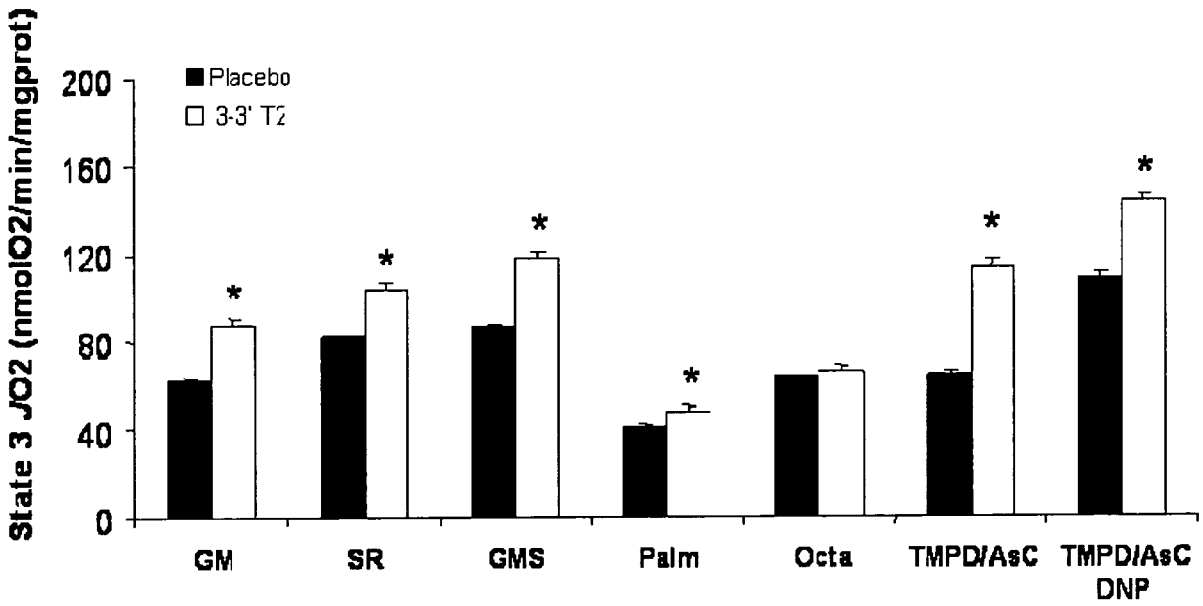


Figure 7D

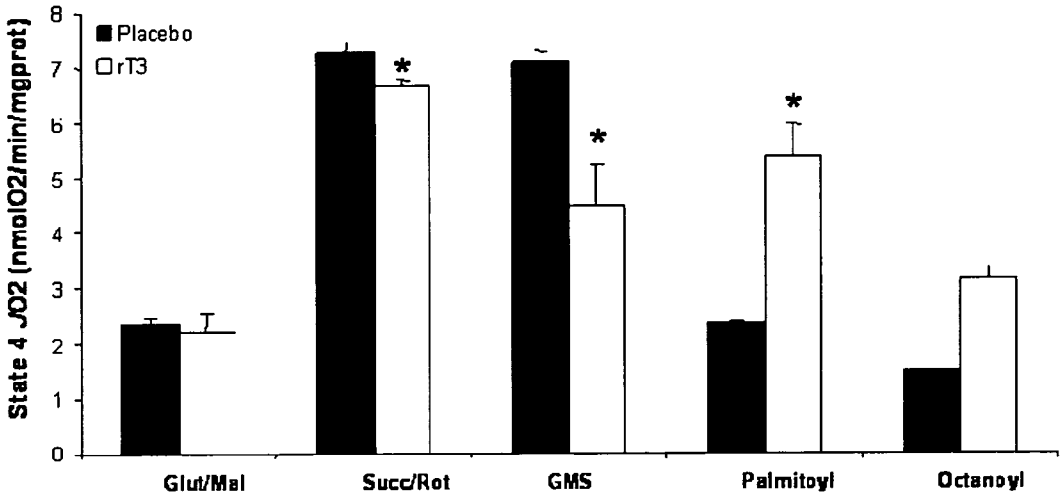


Figure 8A

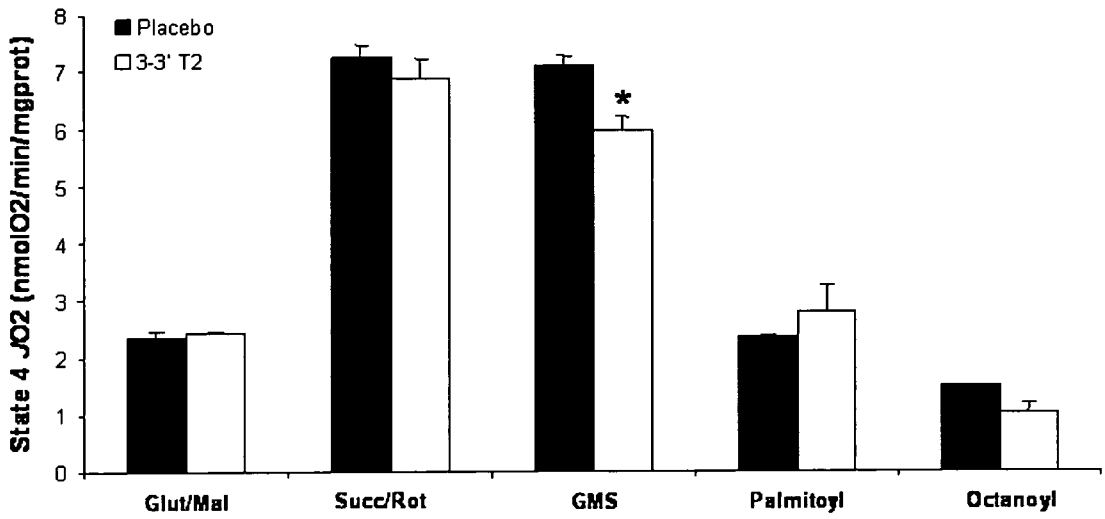
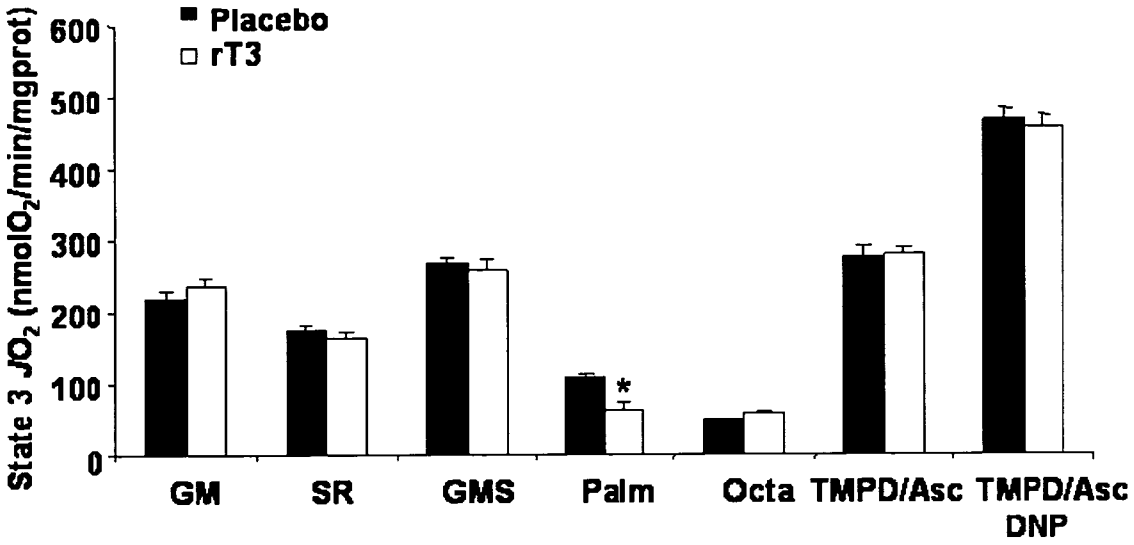


Figure 8B



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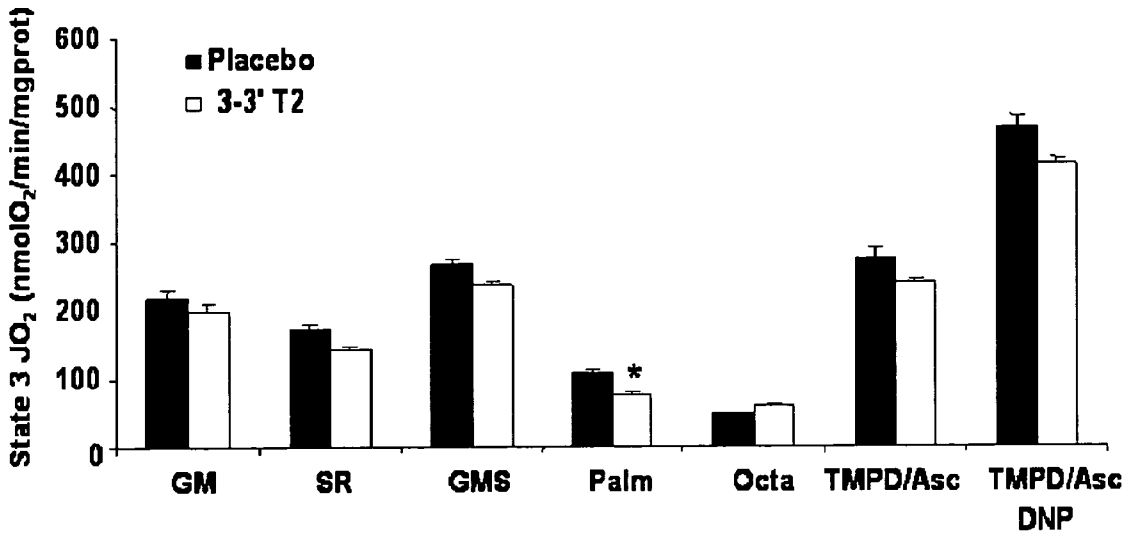


