EGb761, a Ginkgo Biloba Extract, is Effective against Atherosclerosis In Vitro, and in a Rat Model of Type 2 Diabetes

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<tr>
<th>Citation</th>
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Introduction

Ginkgo biloba L. (Ginkgoaceae), known as the ‘maidenhair tree’, is the best-selling herbal remedy in the USA [1]. Traditionally, the fruits and seeds of Ginkgo have been used in Oriental medicine to improve chronic cough or enuresis [2]. Since the early 1990s, EGb761, a standardized extract of Ginkgo leaves, has become the most popularly used dietary supplement for treating vascular diseases such as cerebral ischemia and dementia [3]. EGb761 has also been shown to have various antiapoptotic properties[6] and to inhibit amyloid-beta aggregation [10].

EGb761, a Ginkgo Biloba Extract, Is Effective Against Atherosclerosis In Vitro, and in a Rat Model of Type 2 Diabetes

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1 Department of Internal Medicine, Seoul National University Bundang Hospital, Seongnam, Korea, 2 Department of Internal Medicine, Seoul National University College of Medicine, Seoul National University Hospital, Seoul, Korea, 3 Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland, United States of America, 4 Division of Endocrinology, Diabetes and Metabolism, Department of Medicine, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, Massachusetts, United States of America

* These authors contributed equally to this work.

Abstract

Background: EGb761, a standardized Ginkgo biloba extract, has antioxidant and antiplatelet aggregation and thus might protect against atherosclerosis. However, molecular and functional properties of EGb761 and its major subcomponents have not been well characterized. We investigated the effect of EGb761 and its major subcomponents (bilobalide, kaemferol, and quercetin) on preventing atherosclerosis in vitro, and in a rat model of type 2 diabetes.

Methods and Results: EGb761 (100 and 200 mg/kg) or normal saline (control) were administered to Otsuka Long-Evans Tokushima Fatty rats, an obese insulin-resistant rat model, for 6 weeks (from 3 weeks before to 3 weeks after carotid artery injury). Immunohistochemical staining was performed to investigate cell proliferation and apoptosis in the injured arteries. Cell migration, caspase-3 activity and DNA fragmentation, monocyte adhesion, and ICAM-1/VCAM-1 levels were explored in vitro. Treatment with EGb761 dose-dependently reduced intima-media ratio, proliferation of vascular smooth muscle cells (VSMCs) and induced greater apoptosis than the controls. Proliferation and migration of VSMCs in vitro were also decreased by the treatment of EGb761. Glucose homeostasis and circulating adiponectin levels were improved, and plasma hsCRP concentrations were decreased in the treated groups. Caspase-3 activity and DNA fragmentation increased while monocyte adhesion and ICAM-1/VCAM-1 levels decreased significantly. Among subcomponents of EGb761, kaemferol and quercetin reduced VSMC migration and increased caspase activity.

Conclusions: EGb761 has a protective role in the development of atherosclerosis and is a potential therapeutic agent for preventing atherosclerosis.

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Competing Interests: The authors have declared that no competing interests exist.
Therefore, it has been used to improve cardiovascular and peripheral vascular insufficiency, to protect against neurological disorders such as ischemic injury and to treat cerebral disorders such as cognitive decline and memory impairment [9].

Interestingly, in addition to its neurological and vascular protective effects, EGb761 has been reported to reduce hyperglycemia. Rapin et al. reported that EGb761 increased glucose uptake and glycogen synthesis, and Tanaka et al. showed that the glucose-lowering effect of Ginkgo extracts was caused by the inhibition of alpha-amylase and glucosidase [11,12].

Although EGb761 has beneficial effects on blood circulation and hyperglycemia in patients with diabetes, direct studies on its effects against atherosclerosis are limited. Therefore, we investigated the protective effect of EGb761 on atherosclerosis in a rat model of obese type 2 diabetes. We also examined the possible role of EGb761 and its major subcomponents on the development and progression of atherosclerosis in vivo. In addition, the effects of EGb761 on glucose homeostasis, circulating adipocytokines and inflammatory markers were evaluated.

