

Short communication

Protective effect of resveratrol on arsenic trioxide-induced nephrotoxicity in rats

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BACKGROUND/OBJECTIVES: Arsenic, which causes human carcinogenicity, is ubiquitous in the environment. This study was designed to evaluate modulation of arsenic induced cancer by resveratrol, a phytoalexin found in vegetal dietary sources that has antioxidant and chemopreventive properties, in arsenic trioxide (As₂O₃)-induced Male Wistar rats.

MATERIALS/METHODS: Adult rats received 3 mg/kg As₂O₃ (intravenous injection, iv.) on alternate days for 4 days. Resveratrol (8 mg/kg) was administered (iv.) 1 h before As₂O₃ treatment. The plasma and homogenization enzymes associated with oxidative stress of rat kidneys were measured, the kidneys were examined histologically and trace element contents were assessed.

RESULTS: Rats treated with As₂O₃ had significantly higher oxidative stress and kidney arsenic accumulation; however, pretreatment with resveratrol reversed these changes. In addition, prior to treatment with resveratrol resulted in lower blood urea nitrogen, creatinine and insignificant renal tubular epithelial cell necrosis. Furthermore, the presence of resveratrol preserved the selenium content (0.805 ± 0.059 µg/g) of kidneys in rats treated with As₂O₃. However, resveratrol had no effect on zinc level in the kidney relative to As₂O₃-treated groups.

CONCLUSIONS: Our data show that supplementation with resveratrol alleviated nephrotoxicity by improving antioxidant capacity and arsenic efflux. These findings suggest that resveratrol has the potential to protect against kidney damage in populations exposed to arsenic.

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Keywords: Arsenic, resveratrol, trace element, arsenic efflux

INTRODUCTION

Humans are commonly exposed to arsenic, which is incorporated into food, drinking water, soil, dust, smoke and air [1,2]. Arsenic is known to be a potent carcinogen that can induce the formation of various types of solid tumors, including lung, prostate, bladder, renal, and skin cancers, as well as other malignancies via inhibition of oxidative phosphorylation, interference with cell signaling by binding to hormone receptors, or generation of reactive oxygen species (ROS) [3,4]. Conversely, arsenic has been used for the treatment of various diseases since 400 BC, and it is currently employed as an effective chemotherapeutic agent for the treatment of certain human cancers, such as acute promyelocytic leukemia (APL), non-APL acute myeloid leukemia cells, chronic myeloid leukemia cells, and some solid tumor cells. It is well known that the kidney is a primary target for the toxic effects of arsenic, as evidenced by clinical manifestations and biochemical alterations [5]. Unfortunately, patients being treated for APL also suffer from nephrotoxicity. Among several mechanisms, oxidative stress is a relatively common cause of arsenic toxicity in kidneys [2,5]. Studies have shown that natural antioxidant components could

lower the risk of cardiovascular diseases and several cancers and provide double protection from this disaster [6,7].

Resveratrol is a phytoalexin present in at least 72 plant species, many of which are consumed by humans, such as mulberries, peanuts, and grapes [8]. Numerous reports indicate that resveratrol has anti-inflammatory, antiplatelet, antioxidant, and anti-carcinogenic effects, as well as the ability to attenuate chemical compound-induced kidney injury [8,9]. However, it remains uncertain whether resveratrol can protect against arsenic-induced nephrotoxicity and its potential mechanism. Therefore, in this study, we investigated resveratrol, a novel option to protect arsenic trioxide (As₂O₃)-induced nephrotoxicity in rats.

MATERIALS AND METHODS

Chemicals

As₂O₃ was purchased from Harbin Yida (Harbin, China). Resveratrol (purity, > 99%) was purchased from Sigma-Aldrich (St. Louis, MO, USA). Commercial assay kits for malondialdehyde (MDA), superoxide dismutase (SOD), glutathione peroxidase (GPx), ROS, total sulfhydryl (-SH), and to determine the total

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glutathione (T-GSH) to oxidized glutathione (GSSG) ratio (T-GSH/GSSG) were bought from the Nanjing Jiancheng Bioengineering Institute (Nanjing, China).