Figure 8D

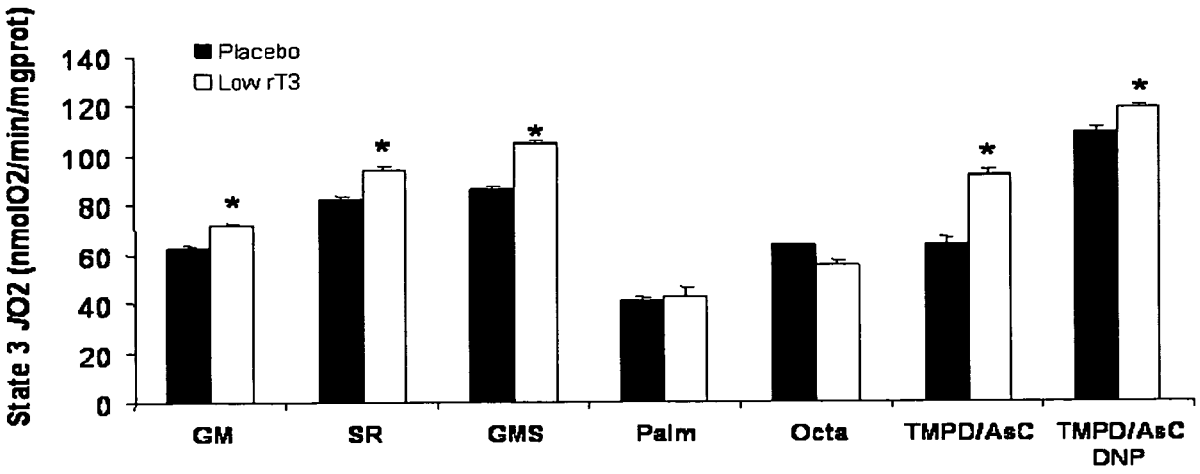


Figure 9A

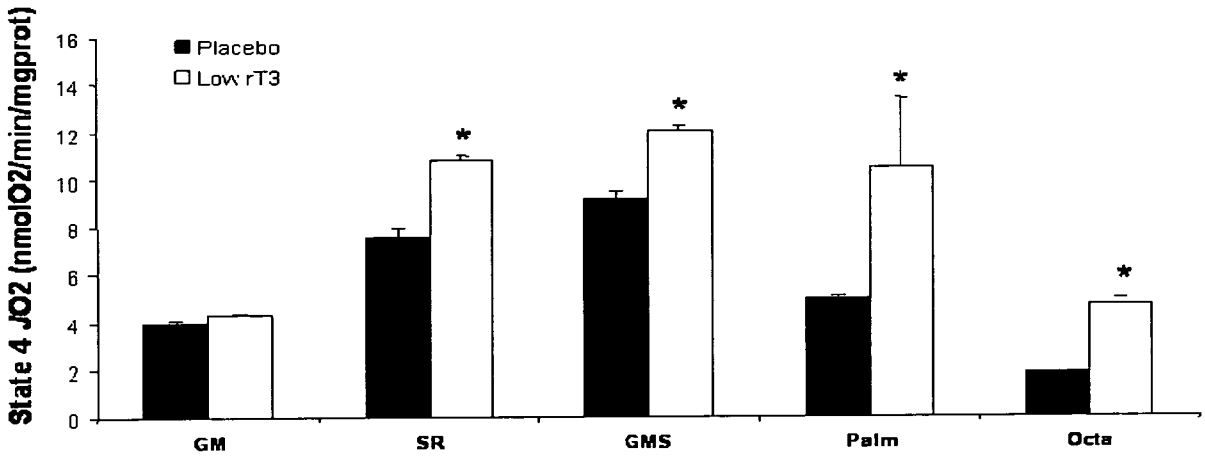


Figure 9B

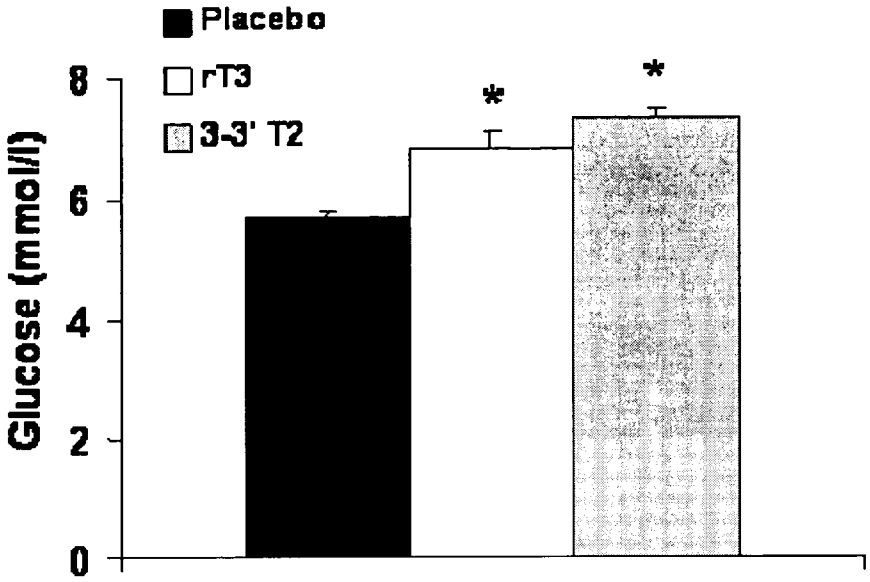


Figure 10A

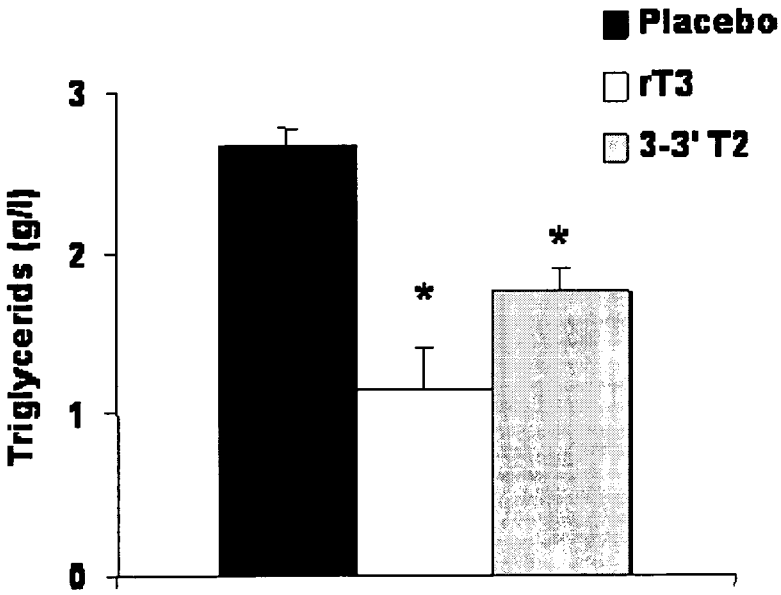


Figure 10B

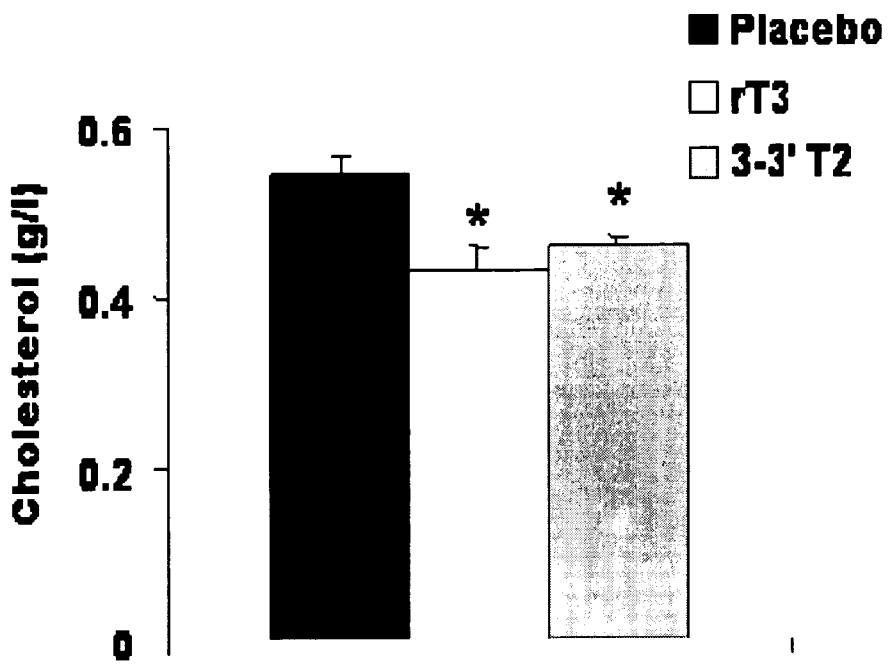


Figure 10C

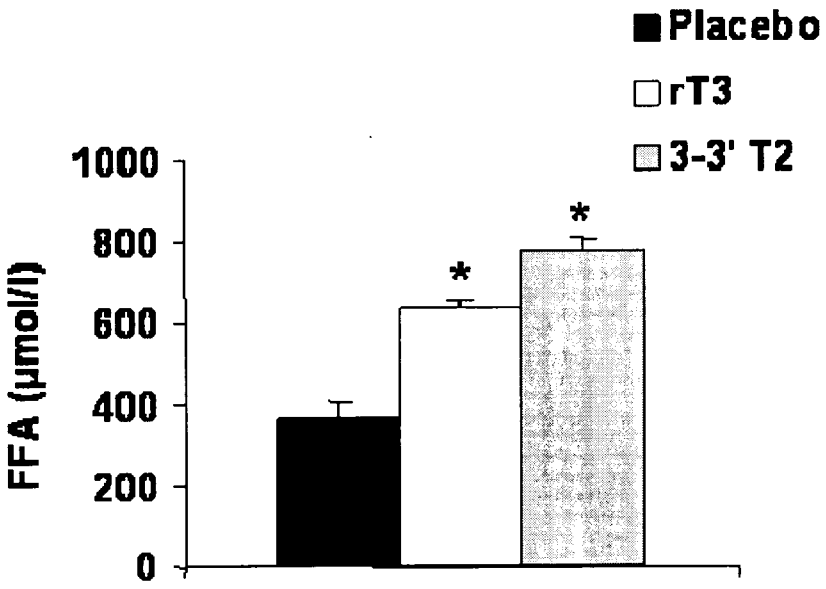


Figure 10D

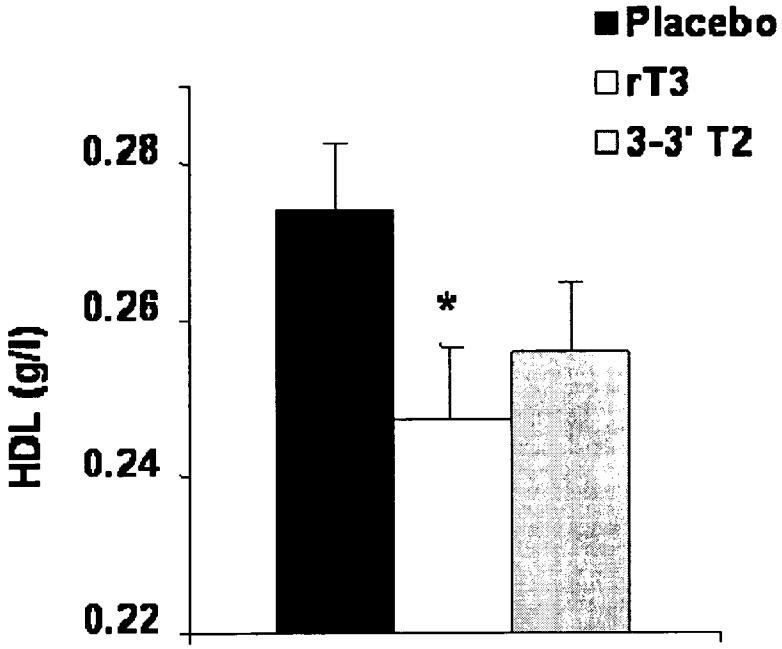


Figure 10E

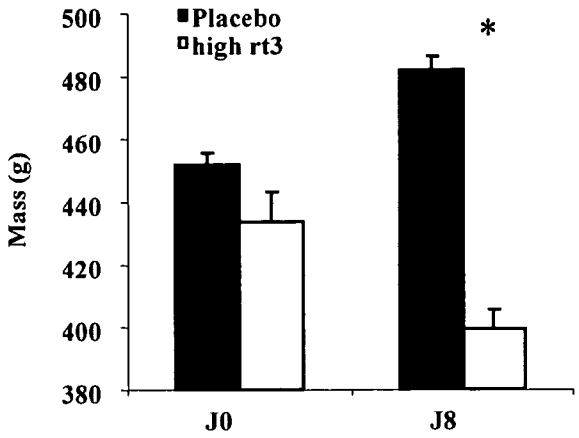


Figure 11 A

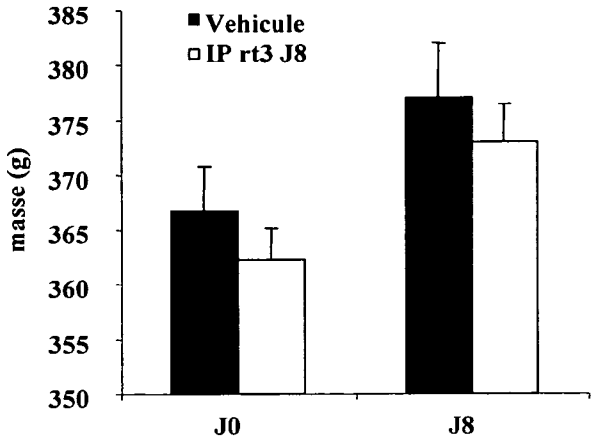


Figure 11 B

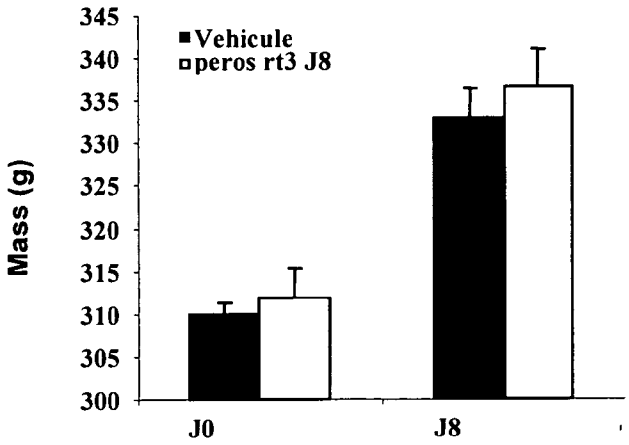


Figure 11 C

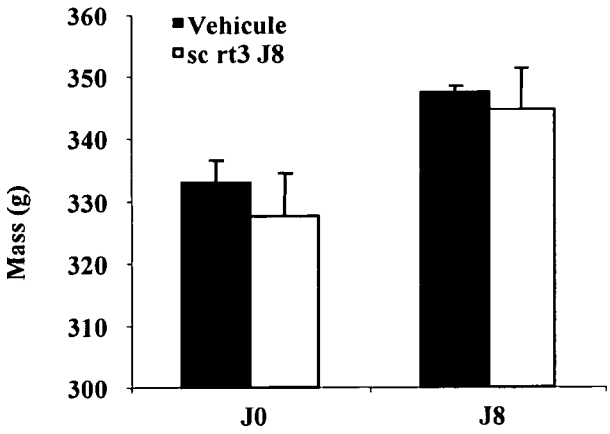


Figure 11 D

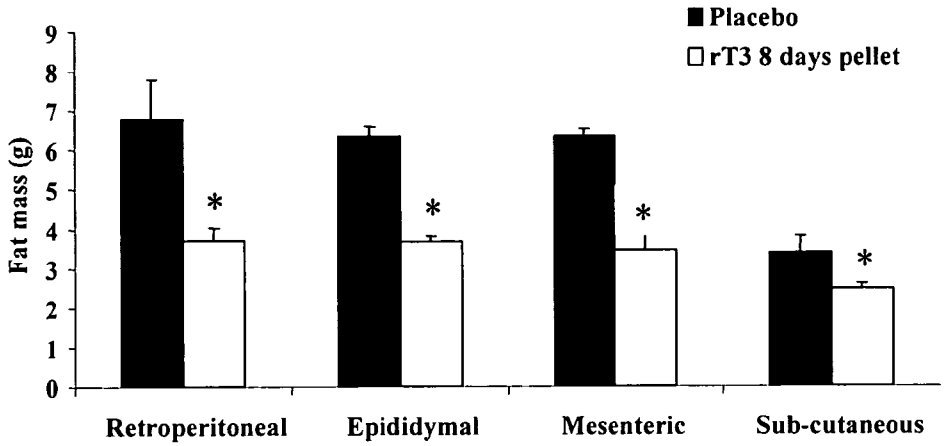


Figure 12 A

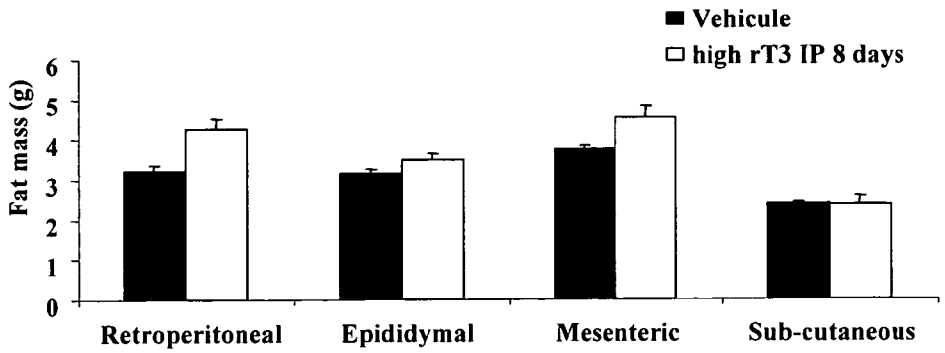


Figure 12 B

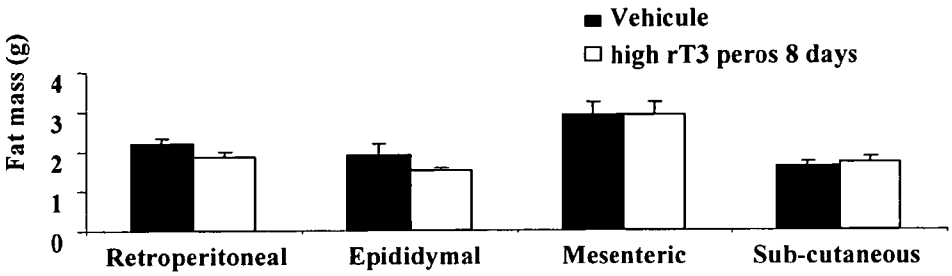


Figure 12 C

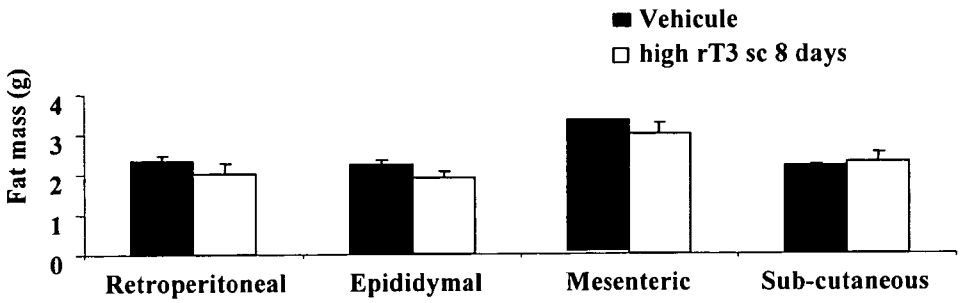


Figure 12 D

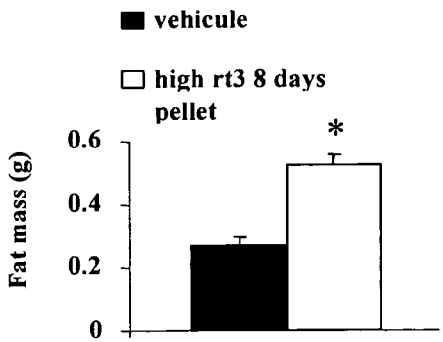


Figure 13A

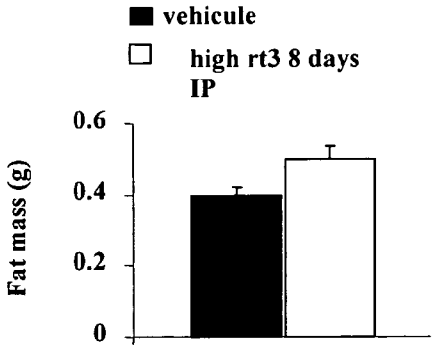


Figure 13B

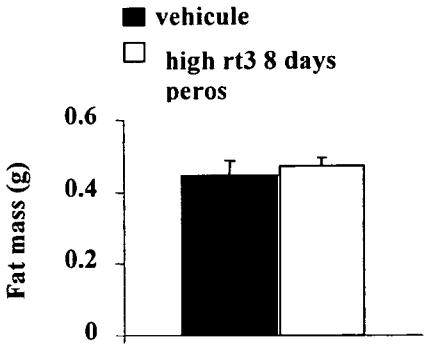


Figure 13C

