ANTIOXIDANT AND VASCULAR EFFECTS OF GLICLAZIDE IN TYPE 2 DIABETIC RATS FED HIGH FAT DIET

CRISTINA M. SENA[1,2], TERESA LOURO[1,2], PAULO MATAFOME[1,2], ELSA NUNES[1,2], PEDRO MONTEIRO[3] AND RAQUEL SEIÇA[1,2]

[1] Institute of Physiology, Faculty of Medicine, University of Coimbra; [2] Center for Neurosciences and Cell Biology of Coimbra, University of Coimbra; [3] Basic Research Unit in Cardiology, Cardiology Department, Coimbra University Hospital and Medical School, Coimbra, Portugal

Corresponding address:

C. M Sena

Institute of Physiology, Sub-unidade 1, Pólo III

Faculty of Medicine, University of Coimbra

Azinhaga de Santa Comba, Celas

3000-504 Coimbra

Telephone: +351-239-480013

Fax: +351-239-480034

email: csena @ ci.uc.pt

Short title: Gliclazide improves endothelial function in diabetic rats

SUMMARY

Diabetes mellitus is characterized by oxidative stress, which in turn determines endothelial dysfunction. Gliclazide is a sulphonylurea antidiabetic drug with anti-oxidant effects due to its azabicyclo-octyl ring. It has been reported to potentially benefit the vasculature through improvements in plasma lipid levels and platelet function. We hypothesized that gliclazide has a beneficial effect on endothelial function in Goto-kakizaki rats (GK), an animal model of type 2 diabetes with dyslipidemia. GK diabetic rats fed with an atherogenic type diet (GKAD) were treated with gliclazide during 4 weeks (GKAD+G) after 3 months of high fat diet. We evaluated the influence of gliclazide on both metabolic and oxidative status and NO-mediated vasodilation. GKAD rats showed increased oxidative stress and impaired endothelial dependent vasodilation. GKAD+G showed increase sensitivity to NO-mediated vasodilation, a significant decrease in fasting glycemia and insulinemia, and a significant decrease in systemic oxidative stress.

In conclusion, our results suggest that gliclazide treatment improves NO-mediated vasodilation in diabetic GK rats with dyslipidemia probably due to its antioxidant effects, although we cannot rule out the substantial benefits due to a reduction in fasting blood glucose. The availability of a compound that simultaneously decreases hyperglycemia, hyperinsulinemia, and inhibits oxidative stress is a promising therapeutic candidate for the prevention of vascular complications of diabetes.

Key words: Endothelium; Nitric oxide; Diabetes mellitus; Gliclazide; Oxidative stress

INTRODUCTION

The increase in oxidative stress that is associated with the chronic hyperglycaemia of diabetes mellitus plays a key role in the genesis of endothelial dysfunction (Giugliano et al., 1996; Pennathur and Heinecke 2004). Agents with antioxidant properties improve the function of the vessels in animal models of diabetes (Da Ros et al., 2004; Hamilton et al 2007). We have recently reported that impaired endothelial dysfunction and increased oxidative stress was improved by α-lipoic acid, in old Goto-Kakizaki diabetic rats (Sena et al., 2007a).

Gliclazide is a second-generation sulfonylurea antihyperglyceamic agent (Campbell et al., 1991) that stimulates insulin secretion from pancreatic β cells by inhibiting ATP-dependent potassium channels. ATP-dependent potassium channels also mediate a variety of functions in heart and blood vessels (Nichols and Lederer, 1992), thus it is possible that sulfonylurea agents would have some effects on the vascular function aside from their effects on glycaemic control. In diabetic animal models, it has also been reported that gliclazide potentially benefits the vasculature through improvements in plasma lipids and in platelet function (Palmer and Brogden, 1993). Mechanisms may include the ability of the drug to increase tissue plasminogen activator, and its properties as a free radical scavenger. (Scott et al., 1991; Jennings et al., 1992; Desfaits et al., 1997; O'Brien et al, 2000). The aim of the present work was to address whether the gliclazide influenced endothelial dysfunction and oxidative stress in Goto-kakizaki diabetic rats fed with a high fat diet.