Study animals and treatments

Male Wistar rats, aged 6-8 weeks, were obtained from the Experimental Animal Centre of Harbin Medical University (Harbin, China). The rats were grouped and housed in polyacrylic cages with not more than four animals per cage under controlled conditions of $25 \pm 2^\circ\text{C}$, $50 \pm 15\%$ relative humidity and normal photoperiod (12 h dark and light), during which time they were provided standard rodent chow (Table 1) and water *ad libitum*. The rats were allowed to acclimatize to the laboratory environment for 7 days prior to the study. All experiments were approved by the Ethics Committee on the Use and Care of Animals, Northeast Agricultural University (Harbin, China) with the following reference number: NEAU2011100145.

Thirty-two rats were randomly divided into four groups: control, As_2O_3 -treated, As_2O_3 + resveratrol, and resveratrol-treated. In the As_2O_3 group, rats were treated with As_2O_3 (3 mg/kg); in the As_2O_3 + resveratrol group, rats were given resveratrol (8 mg/kg) 1 h before As_2O_3 administration; the resveratrol group received 8 mg/kg body weight resveratrol. An equal amount of 0.9% normal saline was administered as a vehicle to control rats. All treatments were administered via the caudal vein on alternate days for 4 days (i.e., days 1, 3, 5, and 7) and measurements were made on the 8th day.

Sample collection

On the 8th day, rats were given ether anesthesia and euthanized. Blood samples were then collected by puncturing

Table 1. Diet composition

Ingredients (mg/kg)	
Ground corn (%)	67.6
Water (%)	10
Corn seed (%)	7
Peanut (%)	1.3
Corn oil (%)	0.5
Minerals, mg/kg	
Calcium	5000
Chloride	500
Copper	1.59
Iodine	0.15
Iron	28.84
Magnesium	44.13
Manganese	10
Phosphorus	3000
Selenium	0.15
Sodium	500
Zinc	12
Vitamins, mg/kg	
Vitamin A	0.7
Vitamin B-6	6
Vitamin B-12	0.05
Vitamin D	0.025
Vitamin E	15

the retro-orbital venous sinus. Samples were centrifuged ($4,000 \times g$ for 20 min, 20°C) and serum was prepared. Blood urea nitrogen (BUN) and creatinine (CRE) levels were assayed using UniCel Dx C800 Synchron (Bekman, USA). Additionally, kidneys were removed from the experimental rats at 4°C and small representative tissue slices were taken for histopathological examinations. A portion of the kidney was also used to estimate the tissue arsenic, zinc and selenium concentrations. The remainder of the kidney was washed with ice-cold saline and homogenized in 4 volumes of ice-cold 0.1M phosphate buffer (pH 7.4) containing 0.15 M potassium chloride. The homogenate was then centrifuged at $10,000 \times g$ at 4°C for 10min.

Analysis of oxidative stress and antioxidant defense

SOD and GPx activities, the content of MDA, ROS, and -SH and the T-GSH/GSSG ratio were measured using assay kits from Nanjing Jiancheng Bioengineering Institute (Nanjing, China) according to the manufacturer's protocol.

Light microscopy

Kidney samples were fixed (10% formalin for 24 h, 37°C), dehydrated, embedded in paraffin and cut into $5\mu\text{m}$ thick sections. The sections were then stained with hematoxylin and eosin, after which they were examined under a light microscope (BX-FM; Olympus Corp, Tokyo, Japan). A minimum of 10 fields for each kidney slide were examined and changes were scored as either none (-), mild (+), moderate (++) or severe (+++) damage.

Tissue total arsenic, zinc and selenium estimation.

Arsenic contents in the kidney tissues of all rats were analyzed according to the method described Csanaky and Gregus [10]. Briefly, a representative sample of kidney was digested three times with a mixture of deionized water, nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) until almost dry, after which the residual mass was dissolved in 1% HNO_3 . The arsenic content of the solution was then estimated using a hydride generation system within an atomic fluorescence spectrometry system.