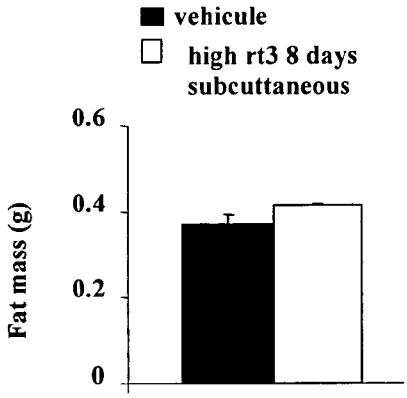


Figure 13D

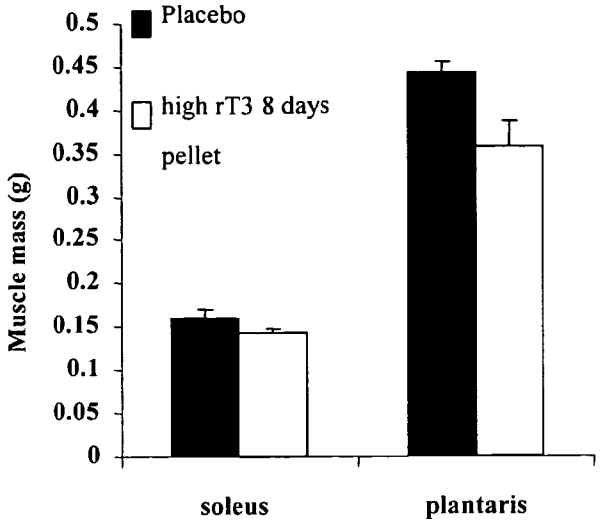


Figure 14A

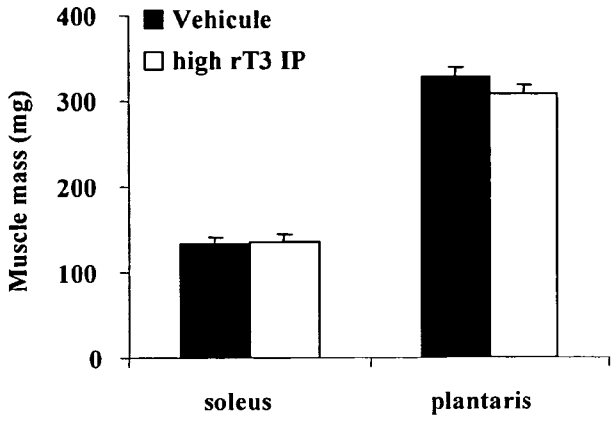


Figure 14B

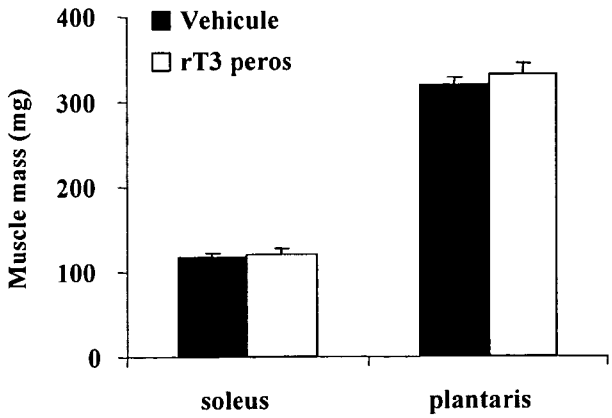


Figure 14C

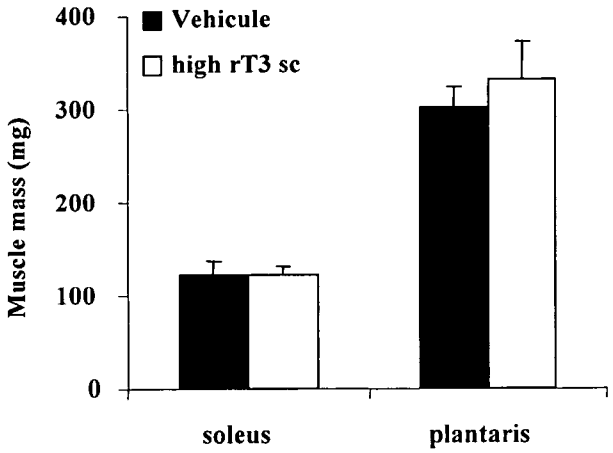


Figure 14D

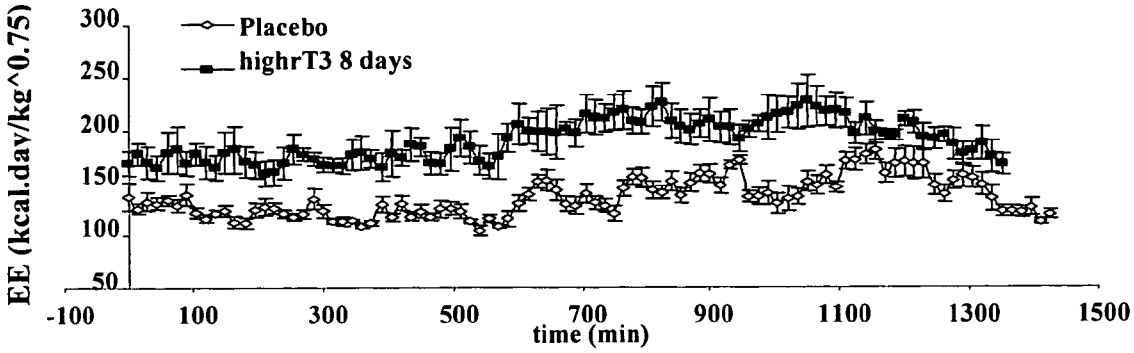


Figure 15A

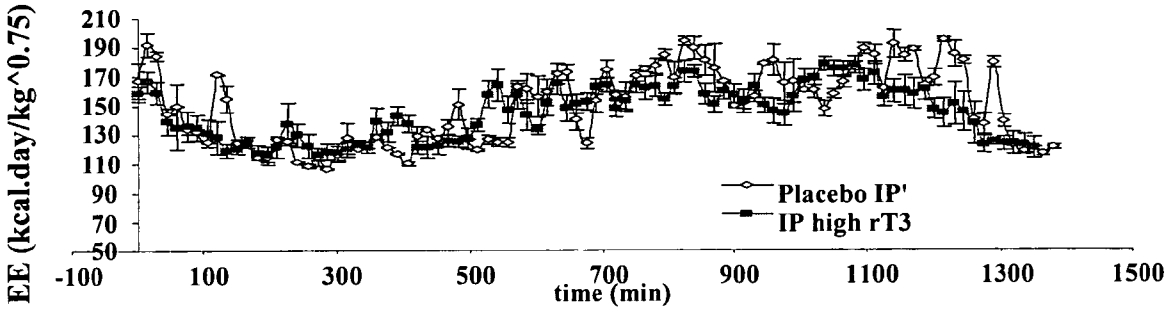


Figure 15B

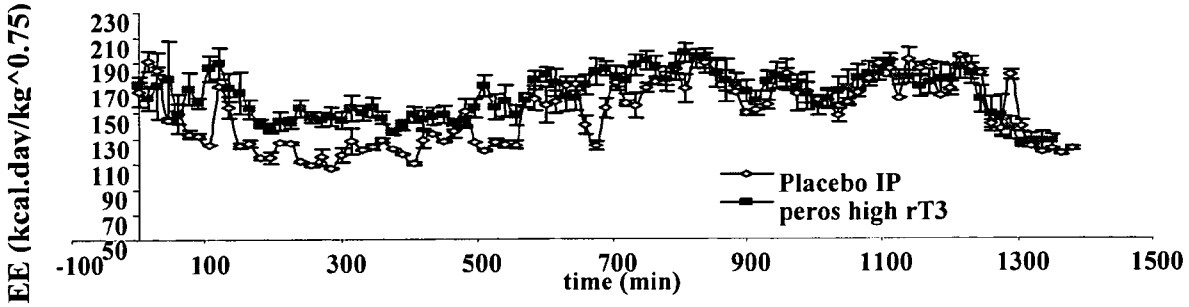


Figure 15C

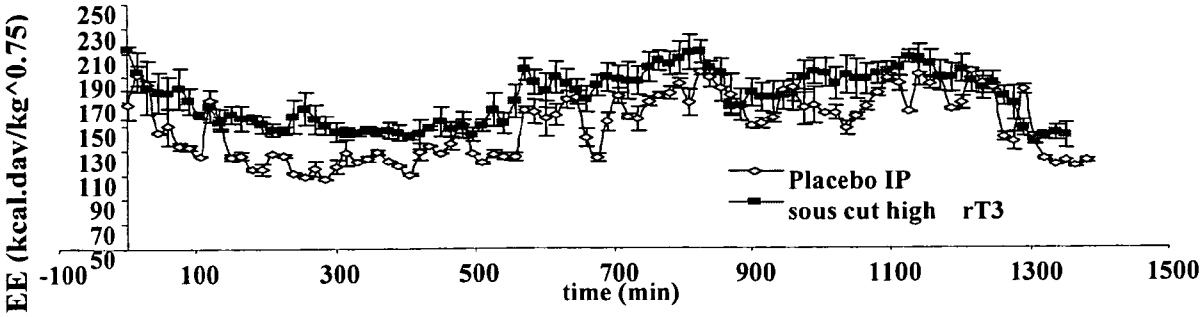


Figure 15D

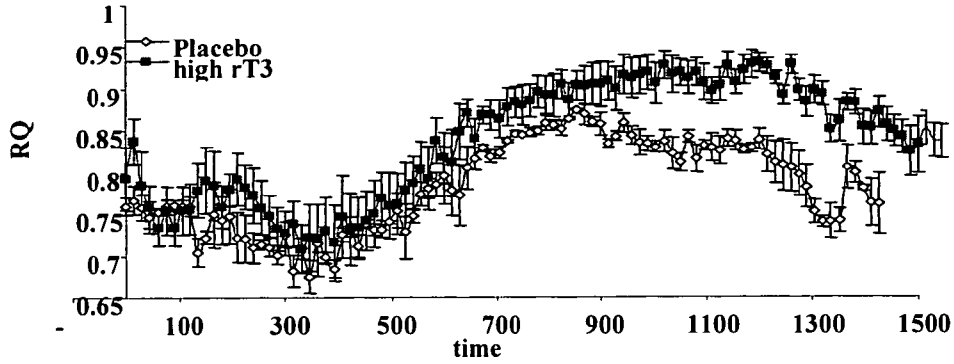


Figure 16A

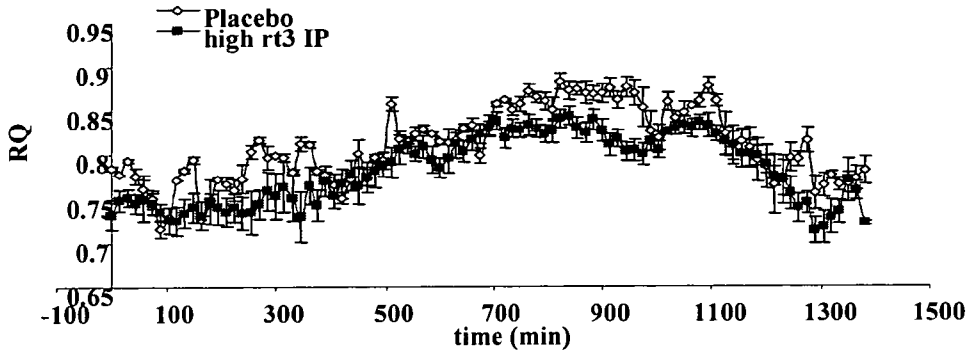


Figure 16B

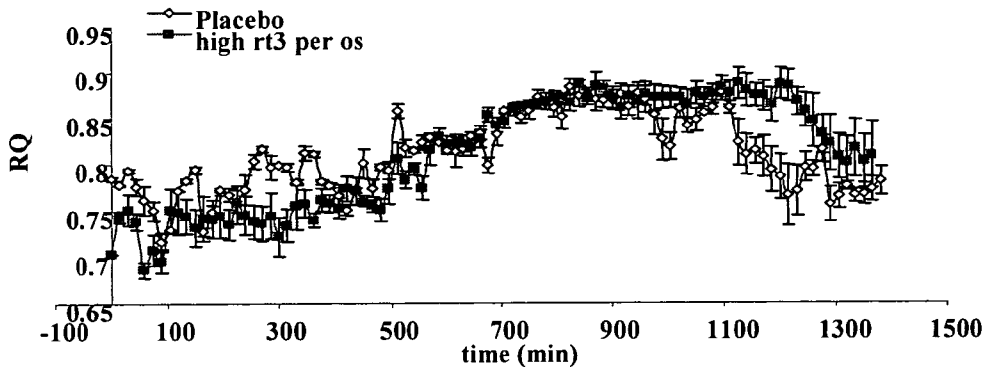


Figure 16C

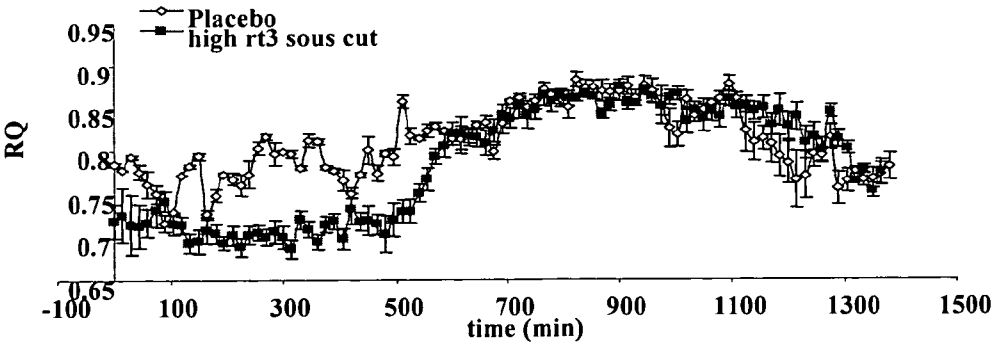


Figure 16D

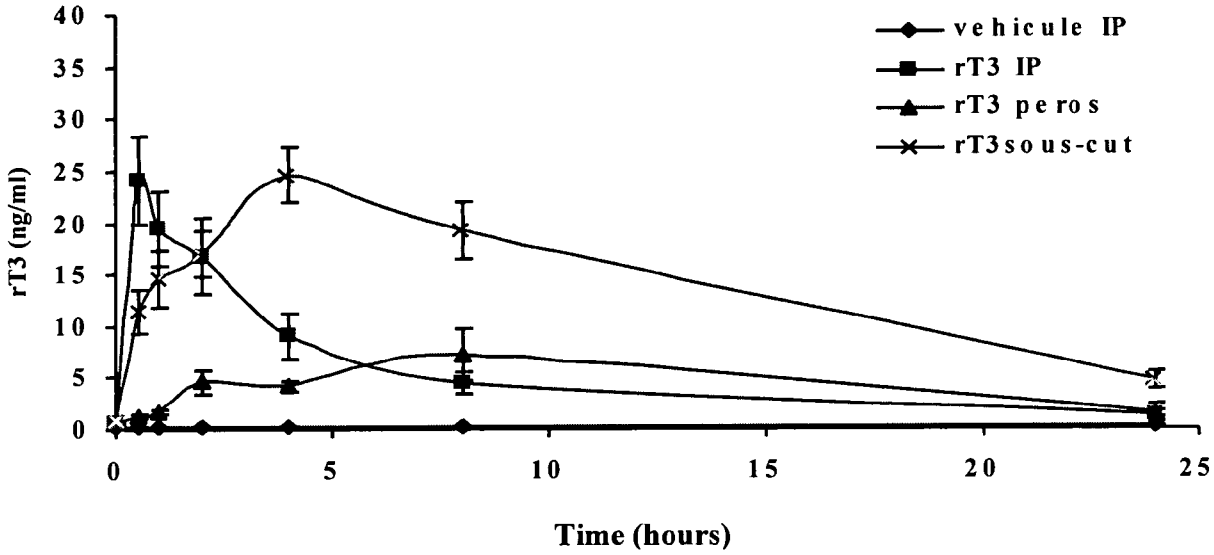


Figure 17

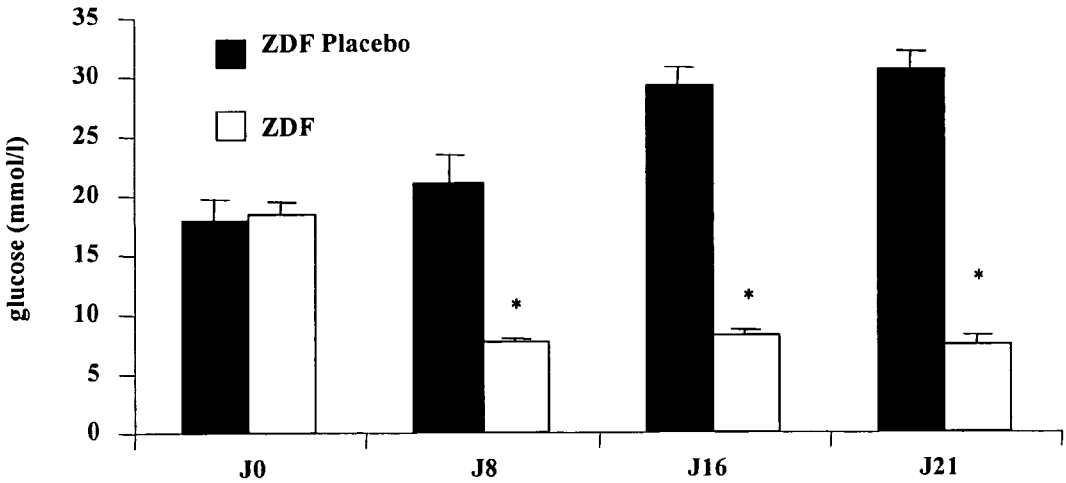


Figure 18

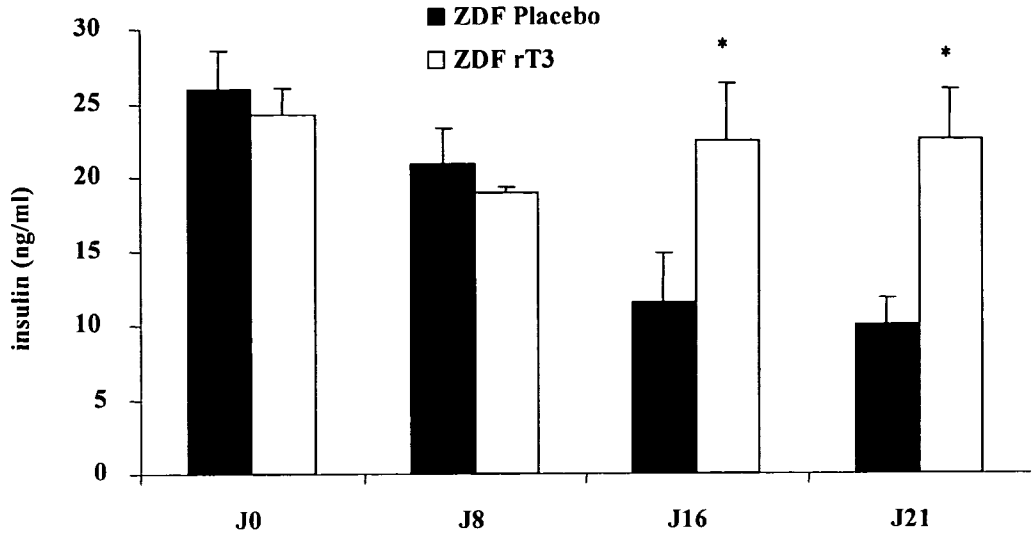


Figure 19

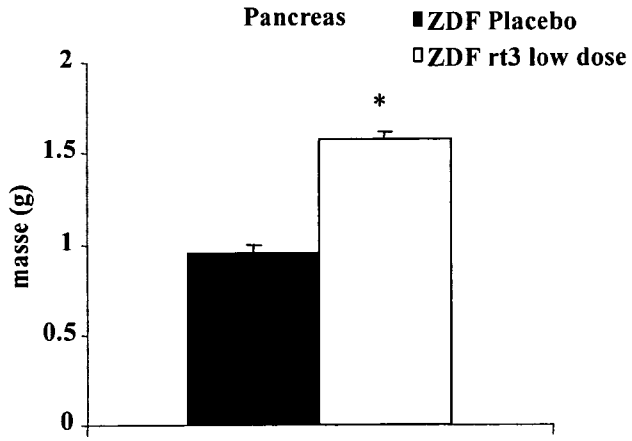


Figure 20

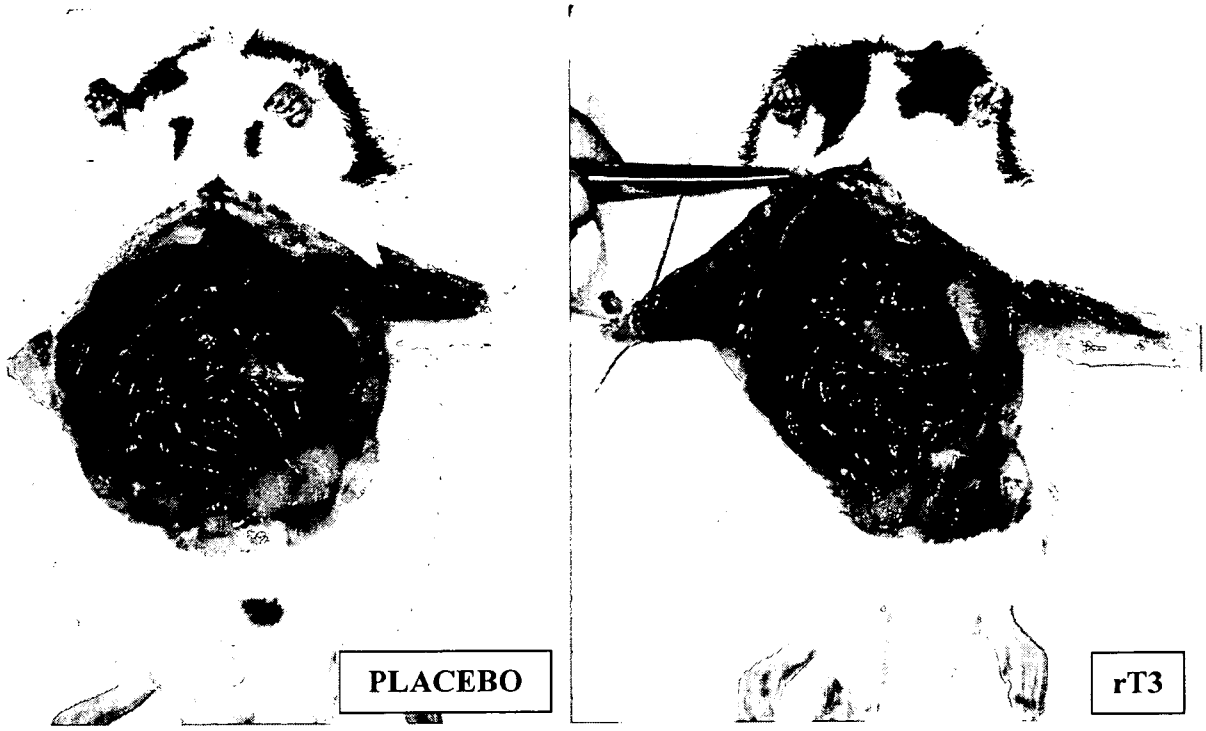


Figure 21

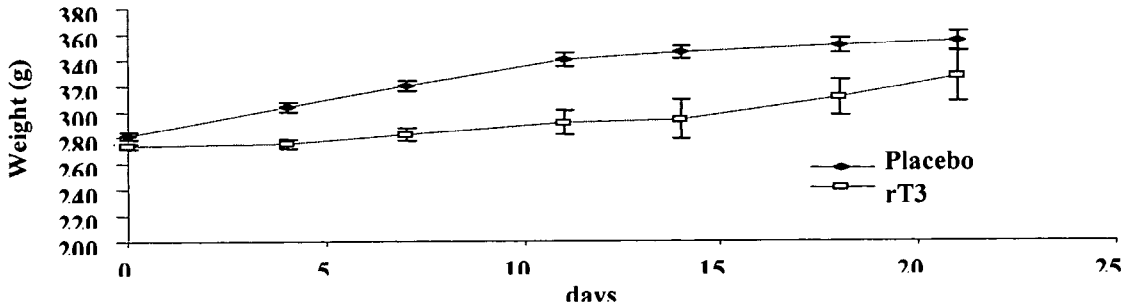