METHODS

Experimental animals

Wistar and Goto-Kakizaki rats were obtained from our local breeding colony (Animal Research Center Laboratory, University Hospital, Coimbra, Portugal). Animals were subjected to a constant daily cycle of 12 hours of light and 12 hours darkness and constant temperature (22 – 24 ºC) and humidity (50 – 60%), with free access to water and to normal or high-fat diet between 2 and 6 months of age [Special diet 0125 (Modified A04 from Charles River), SAFE, France].

Rats were divided in 4 experimental groups accordingly [Wistar nondiabetic rats (W, n=12), GK diabetic rats fed with a normal diet (GK control, n=16), GK diabetic rats fed with an AD diet (GKAD, n=15), and GK rats fed an AD diet treated with gliclazide (GKAD+G, n=14)]. Gliclazide 10 mg /Kg/day was administered orally during four weeks before sacrifice. The experimental protocol was approved by the local Institutional Animal Care and Use Committee.

Determination of metabolic and oxidative stress parameters

After a 15 h fast, animals were anesthetized with ketamine/chlorpromazine. Blood was taken by heart puncture for determination of lipids, lipid peroxides, free fatty acid levels and insulin. For glucose tolerance tests, rats were fasted overnight and were given an intraperitoneal injection of glucose (1.75 g kg^{-1} body weight) in phosphate buffered saline (PBS). Blood glucose was determined by sampling from the tail vein at 0, 30, 60, 90 and 120 min after injection by a glucose-oxidase method using a glucometer (Glucometer-Elite-Bayer, Portugal S.A.) and compatible reactive test strips. Fasting plasma lipids (total and HDL cholesterol, triglycerides and phospholipids) and plasma insulin levels were quantified using commercially available kits and by an in-house enzyme-linked

immunosorbent assay (Seiça *et al*., 2004, Sena et al., 2007b), respectively. Plasma free fatty acids (FFA) levels were evaluated using enzymatic assay kits (Roche Applied Science, Portugal). Rats were placed in metabolic cages for 24 h and urine collected. Urinary 8-hydroxydeoxyguanosine (8-OHdG), and plasma carbonyl protein concentration were measured using ELISA kits (OXIS health Products, Portland, OR, USA, Cayman Chemical Company, USA).

Isometric tension studies

Aorta were rapidly excised and freed of connective tissue. The aorta was divided into two segments (4-mm width). Ring segments were mounted between stainless steel triangles into individual organ chambers filled with oxygenated (95% O_2, 5% CO_2) Krebs-Henseleit buffer (37 °C, pH 7.4) (composition in mmol l^{-1}: NaCl 119; KCl 4.7; $CaCl_2$ 1.6; $MgSO_4$ 1.2; $NaHCO_3$ 25; KH_2PO_4 1.2; Glucose 11.0). Indomethacin in a concentration of 10 µmol l^{-1} was present in all the experiments to inhibit prostaglandin synthesis. Aortic rings were subject to a resting tension of 1.5 g. After equilibration for 60 min all vessels were preconstricted with 0.3 µM phenylephrine. Ligand stimulated receptor-mediated NO bioavailability was assessed by a dose-dependent relaxation to acetylcholine (ACh, 10^{-8} to 10^{-3} M), whereas sodium nitroprusside (SNP, 10^{-8} to 10^{-3} M) was used as an endothelium-independent agonist. Relaxation responses to ACh and SNP were expressed as percentage of relaxation from a submaximal phenylephrine-induced constriction (10^{-7} M). A cumulative dose-efficacy curve was determined. Regression analysis using three data points along the linear section of the concentration–response curve was applied to generate an equation from which the EC_{50} values were determined (Sena et al., 2007a).

Statistical analysis

All data were analysed by standard computer programs (GraphPad Prism PC Software version 3.0, ANOVA) and are expressed as mean ± SEM. Significant differences were evaluated using either the *t*-test or ANOVA. $P < 0.05$ was considered significant. Dose response curves were fitted by nonlinear regression with simplex algorithm. Relaxation responses were given as the percentage of phenylephrine-preconstriction. Comparisons of dose–response curves were evaluated by 2-way ANOVA for repeated measures.

RESULTS

Blood chemistries and body weight

Diabetic GK rats fed with a normal chow diet were hyperglycaemic and hyperinsulinemic compared to Wistar rats. GK rats were normolipidemic and their body weight was decreased when compared with Wistar rats. (table 1).