The concentrations of zinc in kidney tissues were measured with a flame atomic absorption spectrophotometer using standards for zinc for comparison and analyzed according to the method described by Kucukatay *et al.* [11]. Blank and standard solutions were used for calibration of the atomic absorption spectrophotometer.

The selenium content in the tissues was estimated using a method previously described by Entwisle and Hearn [12]. The assay is based on the principle that the selenium contained in samples is converted to selenous acid in response to acid digestion. The reaction between selenous acid and aromatic-o-diamines leads to the formation of 4, 5-benzopiazselenol, which displays a brilliant lime-green fluorescence when excited at 366 nm in cyclohexane and measured by fluorescence spectrometry.

Statistical analysis

Statistical analyses were conducted using the SPSS19.0 computer program (SPSS, Chicago, IL, USA). One-way analysis of variance (ANOVA) followed by Dunnett's test was applied

to calculate the statistical significance between various groups. In all cases, a $P < 0.05$ was considered significant.

RESULTS

Effects of resveratrol on the antioxidant capacity in kidney

The SOD and GPx activities, MDA and ROS concentrations,

and T-GSH/GSSG ratio in kidneys from all groups are shown in Fig.1. In the As_2O_3 -treated group, the MDA and ROS content in the kidney were far higher than in the control group, but the activities of SOD and GPx were lower. However, pretreatment with resveratrol markedly reversed these alterations. Furthermore, the T-GSH/GSSG ratio (4.64 ± 0.48) in the As_2O_3 -treated group was significantly lower than that of the control