Figure 22

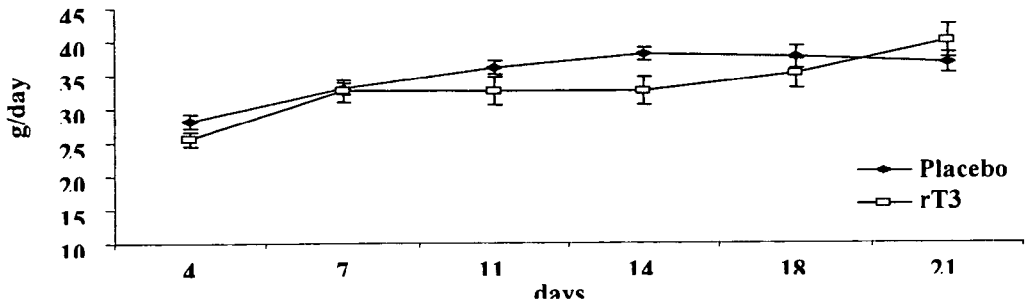


Figure 23

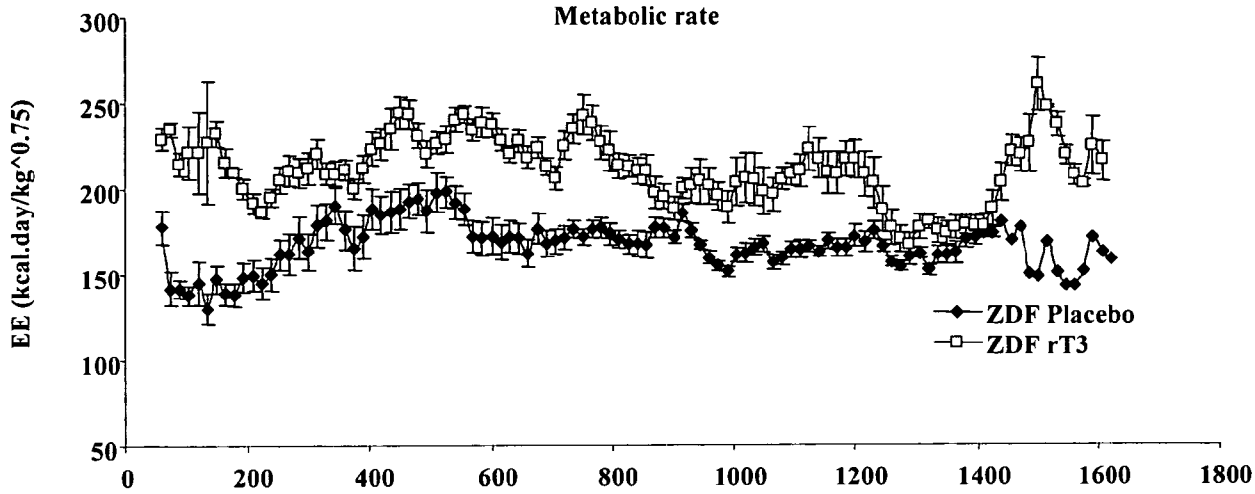


Figure 24

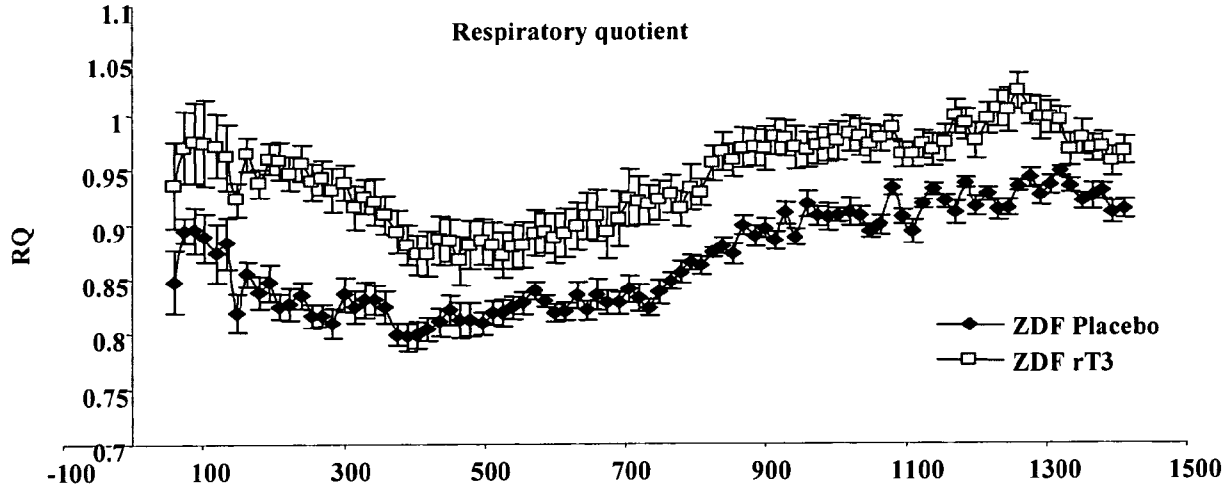


Figure 25

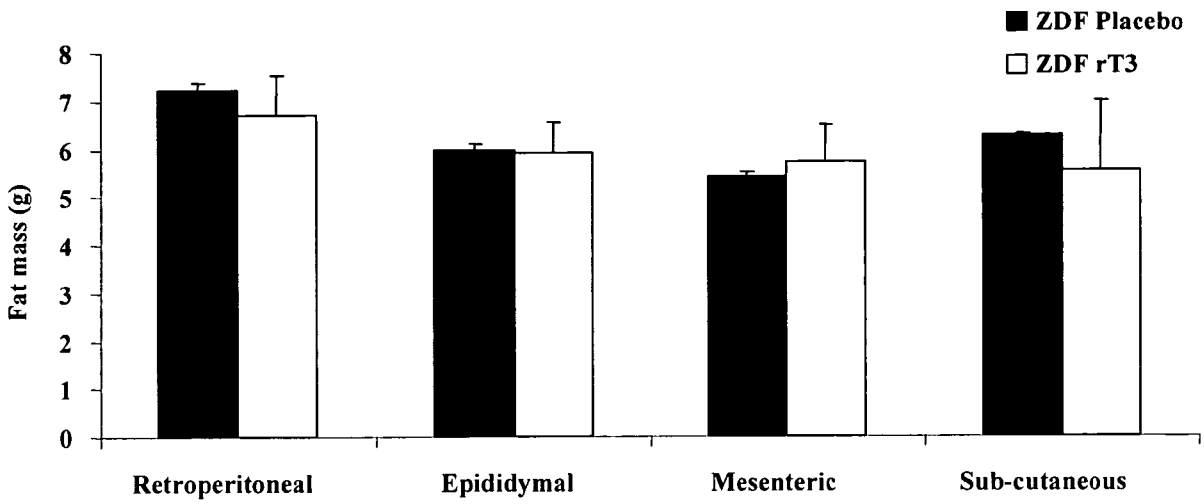


Figure 26

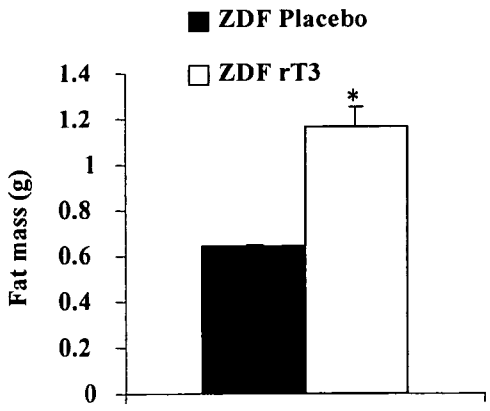


Figure 27

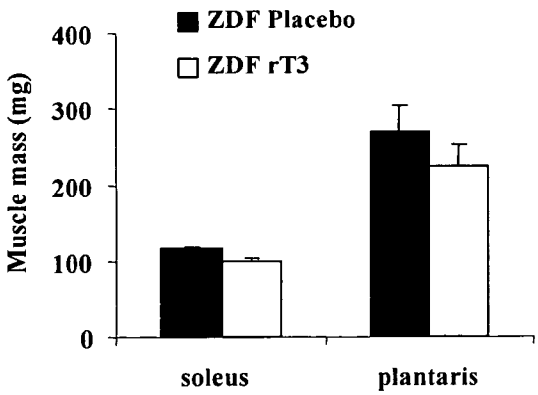


Figure 28

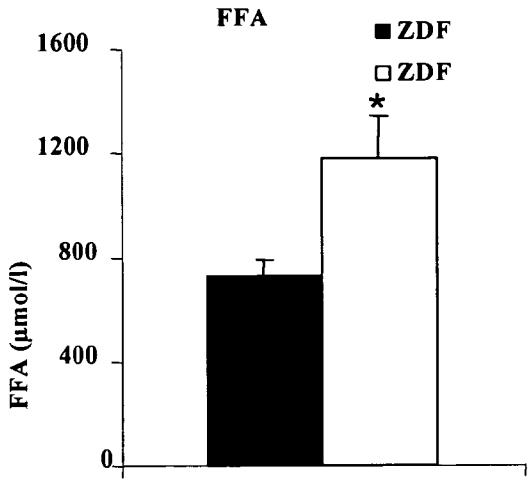


Figure 29

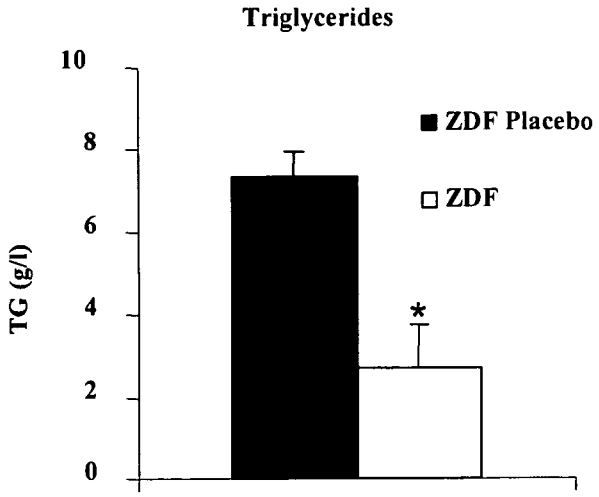


Figure 30

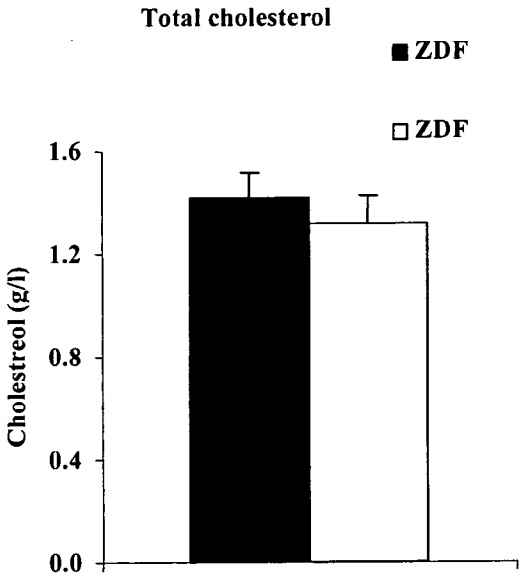


Figure 31

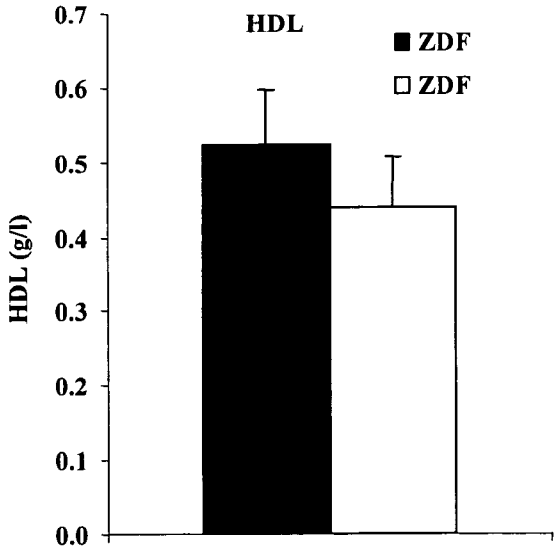


Figure 32

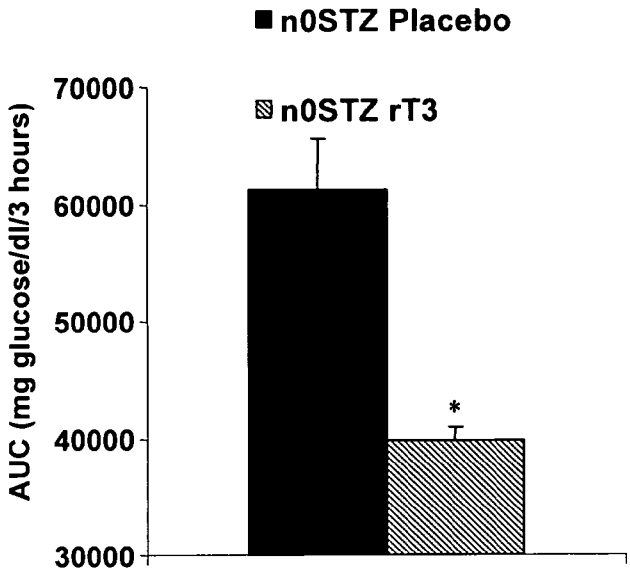


Figure 33

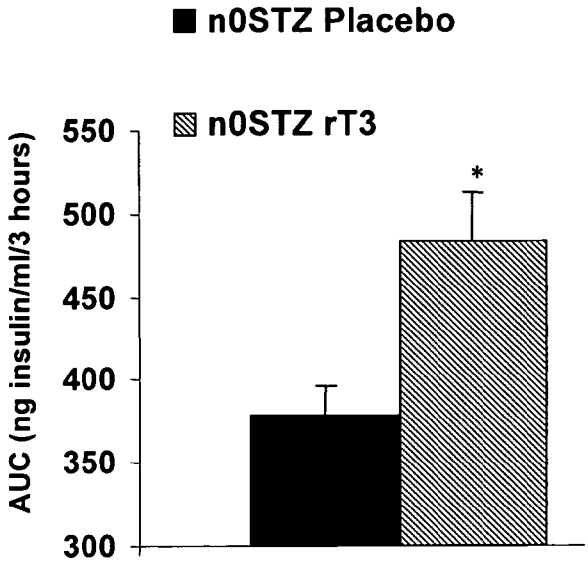


Figure 34

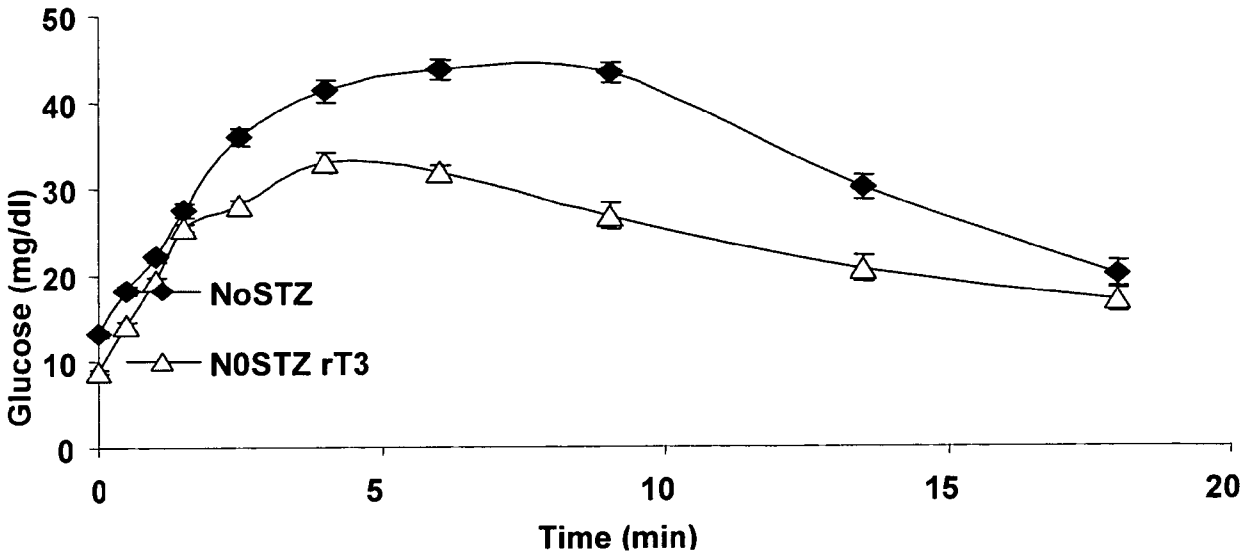
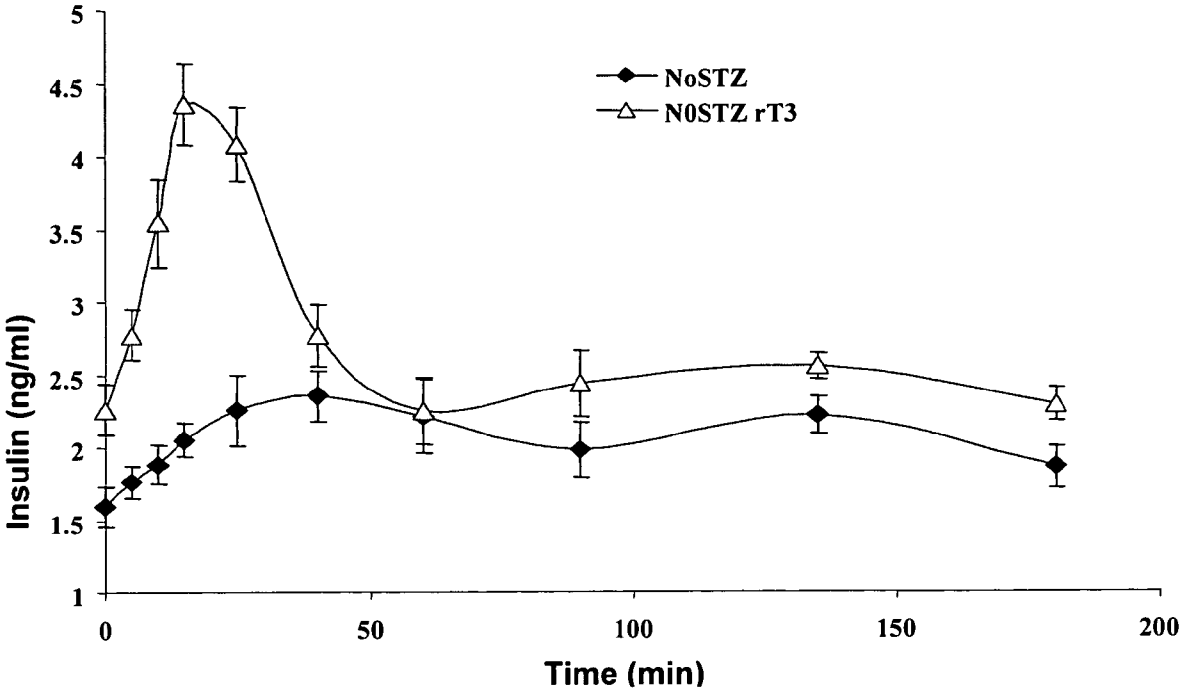


Figure 35



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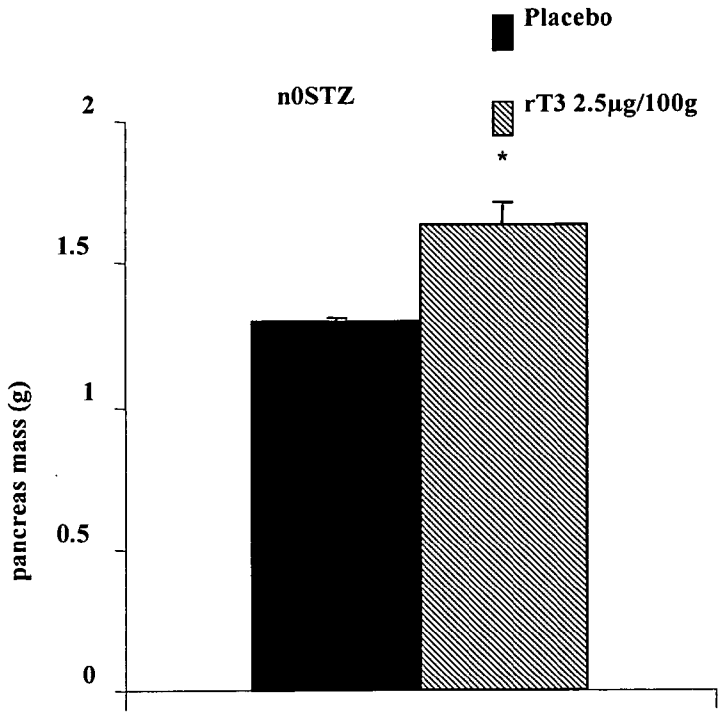
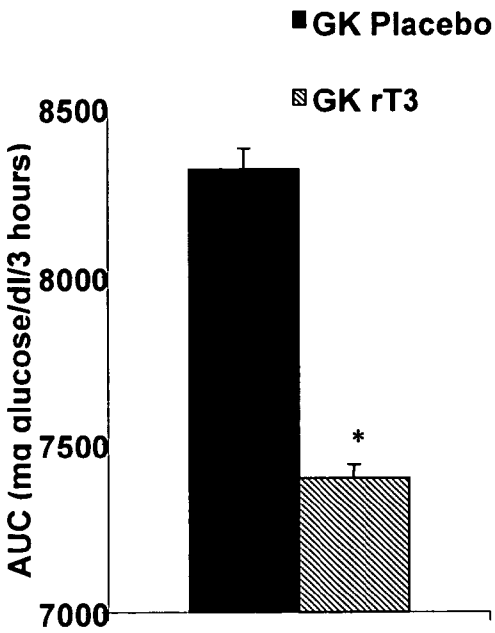


Figure 37



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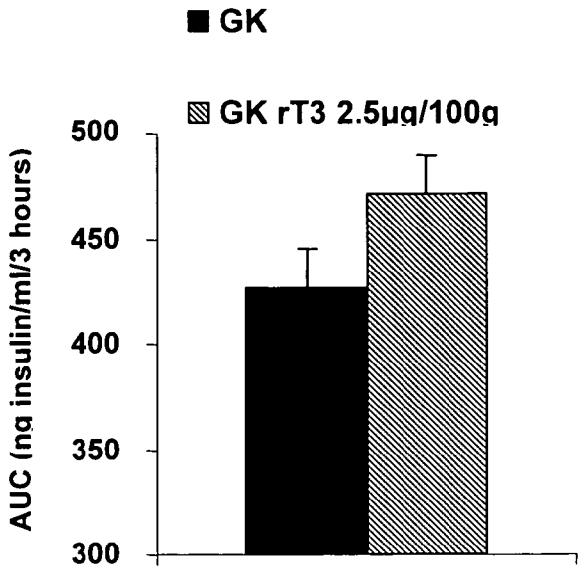