After four months of high fat diet feeding, GK diabetic rats showed a significant increase in body weight, fasting glycemia, total and non-HDL-cholesterol, triglycerides and FFA levels when compared with GK rats receiving a standard diet (table 1). Treatment of the animals with 10 mg/kg gliclazide in drinking water significantly decreased fasting glycemia and insulinemia, total and non-HDL-cholesterol and FFA levels. The treatment did not modify body weight, triglyceride and 2 h after load glucose levels (table 1). Food consumption and water intake did not significantly change over the experimental period between the different groups studied (data not shown).

Oxidative stress biomarkers

Urinary levels of 8-OHdG were significantly higher in GK rats, when compared to age-matched Wistar rats (Fig 1A) while plasma levels of protein carbonyl compounds were not

statistically different between the two groups. Feeding AD diet for 4 months to GK rats significantly increased protein carbonyl compounds levels by 62 % (Fig 1A and B) and did not changed the levels of 8-OHdG. Supplementation with gliclazide significantly reduced these oxidative stress parameters (Fig. 1A and B).

ACh- and NO-induced relaxation in rat aortic segments

The addition of ACh or NO to vessels previously contracted with phenylephrine caused a concentration-dependent relaxation (Fig 2 A, B). In GK rats endothelium-mediated vascular relaxation by ACh of aorta arterial rings that were previously contracted with phenylephrine was impaired compared with age-matched Wistar rats. Indeed, maximal endothelium-mediated relaxation of phenylephrine-precontracted rings in response to ACh was declined by 23% and the EC_{50} value of endothelium-independent relaxation to SNP was significantly increased (Fig. 2A, B). The AD diet further impaired vascular relaxation in response to both ACh and SNP in GK rats. Gliclazide treatment improved endothelium-dependent vascular relaxation during the AD diet. Indeed, when ACh-induced relaxation was observed in aortic segments from GKAD+G a significant increase in sensitivity to ACh was observed without major changes in maximum relaxation (Fig. 2, table 2, $P<0.001$). Endothelium-denuded rings from all groups showed no relaxation to ACh (data not shown). The addition of gliclazide (10 μmol/l) in vitro to aorta from GKAD rats had no significant effect on relaxation in response to acetylcholine (10^{-9}-10^{-3} mol/l, Fig. 3).

The EC_{50} values for ACh- and NO-evoked relaxation in aortic segments from W and GK diabetic rats groups are shown in table 2. The EC_{50} for ACh in the GKAD group was significantly increased ($p < 0.001$ vs. untreated diabetic rats). The sensitivity of the

response evoked by ACh or NO in aortic segments from GKAD+G was significantly higher than in untreated diabetic animals (table 2, EC_{50} values significantly decreased, $P<0.001$). Preincubation of the arterial rings with the NOS inhibitor N^{ω}-nitro-L-arginine methyl ester HCl (L-NAME) and the cyclooxygenase inhibitor indomethacin caused residual relaxations of 15 % in response to ACh in GK rats and Wistar rats (data not shown). When compared to responses from acetylcholine in the presence of L-NAME, the relaxations were not significantly different between the groups studied.

DISCUSSION

Several studies have demonstrated impairment of endothelium-dependent relaxation associated with diabetes (Fortes et al., 1983; Durante et al., 1988). In GK diabetic rats, the reduction in endothelium-dependent vasodilation has been observed both in experiments with isolated aortic rings (Sena et al., 2007a), and mesenteric microvessels (Cheng et al. 2001), indicating that diabetic endothelial dysfunction affects both conductance and resistance vessels. In the present work, the results obtained in aortic rings showed impairment in endothelium-mediated responses over the 6 month period for the evolution of diabetes in the GK rat model. High fat diet significantly impaired endothelial dysfunction and this was improved by treatment with gliclazide for 4 weeks.

