Ruscogenin Protects against High-Fat Diet-Induced Nonalcoholic Steatohepatitis in Hamsters

Lu H-J et al. Ruscogenin Protects against... Planta Med 2014; 80: 870–879

Abstract

The protective effects of ruscogenin on nonalcoholic steatohepatitis in hamsters fed a high-fat diet were investigated. Ruscogenin (0.3, 1.0, or 3.0 mg/kg/day) was orally administered by gavage once daily for eight weeks. A high-fat diet induced increases in plasma levels of total cholesterol, triglycerides, and free fatty acids, while the degree of insulin resistance was lowered by ruscogenin. High-fat diet-induced hepatic steatosis and necroinflammation were improved by ruscogenin. Gene expression of inflammatory cytokines and activity of nuclear transcription factor-κB were also increased in the high-fat diet group, which were attenuated by ruscogenin. Ruscogenin decreased hepatic mRNA levels of sterol regulatory element-binding protein-1c and its lipogenic target genes. The hepatic mRNA expression of peroxisome proliferator-activated receptor α, together with its target genes responsible for fatty acid β-oxidation were upregulated by ruscogenin. In conclusion, these findings suggest that ruscogenin may attenuate high-fat diet-induced steatohepatitis through anti-inflammatory mechanisms, reducing hepatic lipogenic gene expression, and upregulating proteins in the fatty acid oxidation process.

Introduction

Nonalcoholic fatty liver disease (NAFLD) is defined as the accumulation of liver fat exceeding 5% of hepatocytes in the absence of significant alcohol intake (significant alcohol intake being defined as 20 g/10 g per day for men/women, respectively) or other specific etiology [1]. Nonalcoholic steatohepatitis (NASH), the extreme form of NAFLD, is characterized by an increase in fat deposition, fibrosis, oxidative stress, and chronic inflammation in the liver [2]. It is also a common cause of cirrhosis and could later progress to hepato-cellular carcinoma [3]. A “multi-hit” theory has been proposed to depict the key pathogenic processes of NASH development. In this theory, obesity and insulin resistance is thought to be the “first hit” to the liver because it induces a net accumulation of lipid in hepatocytes which may cause the occurrence of following “hits”, such as oxidative stress, inflammation, fibrosis, and apoptosis [4]. Therapies that limit hepatic injury and the related occurrence of inflammation and fibrosis are particularly appealing for this condition. Ruscogenin [(1β,3β,25R)-spirost-5-en-1,3-diol; Fig. 1], first isolated from Ruscus aculeatus, is also a major steroidal sapogenin of the traditional Chinese herb Radix Ophiopogon japonicus, which has been clinically used for a long time to treat acute and chronic inflammatory and cardiovascular diseases [5]. In Chinese medicine, Radix Ophiopogon japonicus is the cardinal herb for yin deficiency. According to the Chinese Herbal Medicine Materia Medica, the herb is sweet, slightly bitter and slightly cold, enters the heart, lungs and stomach channels, and nourishes the yin of the stomach, spleen, heart and lungs, clears heat, and quiets irritability [6]. Ruscogenin acts as an elastase inhibitor, decreases capillary permeability, and is widely used to treat chronic venous insufficiency and vasculitis [7, 8]. It has been previously found to exert significant anti-thrombotic activity, and the possible mechanism of ruscogenin could be attributed to its inhibition of inter-cellular adhesion molecule-1 upregulation via nuclear factor (NF)-κB p65 translocation induced by tumor necrosis factor (TNF)-α [9, 10]. It was also found that ruscogenin significantly attenuated lipopolysaccharide-induced acute lung injury in a model with mice, which was possibly linked to the inhibition of NF-κB activation [11]. Such activities of ruscogenin indicate its potential protec-
tion in NAFLD/NASH-induced hepatic injury; however, there is no report about it until now. The present study was designed to explore the effects of ruscogenin in treating high-fat diet (HFD)-induced steatohepatitis and its possible mechanisms.