Materials and Methods

Animal and Material

Thirty-six 5-week-old male Otsuka Long-Evans Tokushima Fatty (OLETF) rats were donated by the Otsuka Pharmaceutical Co. (Tokushima, Japan). They were allowed to grow to 24 weeks of age, when obesity and insulin resistance develop. The OLETF rats were fed in the Preclinical Laboratory of Seoul National University Bundang Hospital, South Korea, for the study duration. All animals were handled in compliance with the Guide for Experimental Animal Research of the Laboratory, Seoul National University Bundang Hospital. Seoul National University Bundang Hospital Ethics Committee for Animal Study approved this study (06-2008-096).

We divided the rats into three groups (n = 12 each) and treated them as follows: controls (5 ml normal saline per day), rats given 100 mg/kg of EGb761 per day (EGb100), and rats given 200 mg/kg of EGb761 per day (EGb200). All rats were fed a regular chow diet and had free access to water. EGb761 or normal saline were administered using an oral Zonde needle (Natsume, Tokyo, Japan) at 9–10 am for 6 weeks (from 3 weeks before to 3 weeks after balloon injury). EGb761 was supplied by Dr. Willmar Schwabe Pharmaceuticals (KG, Karlsruhe, Germany). Two major ingredients were ginkgo flavone glycoside (24.31%) and terpene trilactones (5.42%). Subcomponents of EGb761 are described in Table S1.

Additional experiments were carried out involving male ApoE/- mice (n = 12) 5 weeks of age, which were purchased from Jackson laboratories (Bar Harbor, Maine). For 2 months all mice were fed high fat cholesterol diet #88137 (Harlan-Teklad; 42% fat, 1.25% cholesterol) beginning at 5 weeks of age. After 2 months, mice were divided into three groups: control, EGb100 and EGb200 (n = 4 each) and continued on the high fat diet. Mice were sacrificed after 2 months post treatment to evaluate the degree of plaque formation. Whole aortas were opened lengthwise, fixed in 10% formalin, stained with oil red O and quantified by computerized morphometrics. The results for atherosclerotic plaque were expressed as the mean±standard error of the mean.

Effect of EGb761 on Atherosclerosis

We divided the rats into three groups (n = 12 each) and treated them as follows: controls (5 ml normal saline per day), rats given 100 mg/kg of EGb761 per day (EGb100), and rats given 200 mg/kg of EGb761 per day (EGb200). All rats were fed a regular chow diet and had free access to water. EGb761 or normal saline were administered using an oral Zonde needle (Natsume, Tokyo, Japan) at 9–10 am for 6 weeks (from 3 weeks before to 3 weeks after balloon injury). EGb761 was supplied by Dr. Willmar Schwabe Pharmaceuticals (KG, Karlsruhe, Germany). Two major ingredients were ginkgo flavone glycoside (24.31%) and terpene trilactones (5.42%). Subcomponents of EGb761 are described in Table S1.

Rat aortic smooth muscle cells (RAsoSMCs; Bio-bud Seoul, Korea) and human umbilical vein endothelial cells (HUVECs; Cambrex, Walkersville, MD) were used for in vitro experiments. See the Table S1 and Figures S1, S2, S3, S4, S5, S6 for detailed information.

Cell Culture

Rat aortic smooth muscle cells (RAsoSMCs; Bio-bud Seoul, Korea) and human umbilical vein endothelial cells (HUVECs; Cambrex, Walkersville, MD) were used for in vitro experiments. See the Table S1 and Figures S1, S2, S3, S4, S5, S6 for detailed information.

Cell Proliferation and Cytotoxicity

Effects of EGb761 on RAsoSMCs proliferation was determined by a modified 3-(4,5-dimethyl-thiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay. To investigate cell viability of EGb761, calcein-acetoxyethyl ester (calcein-AM) cell viability assay kit was used (Biotium, Hayward, CA, USA).

