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Rg3-enriched Korean Red Ginseng enhances blood pressure stability in spontaneously hypertensive ratsHarsha Nagar^{a,1}, Sujeong Choi^{a,1}, Saet-byel Jung^b, Byeong Hwa Jeon^a, Cuk-Seong Kim^{a,*}^a Department of Physiology, BK21Plus CNU Integrative Biomedical Education Initiative, School of Medicine, Chungnam National University, Daejeon, Korea^b Department of Endocrinology, Chungnam National University Hospital, Daejeon, Korea

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ABSTRACT

Background: Korean Red Ginseng (*Panax ginseng*) has been shown to exert antihypertensive effects. In particular, ginsenoside Rg3 is thought to be a potent modulator of vascular function. The present study was performed to examine the antihypertensive efficacy of Korean Red Ginseng (KRG) extract and Rg3-enriched KRG (REKRG) extract.

Methods: Spontaneously hypertensive rats (SHRs) and Wistar–Kyoto rats (WKYs) were divided into six groups (WKY control, WKY-KRG, WKY-REKRG, SHR control, SHR-KRG, and SHR-REKRG), and systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured at the carotid artery, followed by injection of 3 mg/kg KRG or 3 mg/kg REKRG.

Results: REKRG treatment significantly decreased SBP and DBP 3 hours post-treatment in the SHR group compared with SHR control group. However, SBP and DBP were not significantly different in KRG-treated SHRs compared with control SHRs. REKRG treatment did not significantly alter SBP or DBP 3 hours post-treatment in the WKY group compared with WKY control group. Similarly, there were no differences in SBP or DBP with KRG treatment in the WKY group and WKY control group. Both KRG and REKRG increased endothelial nitric oxide synthase phosphorylation levels in the aorta, and the increases in endothelial nitric oxide synthase phosphorylation levels by REKRG treatment were higher than those with KRG treatment. Similarly, nitric oxide production in plasma from WKYs and SHRs was also increased by both KRG and REKRG.

Conclusion: These results suggest that REKRG has a more beneficial effect on blood pressure control than KRG in SHRs.

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1. Introduction

Korean Red Ginseng (*Panax ginseng*) is a traditional Korean tonic medicine known for its efficacy in promoting physical strength and immunity, which may ameliorate certain chronic disease states such as vascular disease and hypertension.¹ Ginsenosides as a biologically effective extract of *P. ginseng* are a mixture of triterpene glycosides. The major fractions of ginsenosides consist of two groups according to chemical structure: the panaxadiol group is represented by Rb1, Rb2, Rb3, Rc, Rd, Rg3, Rh2, and Rs1, while the panaxatriol group consists of Re, Rf, Rg1, Rg2, and Rh1. Ginsenosides are well known to have hypotensive effects in experimental animals and hypertensive patients.^{2–4} Moreover, they enhance cardiovascular functions associated with vasorelaxation and stimulation of nitric oxide (NO) production from endothelial NO synthase (eNOS).^{3,5} Recently, individual ginsenosides have been shown to have different effects via various mechanisms in many tissues. In addition, studies of vascular disease are focusing on purified individual ginsenoside fractions from ginseng to identify the key components instead of using mixed ginsenosides. Among the ginsenosides of the panaxadiol and panaxatriol groups, ginsenoside Rg3 is a potent vasodilator that has been shown to provide vascular protective effects, such as antivasular contraction and antihypertensive effects as well as enhancement of NO production and eNOS activity.^{2,6,7} Previously, we also showed that Rg3 improved vascular function through eNOS activation.²

NO is a major endothelium-dependent relaxing factor, and its production by vascular endothelial cells plays a critical role in the regulation of vascular motor tone and stability of blood flow as well as blood pressure.^{8,9} NO is synthesized by the vascular endothelial cells using L-arginine as a substrate in a process catalyzed by NOS¹⁰ and induces vascular smooth muscle relaxation by activation of guanylate cyclase.¹¹ Because it is an isoform of NOS that produces NO, eNOS also plays an important role in regulating systemic blood pressure.¹² Previous studies have shown that a decrease in NO production can lead to hypertension,¹³ and eNOS mutation leads to impaired endothelium-dependent vasorelaxation and may have hypertensive effects.¹⁴ In addition, blood pressure was enhanced in rats in which eNOS was inhibited with N ω -nitro-L-arginine methyl ester.¹⁵ Recent studies have suggested that production of NO is reduced and endothelium-dependent vasorelaxation is blunted in patients with essential hypertension.¹⁶

Previous studies have shown the effects of *P. ginseng* on vascular regulation and blood pressure control, and effects of total ginsenosides and Rg3 on eNOS activation and NO production. However, there is no previous study for comparison between KRG and Rg3-enriched KRG (REKRG). Therefore, in this study, the efficacy of total ginsenoside (KRG) and REKRG was compared in Wistar–Kyoto rats (WKYs) and spontaneously hypertensive rats (SHRs). We examined the enhancement of blood pressure stability, eNOS phosphorylation and NO production by REKRG in SHRs compared with WKYs.