Results

At the end of eight weeks of treatment, the body weight, visceral fat, and relative liver weights in HFD-fed hamsters were significantly higher than those in the normal diet (ND)-fed group (Table 1). High doses of ruscogenin (3.0 mg/kg/day) suppressed body weight gain. The relative weights of the liver, epididymal adipose tissue, and perirenal adipose tissue were significantly lower in ruscogenin (3.0 mg/kg/day)-supplemented groups than those in the HFD-fed group (Table 1). Similar results were seen in HFD-fed hamsters treated with fenofibrate (Table 1). No significant differences in daily food or water intake were observed between the groups over the experimental period (Table 1). Plasma alanine aminotransferase (ALT) and aspartate aminotransferase (AST) activities in HFD-fed hamsters were higher than those in the ND-fed group (Table 1). The ALT and AST activities were markedly reduced in HFD-fed hamsters treated for eight weeks with a high dose (3.0 mg/kg/day) of ruscogenin (Table 1). The HFD caused elevated concentrations of plasma total cholesterol (TC), triglycerides (TG), and low-density lipoprotein cholesterol (LDL-C). Oral administration of ruscogenin at a dose of 0.3, 1.0, or 3.0 mg/kg/day significantly reduced plasma TC levels (22.8%, 31.4%, and 39.7% reduction, respectively; Fig. 2A). All doses of ruscogenin decreased plasma TG levels in HFD-fed hamsters; the reduction of plasma TG induced by ruscogenin at 3.0 mg/kg/day was nearly 32.1% (Fig. 2A). Ruscogenin at an oral dose of 0.3, 1.0, or 3.0 mg/kg/day significantly reduced total plasma LDL-C levels (32.1%, 42.2%, and 52.8% reduction, respectively) compared to that of vehicle-treated HFD-fed hamsters (Fig. 2A). Plasma TC, TG, and LDL-C concentrations were reduced significantly by 46.7%, 37.8%, and 60.4%, respectively, in fenofibrate-treated HFD-fed hamsters compared with vehicle-treated HFD-fed hamsters (Fig. 2A).

The plasma concentration of high-density lipoprotein cholesterol (HDL-C) in HFD-fed hamsters was reduced to 60.4% of the level observed in the ND-fed group (Fig. 2A). After eight weeks of treatment with ruscogenin (3.0 mg/kg/day) or fenofibrate, the plasma HDL-C concentration in HFD-fed hamsters was elevated to nearly that of the ND-fed group (Fig. 2A). Plasma free fatty acid (FFA) levels in vehicle-treated HFD-fed hamsters were about 2.0-fold of that observed in the ND-fed group (Fig. 2A). The plasma FFA levels decreased by 38.1% in HFD-fed hamsters treated with ruscogenin (3.0 mg/kg/day) compared to their vehicle-treated counterparts (Fig. 2A). Fenofibrate treatment reduced FFA concentrations in HFD-fed hamsters by 38.3% relative to the level in vehicle-treated HFD-fed hamsters (Fig. 2A). The hepatic TC level was significantly higher in HFD-fed hamsters than in hamsters from the ND-fed group, which was reduced by 37.2% in HFD-fed hamsters treated with ruscogenin (3.0 mg/kg/day; Fig. 2B). Ruscogenin treatment (3.0 mg/kg/day) also produced a significant reduction in the hepatic TG concentration by 27.2% of that in the vehicle-treated HFD-fed hamsters (Fig. 2B). Hepatic TC and TG levels were significantly reduced (by 44.5%...
and 35.5%, respectively) in fenofibrate-treated HFD-fed hamsters compared with their vehicle-treated counterparts (Fig. 2B).
The hepatic FFA levels were significantly increased in hamsters fed an HFD, which were decreased by 37.3% and 41.2% in HFD-fed hamsters treated with ruscogenin (3.0 mg/kg/day) and fenofibrate, respectively (Fig. 2B).

Representative histological photomicrographs of liver specimens are shown in Fig. 3. Hamsters fed a ND had normal liver histological findings; however, numerous macrovascular fat droplets and mild necroinflammatory foci were present in the livers of those fed an HFD. The treatment of HFD-fed hamsters with ruscogenin (3.0 mg/kg/day) and fenofibrate, respectively (Fig. 2B).

Plasma glucose and insulin concentrations as well as the homeostasis model assessment of insulin resistance (HOMA-IR) were higher in vehicle-treated HFD-fed hamsters than those in the vehicle-treated ND-fed group (Fig. 4). After eight weeks of treatment with ruscogenin (3.0 mg/kg/day), plasma glucose concentrations were approximately 9.3% lower in HFD-fed hamsters compared with their vehicle-treated counterparts; corresponding plasma insulin and HOMA-IR values were 27.7% and 33.2% lower, respectively (Fig. 4). After eight weeks of treatment with fenofibrate, plasma glucose, plasma insulin, and HOMA-IR values were 7.6%, 32.5%, and 38.4% lower, respectively, in HFD-fed hamsters compared with their vehicle-treated counterparts (Fig. 4).