It is widely accepted that increased oxidative stress occurs in diabetes (Baynes, 1991; Ceriello et al., 1993), as seen by the presence of peroxidation products (Young et al., 1995) or enhanced generation of superoxide anions (Chang et al., 1993). Studies from several laboratories indicate that antioxidants improve NO mediated endothelium-dependent relaxation in vessels from diabetic animals (Diederich et al., 1994; Rodríguez-Mañas et al., 1998, Sena et al., 1997a). The main objective of this work was to analyze whether gliclazide ameliorated normal endothelial function in this rodent model of type 2 diabetes

with dyslipidemia. Gliclazide has metabolic effects since this drug stimulates insulin secretion while also reducing insulin resistance. Therefore, our observed effects can be attributable both to direct vascular actions of gliclazide and improved insulin secretion/function. Oxidative stress and biochemical parameters of the diabetic rats were compared. When diabetic rats were treated with 10 mg/kg gliclazide, a reduction of fasting glycaemia and lipid profile to control diabetic levels was observed; while there were no changes in body weight and two-hour postprandial blood glucose. Furthermore, FFAs, 8-OHdG and protein carbonyl groups were significantly reduced to the same levels as non diabetic Wistar rats after treatment with gliclazide.

It is interesting to note that with isolated vessels from GKAD rats, the addition of 10 μM gliclazide caused no effect. This lack of effect *in vitro* suggests that gliclazide a direct and immediate free radical scavenging effect *in vivo* (Scott et al., 1991) is unlikely to account for the improvement in diabetic endothelial cell dysfunction. The effect of gliclazide in vivo could be due to a chronic increase of endothelium-derived vasodilators or alternatively, a decrease in vasoconstrictors. In addition, there is a reduction in free radical generation or an increase in free radical scavenging. In diabetic patients treated with gliclazide, plasma reduced thiols were increased, lipid peroxides were decreased, and erythrocyte superoxide dismutase activity was elevated (Jennings et al., 1992). Our results are also consistent with the idea that gliclazide improves diabetic endothelial dysfunction by an antioxidant mechanism (Jennings et al., 1992; Desfaits et al., 1997; O'Brien & Luo, 1997). However, we can not rule out that the metabolic effects of gliclazide may also contribute to these observations. It is possible that the effect of gliclazide was at least partly mediated via improved insulin action as evidenced by the observed decrease in blood

glucose levels and insulin resistance. In agreement with our results of improved endothelial function, Pagano et al. (1998) reported that treatment with gliclazide enhances ACh-induced relaxation in isolated aortic segments of alloxan-induced diabetic rabbits.

In addition, improvement in endothelial function has been reported in streptozotocin-induced diabetic rats receiving gliclazide (Vallejo et al., 2000a). Others have previously reported that gliclazide has antioxidant properties in vitro, perhaps reversing the endothelial dysfunction caused by highly glycosylated oxyhemoglobin in human mesenteric microvessels (Vallejo et al., 2000b).

The major limitation of this study is that gliclazide decreased fasting blood glucose thus we cannot rule out that gliclazide due to the improvement in fasting glucose levels leads to improvement of oxidative stress and endothelial dysfunction.

A main conclusion of the present study is that gliclazide ameliorates the endothelial dysfunction associated with diabetic rats fed with a high fat diet. These beneficial effects on the vasculature may be related to the metabolic actions of the drug, to improvements in plasma lipids and fasting glycemia and to its antioxidant properties. Indeed, this work shows that gliclazide is able to reduce fasting hyperglycaemia and systemic oxidative stress, thus contributing to increase the sensitivity to NO-mediated vasodilation in diabetic GK rats with dyslipidemia.

ACKNOWLEDGMENTS

We wish to thank Laboratory of Experimental research for animal care. This work was supported by grants from Faculty of Medicine of Coimbra and III.

REFERENCES

BAYNES JW: Role of oxidative stress in development of complications in diabetes. *Diabetes* **40**: 405-412, 1991.

CAMPBELL DB, LAVIELLE R, NATHAN C: The mode of action and clinical pharmacology of gliclazide: a review. *Diabetes Res Clin Pract* **14**: S21-S36, 1991.

CERIELLO A, QUATRARO A, GIUGLIANO D: Diabetes mellitus and hypertension: the possible role of hyperglycaemia through oxidative stress. *Diabetologia* **36**: 265-266, 1993.

CHANG KC, CHUNG SY, CHONG WS, SUH JS, KIM SH, NOH HW, SEONG BW, KO HJ, CHUN KW: Possible superoxide radical-induced alteration of vascular reactivity in aortas from streptozotocin- treated rats. *J Pharmacol Exp Ther* **266**: 992-1000, 1993.