2. Methods

2.1. Preparation of REKRG

Dried KRG (*P. ginseng*) root was purchased from Gumsan Nonghyup (Gumsan, Korea). Korean ginseng was extracted twice with 10 volumes of ethanol at 50°C for 7 hours (1st 50%, 2nd 85%), and then concentrated under vacuum at 50°C as described previously.² The crude extract was dissolved in water, and enzyme–acid hydrolysis was performed to maximize ginsenoside Rg3 (raw ginsenoside was hydrolyzed to Rg3) under acidic (pH 2.5–3.5) and thermophilic (65–80°C) conditions. The enzyme, which has β -glycosidase activity including cellulose, hemicellulose, and glucosidase activities, was produced by *Aspergillus niger*. To remove the acid solution and concentrate Rg3, the reactant was passed through a column packed with DIAION HP20 resin (Mitsubishi Chemical Industries, Tokyo, Japan). The ginsenoside Rg3, kindly provided by BTGin Corporation (Occheon, Korea), was concentrated to powder under vacuum.

2.2. Animals and blood pressure measurements

Male 10–12-week-old SHRs and WKYs weighing 250–320 g were purchased from Central Lab. Animal Inc. (Seoul, Korea). SHRs and WKYs were randomly divided into six groups: WKY control, WKY-KRG, WKY-REKRG, SHR control, SHR-KRG, and SHR-REKRG, and systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured at the carotid artery for 3 hours, followed by jugular vein injection of 3 mg/kg KRG or 3 mg/kg REKRG, as described previously.¹⁷ Animals were raised under conditions of controlled lighting (06:00–18:00 hours daily) and temperature (24 \pm 1°C). Rats were anesthetized with urethane (1,200 mg/kg), and the left common carotid artery was cannulated with a cannula prefilled with heparinized normal saline (0.5 IU/mL) to measure arterial blood pressure. The arterial pressure was determined using a student physiography/data system (ADInstruments, Dunedin, New Zealand) and analyzed using Chart Pro software (ADInstruments). The jugular vein was cannulated for administration of saline as well as REKRG or KRG.

2.3. Western blotting

Anti-phospho-eNOS antibody was purchased from Cell Signaling (Beverly, MA, USA). Anti-NOS3 antibody was purchased from Santa Cruz Biotechnology (Santa Cruz, CA, USA). Western blotting analysis was performed by adding 30 μ g tissue homogenate (obtained from rat aorta) to SDS–PAGE loading buffer followed by boiling and separation by electrophoresis and transfer onto nitrocellulose membranes. After incubation with appropriate primary and peroxidase-conjugated secondary antibodies (Santa Cruz Biotechnology), the chemiluminescent signal was developed using Super Signal West Pico or Femto Substrate from Thermo Fisher Scientific (Rockford, IL, USA). Blots were imaged and band densities quantified with a Gel Doc 2000 Chemi Doc system using

Quantity One software (Bio-Rad, Hercules, CA, USA). Values were normalized relative to β -actin loading control.

2.4. Nitrite and nitrate measurements

NO metabolites nitrite (NO_2^-) and nitrate (NO_3^-), the stable breakdown products of NO, were quantified using a commercially available kit (Nitrate/nitrite Fluorometric Assay Kit; Cayman Chemicals, Lexington, KY, USA). Plasma obtained from rat blood was deproteinized using a 10-kDa cutoff filter (Microcon YM10; Millipore, Bedford, MA, USA). After subtraction of background fluorescence, values were normalized to determine the total protein level.

2.5. Statistical analysis

All experiments were performed at least three times. Statistical analysis was performed using SPSS version 13.0 (SPSS Inc., Chicago, IL, USA). Data are presented as the mean \pm standard deviation. Statistical significance was determined by analysis of variance followed by the multiple comparison test with Bonferroni adjustment. In all analyses, $p < 0.05$ was taken to indicate statistical significance.