The hepatic levels of monocyte chemoattractant protein (MCP)-1, TNF-α, and interleukin (IL)-6 in HFD-fed hamsters were significantly higher (2.4-, 2.3-, and 2.9-fold, respectively) than those of the ND-fed group (Fig. 5). Administration of ruscogenin (3.0 mg/kg/day) to HFD-fed hamsters for eight weeks significantly downregulated the hepatic levels of MCP-1, TNF-α, and IL-6 to 51.1%, 63.3%, and 53.3%, respectively, compared with those in the vehicle-treated counterparts (Fig. 5). Fenofibrate treatment reversed the HFD-induced increase of hepatic levels of MCP-1, TNF-α, and IL-6 to 36.1%, 57.0% and 44.9%, respectively, compared with their vehicle-treated counterparts (Fig. 5).
An HFD significantly increased NF-κB activity (by 3.2-fold relative to that of the vehicle-treated ND-fed group) in the livers of hamsters (Fig. 6A). The HFD-induced upregulation of NF-κB activity was reduced 39.1% and 48.1% relative to that of the HFD-fed hamsters after eight weeks of treatment with ruscogenin (3.0 mg/kg/day) or fenofibrate, respectively (Fig. 6A). The phosphorylation degree of hepatic NF-κB in HFD-fed hamsters was also higher by 2.5-fold relative to their vehicle-treated

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Summary of steatosis and necroinflammation scores of ND- or HFD-fed hamsters receiving eight weeks of treatment.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ND-fed Vehicle</td>
</tr>
<tr>
<td></td>
<td>Steatosis</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Necroinflammation</td>
</tr>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>

There were eight animals in each group. Data are expressed as the number of hamsters exhibiting the grade of steatosis or necroinflammation indicated.
counterparts (Fig. 6B). Treatment for eight weeks with rusco-
genin (3.0 mg/kg/day) or fenofibrate decreased phosphorylated NF-κB in the livers of HFD- fed hamsters to 59.3% and 49.1%, re-
spectively, relative to the vehicle-treated controls (Fig. 6 B).

An HFD markedly increased the hepatic mRNA levels of sterol regulatory element-binding protein (SREBP)-1c in hamsters 3.2-
fold relative to those in the ND-fed group (Fig. 7 A). Ruscogenin
(3.0 mg/kg/day) suppressed the HFD-induced stimulation in he-
aptic mRNA levels of SREBP-1c to 63.5% relative to those in the
vehicle-treated group (Fig. 7 A). Hepatic mRNA levels of
SREBP-1c were reduced (by 46.9%) in fenofibrate-treated
HFD-fed hamsters compared with their vehicle-treated counter-
parts (Fig. 7 A).

An HFD caused a 2.8-fold induction of hepatic acetyl-CoA carbox-
ylase (ACC) mRNA and a 2.5-fold induction of hepatic fatty acid
synthase (FAS) mRNA relative to those in the ND-fed group. The
hepatic mRNA levels of ACC and FAS were downregulated by rus-
cogenin (3.0 mg/kg/day) treatment, with a decrease of 23.5% and
36.7%, respectively, when compared with those observed in the
vehicle-treated group (Fig. 7 A). The HFD-induced mRNA levels
of ACC and FAS in the liver were reversed after fenofibrate treat-
ment (a 48.6% and 47.1% decrease, respectively) compared to
those in the vehicle-treated group (Fig. 7 A).

The mRNA levels of peroxisome proliferator-activated receptor
(PPAR)α in the livers of HFD-fed hamsters were lowered to
55.1% compared with those from the ND-fed group (Fig. 7 B).
HFD-fed hamsters administered ruscogenin (3.0 mg/kg/day) or
fenofibrate for eight weeks upregulated the hepatic PPARα mRNA
levels to 1.6- and 1.7-fold relative to those in the vehicle-treated
group, respectively (Fig. 7 B).