CHENG ZJ, VASKONEN T, TIKKANEN I, NURMINEN K, RUSKOAHO H, VAPAATALO H, MULLER D, PARK JK, LUFT FC, MERVAALA EM: Endothelial dysfunction and salt-sensitive hypertension in spontaneously diabetic Goto-Kakizaki rats. *Hypertension* **37**: 433-439, 2001.

DA ROS R, ASSALONI R, CERIELLO A: Antioxidant therapy in diabetic complications: what is new? *Curr Vasc Pharmacol* **2**: 335-341, 2004.

DESFAITS AC, SERRI O, RENIER G: Gliclazide decreases cell mediated low-density lipoprotein (LDL) oxidation and reduces monocyte adhesion to endothelial cells induced by oxidatively modified LDL. *Metabolism* **46**: 1150-1156, 1997.

DIEDERICH D, SKOPEC J, DIEDERICH A, DAI FX: Endothelial dysfunction in mesenteric resistance arteries of diabetic rats: role of free radicals. *Am J Physiol* **266**: H1153-H1161, 1994.

DURANTE W, SEN AK, SUNAHARA FA: Impairment of endothelium- dependent relaxation in aortae from spontaneously diabetic rats. *Br J Pharmacol* **94**: 463-468, 1988.

FORTES ZB, LEME JG, SCIVOLETTO R: Vascular reactivity in diabetes mellitus: role of the endothelial cells. *Br J Pharmacol* **79**: 771-781, 1983.

GIUGLIANO D, CERIELLO A, PAOLISSO G: Oxidative stress and diabetic vascular complications. *Diabetes Care* **19**: 257-267, 1996.

HAMILTON SJ, CHEW GT, WATTS GF: Therapeutic regulation of endothelial dysfunction in type 2 diabetes mellitus. *Diabetes Vasc Dis Res* **4**: 89-102, 2007.

JENNINGS PE, SCOTT NA, SANIABADI AR, BELCH JJF: Effects of gliclazide on platelet reactivity and free radicals in type II diabetic patients: clinical assessments. *Metabolism* **41**: 36-39, 1992.

NICHOLS CG, LEDERER WJ: Adenosine triphosphate sensitive potassium channels in the cardiovascular system. *Am J Physiol* **261**: H1675-H1686, 1992.

O'BRIEN RC, LUO M, BALAZS N, MERCURI J: In vitro and in vivo antioxidant properties of gliclazide. J Diab Complications **14**, 201– 206, 2000.

O'BRIEN RC, LUO M: The effects of gliclazide and other sulfonylureas on low-density lipoprotein oxidation in vitro. *Metabolism* **46**: 22-25, 1997.

PAGANO PJ, GRISWOLD MC, RAVEL D, COHEN RA: Vascular action of the hypoglycaemic agent gliclazide in diabetic rabbits. *Diabetologia* **41**: 9-15, 1998.

PALMER KJ, BROGDEN RN: Gliclazide. An update of its pharmacological properties and therapeutic efficacy in non-insulin dependent diabetes mellitus. *Drugs* **46**: 92-125, 1993.

PENNATHUR S, HEINECKE JW: Mechanisms of oxidative stress in diabetes: implications for the pathogenesis of vascular disease and antioxidant therapy. *Front Biosci* **9**:565-574, 2004.

RODRÍGUEZ-MAÑAS L, ANGULO J, PEIRÓ C, LLERGO JL, SÁNCHEZ-FERRER P, LÓPEZ-DÓRIGA P, SÁNCHEZ-FERRER CF: Endothelial dysfunction and metabolic control in streptozotocin-induced diabetic rats. *Br J Pharmacol* **123**: 1495-1502, 1998.

SCOTT NA, JENNINGS PE, BROWN J, BELCH JJF: Gliclazide: a free radical scavenger. *Eur J Pharmacol* **208**: 175-177, 1991.

SEIÇA RM, SUZUKI KI, SANTOS RM, ROSÁRIO LM: Deficiência primária da secreção de insulina de ilhéus isolados de ratos Goto-Kakizaki, um modelo animal de diabetes tipo 2 não obesa. *Acta Med Port* **17**: 42-48, 2004.