Cell Migration

RAsoSMCs were grown to confluence in 6-well plates (SonicSeal Slide Wells, Nalge Nunc, Rochester, NY) and then starved in DMEM with 0.5% FBS for 48 h. Thereafter, each well was divided into a 2 x 3 grid. Using 100-1000 μL pipette tips, a linear
Figure 1. In vivo inhibition of neointimal formation after 6 weeks of treatment with EGb761. A. H&E stained sections of the three groups. Treatment with EGb761 produced a lower IMR than controls in a dose-dependent manner (the lower IMR with the higher dose of EGb761, p<0.05). B. Representative examples of aortas from ApoE-/- mice stained en-face with Oil-Red. Red color indicates the aortic arch where plaque accumulation is the highest. C. Quantification of aortic arch plaque in the three groups expressed as the mean±SEM percent. A dose-dependent decreased plaque volume was found in the EGb groups.

**Figure 1. In vivo inhibition of neointimal formation after 6 weeks of treatment with EGb761.** A. H&E stained sections of the three groups (n = 10 in each group). Treatment with EGb761 produced a lower IMR than controls in a dose-dependent manner (the lower IMR with the higher dose of EGb761, p<0.05). B. Intima to media ratios (IMRs) in the three groups. C. Representative examples of aortas from ApoE-/- mice stained en-face with Oil-Red. Red color indicates the aortic arch where plaque accumulation is the highest. D. Quantification of aortic arch plaque in the three groups expressed as the mean±SEM percent. A dose-dependent decreased plaque volume was found in the EGb groups.

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wound was made in each hemisphere of the well. Immediately after this, the medium was replenished with starvation medium. TNF-α (10 ng/ml) was mixed in starvation medium. Cells were allowed to migrate for 24 h at 37°C. Images were taken of the intersections of the linear wound and each grid line, which resulted in 3 fields per well.

Figure 2. Effects of EGb761 (100 or 200 mg/kg) treatment or normal saline (control) on the proliferation and apoptosis of vascular smooth muscle cells. A. Cell proliferation measured by immunostaining for proliferating cell nuclear antigen (PCNA) was markedly lower in the EGb761-treated groups than in the controls (open arrow). B. The proliferation index was significantly lower in the EGb761-treated groups than in the control group. There was a dose-dependent pattern in the level of proliferation between EGb761-treated groups (* p<0.05 vs. control and † p<0.05 vs. EGb100). C. TUNEL staining of the three groups (open arrow). D. Apoptosis index (%) at 3 weeks after balloon injury. Apoptosis was significantly higher in the EGb761-treated groups than in the control group, and there was a dose-dependent pattern in the level of apoptosis between EGb761-treated groups (* p<0.05 vs. control and † p<0.05 vs. EGb100). doi:10.1371/journal.pone.0020301.g002
Monocyte Adhesion Assay

U937 cells (Human leukemic monocyte lymphoma cell line; Abcam, Cambridge, MA) were washed 3 times with serum-free RPMI medium and then resuspended in the same medium. The U937 cells (1.25×10⁴) were added to the HUVEC monolayers stimulated with TNFα (10 ng/ml) for 18 h and incubated for 30 min at 37°C under 5% CO₂ in air. Unbound cells were removed by washing 3 times with PBS. EBM-2 medium was then added and all U937 cells adhering to an endothelial cell were counted in 3–5 randomly selected fields of view in each well using a phase-contrast microscope.

Intercellular Adhesion Molecule (ICAM) and Vascular Cell Adhesion Molecule (VCAM)

For reverse transcription–polymerase chain reaction (RT-PCR), RNA was isolated from HUVECs according to the TRIZOL protocol (Gibco Life Technology). Primer and probe sequences for ICAM and VCAM were described previously [16]. The RT-PCR was performed with the TaqMan system (Prism 7700 Sequence Detection System, PE Biosystems, Foster City, CA). Thermal cycling conditions comprised an initial denaturation step at 94°C for 5 min, followed by 94°C for 30 sec, 58°C for 60 sec, and 72 for 30 sec for 40 cycles. For quantification, the target sequences were normalized in relation to the human GAPDH product (Clonetech, Heidelberg, Germany).

Immunoblot Analysis for Caspase-3 Activity

Immunoblot analysis was performed with primary antibodies directed against pro-caspase-3; cleaved caspase-3; β-actin (all from Santa Cruz Biotechnology). The bands were visualized with enhanced chemiluminescence and quantified by densitometry. Cleaved caspase 3-expression data were normalized by β-actin levels.