Compared with the ND-fed group, the hepatic mRNA levels of
carnitine palmitoyl transferase (CPT)-1 and acyl-CoA oxidase
(ACO) in HFD-fed hamsters decreased obviously, and were upre-
gulated by fenofibrate treatment (a 1.9- and 2.3-fold increase, re-
spectively). The hepatic mRNA levels of CPT-1 and ACO in
HFD-fed hamsters receiving ruscogenin (3.0 mg/kg/day) supple-
mentation were increased 1.6- and 2.0-fold relative to the ex-
pression levels in their vehicle-treated counterparts, respectively (Fig. 7 B).
In our model, HFD-fed hamsters developed hepatic steatosis, visceral obesity, hyperlipidemia, and increased FFA and HOMA-IR values, mimicking almost all of the clinical features of human NAFLD [12]. Fenofibrate, a fibric acid derivative, is a commercially available drug in the management of hyperlipidemia and NAFLD [13]. Fenofibrate was used to compare the efficacy of ruscogenin. Similar to the effects of fenofibrate, we found that ruscogenin supplementation significantly decreased body and liver weights, and plasma and liver contents of TG, TC, and FFA. In addition, ruscogenin attenuated the development of HFD-induced hepatic steatosis and injury as assessed by microscopic analysis. These data demonstrated that ruscogenin shows biological activity towards the regulation of lipid metabolism and steatosis development in the liver.

As inflammation plays a pivotal role in NAFLD, its modulation represents an important pharmacological target of inflammatory activation [14]. We therefore investigated whether ruscogenin could improve fatty liver changes by decreasing inflammatory cytokines in the HFD-induced NAFLD hamsters. Administration of ruscogenin during NAFLD development significantly attenuated the expression of MCP-1, TNF-α, and IL-6 in the liver of HFD-fed hamsters. These data indicate that ruscogenin might be effective for preventing and reversing the inflammatory response, which may accelerate the lipid metabolism disorder and/or more severe liver injuries. Actually, these inflammatory cytokines are shown to be involved in the development of insulin resistance [15].
observed that not only hyperinsulinemia but also higher HO-MA-IR values were alleviated by ruscogenin treatment in HFD-fed hamsters. These results further suggest that ruscogenin could ameliorate fatty liver in the insulin-resistant state. NF-κB is a ubiquitous and well-known transcription factor, which undergoes phosphorylation on serine 276 in its p65 subunit and associates with surrounding chromatin components. It subsequently binds with DNA and promotes the transcription of proinflammatory cytokines, chemokines, and adhesion molecules [16]. Thus, detection of the phosphorylated p65 subunit of NF-κB was effective for evaluating NF-κB activation [17]. Ruscogenin has been reported to have anti-inflammatory activity through inhibiting NF-κB activity [10, 11]. The inhibition of NF-κB by ruscogenin might be a critical step for prevention of the cascading inflammatory response during NAFLD development. In the present study, ruscogenin significantly inhibited hepatic NF-κB activation in HFD-fed hamsters, as evidenced by a decrease in NF-κB activity and downregulation of phosphorylated NF-κB. These results suggest that ruscogenin inhibits the activation of NF-κB, leading to the downregulation of inflammatory mediators and, therefore, shows a promising effect in preventing NAFLD. Whether ruscogenin can directly target NF-κB or act as the upstream signaling molecules for its activation requires further investigation. To explore the possible mechanisms whereby ruscogenin decreases hepatic lipid accumulation, we then investigated the expression levels of several genes related to lipid metabolism, including lipogenesis and β-oxidation. SREBP-1c has been shown to regulate the transcription of genes in the lipogenic pathway including ACC and FAS [17]. Liver-specific ACC knockout mice showed a decreased hepatic triglyceride accumulation, suggesting that ACC plays a crucial role in the regulation of lipogenesis [18]. FAS catalyzes the last step in fatty acid biosynthesis and is thus believed to be a major determinant of the maximal hepatic capacity to generate fatty acids by de novo lipogenesis [19]. Low levels of SREBP-1c mRNA in the livers of HFD-fed hamsters receiving ruscogenin were accompanied by a concomitant reduction in the expression of ACC and FAS mRNA. Ruscogenin is thus likely to have an inhibitory effect on SREBP-1c expression, which in turn decreases transcription of its target lipogenic genes, thereby reducing enzyme activity and resulting in a low rate of lipid synthesis. Ruscogenin appeared to mediate its beneficial effects on HFD-induced hepatic steatosis by downregulating expression of hepatic genes related to lipid synthesis. PPARα mediates β-oxidation of fatty acids, and agonists of PPARα possess the property of reducing lipid dystrophy and obesity [20]. PPARα activates some of the key enzymes of β-oxidation and β-oxidation of fatty acids in the liver [21]. HFD-fed hamsters displayed a reduced expression of PPARα in the liver. A multitude of studies have postulated that during diet-induced obesity, fatty acid oxidation is left incomplete accompanied by mitochondrial lipid overload and dysfunction. To explore whether the effect of ruscogenin on the attenuation of HFD-induced hepatic steatosis was related to the PPARα-mediated pathway, mRNA expression of PPARα and its target genes responsible for β-oxidation of fatty acids was measured. Ruscogenin markedly increased the HFD-induced low expression of hepatic PPARα mRNA. Furthermore, ruscogenin treatment upregulated the PPARα-mediated transcription of CPT-1 and ACO mRNA in the liver of HFD-fed hamsters. CPT-1 and ACO are major enzymes that catalyze fatty acid β-oxidation and are responsive to PPARα activation [22, 23]. The similar trend in expression among these genes suggests that ruscogenin enhanced β-oxidation of fatty acids via the pathway involving PPARα-mediated gene transcription.