SENA CM, BAROSA C, NUNES E, SEICA R, JONES JG: Sources of endogenous glucose production in the Goto-Kakizaki diabetic rat. *Diabetes Metab* **33**: 296-302, 2007b.

SENA CM, NUNES E, LOURO T, PROENÇA T, FERNANDES R, BOARDER MR, SEIÇA RM: Effects of alpha-lipoic acid on endothelial function in aged diabetic and high-fat fed rats. *Br J Pharmacol* doi: **10.1038**/sj.bjp.0707474, 2007a.

VALLEJO S, ANGULO J, PEIRÓ C, NAVADO J, SÁNCHEZ-FERRER A, PETIDIER R, SÁNCHEZ-FERRER CF, RODRÍGUEZ-MAÑAS L: Highly glycated oxyhaemoglobin impairs nitric oxide relaxations in human mesenteric microvessels. *Diabetologia* **43**: 83-90, 2000b.

VALLEJO S, ANGULO J, PEIRÓ C, SÁNCHEZ-FERRER A, CERCAS E, LLERGO JL, NEVADO J, SÁNCHEZ-FERRER CF, RODRÍGUEZ-MAÑAS L: Prevention of

endothelial dysfunction in streptozotocin-induced diabetic rats by gliclazide treatment. *J Diabetes Complications* **14**: 224-233, 2000a.

YOUNG IS, TATE S, LIGHTBODY JH, MCMASTER D, TRIMBLE ER: The effects of desferoxamine and ascorbate on oxidative stress in the streptozotocin diabetic rat. *Free Radical Biol Med* **18**: 833-840, 1995.

Table 1. Influence of gliclazide on body weight, blood glucose, fasting insulin, lipids and free fatty acids (FFAs) in GKAD rats.

	Wistar	GK	GKAD	GKAD+G
Body weight (g)	403.9 ± 6.9	312.7 ± 5.8***	387.3 ± 4.3§§§	395.3 ± 5.2§§§
FBG (mmol/l)	3.64 ± 0.11	5.17 ± 0.14***	7.78 ± 0.16*** §§§	5.45 ± 0.13*** ^{ϕϕϕ}
BG 2 h after load (mmol/l)	4.65 ± 0.15	16.62 ± 0.4***	16.83 ± 0.83***	17.61 ± 1.57***
Insulin (pmol/l)	119.8 ± 30.1	265.9 ± 18.6***	189.9 ± 19.1* §	105.0 ± 19.2§§§ ^{ϕ}
Cholesterol (mmol/l)	1.82 ± 0.04	2.3 ± 0.05	2.6 ± 0.14*** §§§	2.4 ± 0.06*** ^{ϕ}
Non-HDL cholesterol (mmol/l)	0.7 ± 0.04	0.71 ± 0.07	1.29 ± 0.13*** §§§	1.18 ± 0.05*** ^{ϕ}
Triglycerides (mmol/l)	1.23 ± 0.09	1.69 ± 0.13*	2.52 ± 0.23*** §§§	2.24 ± 0.08*** §§
FFAs (mmol/l)	0.71 ± 0.08	0.79 ± 0.04	1.13 ± 0.04*** §§	0.66 ± 0.09^{ϕϕϕ}

Values are mean ± SEM. * P<0.05, *** P<0.001 *vs* Wistar rats; § P<0.05, §§ P<0.01, §§§ P<0.001 *vs* GK rats; ϕ P<0.05, ϕϕϕ P<0.001 *vs* GKAD rats.
FBG – fasting blood glucose; BG – blood glucose.

Table 2. Maximal relaxation responses (%) and -log EC_{50} in isolated aorta arteries of 6-months-old variously treated spontaneously diabetic Goto-kakizaki (GK) rats and age-matched non-diabetic Wistar rats.