DNA fragmentation

DNA fragmentation, a distinctive feature of apoptosis at the biochemical level, was evaluated with EGb761 (100 and 200 μg/ml) and its subcomponents; kaemferol, quercetin and bilobalide (10, 20 and 50 μg/ml, respectively).

Statistical Analysis

Results are reported as the mean±standard error (SE). Mean values were compared for the EGb761-treated groups and control group by ANOVA with a post hoc test and p<0.05 was considered statistically significant. Analysis was done using SPSS for Windows version 11.0 (SPSS Inc., Chicago, IL).

Results

In vivo Inhibition of Neointimal Formation and Plaque Development

Three weeks after injury, the EGb761-treated groups showed a significant reduction in neointimal formation compared to the control group (Fig. 1A). The EGb200 group showed less neointimal formation than the EGb100 group (Fig. 1A, B). As shown in Fig. 1B, there was a dose-dependent reduction of the IMR between the two EGb761-treated groups (Control, 1.40±0.20; EGb100, 0.90±0.14; EGb200, 0.43±0.09, p<0.05).

Representative examples of aortas from ApoE-/- mice stained en-face with Oil-Red are shown in Fig. 1C. Red color indicates the aortic arch where plaque accumulation is the highest. Fig. 1D shows the quantification of aortic arch plaque in the three groups.

![Figure 3. Effects of EGb761 on proliferation and TNFα-stimulated migration of rat aortic smooth muscle cells (RAoSMC).](image-url)

A. In MTT viability assays, cell proliferation was significantly decreased in a dose dependent manner by EGb761 treatment (* p<0.05 and ** p<0.01 compared with untreated RAoSMC). B. Measurement of cell migration assessed by wound healing assay. C. Quantification of the migration distance as a percentage of the control value (** p<0.01 compared with TNFα only treatment).

doi:10.1371/journal.pone.0020301.g003

Effect of EGb761 on Atherosclerosis
expressed as the mean±SEM percent. A dose-dependent decreased plaque volume was found in the EGb groups.

Inhibited Proliferation and Sustained Apoptosis of Vascular Smooth Muscle Cells and Reduced Inflammatory Cells

Cell proliferation and apoptosis are important contributors to neointimal formation after balloon injury. We performed experiments investigating the role of EGb761 in reducing proliferation and promoting apoptosis of cells. As shown in Fig. 2A, the proliferative index was significantly lower in the EGb761 treated groups than in the control (control, 16.8±4.1%; EGb100, 12.7±2.1%; EGb200, 8.2±3.2%, p<0.05 vs. control, respectively). There was a dose-dependent decrease in proliferation between the two EGb761-treated groups (p<0.05) (Fig. 2B). At 3 weeks after injury, the apoptosis index was significantly higher in the EGb761-treated groups than in the control group (Fig. 2C). There was also a dose-dependent increase in the level of apoptosis between the two EGb761 groups (control 6.9±0.6%; EGb100, 11.0±0.6%; EGb200, 20.4±1.9%, p<0.05) (Fig. 2D). Immunohistochemical staining for ED-1 (an inflammatory cell marker in the rat) in the injured carotid vessel wall also showed that ED-1 positive cells were more frequent in the control group than in the EGb761-treated groups (Fig. S1).

Decrease in Proliferation and TNFα-directed Migration of RAoSMCs

As shown in Fig. 3A, EGb761 treatment inhibited proliferation of RAoSMCs. This effect was initiated at 50 μg/ml of EGb761 and was increased dose-dependently to 200 μg/ml. This anti-proliferative property of EGb761 did not induce cytotoxicity, as shown by the results of the calcein measurement (Fig. S2). EGb761 treatment also inhibited platelet-derived growth factor (PDGF)-stimulated RAoSMC proliferation (Fig. S3). Furthermore, EGb761 treatment inhibited TNFα-directed migration in rat RAoSMCs dose-dependently (Fig. 3B, C). When subcompounds of EGb761 were used, kaemferol and quercetin inhibited TNFα-directed RAoSMC migration while bilobalide showed no change (Fig. S4).