ALT and AST are considered to be sensitive indicators of hepatocellular damage and, within limits, can provide a quantitative evaluation of the degree of damage to the liver [24]. We found that the ALT and AST activities were markedly reduced in HFD-fed hamsters treated for eight weeks with ruscogenin. It seems that animals treated with ruscogenin at the chosen doses exhibited no evidence of hepatotoxicity. For a more reliable safety evaluation performed on the basis of the acceptable daily intake concept, data on the chronic toxicity, reproductive toxicity, genotoxicity, and carcinogenicity of ruscogenin would also be required.

In conclusion, the results of this study demonstrated that ruscogenin exerted a protective effect on HFD-induced hepatic steatosis in hamsters by modulating lipid metabolism-associated genes. It is also possible that the inhibition of NF-κB activation thereby led to the downregulation of inflammatory mediators and this is integral to the protective functions of ruscogenin in HFD-induced hepatocellular injury and its subsequent progression to steatohepatitis.

Materials and Methods

Animal models

Male Golden Syrian hamsters, eight weeks old and weighing 90 ± 10 g, were obtained from the National Laboratory Animal Center. They were maintained in a temperature-controlled room (25 ± 1 °C) on a 12-h:12-h light–dark cycle (lights on at 06:00 h) in our animal center. Food and water were provided ad libitum. An ND (#D12450B, Research Diets) with 20 kcal% protein, 70 kcal% carbohydrate, and 10 kcal% fat from lard was used as the maintenance and control diet. A purified ingredient HFD with 20 kcal% protein, 35 kcal% carbohydrate, and 45 kcal% fat primarily from lard (#D12451, Research Diets) was used to induce weight gain [25]. All animal procedures were performed according to the Guide for the Care and Use of Laboratory Animals of the National Institutes of Health, as well as the guidelines of the Animal Welfare Act. These studies were conducted with the approval of the Institutional Animal Care and Use Committee (IACUC) at Tajen University (approval number, IACUC 101–16; approval date, December 24, 2012).

Treatment protocols

After being fed an HFD for two weeks, hamsters were dosed by oral gavage once per day for eight weeks with ruscogenin (doses of 0.3, 1.0 or 3.0 mg/kg) in a volume of 1.5 ml/kg distilled water. The dosage regime was selected based on a previous report demonstrating that ruscogenin (±98%; Chengdu Biopurify Phytochemicals Ltd.; Cat. No. 472–11–7) at the indicated dosage regimen was potentially effective in inhibiting inflammation in mice [11]. Another group of HFD-fed hamsters was treated orally for eight weeks with 100 mg/kg/day fenofibrate (isopropyl 2-[4-(4-chlorobenzoyl)phenoxyl]-2-methylpropionate; Laboratories Fournier SA) with a purity greater than 99.5%. Two g of powdered fenofibrate was dissolved in 20 ml of distilled water, so that 1 ml will contain 100 mg of fenofibrate. The dose of fenofibrate was based on a study reporting that long-term fenofibrate treatment could ameliorate hepatic insulin resistance and steatosis in high-fructose-fed mice [26]. The control groups received water by gavage instead of ruscogenin or fenofibrate. Water consumption,
food intake, and body weight were measured individually at the same time (09:00 h) on each day throughout the experiment. Food cups containing fresh food were weighed at the beginning and end of each 24-h period. Food intake was calculated by determining the difference in food cup weights, adjusting for any spillage that occurred. Water intake was calculated by measuring the difference in water bottle weights at the beginning and end of the daily change of water.