3. Results

3.1. REKRG reduces BP of SHRs

In our previous study, we showed that the concentration of ginsenoside Rg3 in REKRG is ~ 300 -fold higher than that in KRG, and that REKRG improves impaired endothelium-dependent vasorelaxation in the aorta in SHRs.² In this study, we examined the effects of REKRG or KRG treatment on SBP and DBP in SHRs and WKYs. For this, REKRG and KRG were injected into the jugular vein of SHRs and WKYs at a dose of 3 mg/kg and the blood pressure was recorded for 3 hours. Measurements were taken at baseline and then at 30 minutes, 1 hour, 90 minutes, 2 hours, 150 minutes, and 3 hours. Many previous studies have shown that ginsenosides reduce BP via increases in the production of endothelial NO,⁷ and that Rg3 is the most potent ginsenoside that activates eNOS in the rat aorta. As shown in Fig. 1, administration of both KRG and REKRG to WKYs caused no changes in either SBP (Fig. 1A) or DBP (Fig. 1B) recorded from 0 hours to 3 hours following treatment. By contrast, administration of REKRG caused significant decreases in both SBP and DBP in SHRs (Figs. 2A and 2B) starting as early as 30 minutes post-treatment of REKRG. However, both SBP and DBP were unaffected by administration of KRG in SHR.

3.2. REKRG stimulates phosphorylation of eNOS

eNOS serves an important basal regulatory function in the vasculature. When subjected to stimuli, such as shear stress or acetylcholine, eNOS constitutively expressed in endothelial cells oxidizes L-arginine to generate L-citrulline and NO. Rg3 is one of the major biologically active components of ginseng and is regarded as the main compound responsible for its many pharmacological actions, including enhancement

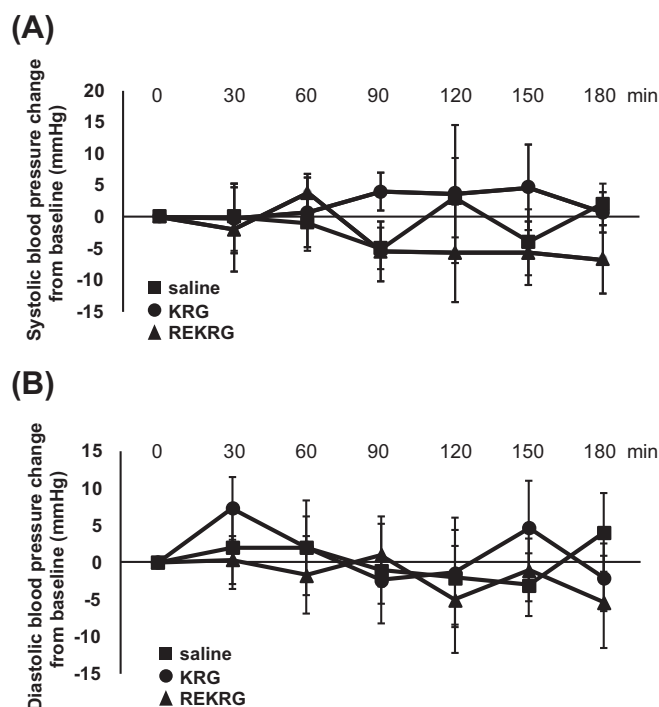


Fig. 1 – Acute effects of Rg3-enriched Korean Red Ginseng extract (REKRG) on changes in blood pressure in Wistar-Kyoto rats (WKYs). Korean Red Ginseng extract (KRG) and REKRG were injected intravenously at 3 mg/kg, and both systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured in WKYs for 3 hours. (A) KRG and REKRG did not significantly alter SBP compared with controls. ($n = 6$). (B) KRG and REKRG did not significantly alter DBP compared with controls. ($n = 7$).

of eNOS phosphorylation and NO production. We examined eNOS phosphorylation by western blotting analysis of tissue homogenate from the aortas of both WKYs and SHRs after administration of KRG or REKRG. As shown in Fig. 3A, administration of both KRG and REKRG stimulated Ser-1177 phosphorylation of eNOS in WKYs. Similarly, Ser-1177 phosphorylation of eNOS was also increased in SHRs after administration of KRG and REKRG (Fig. 3B), but the overall level of phosphorylation was higher in SHRs than in WKYs. In addition, the efficiency of REKRG to stimulate eNOS phosphorylation was much higher than that of KRG in both groups.