Figure 39

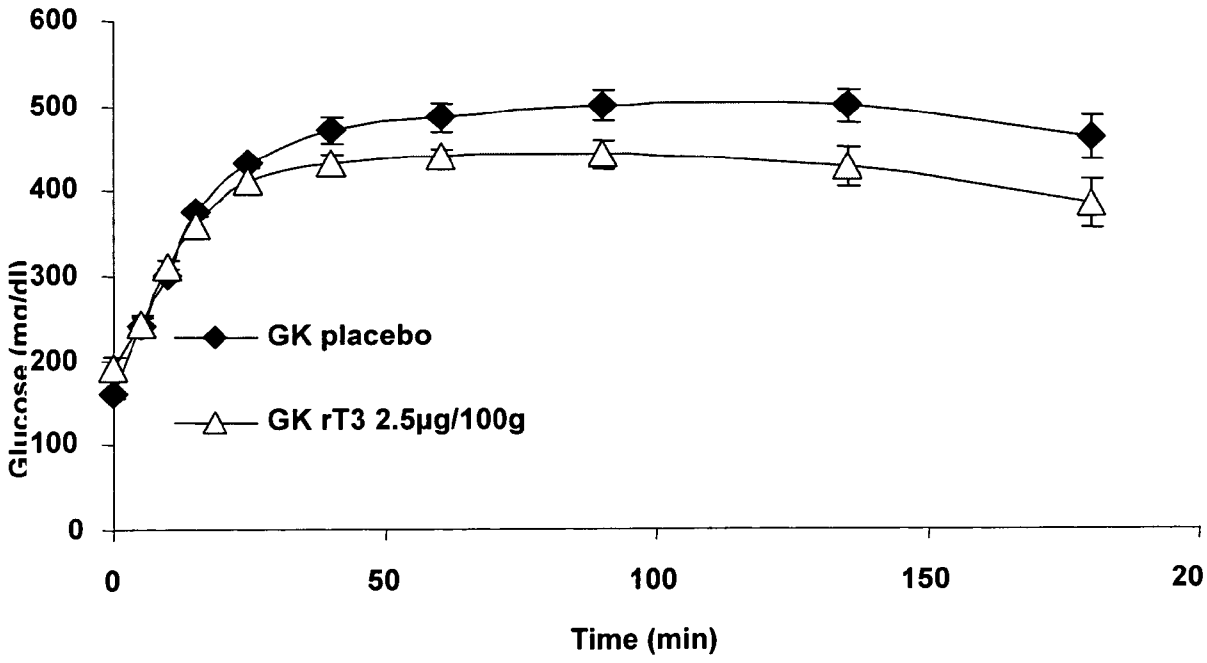

Figure 40

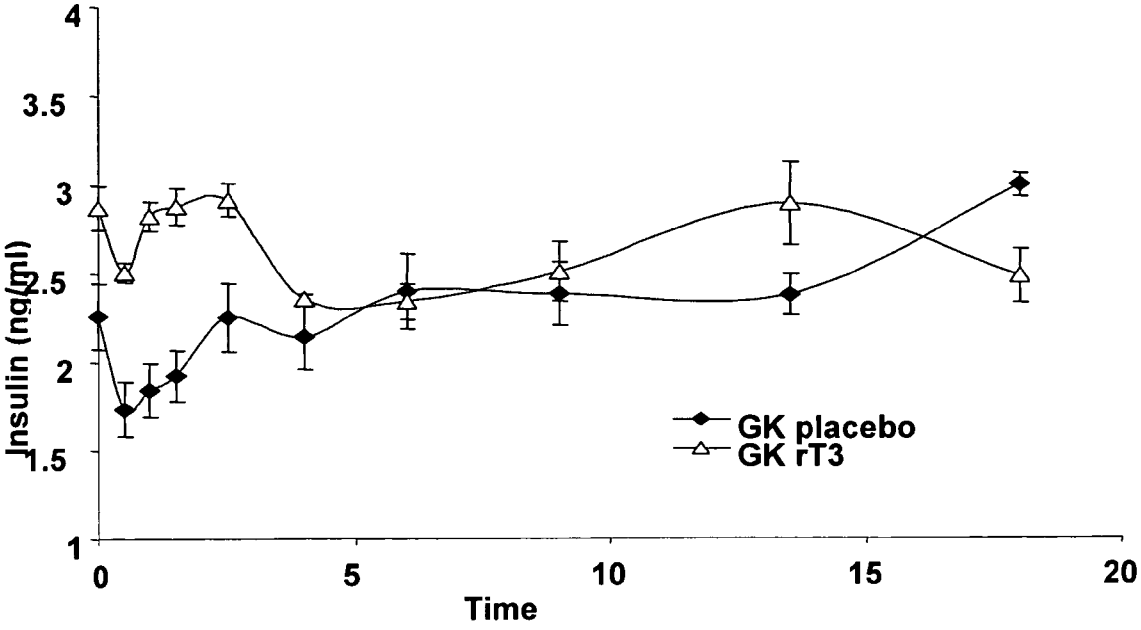

Figure 41

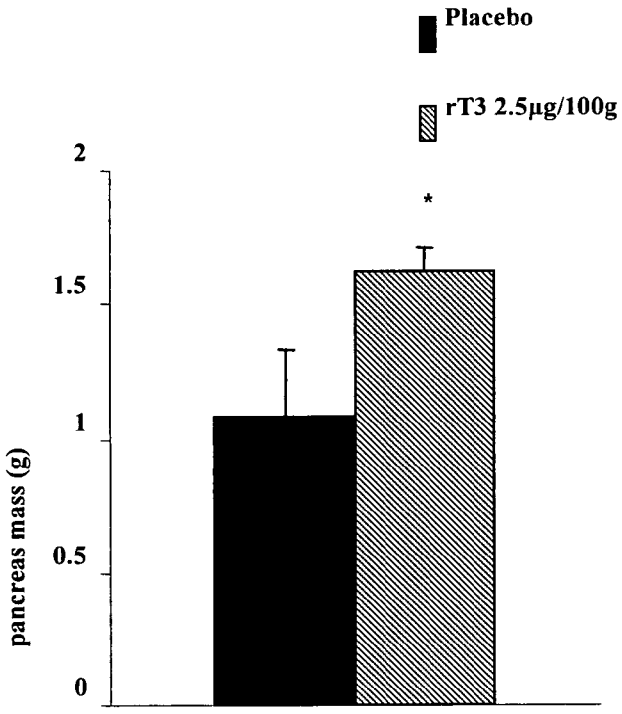

Figure 42

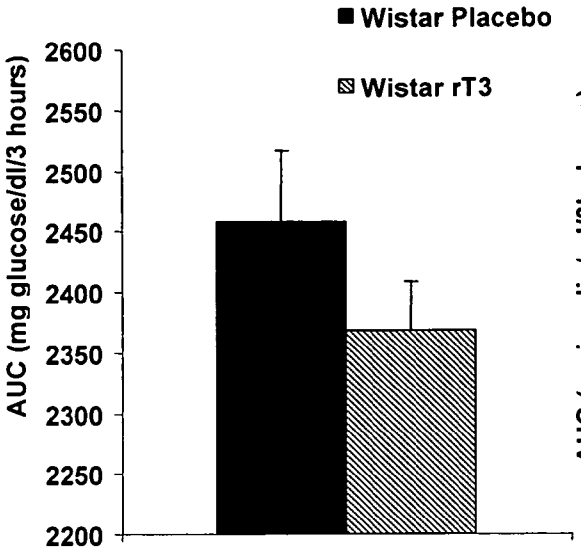

Figure 43

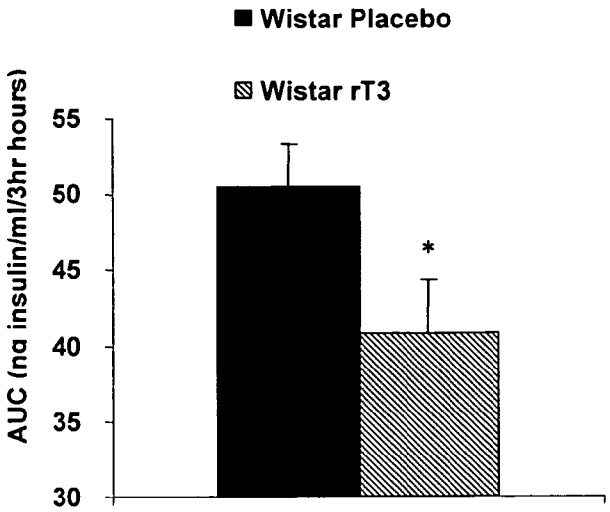

Figure 44

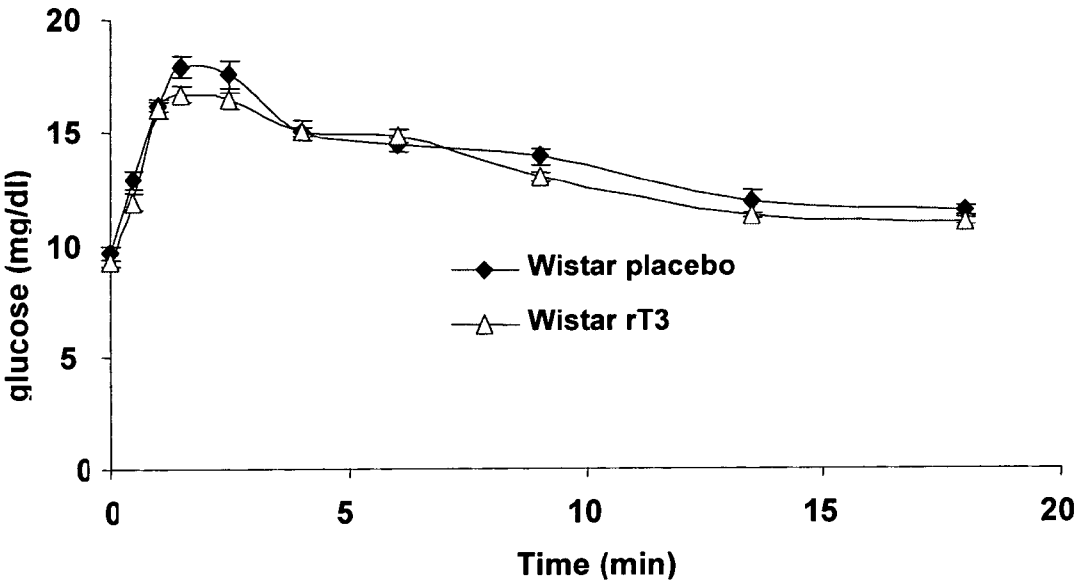

Figure 45

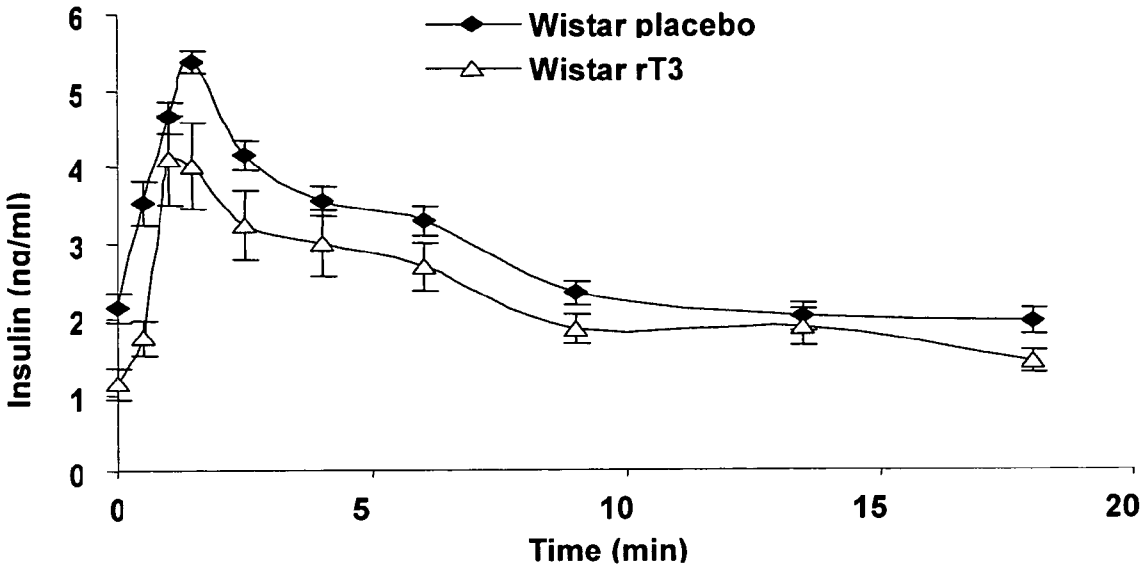

Figure 46

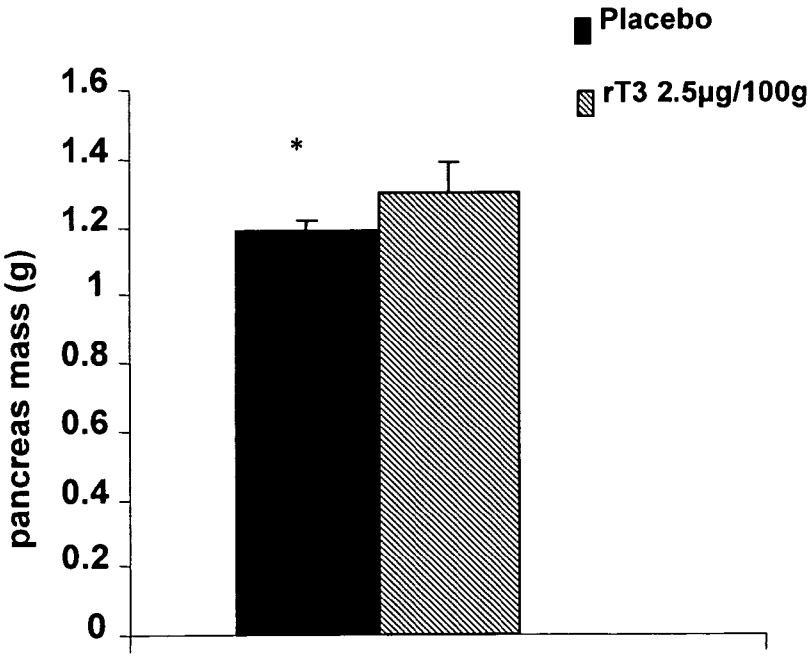

Figure 47

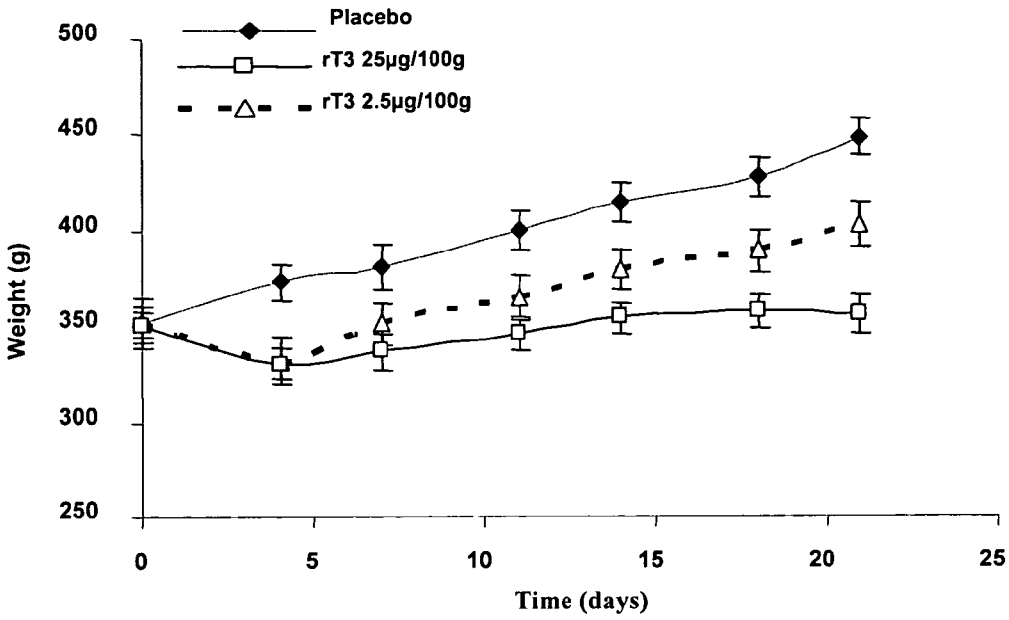

Figure 48

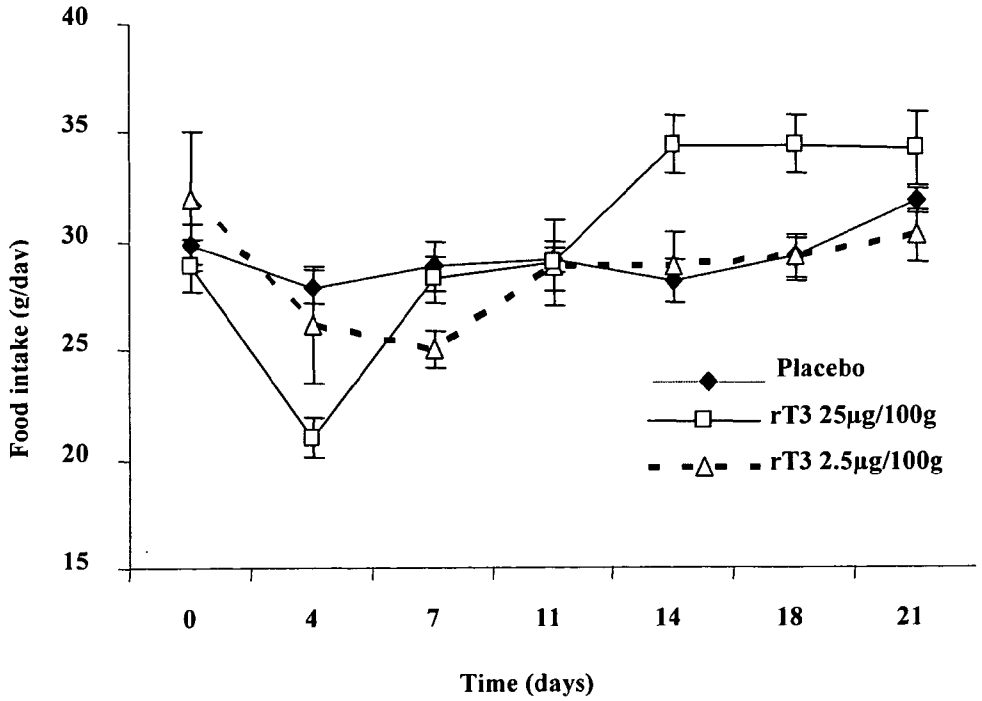

Figure 49

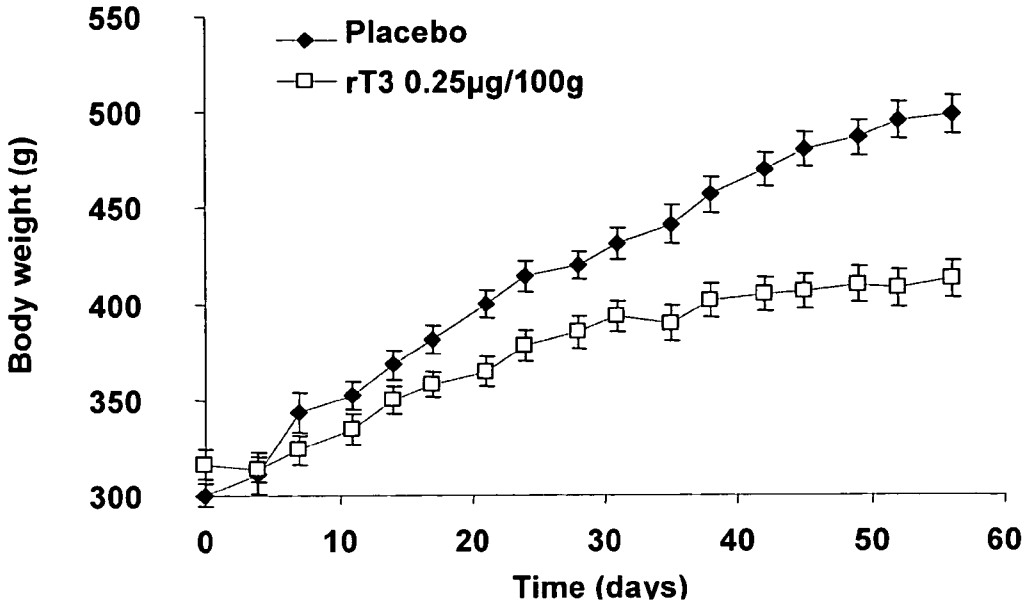
Placebo
rT3 0.25µg/100g
Body weight (g)
550
500
450
400
350
300
0
10
20
30
40
50
60
Time (days)