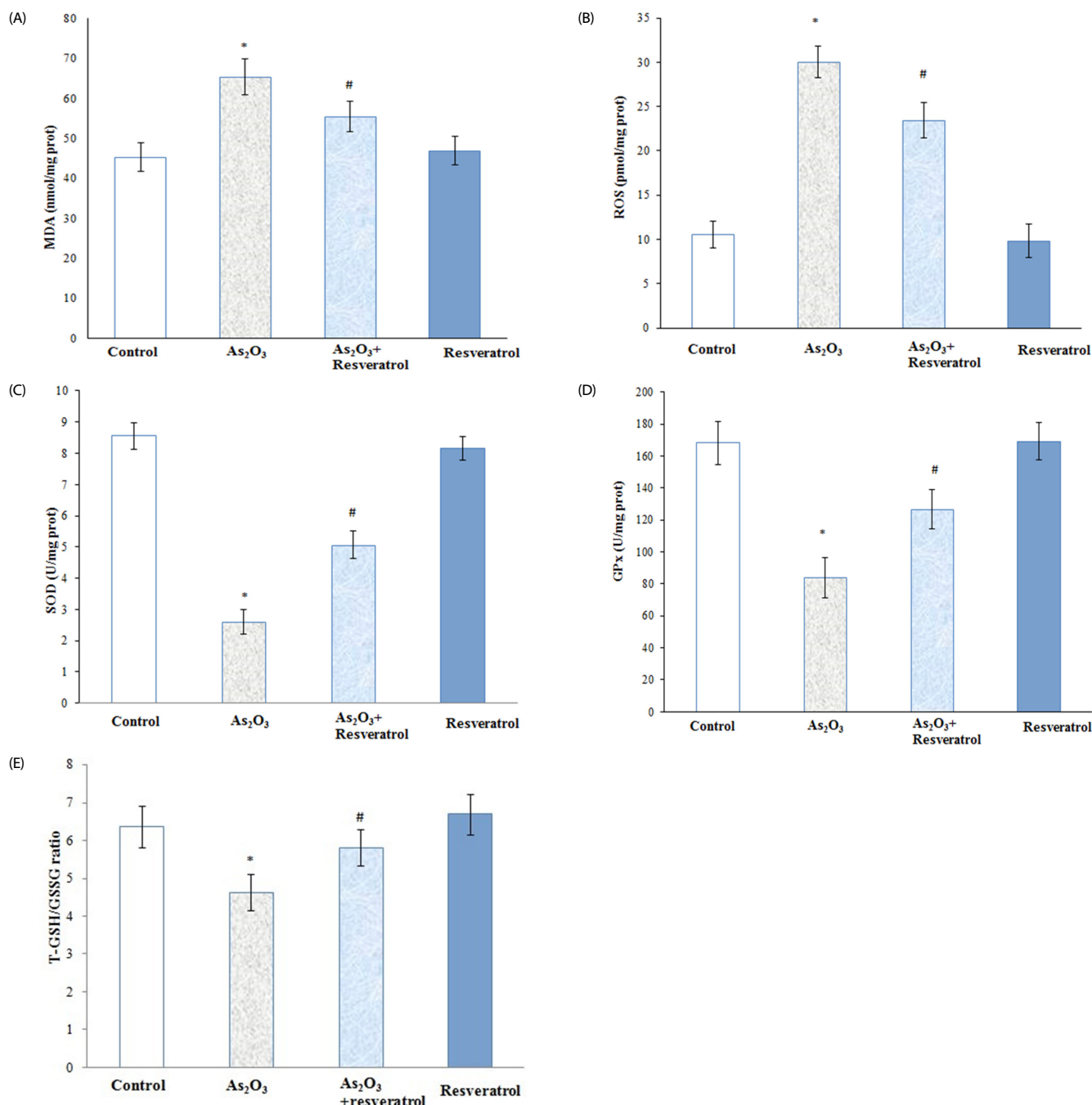


Fig. 1. Effect of resveratrol on ROS level and activities of antioxidant enzymes in kidneys of As_2O_3 -treated rats. (A) Level of MDA; (B) ROS Level; (C) SOD activity; (D) GPx activity; (E) T-GSH/GSSG ratio. Each value is expressed as the mean \pm SEM ($n = 8$). * $P < 0.05$ when compared with the control group; # $P < 0.05$ when compared with the As_2O_3 -treated group. MDA, malondialdehyde; ROS, reactive oxygen species; SOD, superoxide dismutase; GPx, glutathione peroxidase; T-GSH/GSSG, total glutathione to oxidized glutathione ratio.