After eight weeks of treatment, animals were weighed and sacrificed by being deeply anesthetized with ketamine (50–75 mg/kg) after fasting for 12 hours. Blood samples were taken from the inferior vena cava for analysis. After blood collection, the left lobe of the liver, and visceral and subcutaneous white adipose tissue (WAT) were removed, rinsed with a physiological saline solution, and immediately stored at −80 °C in liquid nitrogen until assayed. The hepatic weight coefficient was also calculated as liver weight (g) divided by body weight (100 g). The right hepatic lobe was fixed in 10% neutralized formalin for histology.

**Determination of plasma biochemical parameters and insulin sensitivity**

Blood samples were centrifuged at 2000 × g for 10 min at 4 °C. The plasma was then removed and placed into aliquots for the respective analyses. Kits for determining plasma glucose (Cat. No. 10009582) concentration was purchased from Cayman Chemical Company. Commercial enzyme-linked immunosorbent assay (ELISA) kits were used to quantify plasma insulin concentration (LINCO Research, Inc.; Cat. # EZRMI-13K). Whole-body insulin sensitivity was estimated using HOMA-IR with the following formula: [fasting plasma glucose (mmol) × fasting plasma insulin (mU/mL)]/22.5 [27]. Diagnostic kits for determination of plasma levels of TC (Cat. # 10007640) and TG (Cat. # 10010303) were purchased from Cayman Chemical Company. The diagnostic kit for determination of plasma levels of HDL-C was purchased from Bio-Quant Diagnostics (Cat. # BQ 019CR). LDL-C concentrations in plasma were determined by a commercial ELISA kit (antibodies-online, Inc.; Cat. # ABIN416222). The plasma FFA level was determined using an FFA quantification kit obtained from Abcam plc (Cat. # ab65341). Kits for determination of plasma ALT (EC 2.6.1.2) (Cat. No. A524-780TM and AST (EC 2.6.1.1) (Cat. No. A559-780TM) concentrations were purchased from Teco Diagnostics. All analyses were performed in triplicate in accordance with the manuals provided by the manufacturers.

**Measurement of hepatic lipids**

Liver tissue (0.5 g) was homogenized for 5 min in 1 mL of ice-cold phosphate-buffered saline (PBS) using a tissue homogenizer (Teflon Potter-Elvehjem tissue homogenizer in 10 mmol/L Tris-HCl buffered solution (pH 7.4) containing 2 mol/L NaCl, 1 mmol/L EDTA, 0.01% Tween 80, and 1 mmol/L PMSF, and centrifuged at 9000 × g for 30 min at 4 °C. The resultant supernatant was used for cytokine determination. ELISA kits for the determination of MCP-1 (Cat. No. ab100777), TNFα (Cat. No. ab46070), and IL-6 (Cat. No. ab100772) were obtained from Abcam, Inc. Samples were assayed in triplicate according to the manufacturer’s instructions. The protein concentrations of liver filtrate were determined using a Bio-Rad protein assay kit (Bio-Rad Laboratories) and bovine serum albumin (BSA) as a standard.

**Hepatic histology**

After the liver samples were fixed in 10% formalin solution at room temperature, they were processed by the standard method. Briefly, tissues were embedded in paraffin, sectioned at 5 µm, and stained with hematoxylin and eosin (H&E), and then picked up on glass slides for light microscopy. All samples were evaluated by an experienced pathologist who was blinded to the experiment. A semiquantitative scoring system was used to assess the severity of hepatic steatosis and necroinflammation in 10 microscopic fields examined at 200× magnification as described previously [28]. Steatosis was scored as the percentage of parenchymal cells containing fat: 0 = no parenchymal cells containing fat, 1 = < 20% of parenchymal cells containing fat, 2 = 20–39% of parenchymal cells containing fat, 3 = 40–50% of parenchymal cells containing fat, and 4 = > 51% of parenchymal cells containing fat. Inflammation and necrosis were scored by the number of foci of inflammation and necrosis identified under a low-power field of a light microscope: 0 = no inflammation and necrosis, 1 = 1 focus of inflammation and necrosis per low-power field, 2 = 2 foci of inflammation and necrosis per low-power field, and 3 = 3 foci of inflammation and necrosis per low-power field.