Figure 50

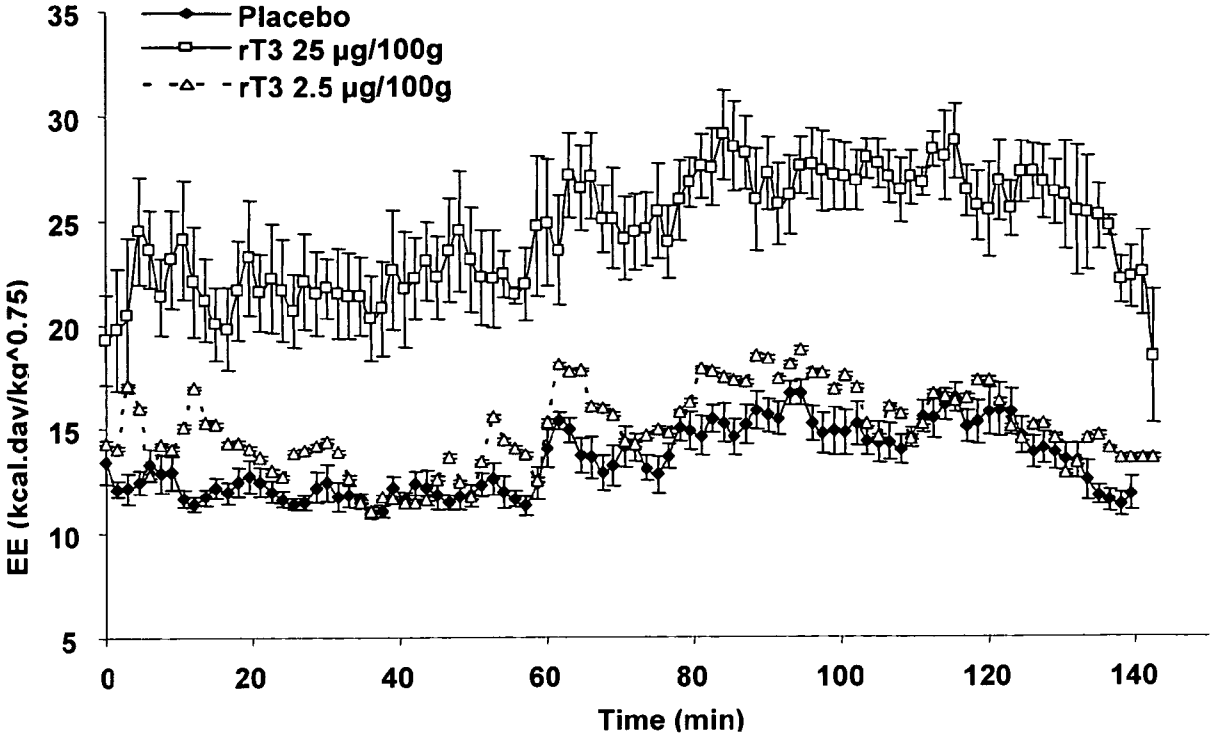

Figure 51

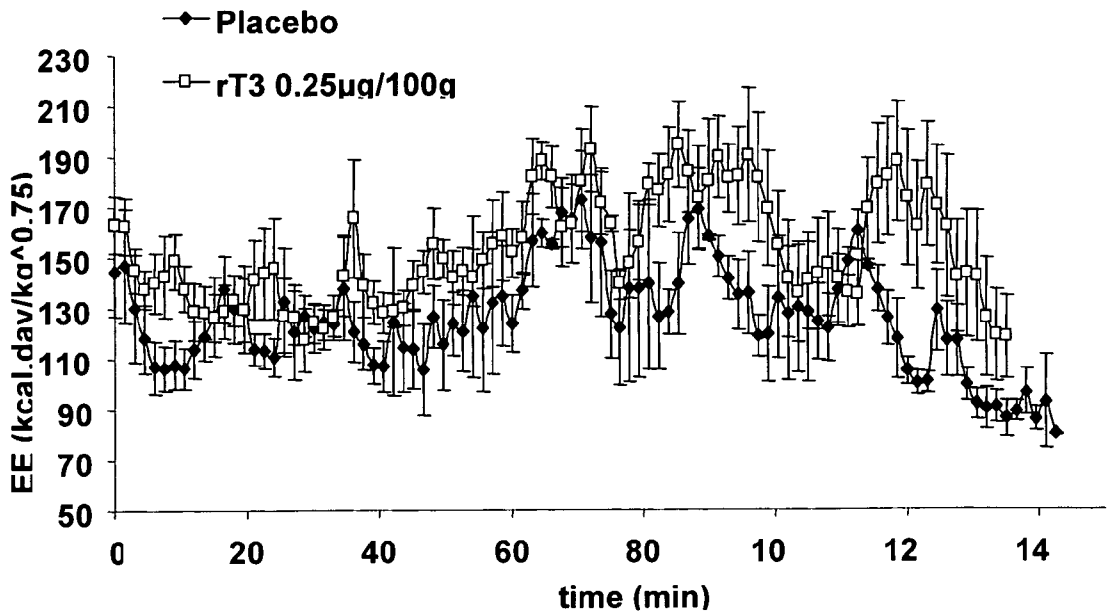

Figure 52

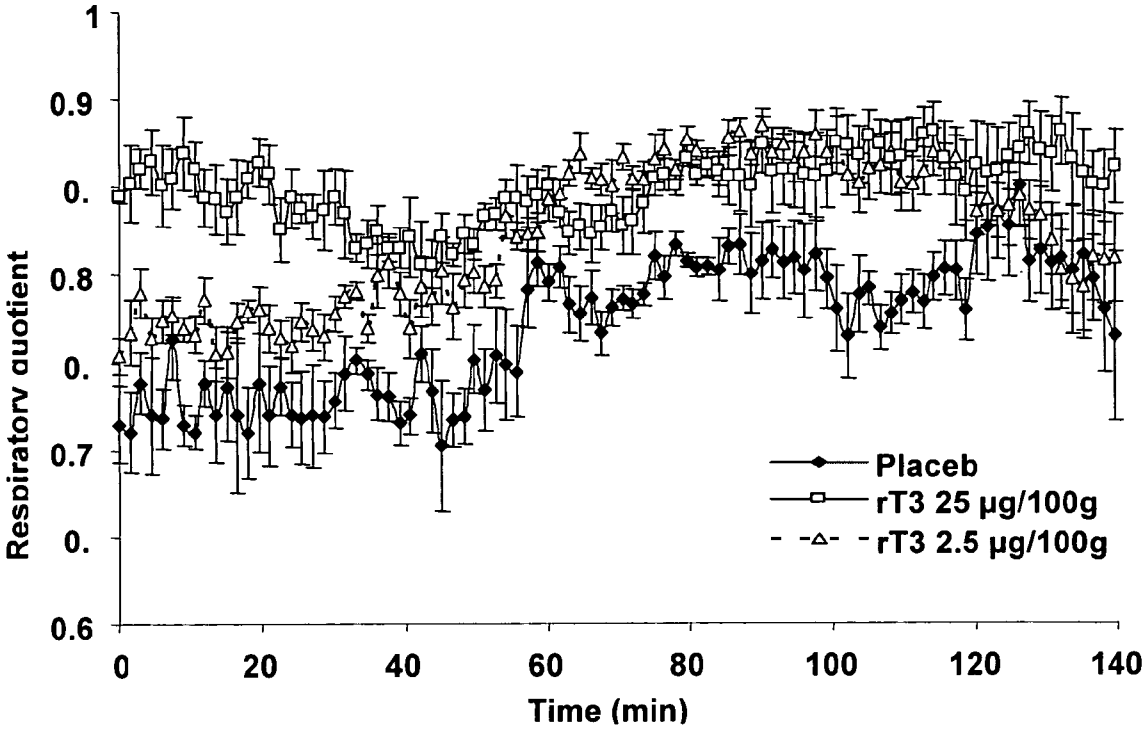

Figure 53

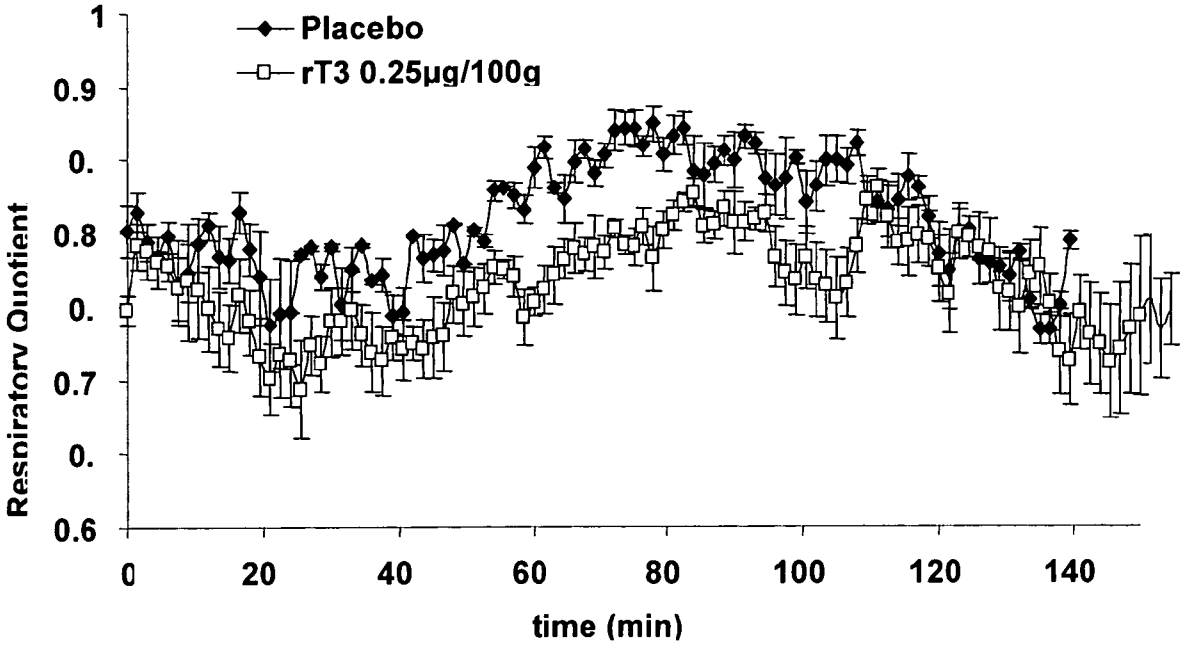

Figure 54

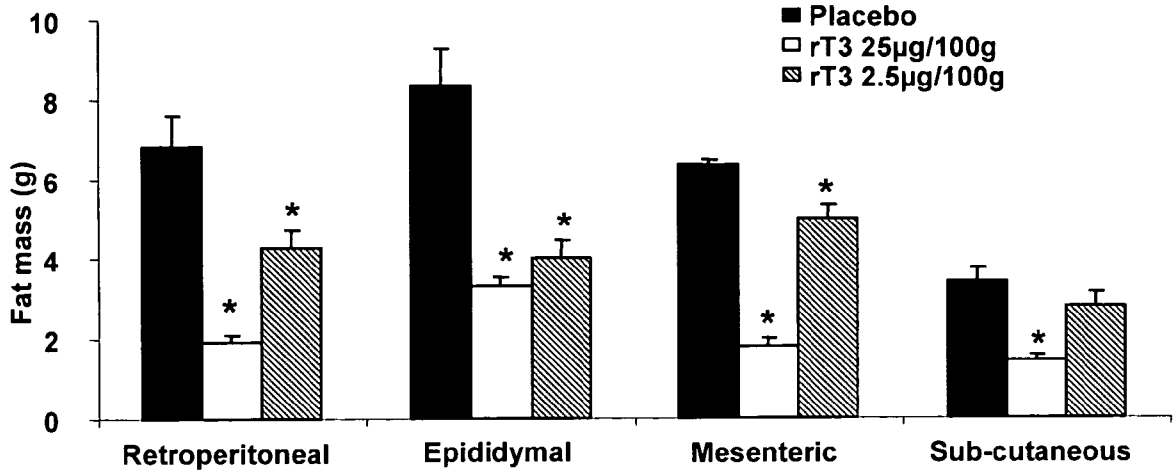

Figure 55

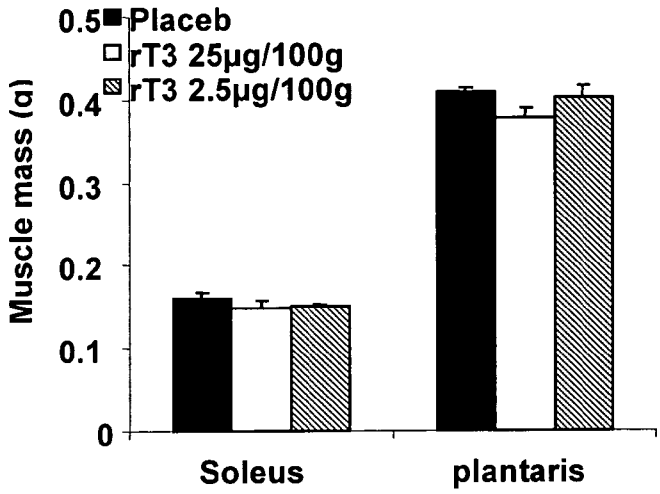

Figure 56

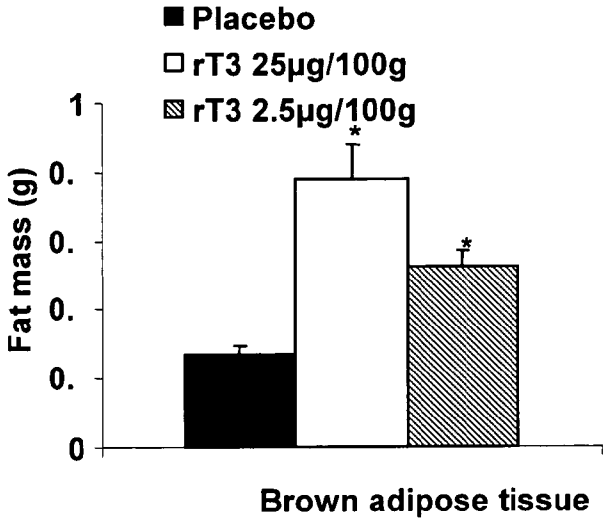

Figure 57

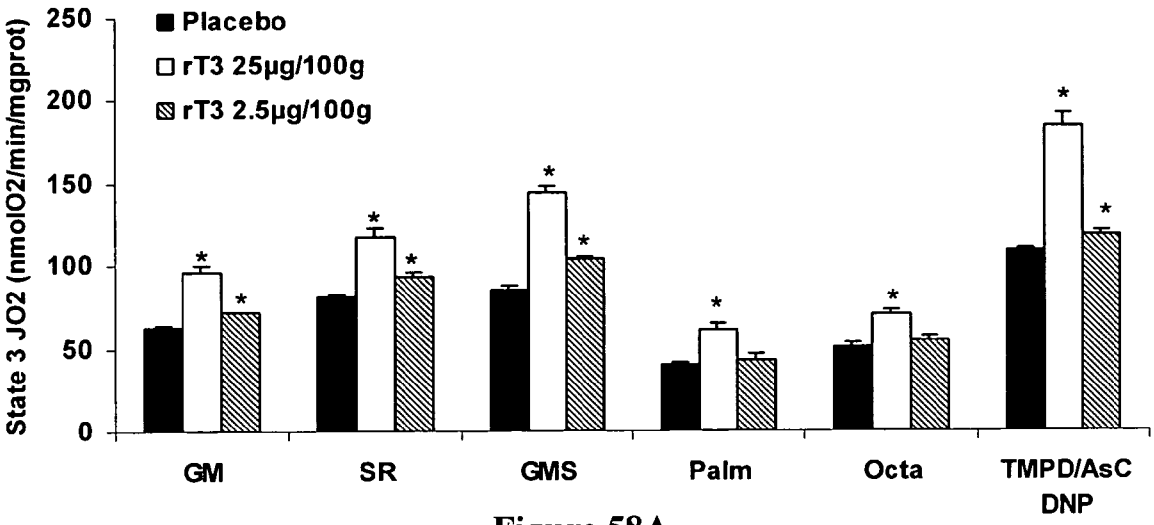

Figure 58A

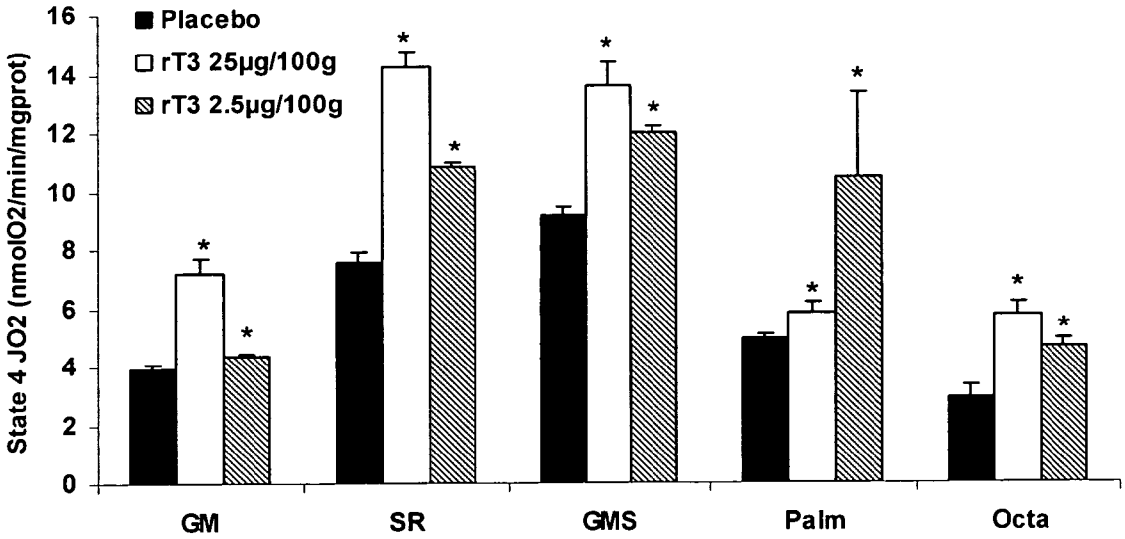

Figure 58B

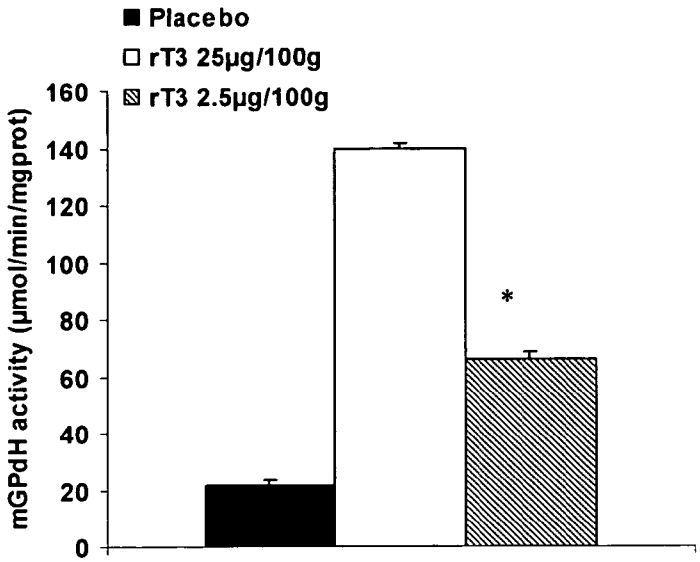
Placebo
rT3 25µg/100g
rT3 2.5µg/100g
mGPdH activity (µmol/min/mgprot)
160
140
120
100
80
60
40
20
0
*