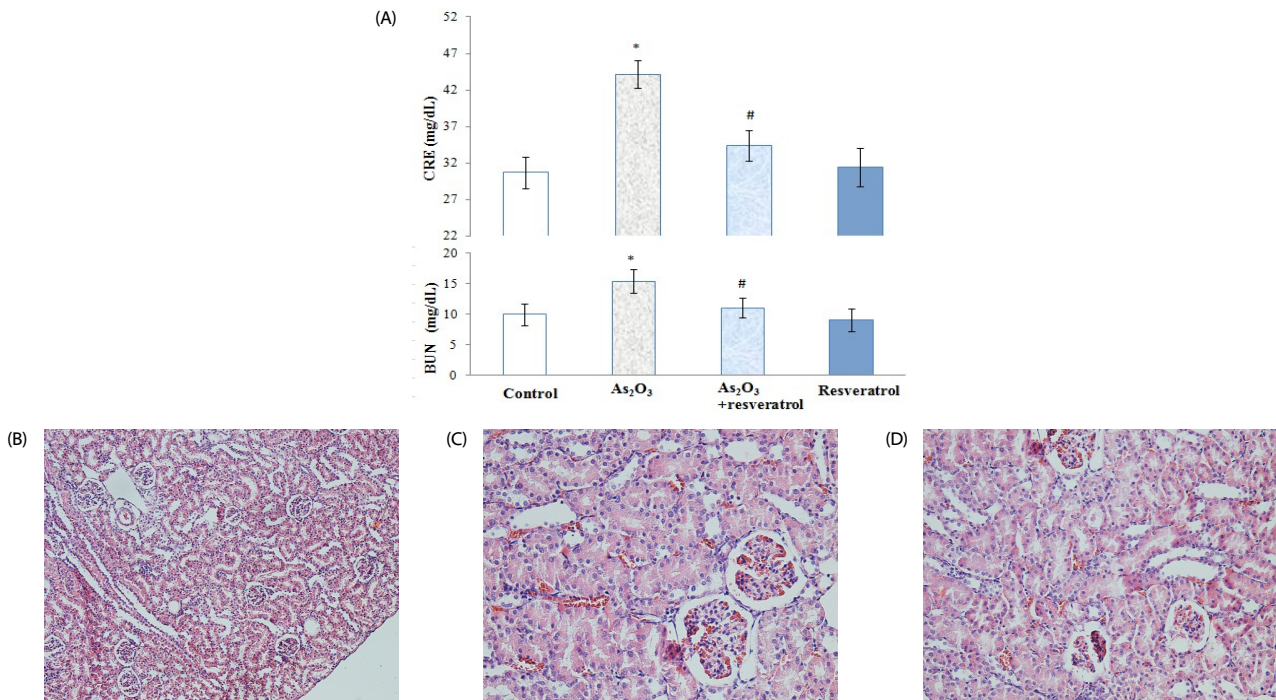


Fig. 2. Functional markers and morphological evaluation of rat kidneys. (A) BUN and CRE content in serum; (B) control rats; (C) As₂O₃-treated rats; (D) As₂O₃-treated rats with resveratrol. All values are expressed as the mean ± SEM (n = 8). * *P* < 0.05 when compared with the control group; # *P* < 0.05 when compared with the As₂O₃-treated group. Original magnification, 10×20

Table 2. Effect of resveratrol treatment on morphological changes as assessed by histopathological examination of the kidneys of rats exposed to As₂O₃.

Group	Cortex edema	Tubular cell swelling	Interstitial edema	Necrosis of epithelium	Glomeruli dilation and hyperemia
Control	-	-	-	-	-
As ₂ O ₃	++	+++	+++	++	+++
As ₂ O ₃ +resveratrol	+	++	++	+	++
Resveratrol	-	-	-	-	-

none (-), mid (+), moderate (++) , severe (+++)

group (6.36 ± 0.56). Conversely, resveratrol pre-administration (5.82 ± 0.47) significantly (*P* < 0.05) normalized content in the kidney (Fig. 1E).

Effects of resveratrol on histopathological study in kidney and renal biochemical alterations

The BUN (15.47 ± 1.91) and CRE (44.14 ± 1.90) levels were significantly increased following 4 days of alternating arsenic exposure (Fig. 2A); however, the administration of resveratrol led to a significant improvement in this value (11.86 ± 1.63; 34.40 ± 2.15, *P* < 0.05). The toxic effects of As₂O₃ were also confirmed by the detection of morphological alterations in kidney slices (Fig. 2).

The histopathological changes were graded and summarized in Table 2. The control group showed no morphological changes. In contrast, the kidneys of As₂O₃-treated rats showed cortex edema, tubular cell swelling, interstitial edema, glomeruli dilation and hyperemia, pyknotic nuclei and severe necrosis, and denudation of the tubular cells. Treatment with resveratrol attenuated renal morphological alterations (Fig. 2), which showed moderate glomeruli dilation, slight tubular cell swelling

and edema.

Effects of resveratrol on -SH concentration in kidney

Treatment with resveratrol alone did not induce a significant increase in -SH concentration relative to the control group. However, a single dose of As₂O₃ resulted in a significant 45.3% decrease in -SH level when compared with the control group. Similarly, treatment with resveratrol resulted in complete reversal of the As₂O₃-induced decrease in -SH level (Fig. 3).

Effects of resveratrol on total arsenic, zinc and selenium concentration in kidney

Fig. 4 shows the effects of As₂O₃ on total arsenic, zinc and selenium concentration in kidney tissues from resveratrol-supplemented rats. Rats treated with As₂O₃ showed a significant 317.8% increase in total arsenic level in kidney tissues relative to the control group, while administration of resveratrol for 4 alternate days resulted in a 53% decrease when compared with the As₂O₃-treated group. In addition, to evaluate whether pre-treatment with resveratrol modulated the essential elements, we assessed the zinc and selenium levels in kidneys. Resveratrol