3.3. REKRG stimulates production of NO

NO is an endothelium-derived relaxing factor that plays an important role in the control of vascular tone and vascular functions. The synthesis of NO by the vascular endothelium is responsible for vasodilator tone, which is essential for the regulation of BP. High BP is characterized by deficiency of eNOS and decreased NO production, especially in the endothelium. Therefore, we measured the plasma levels of NO in WKYs and SHRs after administration of KRG or REKRG. As expected, administration of both KRG and REKRG stimulated NO production in WKYs and SHRs (Figs. 4A and 4B). The

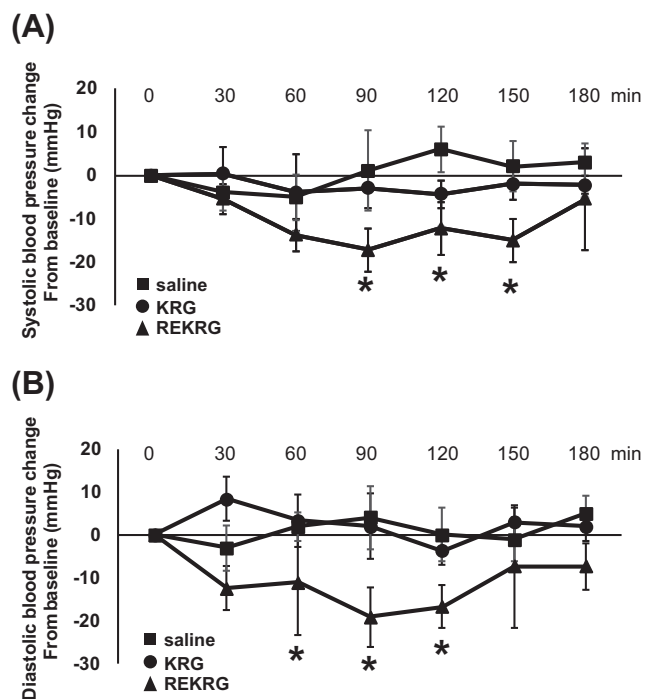


Fig. 2 – Acute effects of Rg3-enriched Korean Red Ginseng extract (REKRG) on changes in blood pressure in spontaneously hypertensive rats (SHRs). Korean Red Ginseng extract (KRG) and REKRG were injected intravenously at 3 mg/kg, and both systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured in SHRs for 3 hours.

(A) REKRG significantly decreased SBP compared with controls. However, KRG did not. (B) REKRG significantly decreased DBP compared with controls. However, KRG did not.

Data are presented as mean \pm standard deviation ($n = 6$ or $n = 7$).

*** $p < 0.05$ compared with control.**

efficiency of REKRG to stimulate NO production was higher than that of KRG in both groups. These results suggest that REKRG stimulates the eNOS signaling pathway, leading to its phosphorylation, which in turn leads to an increase in NO production in SHR.

4. Discussion

High BP is one of the major risk factors for the development of vascular diseases such as atherosclerosis, coronary heart disease, and stroke,¹⁸ and several studies have reported cardiovascular risks associated with elevated BP.^{19,20} High BP is related to morphological changes and impaired function of vascular smooth muscle and endothelial cells. The beneficial effects of ginsenosides have been widely studied and shown to have new antihypertensive effects³ and prevent or ameliorate various diseases, including atherosclerosis, cancer, and thrombosis.^{21–23} In this study, we demonstrated that REKRG increased eNOS phosphorylation and NO production and decreased BP in SHRs. These results indicate that REKRG

administration has the potential to stabilize BP and prevent cardiovascular disease.