	Wistar	GK	GKAD	GKAD+G
Acetylcholine				
EC_{50}	6.88 ± 0.04	6.9 ± 0.09	5.02 ± 0.14$^{***\ §§§}$	6.69 ± 0.16^{ϕϕϕ}
Maximal relaxation (%)	99.1 ± 0.9	72.9 ± 1.7***	60.2 ± 2.1$^{***\ §§}$	55.4 ± 5.4$^{***\ §§§}$
Sodium nitroprusside				
EC_{50}	6.47 ± 0.04	6.2 ± 0.04***	5.6 ± 0.04$^{***\ §§§}$	6.67 ± 0.03$^{***\ §§§\ ϕϕϕ}$
Maximal relaxation (%)	99.3 ± 1.3	99.9 ± 1.3	99.1 ± 1.6	99.5 ± 1.1

Values are mean ± SEM. EC_{50} values are presented as the negative logarithm ($-\log_{10} EC_{50}$) of concentration of the agonist.

*** P<0.001 *vs* Wistar rats; §§ P<0.01, §§§ P<0.001 *vs* GK rats; ϕϕϕ P<0.001 *vs* GKAD rats.

Figure Legends

Figure 1 Reduction of oxidative stress parameters by gliclazide. Panels show urinary 8-OHdG (A) and plasma protein-bound carbonyls (B) levels in Wistar, GK control and GK rats fed with high-fat diet with (GKAD+G) or without gliclazide (GKAD). Results are mean±SEM. In A through B ***P<0.001 vs Wistar group; §P<0.05, §§§ P<0.001 vs GK group; ϕ P<0.05 vs GKAD group.

Figure 2 Effects of diabetes, high fat diet and gliclazide treatment on vasodilatory responses to acetylcholine (A) and sodium nitroprusside (B) of phenylephrine-contracted rat thoracic aortic rings. Vasorelaxation was measured using an isometric force displacement transducer. Data are expressed as mean±SEM. In A through B *** P<0.001 *vs* Wistar group; §§P<0.01, §§§ P<0.001 *vs* GK group; ϕϕ P<0.01, ϕϕϕ P<0.001 *vs* GKAD group.

Figure 3 Acetylcholine-induced relaxations of phenylephrine-contracted rat thoracic aortic rings from diabetic GK rats fed with high fat diet (GKAD). In vitro addition of gliclazide (10 μM) to rings from GKAD rats had no significant effect.

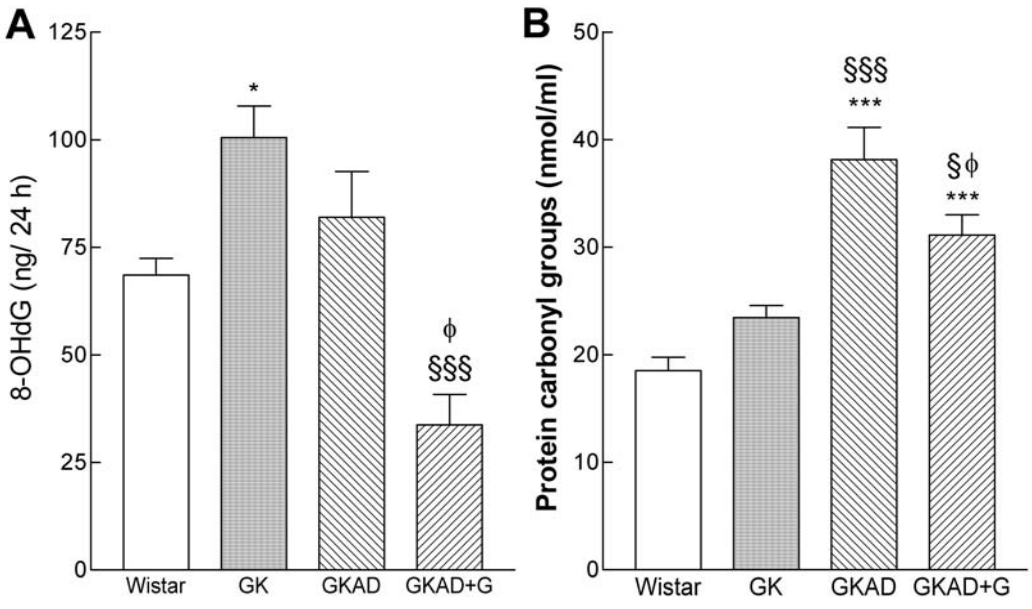
A
8-OHdG (ng/ 24 h)
125
100
75
50
25
0
*
ϕ
§§§
Wistar
GK
GKAD
GKAD+G
B
Protein carbonyl groups (nmol/ml)
50
40
30
20
10
0
§§§
***
§ϕ
***
Wistar
GK
GKAD
GKAD+G