Decrease in Monocyte Adhesion

The adhesion of inflammatory cells has a critical role in the development of atherosclerosis. Increased monocyte adhesion was

![A] Control
![B] TNFα only
![C] TNFα+EGb 50 μg/ml
![D] TNFα+EGb 100 μg/ml
![E] TNFα+EGb 200 μg/ml

Figure 4. Effect of EGb761 on monocyte adhesion and adhesion molecule expression. A. EGb761 treatment reduced TNFα-stimulated monocyte adhesion using U937 cells (Open arrows indicate adhered monocytes). B. Monocyte adhesion rate as a percentage of the control value (** p<0.01 compared with TNFα only treated group). C and D. ICAM and VCAM expression levels in human umbilical vein endothelial cells. (*) p<0.05 and ** p<0.01 compared with TNFα treatment).

doi:10.1371/journal.pone.0020301.g004
observed after TNFα stimulation of HUVECs in the monocyte adhesion assay (Fig. 4A). As shown in Fig. 4B, EGb761 treatment significantly and dose-dependently decreased monocyte adhesion.

Effect of EGb761 on ICAM and VCAM Expression in HUVECs

Adhesion molecules such as ICAM and VCAM are also involved in the development of restenosis. In this study, expression of ICAM and VCAM were significantly decreased by treatment with EGb761 at both 100 and 200 μg/ml (Fig. 4C and 4D).

Caspase-3 Activity and DNA fragmentation

Apoptosis of cells is an important contributor to neointimal formation inhibition. To evaluate effect of EGb761 and its subcompounds on apoptosis in vitro, caspase-3 activity and DNA fragmentation assay were used. EGb761 treatment increased the level of cleaved caspase-3, reflecting apoptosis in RAoSMCs (Fig. 5A and 5B). Treatment of kaemferol or quercetin also increased caspase activity significantly (Fig. 5C). Treatment of kaemferol and quercetin and EGb761 increased DNA fragmentation compared to control group. Subcompound bilobalide also did not increase DNA fragmentation (Fig. 5C).

Effect of EGb761 Treatment on Glucose Metabolism, Plasma Adiponectin and Inflammatory Markers

After 6 weeks of treatment with EGb761, significant improvement of postload glucose excursion was found in both EGb100 and EGb200 groups compared with control (Table 1). Furthermore, EGb761 treatment increased plasma adiponectin concentrations and decreased hsCRP concentrations (Table 1). Although the EGb761-treated groups showed lower fasting insulin levels and HOMA-IR than controls, these were not statistically significant. Similarly, the levels of other inflammatory markers such as MCP1, TNFα and PAI1 were lower in EGb761-treated rats than in controls, but these were not statistically significant.

Discussion

Six weeks of treatment with EGb761, a standardized Ginkgo biloba extract, produced significantly less neointimal formation in balloon injured carotid arteries than in the control group in a dose-dependent manner (35.5% in the EGb100 group and 69.3% in EGb200) which was accompanied by reduced proliferation and increased apoptosis of vascular smooth muscle cells (VSMCs). EGb761 treatment also showed anti-atherosclerotic effects in vitro. It decreased proliferation and migration, and increased apoptosis of VSMCs. It also decreased monocyte adhesion and levels of adhesion molecules in HUVECs. Among subcomponents of EGb761, kaemferol and quercetin played a major role in the prevention of atherosclerosis.

The proliferation and migration of VSMCs are important contributors to neointimal formation after balloon injury [17,18]. Apoptosis is also important in this process [19]. Therefore, prior efforts to reduce the extent of restenosis have focused on various interventions that reduced the proliferation and migration of VSMCs or of increased their apoptosis [19,20]. EGb761 has antioxidant, anti-inflammatory and anti-platelet aggregation effects [2,5–7,9,10]. In our study, EGb761 also increased caspase-3 activity in VSMCs. It is known that EGb761 has anti-

![Figure 5. Effect of EGb761 on apoptosis. A. Induction of apoptosis shown by the activation of caspase-3 with EGb761 treatment. B. Dose-dependent increasing pattern of caspase-3 activity by EGb761 (**p<0.05 compared with TNFα only treatment). C. DNA fragmentation by bilobalide, kaemferol, quercetin and EGb761. doi:10.1371/journal.pone.0020301.g005](figure)

