

RETRACTED ARTICLE: Protective effect of picoside II on myocardial ischemia reperfusion injury in rats

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Abstract: The aim of this study was to determine the effect of picoside II on myocardial ischemia reperfusion injury in rats and to explore its underlying mechanism. Isolated rat hearts underwent 30 minutes of global ischemia followed by 20 minutes of reperfusion. Different doses of picoside II (1 μ M, 10 μ M, and 100 μ M) were given 20 minutes before ischemia. Phosphoinositide 3-kinase inhibitor (wortmannin) and nitric oxide synthase (NOS) inhibitor (L- N^G -nitroarginine methyl ester) were given 10 minutes before picoside II treatment. The cardiac function, myocardial infarct size, apoptosis, myocardial nitric oxide content, the expressions of Bcl-2 and Bax, and the activation of the phosphoinositide 3-kinase/Akt/endothelial NOS pathway were evaluated. Treatment with 10 μ M and 100 μ M picoside II significantly improved postischemic myocardial function, reduced myocardial infarct size, inhibited apoptosis, increased myocardial NO content, upregulated Bcl-2, downregulated Bax, and increased the phosphorylation of Akt and endothelial NOS, but cardioprotection was not shown in the 1 μ M picoside II treatment group and was abrogated by wortmannin and L- N^G -nitroarginine methyl ester. Furthermore, cardioprotection in the 100 μ M picoside II treatment group was superior to that in the 10 μ M picoside II treatment group. In conclusion, the data reveals that picoside II has a significant protective effect on myocardial ischemia reperfusion injury in a dose-dependent manner, which was mediated by upregulating the phosphoinositide 3-kinase/Akt/endothelial NOS pathway to increase nitric oxide production and regulating the expressions of Bcl-2 and Bax to inhibit apoptosis.

Keywords: picoside II, ischemia reperfusion injury, apoptosis, nitric oxide, endothelial nitric oxide synthase

Introduction

Ischemic heart disease is a leading cause of morbidity and mortality worldwide.¹ Restoration of blood supply to the heart immediately is a key step in avoiding further damage of the heart.² However, the abrupt reperfusion of an ischemic myocardium can itself further damage the ischemic tissue, which is termed as myocardial ischemia reperfusion injury (MIRI).³ Although ischemic preconditioning or ischemic postconditioning – a short series of repetitive cycles of brief reperfusion and ischemia performed immediately before or after sustained ischemia – increases the resistance against sustained ischemia of longer duration, they cannot really be widely used in the clinic treatment due to their traumatic manipulation.^{4–7} Therefore, much greater attention has been paid to exploring new drugs to prevent ischemia reperfusion injury that are free from the trauma resulting from ischemic preconditioning and ischemic postconditioning.⁸

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In the control group, the isolated rat heart preparations were perfused for 30 minutes with KH solution. Then, the preparations were subjected to ischemia reperfusion as described above. Three different concentrations of picoside II (1 μ M, 10 μ M, and 100 μ M) were tested in the pre-treatment groups (picoside II-1 group, picoside II-10 group, and picoside II-100 group, respectively). The isolated rat hearts were perfused for 10 minutes with KH solution, and then perfused with KH solution containing different concentrations of picoside II at the speed of 10 mL/minute for 20 minutes before ischemia.

To further determine whether the PI3K/Akt/eNOS pathway is involved in regulating the cardioprotection of picoside II on MIRI, four more groups treated with PI3K specific inhibitor (wortmannin) and NOS specific inhibitor (L-NAME) were added. In the picoside II-100+wortmannin group, the isolated rat hearts were perfused with KH solution containing 100 nM wortmannin at the speed of 10 mL/minute for 10 minutes; the rest of the procedure was the same as picoside II-100 group. In the picoside II-100+L-NAME group, the isolated rat hearts were perfused with 30 μ M L-NAME at the speed of 10 mL/minute for 10 minutes; the rest of procedure was similar to the picoside II-100 group. In the wortmannin control group, wortmannin was given as described in the picoside II-100+wortmannin group, but 20 minutes of picoside II treatment was replaced by 20 minutes of perfusion with KH solution before ischemia. In the L-NAME control group, L-NAME was given as described in the picoside II-100+L-NAME group replaced by perfusion with KH solution for 20 minutes instead of 20 minutes of picoside II treatment before ischemia.

Cardiac function monitoring

The assessment of cardiac function included heart rate (HR), left ventricular developed pressure (LVDP), positive first-order derivative of ventricular pressure (+dp/dt), negative first-order derivative of ventricular pressure (−dp/dt), and coronary flow (CF). These parameters were continuously monitored throughout the experimental protocol. The HR, LVDP, +dp/dt, −dp/dt, and CF were sampled and digitally processed via a homodynamic system (MP150; BIOPAC Systems, Inc., Goleta, CA, USA).