Figure 1

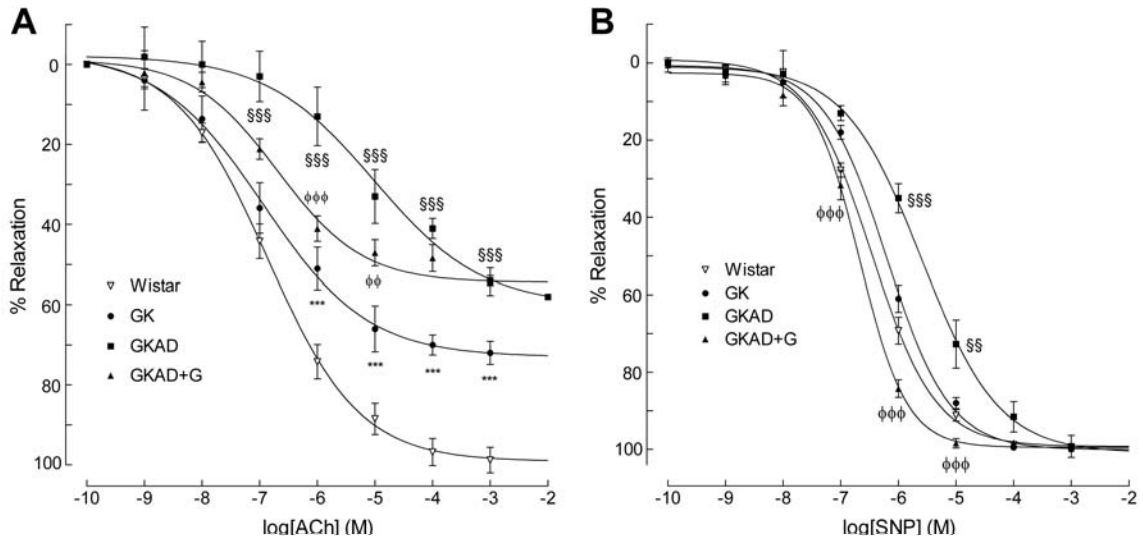
A
% Relaxation
0
20
40
60
80
100
-10
-9
-8
-7
-6
-5
-4
-3
-2
log[ACh] (M)
Wistar
GK
GKAD
GKAD+G
§§§
§§§
§§§
§§§
§§§
ϕϕϕ
ϕϕ
***
***
***
***
B
% Relaxation
0
20
40
60
80
100
-10
-9
-8
-7
-6
-5
-4
-3
-2
log[SNP] (M)
Wistar
GK
GKAD
GKAD+G
§§§
§§
ϕϕϕ
ϕϕϕ
ϕϕϕ

Figure 2

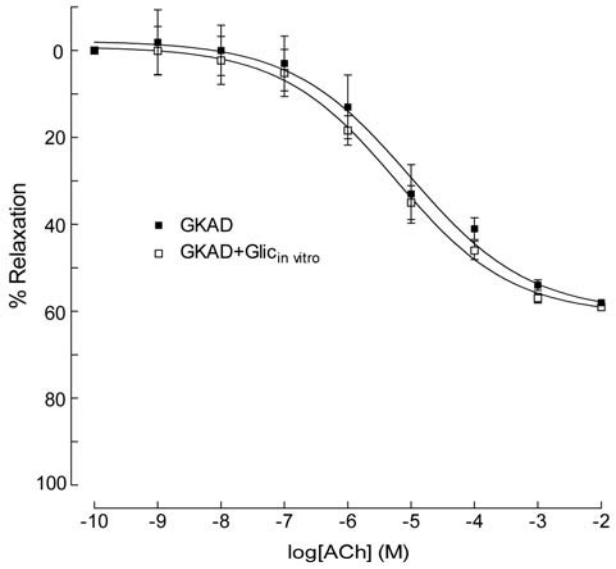
% Relaxation
0
20
40
60
80
100
GKAD
GKAD+Glic in vitro
-10
-9
-8
-7
-6
-5
-4
-3
-2
log[ACh] (M)

Figure 3