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**Table 1.** Effect of EGb761 on Atherosclerosis

<table>
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<th>Group</th>
<th>Glucose Metabolism</th>
<th>Plasma Adiponectin</th>
<th>Inflammatory Markers</th>
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<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EGb100</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>EGb200</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
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</table>

(Where X signifies a statistically significant change compared to control)
Atherosclerosis. Recent studies showed that EGb761 had proapoptotic effects in high turnover state such as cancer [21–23]. Thus, EGb761 could have different effects on cell survival under specific conditions such as target cells and the dosage used. Several studies suggested that EGb761 may also have different effects on cell survival under apoptotic properties particularly in neuronal cells. However, EGb761 may also have different effects on cell survival under specific conditions such as target cells and the dosage used. Several studies showed that EGb761 had proapoptotic effects in high turnover state such as cancer [21–23]. Thus, EGb761 could have proapoptotic effects on VSMCs in the development of atherosclerosis.

It is well known that infiltration of inflammatory cells occur early after endothelial denudation [24–27] and its inhibition is associated with a reduction in medial VSMC proliferation [24]. These data suggest a central role of inflammatory cells in restenosis and provide insights as to how EGb761 might reduce neointimal thickening through blocking early monocyte recruitment by anti-inflammatory drugs [28]. In this study, EGb761 significantly and dose-dependently decreased restenosis, although there is no clear explanation for the lack of a dose-dependent response. Other possible relevant factors affecting the degree of neointimal formation were also evaluated in this study. Circulating levels of adiponectin were increased significantly in EGb761 treatment in a dose-dependent manner. Adiponectin has attracted considerable attention recently as an adipokine that may have critical roles in the development of atherosclerosis [32]. Importantly, low adiponectin level is a risk factor for the subsequent development of cardiovascular diseases [33–37]. Adiponectin directly stimulates NO production from endothelium via activation of AMP-activated protein kinase and eNOS synthase [38]. Therefore, increasing adiponectin levels are predicted to improve both insulin sensitivity and endothelial function by multiple mechanisms [39]. In this study, there was a negative correlation between adiponectin and TNFα concentration (r = −0.369, P = 0.027), although TNFα levels were not significantly decreased by EGb761 treatment. This data suggests that reducing restenosis by EGb761 treatment may be mediated by increased adiponectin with decreased TNFα level. In addition, hsCRP, an inflammatory marker, was significantly decreased by EGb761 treatment. This data thus suggest that EGb761 enhances pancreatic beta cell function. Consistent with these studies, the AUCglucose calculated from the IPGTT in our study was decreased slightly but significantly in EGb761-treated groups compared with controls.

### Table 1. Weight, Biochemical Parameters, Insulin Resistance Index and Inflammatory Markers in Obese Rat Model of Type 2 Diabetes at the End of 6 Weeks of EGb761 Treatment.