Several recent studies regarding cardiovascular disease focused on purified individual ginsenoside components of ginseng to show specific mechanisms instead of using whole ginseng extracts. Various components of whole ginseng extracts (i.e., ginsenosides Rg3, Rb1, and Re) display antihypertensive and cardiovascular protective effects.^{7,24} Therefore, they are considered potential components for vascular protection. In particular, ginsenoside Rg3 has been studied extensively because it is the most potent vasodilator among the ginsenosides characterized to date. For example, Rg3 induces endothelium-independent vasorelaxation through inhibition of vascular smooth muscle tone by prevention of Ca^{2+} influx and stimulation of K^+ efflux.⁷ Moreover, it stimulates vascular-endothelium-derived NO and induces vasodilation in the rat aorta.^{23,24} Another important factor is that it can be easily extracted from red ginseng by a steaming and drying process. Processed ginseng, which contains high levels of Rg3, has emerged as a health-supporting agent in some East Asian countries, including Korea and China. In this study, we further investigated the vasoactive efficacy of the selected ginsenosides on vascular function and compared the effects of ginsenosides to two major isolated fractions (KRG and REKRG). In our previous study, we analyzed 11 ginsenosides (Rg1, Re, Rf, Rh1, Rg2, Rb1, Rc, Rb2, Rg3, Rk1, and Rg5) by high-performance liquid chromatography.² The REKRG fraction was shown to contain Rg1, Re, Rf, Rh1, Rg2, Rb1, Rc, Rb2, Rg3, Rk1, and Rg5 at levels of 0.6 mg/g, 1.9 mg/g, 12.3 mg/g, 5.0 mg/g, 4.2 mg/g, 3.8 mg/g, 1.2 mg/g, 1.0 mg/g, 100.0 mg/g, 12.0 mg/g, and 21.0 mg/g, respectively, while the levels in KRG were 2.9 mg/g, 4.2 mg/g, 0.3 mg/g, 0.1 mg/g, 0.2 mg/g, 5.9 mg/g, 2.2 mg/g, 2.1 mg/g, 0.3 mg/g, 0.05 mg/g, and 0.12 mg/g, respectively. These results indicate that the concentration of ginsenoside Rg3 in REKRG is ~ 300 -fold greater than that in KRG. We showed that REKRG improved endothelium-dependent vasorelaxation in the WKYs and SHRs compared with controls, and that REKRG treatment for 6 weeks reduced the mean aortic intima-media thickness compared with controls. The results of the present study also indicate that REKRG stimulates endothelium-dependent vasorelaxation through not only eNOS phosphorylation but also NO production. Although REKRG did not significantly decrease BP in WKYs, it markedly decreased BP in SHRs. In addition, REKRG has a greater antihypertensive effect than KRG at the same dose even though KRG is known to have an effect on high BP. Therefore, these data suggest that Rg3 is the principal pharmacologically active component of KRG and that it could be an excellent candidate for use in antihypertensive therapy.

One of the limitations of our study was that we measured the BP of rats under anesthesia. It has been shown previously that anesthesia itself can have an influence on cardiovascular function.²⁵ Anesthetic drug administration has an effect on the autonomic nervous system, thus limiting the evaluation of changes in BP. Therefore, in this study, administration of KRG or REKRG to the rats under anesthesia may have caused changes in parameters, such as heart rate, resulting in tachycardia or bradycardia in anesthetized rats as a compensation against hypotension by the decrease of

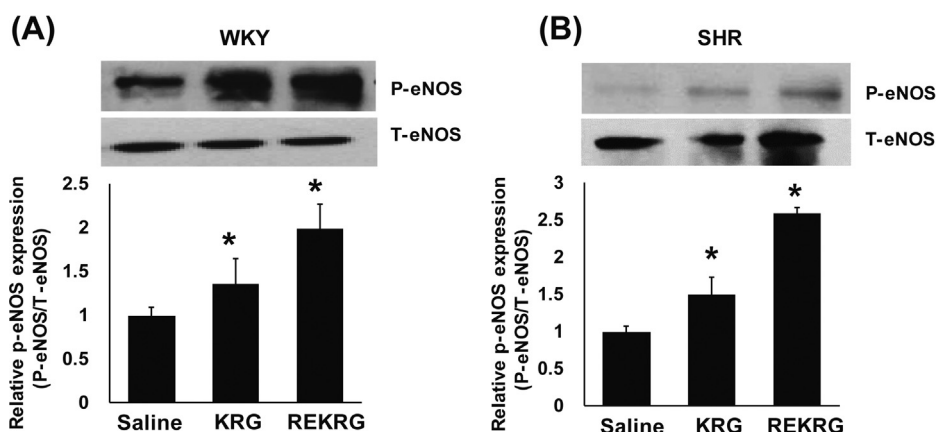


Fig. 3 – Effects of Rg3-enriched Korean Red Ginseng extract (REKRG) on phosphorylation of endothelial nitric oxide synthase (eNOS). The phosphorylation of eNOS was measured in the aorta 3 hours after intravenous injection of Korean Red Ginseng extract (KRG) and REKRG 3 mg/kg.