**Nuclear transcription factor-κB activity measurement**

Nuclear extracts of livers from the above-mentioned groups were prepared using the nuclear extraction kit (Active Motif; Cat. No. 40010). In brief, the liver (0.5 g) was pulverized under liquid nitrogen. Powdered tissue was suspended in hypotonic buffer containing a protease inhibitor cocktail, phosphatase inhibitors, EDTA, and detergent (Active Motif). Samples were dounce homogenized, incubated on ice for 15 min, and then centrifuged (850 × g, 10 min, 4 °C). The pellet was suspended in hypotonic buffer containing detergent and then centrifuged (14000 × g, 30 s, 4 °C). The resulting pellet was suspended in lysis buffer and incubated on ice for 30 min, and then nuclear extracts were obtained by centrifugation (14000 × g, 10 min, 4 °C). Twenty micrograms of nuclear extract were used for the determination of NF-κB activity with the TransAM® NF-κB p65 transcription factor assay kit (Active Motif; Cat. No. 40096), according to the manufacturer’s instructions.

**Western blotting**

Liver tissues were homogenized in 1 mL of ice-cold hypotonic buffer A [10 mmol/L HEPES (pH 7.8), 10 mmol/L KCl, 2 mmol/L MgCl2, 1 mmol/L DTT, 0.1 mmol/L EDTA, 0.1 mmol/L phenylmethylsulfonylfluoride]. The cells were then lysed with 12.5 µL 10% Nonidet P-40. The homogenate was centrifuged and the supernatant containing the cytoplasmic extracts was stored frozen at −80 °C. The nuclear pellet was resuspended in 25 µL ice-cold nuclear extraction buffer. After 30 min of intermittent mixing, the extract was centrifuged, and the supernatants containing nuclear extracts were secured. Before immunoblotting, the protein concentration of each tissue was determined using a Bio-Rad protein assay kit (Bio-Rad Laboratories).
and 5 independent experiments. This adjusted mean value. Tissue sections were sampled from four All experimental sample values were then expressed relative to the manufacturer TBST washes, the immunoreactive bands were visualized by en- permed using ATTO Densitograph Software (ATTO Corporation). Analysis of mRNA expression of hepatic genes Total RNA was extracted from 100 mg frozen liver samples using Trizol reagent (Invitrogen). RNA was quantified by A260 and its integrity verified by agarose gel electrophoresis using ethidium bromide for visualization. For the reverse transcriptase reaction, 1 µg of total RNA per sample and 8.5 µg/µL random hexamer pri- mers were heated at 65 °C for 5 min and then quenched on ice. This mixture was combined with 500 µmol/L each of dATP, dTTP, dCTP, and dGTP, 10 mmol/L DTT, 20 mmol/L Tris–HCl (pH 8.4), 50 mmol/L KCl, 5 mmol/L MgCl2, 40 units of RNaseOUT™ re- combinant ribonuclease inhibitor (Invitrogen), and 100 units SuperScript III reverse transcriptase (Invitrogen). Samples were subjected to DNase (Promega) treatment at 37 °C for 20 min in a GeneAmp 9700 Thermal Cycler (Applied Biosystems) and then held at 4 °C. After the aliquots were taken for immediate use in PCR, the remainder of the cDNA was stored at −20 °C. mRNA expression was measured by real-time quantitative reverse transcrip- tion polymerase chain reaction (RT-PCR) in a fluorescent temperature Lightcycler 480 (Roche Diagnostics). The following primer sequences were used: 5′-TCAACAACAAAGACATGTACT- TCCCTGGCC-3′ (forward) and 5′-GGTTCCTGGTCTAGCTG- GTTCTGTG-3′ (reverse) for SREBP-1c; 5′-GCTGGTCTATACTGAGA- CATGTT-3′ (forward) and 5′-GCCCTCTGAAGACTGAAGAA-3′ (re- verse) for FAS; 5′-CTGTAAGAAACCCCGAAGACGAA-3′ (for- ward) and 5′-GTGACCATACATCCTCGT-3′ (reverse) for ACC; 5′-CTGCCGTGCTACTCTAG3′-forward and 5′-CCTGTA- CATTTCTGTCTAGGC-3′ (reverse) for PPAR α; 5′-ATGGCGA- GAGGCTCACAATGGC-3′ (forward) and 5′-CCTCCTGTGAC- CAACAATGTG-3′ (reverse) for CPT-1; 5′-ACTATATTGCTGCCAAT- TTTGTT-3′ (forward) and 5′-CTGGCCATGTTCTCAACCC-3′ (re- verse) for ACO; 5′-TGATGCTGAGATGGTCG-3′(forward) and 5′-TGTAGATGACGCGATTTCC-3′ (reverse) for β-actin. Pri- mers were designed using Primer Express Software version 2.0 System (Applied Biosystems). The PCR reaction was performed using the following cycling protocol: 95 °C for 5 min, followed by 45 cycles of 95 °C for 5 s, 58 °C for 15 s, and 72 °C for 20 s. Dissoci- ation curves were run after amplification to identify the specific PCR products. The mRNA expression levels were normalized to β- actin mRNA levels and calculated according to the delta-delta Ct method [29]. Statistical analysis Data are expressed as the mean ± standard deviation (S.D.). Statisti- cal analysis was performed with one-way analysis of variance (ANOVA, Dunnett range post hoc comparisons were used to de- termine the source of significant differences, where appropriate. For the histological study, a nonparametric Kruskal-Wallis test was performed and Mann-Whitney’s U test was used to compare data within the groups. The SigmaPlot (Version 11.0) program was used for statistical analysis. A p value < 0.05 was considered statistically significant. Acknowledgements ▼ The present study was supported by a grant from the National Science Council Grant (Grant No: NSC 102–2320-B-127-001- MY3) of Taiwan. Conflict of Interest ▼ No competing financial interests exist. References 1 Neuschwander-Tetri BA, Caldwell SH. Nonalcoholic steatohepatitis: summary of an AASLD Single Topic Conference. Hepatology 2003; 37: 1202–1219 2 Asrili M, Jornayvaz FR. Inflammation as a potential link between non- alcoholic fatty liver disease and insulin resistance. J Endocrinol 2013; 218: R25–R36 3 Mittal S, El-Serag HB. Epidemiology of hepatocellular carcinoma: con- sider the population. J Clin Gastroenterol 2013; 47: S2–S6 4 Day CR James OF. Steatohepatitis: a tale of two “hits”? Gastroenterology 1998; 114: 842–845 5 Yu BY. Exploration on the modern research methodology of traditional Chinese medicine; basing on the systemic research of Radix Ophiopog- on. Chin J Nat Med 2007; 5: 10–14 6 Bensky D, Clavey S, Stoger E, Gamble A. Chinese herbal medicine materia medica, third edition. Seattle: Eastland Press; 2004 7 Capra C. Pharmacology and toxicology of some components of Ruscus aculeatus. Fitoterapia 1972; 43: 99–113 8 Bouskela E, Cyrino EZ, Marcellin G. Possible mechanisms for the inhib- itory effect of Ruscus extract on increased microvascular permeability induced by histamine in hamster cheek pouch. J Cardiovasc Pharmacol 1994; 24: 281–285 9 Kou JP, Tian YQ, Tang YK, Yan J, Yu BY. Antithrombotic activities of aque- ous extract from Radix Ophiopogon japonicus and its two constituents. Biol Pharm Bull 2006; 29: 1267–1270 10 Huang YL, Kou JP, Ma L, Song JX, Yu BY. Possible mechanism of the anti- inflammatory activity of ruscogenin: role of intercellular adhesion molecule-1 and nuclear factor-kappaB. J Pharmaco Sci 2008; 108: 198–205 11 Sun Q, Chen L, Gao M, Jiang W, Shao F, Li J, Wang J, Kou J, Yu B. Ruscoge- nin inhibits lipopolysaccharide-induced acute lung injury in mice: in- volvement of tissue factor, inducible NO synthase and nuclear factor (NF)-κB. Int Immunopharmacol 2012; 12: 88–93 12 Bhathena J, Kulamnarva A, Martoni C, Urbanska AM, Malhotra M, Paul A, Prakash S. Diet-induced metabolic hamster model of nonalcoholic fatty liver disease. Diabetes Metab Syndr Obes 2011; 4: 195–203 13 Kostapanos MS, Koi A, Elisaf MS. Current role of lfenofibrate in the preven- tion and management of non-alcoholic fatty liver disease. World J Hepatol 2013; 5: 470–478 14 Braunersreuther V, Viviani GL, Mach F, Montecucco F. Role of cytokines and chemokines in non-alcoholic fatty liver disease. World J Gastroen- terol 2012; 18: 727–735
19 Jensen-Urstad AP, Semenkovich CF. Fatty acid synthase and liver triglyceride metabolism: housekeeper or messenger? Biochim Biophys Acta 2012; 1821: 747–753

Lu H-J et al. Ruscogenin Protects against... Planta Med 2014; 80: 870–879