Measurement of infarct size

Infarct size was determined as previously described.¹⁴ Briefly, after 2 hours of reperfusion, the hearts were harvested, and the left ventricles were sectioned from apex to base into 2–3 mm sections following incubation for 20 minutes at 37°C in 1%

2,3,5-triphenyltetrazolium chloride; unstained tissue was carefully separated from stained tissue by an independent observer. In fact, while the unstained tissue represents the dead cells, the stained tissue represents the viable cells. The unstained mass was expressed as a percentage of total left ventricular mass. In fact, the total left ventricular mass also corresponds to the risk area because a global ischemia was induced.

Measurement of myocardial apoptosis

At the end of 120 minutes of reperfusion, the heart was removed as described earlier.¹⁴ Cardiac myocyte apoptosis was detected using an In Situ Cell Death Detection Kit (Hoffman-La Roche Ltd, Basel, Switzerland) according to the manufacturer's instruction. Briefly, the tissue sections were washed with phosphate-buffered saline and then fixed in 4% paraformaldehyde solution before incubation in 20 μ g/mL proteinase K for 10 minutes. After being washed with phosphate buffered saline three times, the tissue sections were incubated with terminal deoxynucleotidyl transferase in a humidified chamber at 37°C for 60 minutes for incorporation of biotinylated nucleotides at the 3'-OH DNA ends. The reaction was terminated by transferring the slides to a 2× sodium citrate saline solution. Endogenous peroxidase activity was quenched by incubation in 0.3% hydrogen peroxide. Finally, avidin-biotin horseradish peroxidase was bound to the biotinylated nucleotides and peroxidase activity was demonstrated in each section by the application of a stable chromogen diaminobenzidine. In this technique, the apoptotic nuclei were stained dark brown. Normal nuclei were stained blue with hematoxylin. Six sections from each myocardial sample were randomly selected and ten microscopic fields (BX51 microscope; Olympus Corporation, Tokyo, Japan) per section were evaluated by two independent blind observers. In each field, the nuclei were counted and the percentage of terminal deoxynucleotidyl transferase deoxyuridine triphosphate nick end labeling-positive nuclei was calculated.

Measurement of NO content

After 30 minutes of global ischemia followed by 30 minutes of reperfusion, the hearts were removed quickly from the Langendorff apparatus and homogenized. The content of NO was measured using an NO assay kit (Jiancheng Bioengineering Institute, Nanjing, People's Republic of China) according to the manufacturer's instructions.

Western blotting

At the end of 30 minutes of reperfusion, the left ventricles were homogenized in a lysis buffer containing 10 mmol/L

Tris-HCl, 20 orthophosphate, 1 mmol/L ethylene glycol tetraacetic acid, 1 mmol/L ethylenediaminetetraacetic acid, 2 mmol/L Na_3VO_4 , and 1 mmol/L phenylmethylsulfonyl fluoride (pH=7.4). After sonication, the lysates were centrifuged, and the proteins were separated by electrophoresis on sodium dodecyl sulfate polyacrylamide gel electrophoresis and transferred onto polyvinylidene difluoride-plus membranes. The membranes were blocked with 5% skim milk followed by incubation overnight at 4°C with the antibodies Bcl-2 (1:1000) and Bax (1:1000; Abcam, Cambridge, UK) and Akt (1:500), β -actin (1:1000), phospho-Akt (at Ser473, 1:500), eNOS (1:500), and phospho-eNOS (at Ser1177, 1:500; Santa Cruz Biotechnology, Santa Cruz, CA, USA). After incubation, the membranes were washed three times with 0.1% Tween-20 for 15 minutes and incubated with horseradish peroxidase-conjugated goat anti-rabbit immunoglobulin G (1:2000; Santa Cruz Biotechnology) at 37°C for 2 hours. Relative densitometry was performed using a computerized software package (ImageJ 1.63; National Institutes of Health).

Statistical analysis

All results were expressed as mean $\pm$ standard deviation. Statistical analysis was performed by using SigmaStat software version 3.5 (Systat Software, Inc., San Jose, CA, USA). Differences between groups were evaluated using one-way analysis of variance, followed by Student–Newman–Keuls post hoc test. $P < 0.05$ was considered statistically significant.