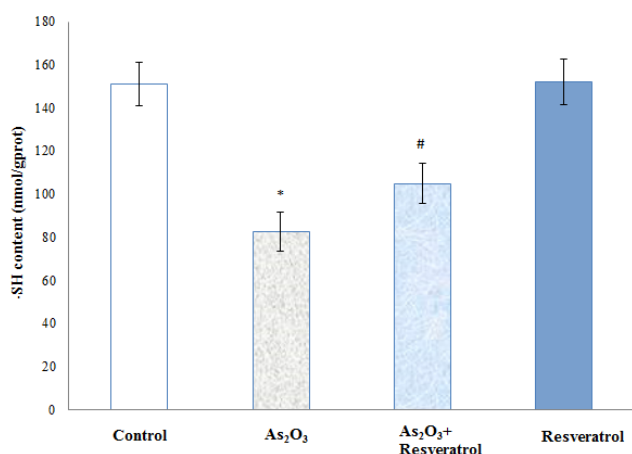


Fig. 3. Effect of resveratrol on arsenic induced renal -SH content in rat. All values are expressed as the mean \pm SEM, (n = 8), * $P < 0,05$ when compared with the control group; # $P < 0,05$ when compared with the As_2O_3 -treated group. -SH, total sulfhydryl.

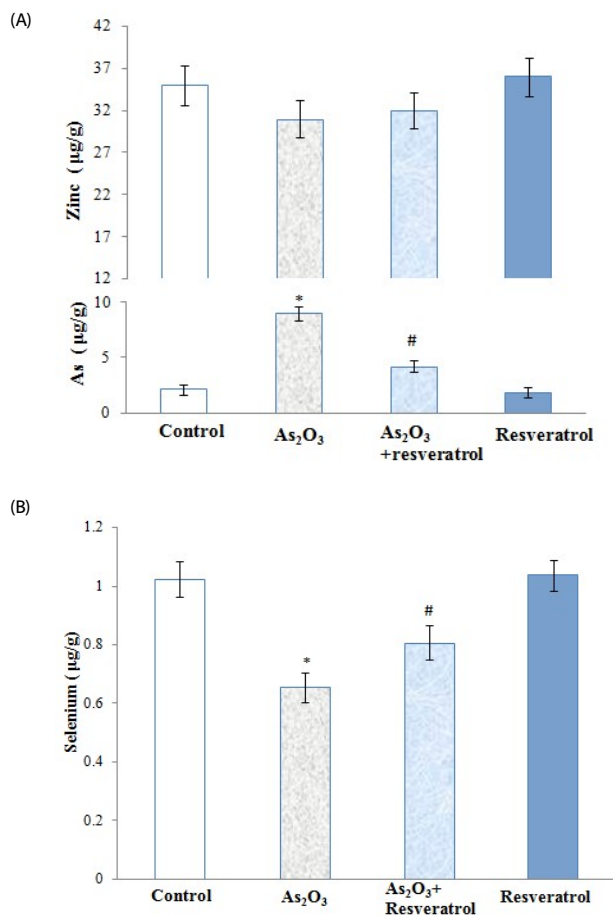


Fig. 4. Effect resveratrol on arsenic, zinc and selenium concentration ($\mu\text{g/g}$ for tissue) in exposed rats. (A) arsenic and zinc concentration in kidney; (B) selenium concentration in kidney. Values are expressed as the mean \pm SEM, (n = 8), * $P < 0,05$ when compared with the control group; # $P < 0,05$ when compared with the As_2O_3 -treated group.

had a markedly protective effect in the selenium level of kidneys during arsenic exposure, whereas treatment with or without resveratrol had no beneficial effect on zinc concentration (Fig. 4).

DISCUSSION

In several studies, small doses (0.02-8 mg/kg) of resveratrol administered prophylactically reduced or prevented the development of tumors in rats given different carcinogens [13,14]. Another small study found that a single dose of up to 5 g of trans-resveratrol caused no serious adverse effects in healthy volunteers [15]. In addition, our colleagues demonstrated that resveratrol (8 mg/kg, iv.) protected against arsenic-induced hepatotoxicity [16]. This dose of resveratrol (< 8 mg/kg) did not show a protective effect against As_2O_3 -induced nephrotoxicity in a pre-experiment. Therefore, the dose of resveratrol in our study was 8 mg/kg administered iv.