<table>
<thead>
<tr>
<th></th>
<th>Control (n = 10)</th>
<th>EGb100 (n = 10)</th>
<th>EGb200 (n = 10)</th>
<th>P Value†</th>
</tr>
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<tbody>
<tr>
<td>Weight, g</td>
<td>583.1 ± 29.3</td>
<td>576.3 ± 27.5</td>
<td>575.5 ± 33.8</td>
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<td>Liver weight, g</td>
<td>3.30 ± 0.65</td>
<td>3.03 ± 0.26</td>
<td>2.98 ± 0.22</td>
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<tr>
<td>White adipose fat weight, g</td>
<td>1.35 ± 0.21</td>
<td>1.27 ± 0.16</td>
<td>1.29 ± 0.20</td>
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<tr>
<td>Fasting glucose, mg/dl</td>
<td>119.6 ± 12.6</td>
<td>117.2 ± 8.6</td>
<td>116.2 ± 11.8</td>
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<td>2h postload glucose, mg/dl</td>
<td>204.9 ± 28.0</td>
<td>168.8 ± 27.2</td>
<td>169.4 ± 15.8</td>
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<tr>
<td>AUCglucose</td>
<td>808.5 ± 45.7</td>
<td>659.0 ± 66.3</td>
<td>703.7 ± 66.7</td>
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<tr>
<td>Fasting insulin, pg/ml</td>
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<td>177.6 ± 79.9</td>
<td>168.6 ± 90.9</td>
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<td>Total cholesterol, mg/dl</td>
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<td>81.9 ± 12.9</td>
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<td>Triglyceride, mg/dl</td>
<td>60.5 ± 21.9</td>
<td>58.4 ± 26.9</td>
<td>48.7 ± 17.2</td>
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<td>HDL-cholesterol, mg/dl</td>
<td>23.5 ± 4.1</td>
<td>23.2 ± 4.3</td>
<td>22.9 ± 2.2</td>
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<td>LDL-cholesterol, mg/dl</td>
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<td>47.0 ± 12.5</td>
<td>44.9 ± 8.9</td>
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<td>MCP1, pg/ml</td>
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<td>160.5 ± 53.0</td>
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<td>TNFα, pg/ml</td>
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<td>PAI1, pg/ml</td>
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<td>212.0 ± 82.9</td>
<td>259.6 ± 108.7</td>
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<td>Adiponectin, µg/ml</td>
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<td>HsCRP, mg/l</td>
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<tr>
<td>HOMA-IR</td>
<td>55.3 ± 34.2</td>
<td>51.2 ± 24.0</td>
<td>47.4 ± 26.5</td>
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<tr>
<td>HOMA-B</td>
<td>1162.0 ± 713.4</td>
<td>1228.1 ± 607.5</td>
<td>1230.9 ± 647.0</td>
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</table>

Key: AUCglucose, Area under the curve of glucose; HOMA-IR, homeostasis model assessment of insulin resistance; HOMA-B, homeostasis model assessment of beta cell function.

†ANOVA with post hoc test (Tukey’s-b) was used (A, B and C; mean significant difference between two groups: A = Control vs. EGb100, B = Control vs. EGb200, C = EGb100 vs. EGb200, p < 0.05 in all cases). doi:10.1371/journal.pone.0020301.t001
states on glucose homeostasis and on adiponectin and hsCRP in inflammatory processes. In addition, EGb761 showed favorable restenosis in obese rats with type 2 diabetes after balloon injury to responsible for preventing restenosis.

In conclusion, treatment with EGb761 was found to reduce restenosis in obese rats with type 2 diabetes after balloon injury to the carotid artery. EGb761 significantly suppressed the proliferation and migration of VSMCs, promoted apoptosis and reduced inflammatory processes. In addition, EGb761 showed favorable effects on glucose homeostasis and on adiponectin and lhsCRP levels. Among subcomponents of EGb761, kaemferol and quercetin seem to play a major role in the prevention of atherosclerosis. These findings support an emerging role of EGb761 in reducing cardiometabolic risks. Specific intervention studies are needed to confirm the positive effects of EGb761 in type 2 diabetic patients.

Supporting Information

Figure S1 Immunohistochemical staining of ED-1 in the injured carotid vessel wall I. Arrows indicate ED-1 positive cells in the representative examples. II. Quantification of ED-1 positive cells among control, EGb100 and EGb200.

Figure S2 Effect of EGb761 (a) and its subcomponents (bilobalide, kaemferol and quercetin) (b) on cell survival with calcine measurement.

Figure S3 Effect of EGb761 on PDGF-induced RAoSMC proliferation (** p<0.01 compared with PDGF only treatment).

Figure S4 Effect of EGb761 subcomponents on migration of RAoSMC by wound-healing assay (a). Quantification of the migration distance as a percentage of the control value (b) (** p<0.01 compared with TNFα only treatment).

Figure S5 Measurement of caspase activity by treatment of subcompound of EGb761 (kaemferol, quercetin, and bilobalide) (**p<0.01 compared with TNFα only treatment).

Table S1 Component of EGb761.

Author Contributions

Conceived and designed the experiments: SL JYV SMK SHC. Performed the experiments: BJC MK. Analyzed the data: Y-BK HCJ KSP. Contributed reagents/materials/analysis tools: HSP HJC HSK. Wrote the paper: SL JYV HS.

References