(A) REKRG and KRG significantly increased eNOS phosphorylation compared with saline control in Wistar Kyoto rat (WKY). The levels of eNOS phosphorylation were quantified by densitometric analysis (lower panels). (B) REKRG and KRG significantly increased eNOS phosphorylation compared with saline control in spontaneously hypertensive rat (SHR). The levels of eNOS phosphorylation were quantified by densitometric analysis (lower panels) western blots shown are representative of three independent experiments.

Data are presented as mean \pm standard deviation ($n = 6$ or $n = 7$).

* $p < 0.05$ compared with control.

peripheral resistance.³ Similarly, KRG or REKRG administration may also cause a decrease in heart contractility directly in anesthetized rats because rats under anesthesia may have reduced nervous reflex control and synaptic transmission in the autonomic nervous system.

NO is a radical generated from L-arginine by NOS, which plays a critical role as a second messenger in cell signaling.¹⁰ Low levels of NO produced and released by the endothelial cells play critical roles in the maintenance of basal vascu-

lar tone. Some biochemical stimuli, such as thrombin, ADP, serotonin, acetylcholine, and bradykinin, as well as mechanical stimuli including shear stress and cyclic strain, result in increased synthesis of endothelial NO. Previous studies have shown a relationship between NO and hypertension. Inhibition of NO synthesis in the vasculature may lead to hypertension or ischemic stroke, likely through its effects on vascular tone. NO produced by vascular endothelial cells has been implicated in many of the effects of ginsenosides, including those on vessel relaxation, protection of the cardiovascular system, and antithrombotic and antiplatelet effects.^{23,26}

Various factors can inhibit NO synthesis; one of which is excessive production of reactive oxygen species (ROS) by endothelial cells. ROS refers to oxygen radicals such as superoxide anion, hydroxyl radical, hydrogen peroxide, and peroxynitrite.²⁷ Studies over the past decade have indicated that ROS generated by endothelial cells play key roles in the signaling mechanisms and affect vascular homeostasis. Endothelial cells are not only major sources but also targets of ROS. Among the various ROS species, the superoxide anion destroys most of the NO²⁸ and further increases oxidative stress.²⁹ The superoxide anion level has also been shown to be increased in endothelial cells in SHRs,³⁰ which scavenges NO as soon as it is produced. Similarly, concentrations of superoxide anions produced by the aortic rings from SHRs were greater than those produced by these structures from WKYs.³¹ Our results were consistent with this observation and showed that the level of NO production under basal conditions in WKYs was higher than that in SHRs because increased ROS in SHRs immediately destroyed endothelium-derived NO. Some previous reports have demonstrated the antihypertensive effect of REKRG in human randomized control trials.^{32,33} Our results demonstrate the antihypertensive effect of REKRG in compar-

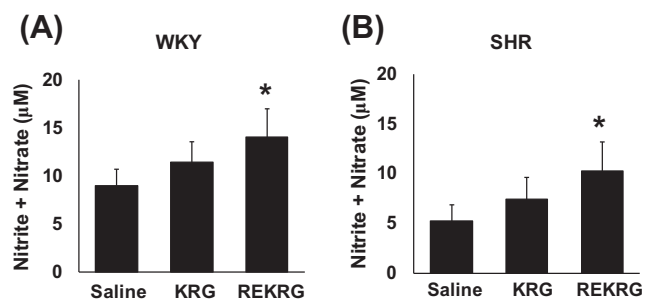


Fig. 4 – Effects of Rg3-enriched Korean Red Ginseng extract (REKRG) on nitric oxide (NO) production. Metabolites of NO (nitrite and nitrate) were measured in the plasma of rats 3 hours after intravenous injection of Korean Red Ginseng extract (KRG) and REKRG 3 mg/kg.

(A) REKRG significantly increased NO production compared with saline control in Wistar Kyoto rat (RAT). (B) REKRG significantly increased NO production compared with saline control in spontaneously hypertensive rats (SHR).

Data are representative of three independent experiments and are presented as mean \pm standard deviation.

* $p < 0.05$ compared with control.

ison to KRG in a rat model and we provide the mechanistic pathway for its antihypertensive effect. We show that the vasodilatory effect of REKRG is endothelium dependent, and eNOS phosphorylation followed by NO production is the major contributory factor to the observed vascular dilatation shown in human trials.

In conclusion, the present results indicate that REKRG has a significant antihypertensive effect in SHR, which may be due to activation of eNOS and stimulation of NO production, and that REKRG intake may be beneficial for individuals with high risks of hypertension and cardiovascular diseases.

Conflicts of interest

No competing financial interests exist.

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