Figure 59

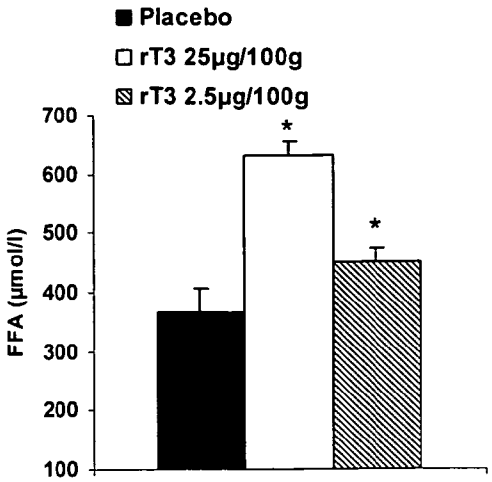

Figure 60A

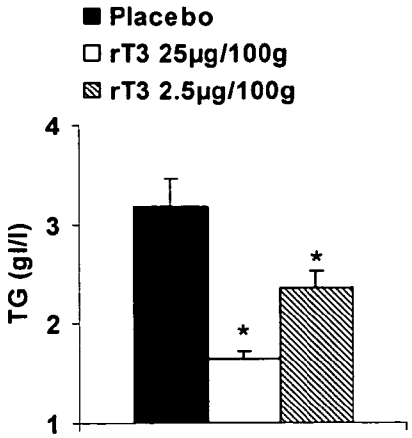

Figure 60B

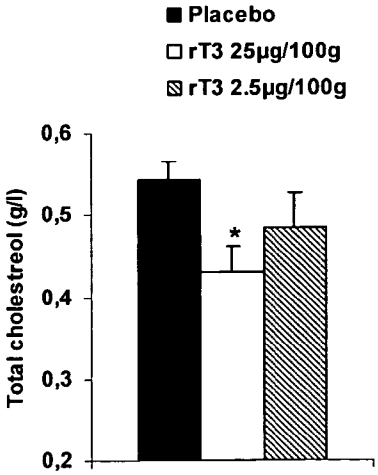

Figure 60C

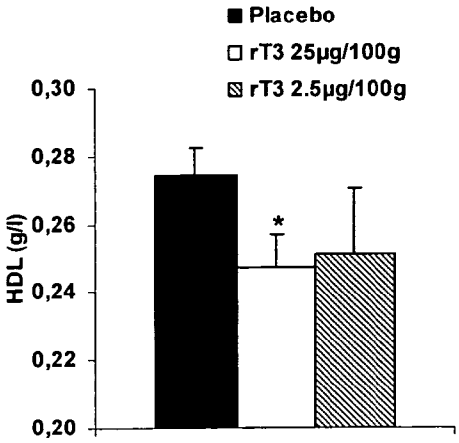

Figure 60D

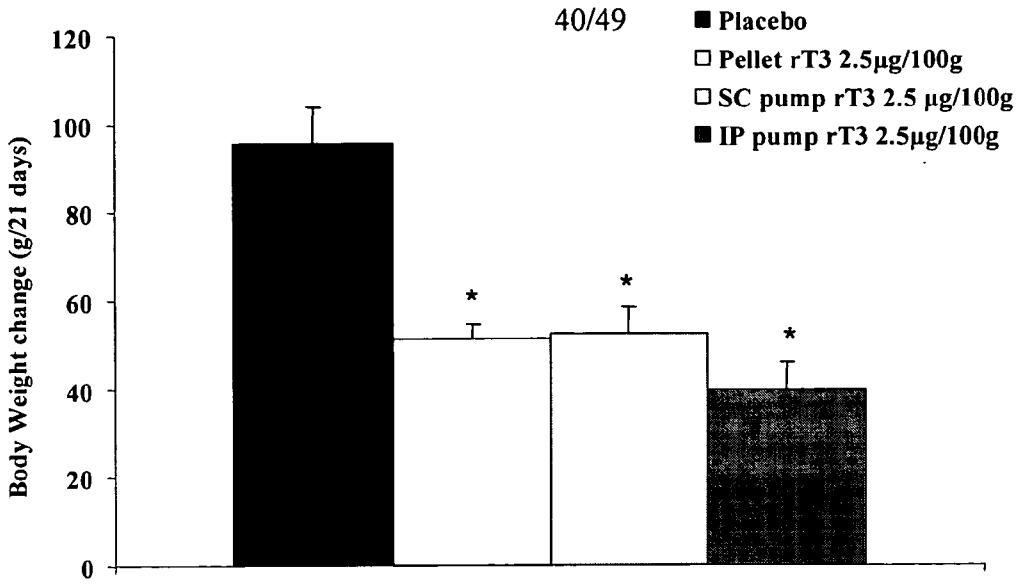

Figure 61

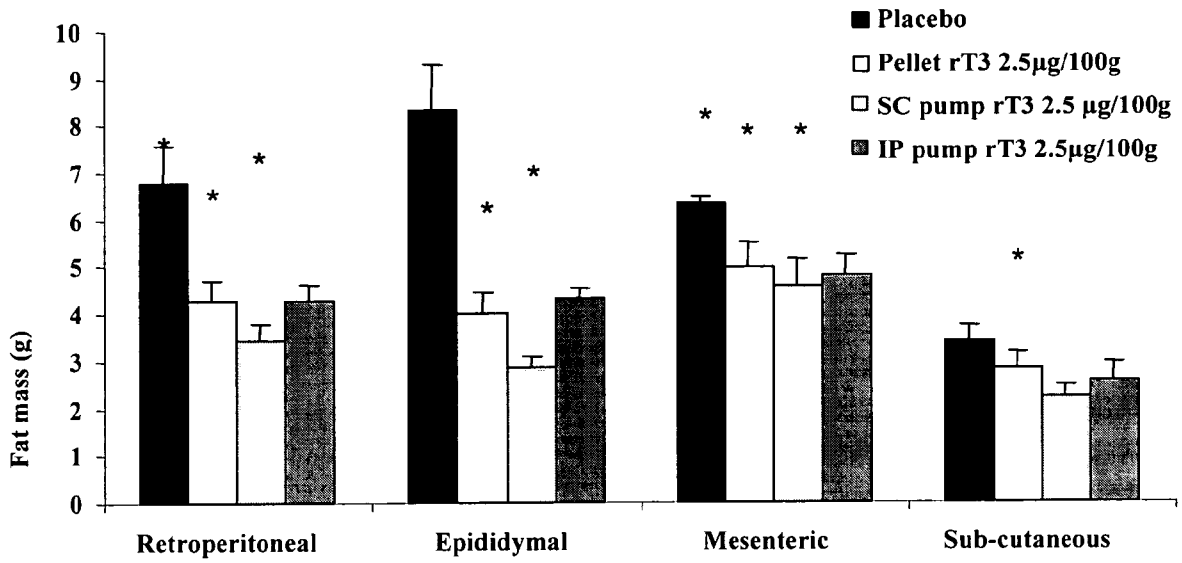

Figure 62

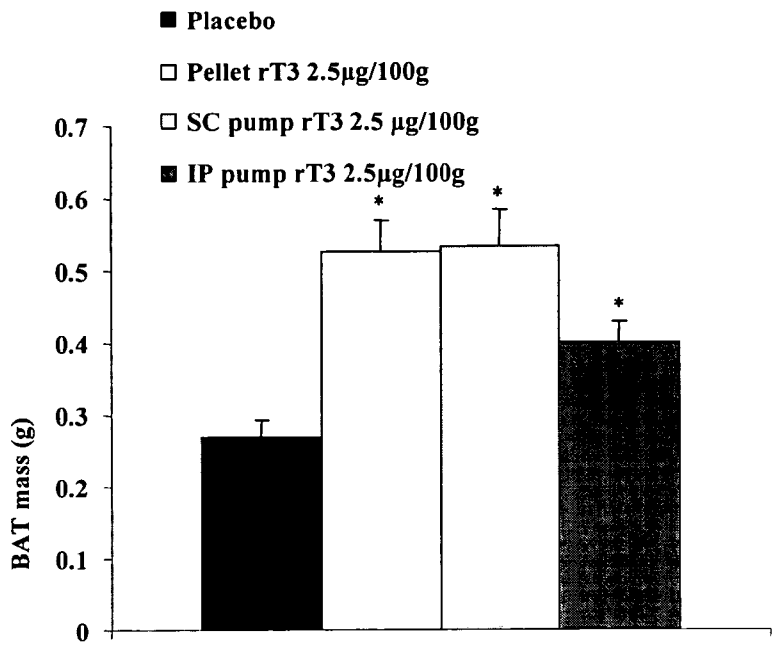

Figure 63

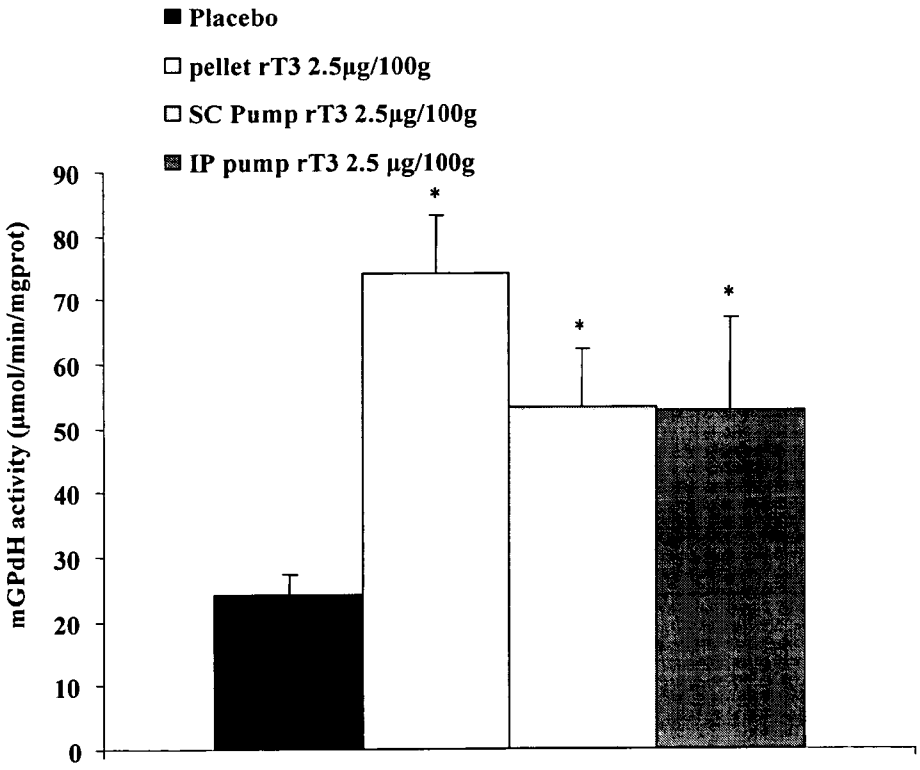

Figure 64

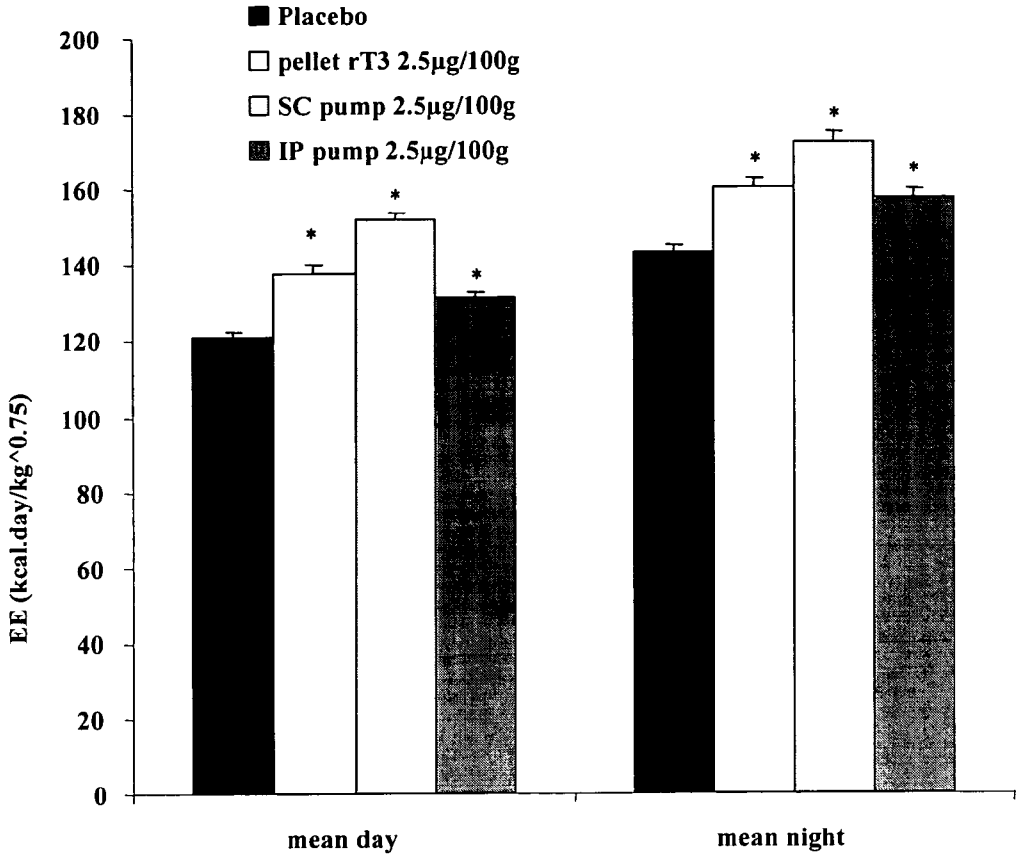

Figure 65

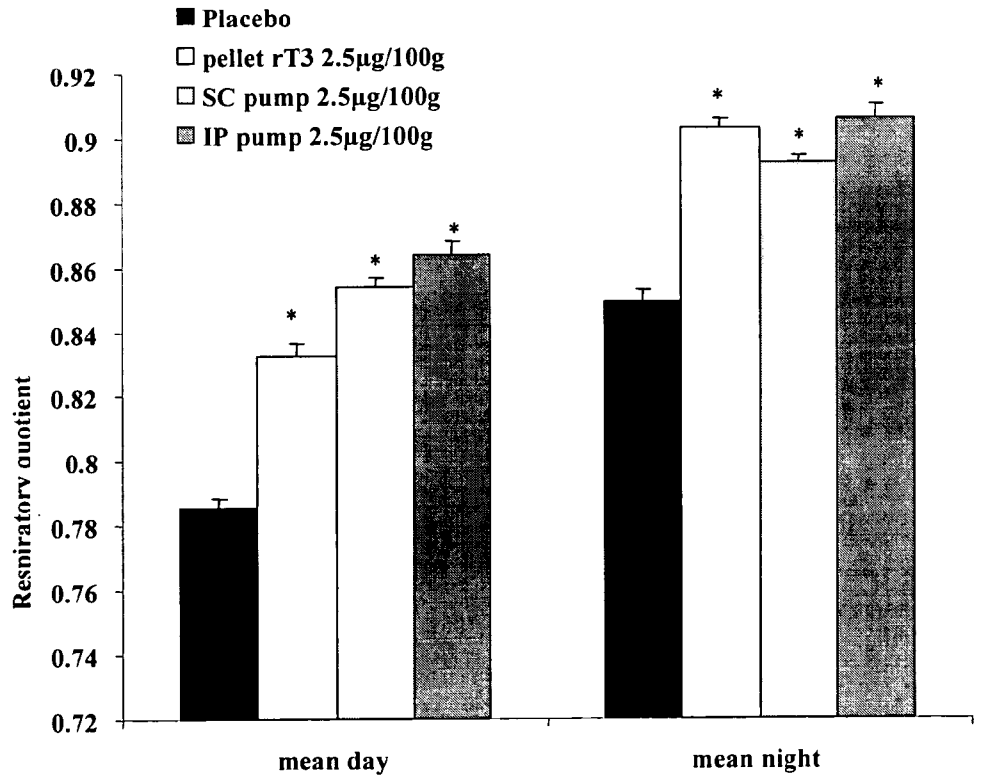

Figure 66

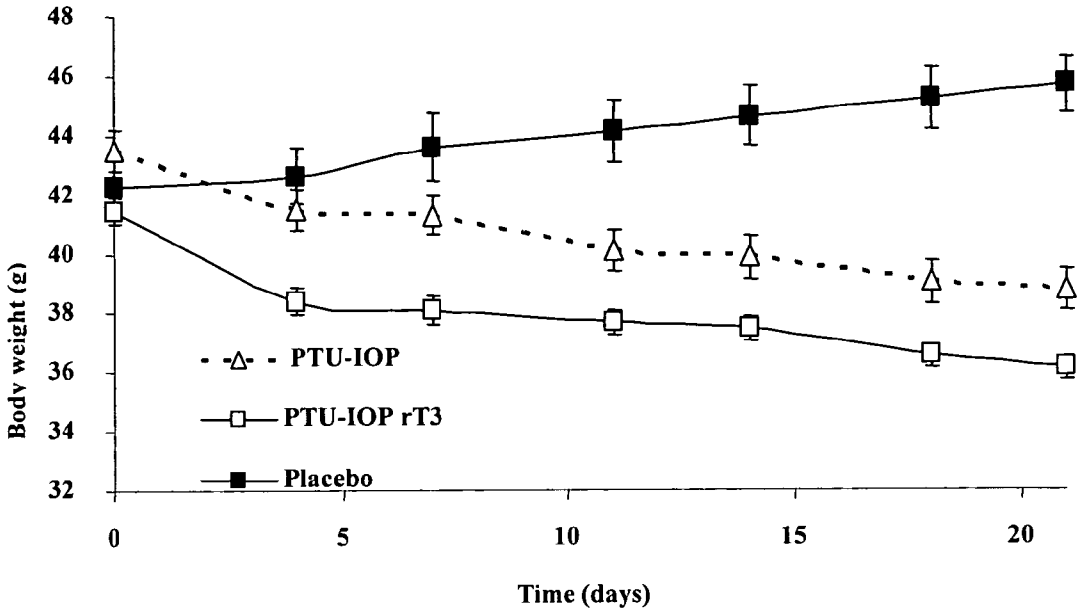

Figure 67

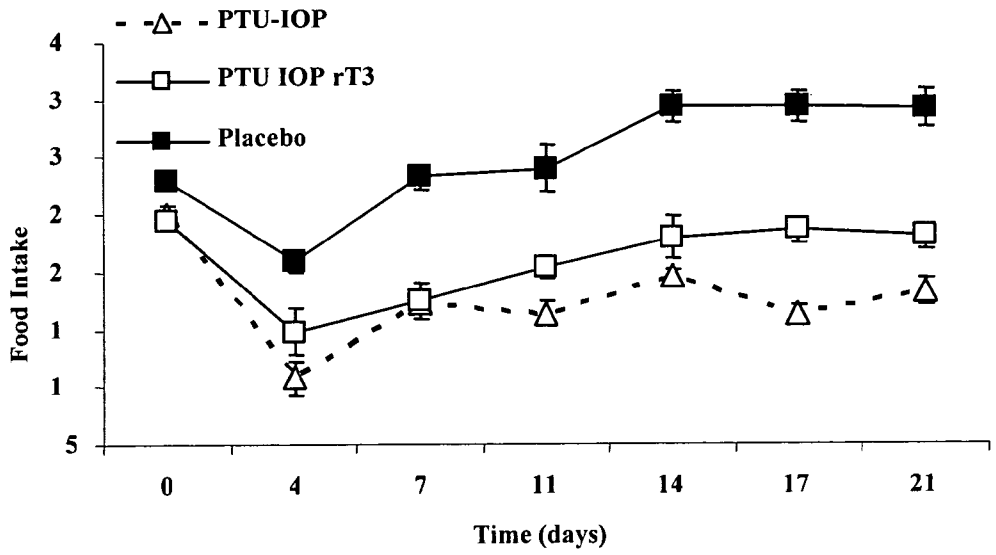

Figure 68

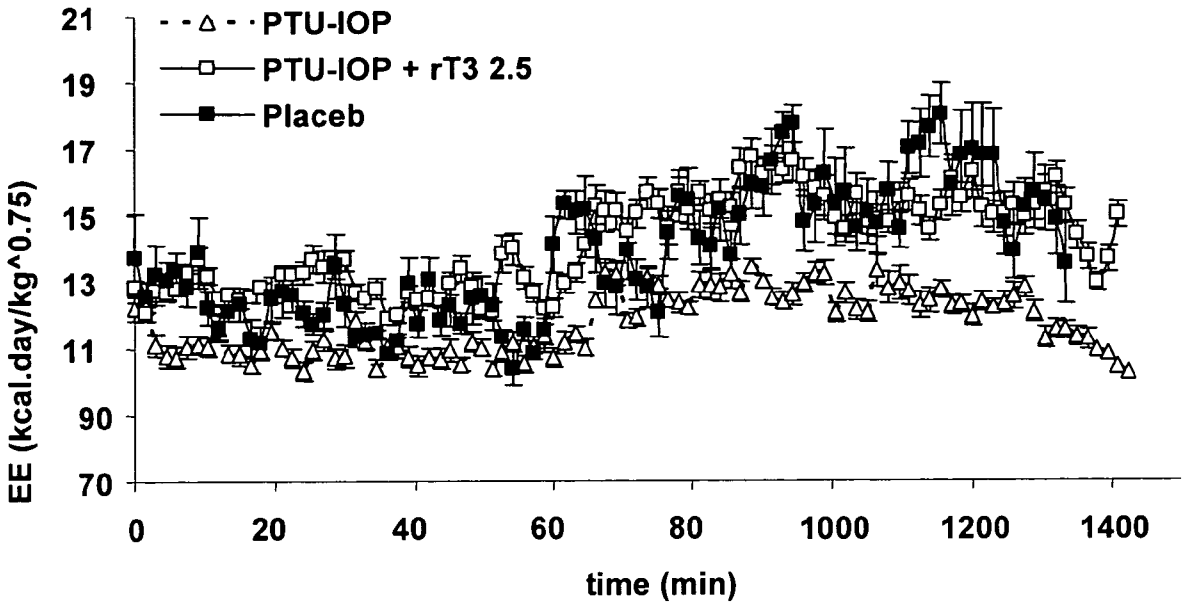

Figure 69

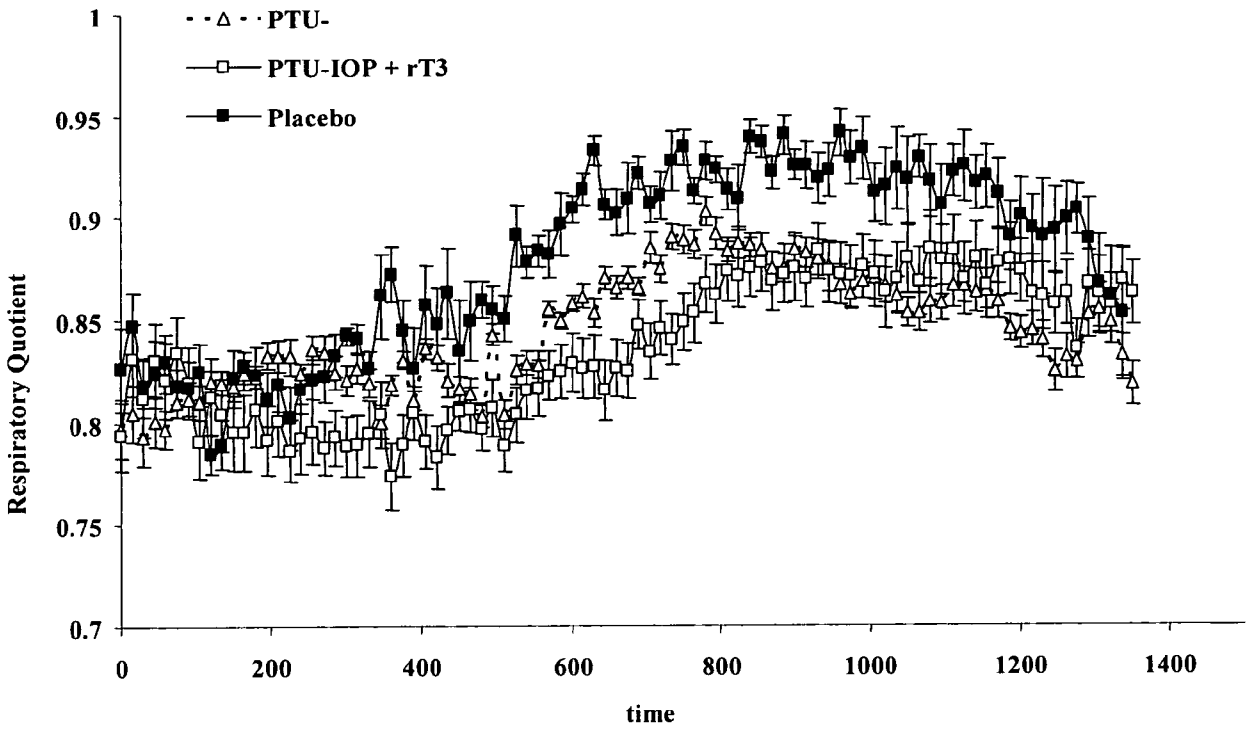

Figure 70

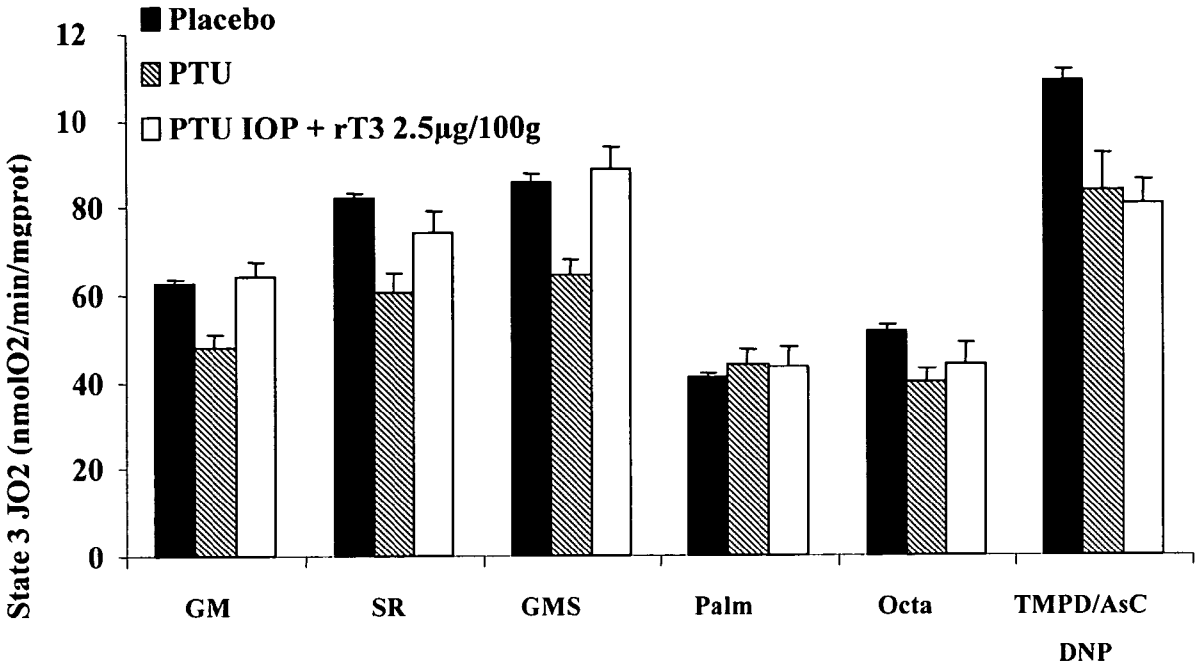

Figure 71

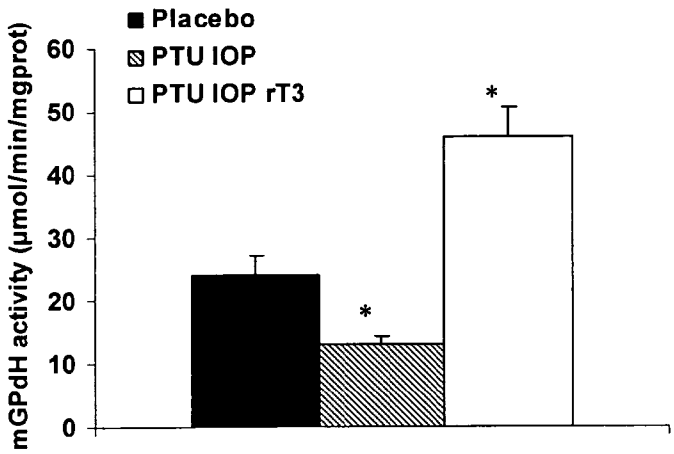

Figure 72

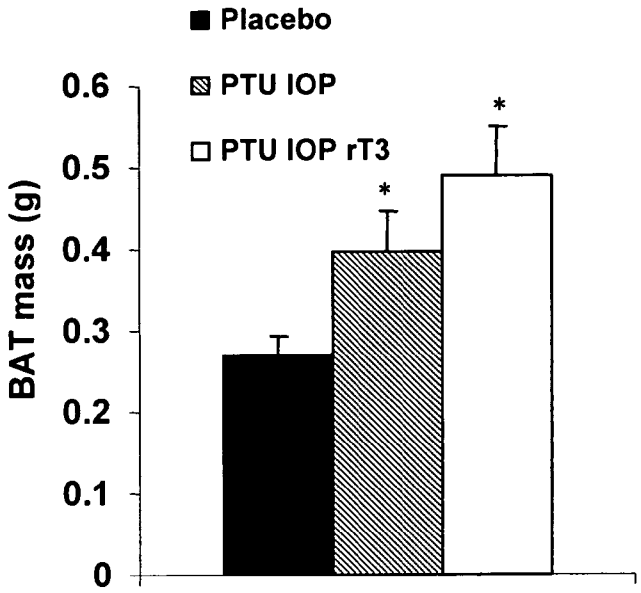

Figure 73

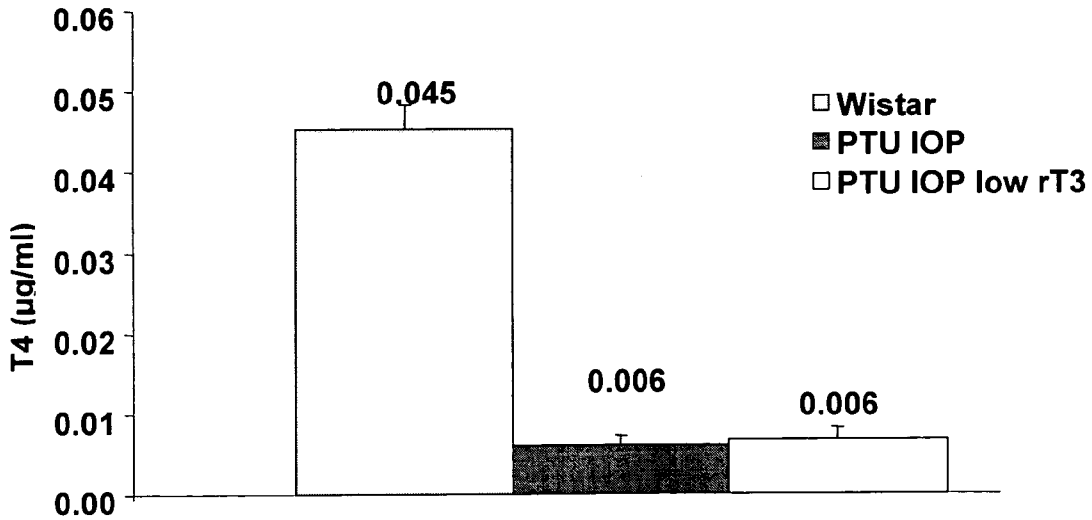

Figure 74

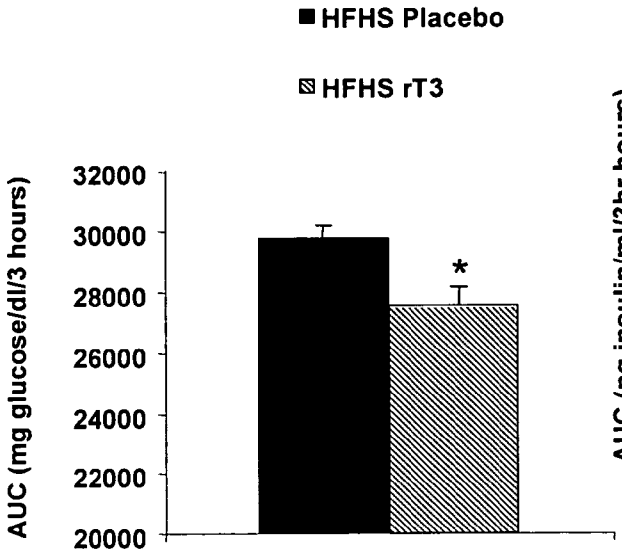

Figure 75

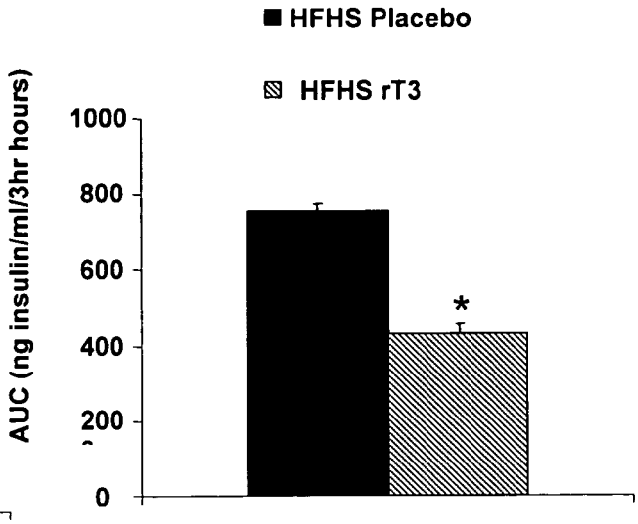

Figure 76

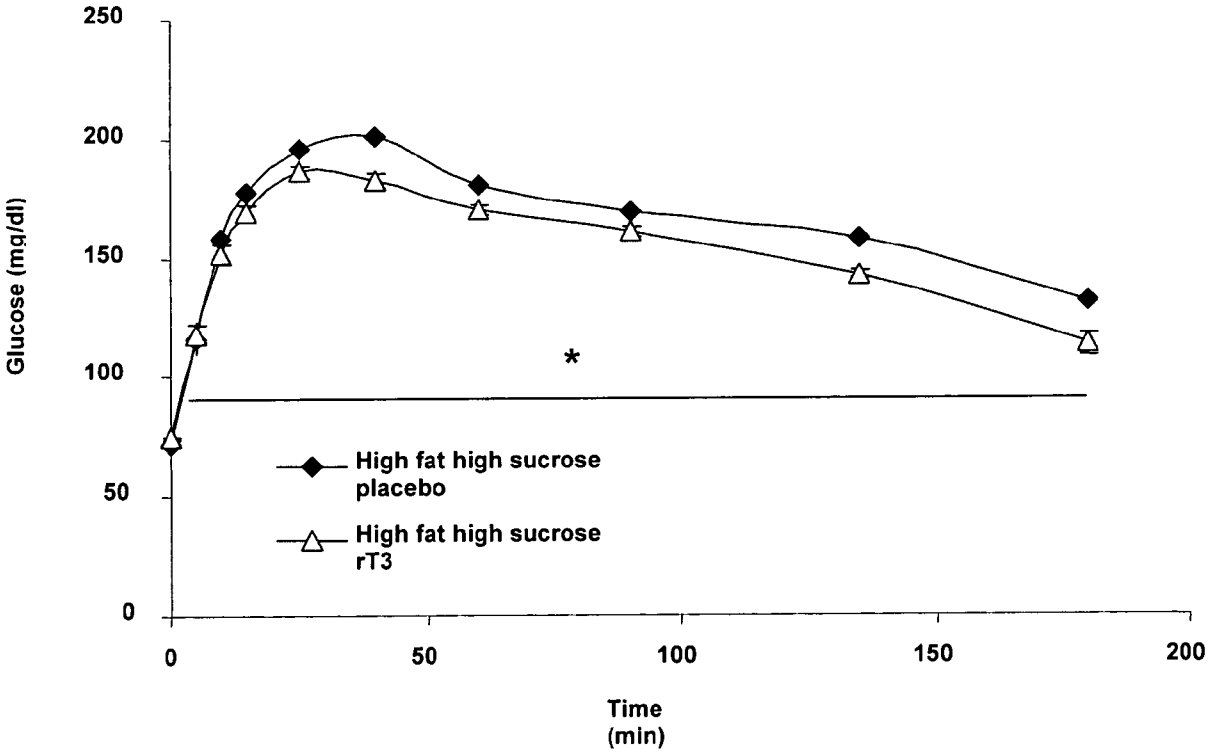

Figure 77

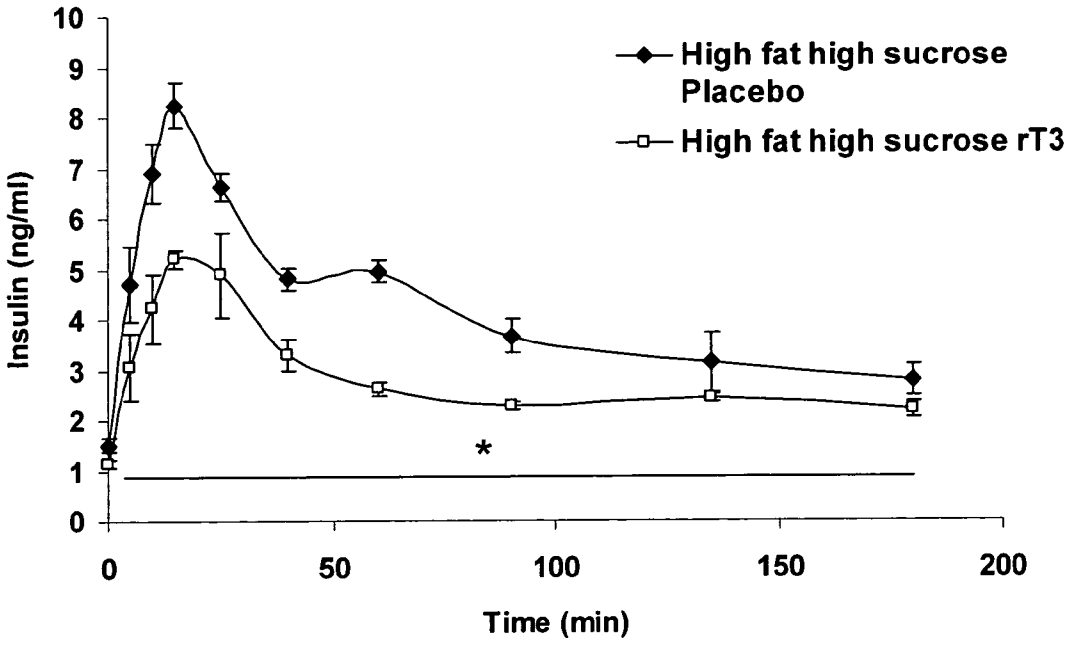

Figure 78

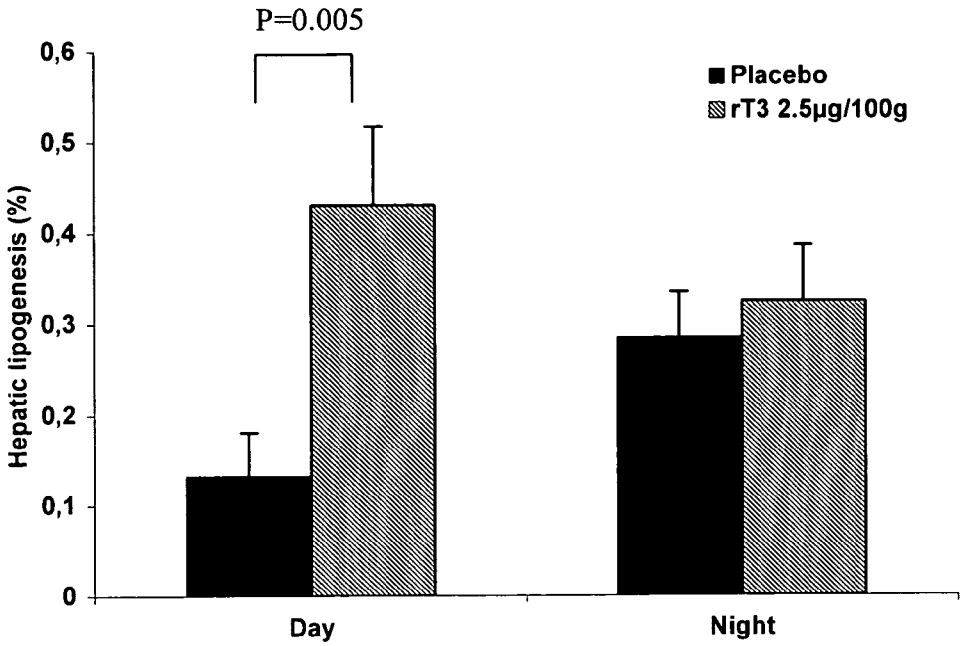
P=0.005
Placebo
rT3 2.5µg/100g
Hepatic lipogenesis (%)
0,6
0,5
0,4
0,3
0,2
0,1
0
Day
Night

Figure 79

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/056076