Arsenic toxicity is associated with its reactivity and generation of ROS and sulfur containing compounds [2,17]. The kidney is highly vulnerable to damage caused by ROS, which are involved in the pathogenic mechanism of conditions [18]. Our study also showed that, after arsenic exposure, ROS-induced oxidative damage increased MDA and GSSH production in the kidney, which is consistent with the results of previous studies [18]. However, the intrinsic antioxidant defenses of cells play a crucial role in the elimination of free radicals, including enzymatic antioxidant and non-enzymatic systems [19]. Both SOD and GPx are important endogenous antioxidant enzymes that destroyed the superoxide anion radical through dismutation and generated H_2O_2 . In addition, GSH is an important non-protein compound-containing thiol group associated with the maintenance of redox homeostasis [16,20]. Maiti and Chatterjee [20] reported that GSH also stimulated the arsenic detoxification processes by modulating arsenic methylation and increasing hepatobiliary excretion of arsenic. Resveratrol is a naturally occurring stilbene, a potent free radical scavenger and may also stimulate endogenous antioxidant enzyme activities [21,22]. As expected, As_2O_3 treatment resulted in significant nephrotoxicity in rats, and pre-treatment with resveratrol attenuated or prevented the oxidative stress, thereby mitigating the subsequent renal damage. These data indicated that resveratrol could markedly renew the activities of those antioxidant enzymes in the kidneys of As_2O_3 -treated rats and at least partly attenuate oxidative stress by increasing the SOD, GPx and GSH/GSSG ratio as well as decreasing MDA and ROS levels in As_2O_3 -treated rat kidney, thereby ameliorating the defense capacity of rats.

To further understand the protective mechanism of resveratrol against As_2O_3 -induced nephrotoxicity, we analyzed the content of -SH, zinc and selenium. Toxicity due to trivalent arsenic might be attributed to direct binding with the -SH group [3]. In addition, zinc and selenium are essential for the activity of many enzymes that defend biological systems against damage caused by activated oxygen [10,11]. Recent advances have shown that supplemental sulfhydryl (thiol), zinc or selenium can act as complementary chelator (adjuvant) agents, increasing the efficacy of known chelators, or by acting independently [12, 23,24]. Therefore, it is likely that maintenance of -SH, zinc and selenium content can attenuate toxicity. In the present study,

we demonstrated that treatment of rats with resveratrol preserved the depletion of -SH content after arsenic exposure, indicating that resveratrol acted as an alternative agent or agonist of -SH directly or indirectly. Although the concentration of selenium in the kidney is very low, the antioxidant function is apparent due to a component of the antioxidant enzyme, GPx. Consequently, the presence of resveratrol restored the depletion of selenium rats with As₂O₃. However, arsenic exposure resulted in no difference in the zinc content between rats treated with and without resveratrol. These findings indicate that, the depleted renal zinc concentration remained insensitive after arsenic absorption, regardless of the presence of resveratrol. A second finding of interest is our observation that resveratrol affected arsenic metabolism and facilitated arsenic efflux. GSH reportedly plays a vital role in arsenic metabolism via involvement in arsenic reduction and efflux [16]. Moreover, Flora *et al.* [25] suggested that arsenic increased hepatobiliary transport of selenium and selenite, which led to increased biliary excretion of arsenic. Therefore, we suggest that arsenic efflux was facilitated by maintenance of the GSH/GSSG ratio and selenium content, as might be achieved with resveratrol supplementation.

In conclusion, the protective actions of resveratrol against As₂O₃ are believed to stem from its direct free radical scavenging, indirect antioxidant activities, and/or the maintenance of -SH and selenium content. However, we cannot rule out the possibility that the observed results are due to a positive association between resveratrol and several families of multispecific drug transporters, in evidence, nephrotoxicity will occur only after being transported into the renal cells [26] and metabolomics [27]. Therefore, additional evidence should be provided and extensive clinical trials should be conducted to confirm the beneficial effects of resveratrol in humans and other animals.

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