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61K31/198 A61P3/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61K A61P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, BIOSIS, EMBASE, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005/009433 A (GOGLIA FERNANDO [IT]; LANNI ANTONIA [IT]; LOMBARDI ASSUNTA [IT]; MOREN) 3 February 2005 (2005-02-03) claim 6 page 7, line 13 - line 14 page 8, line 11	1,3-6, 8-11
X	CETTOUR-ROSE P ET AL: "Inhibition of pituitary type 2 deiodinase by reverse triiodothyronine does not alter thyroxine-induced inhibition of thyrotropin secretion in hypothyroid rats" EUROPEAN JOURNAL OF ENDOCRINOLOGY, vol. 153, no. 3, September 2005 (2005-09), pages 429-434, XP002454758 ISSN: 0804-4643 page 153, left-hand column, last paragraph - right-hand column, paragraph 1	1-4,8-10

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 August 2008	21/08/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Loher, Florian

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2008/056076

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TIEN ERIC S ET AL: "The nuclear receptor constitutively active/androstane receptor regulates type 1 deiodinase and thyroid hormone activity in the regenerating mouse liver" JOURNAL OF PHARMACOLOGY AND EXPERIMENTAL THERAPEUTICS, vol. 320, no. 1, January 2007 (2007-01), pages 307-313 URL, XP009090654 ISSN: 0022-3565 page 308, right-hand column, paragraph 1	1-4,8-10

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2008/056076

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2005009433 A	03-02-2005	NONE	