Results

Effect of picoside II on cardiac function

The values of HR, LVDP, +dp/dt, -dp/dt, and CF at baseline and different times of reperfusion are shown in Figure 2. There were no significant differences in the values of HR, LVDP, +dp/dt, -dp/dt, and CF at baseline among groups. In the picoside II-10 μM group and picoside II-100 μM group, the values of HR, LVDP, +dp/dt, -dp/dt, and CF were significantly increased compared with the control group ($P < 0.05$). Furthermore, all values in the picoside II-100 μM group were

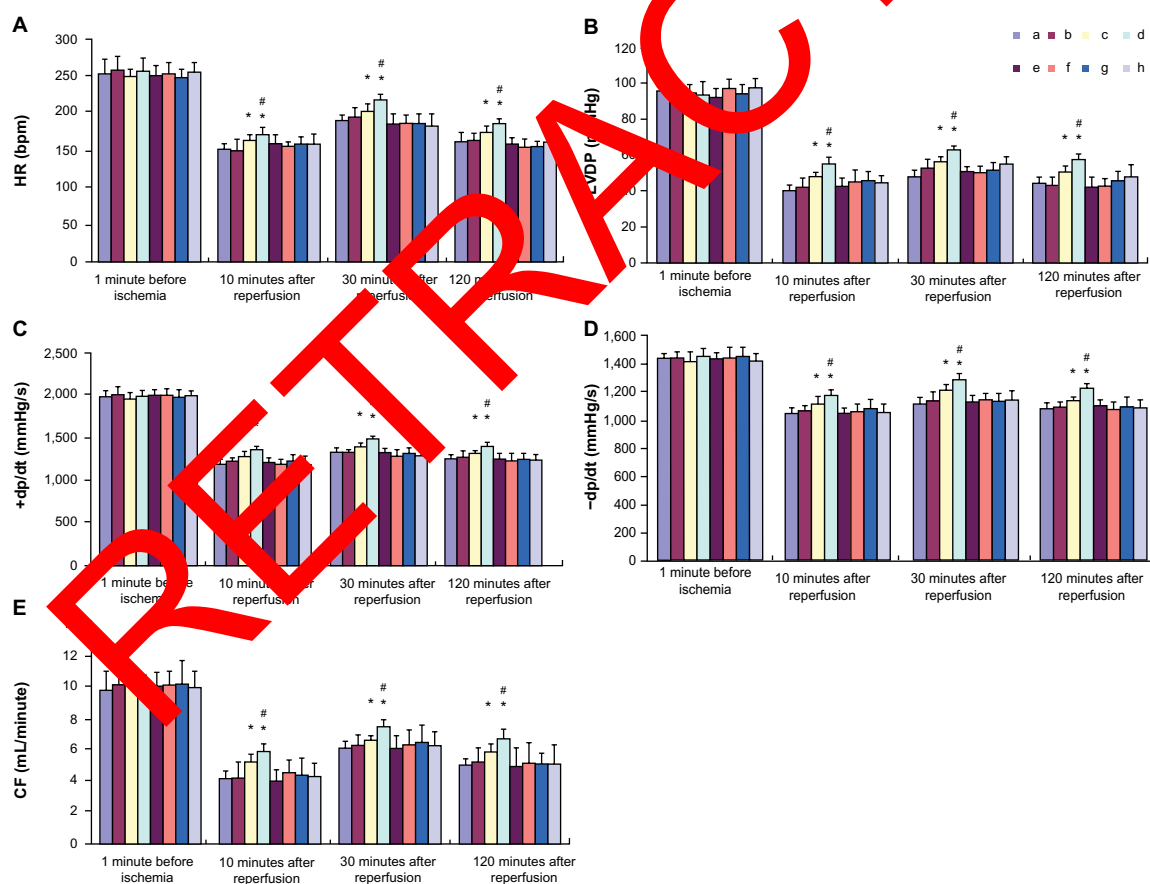


Figure 2 Cardiac function parameters before and during reperfusion. (A) Control group; (B) 1 μM picoside II pretreatment group; (C) 10 μM picoside II pretreatment group; (D) 100 μM picoside II pretreatment group; (E) 100 μM picoside II pretreatment+wortmannin group; (F) 100 μM picoside II pretreatment+L-NAME group; (G) wortmannin control group; and (H) L-NAME control group.

Notes: Values represent mean $\pm$ standard deviation; $n=13-15$; * $P < 0.05$ versus control; # $P < 0.05$ versus 10 μM picoside II pretreatment group.

Abbreviations: +dp/dt, positive first-order derivative of ventricular pressure; -dp/dt, negative first-order derivative of ventricular pressure; CF, coronary flow; HR, heart rate; LNAME, L-N^G-nitroarginine methyl ester; LVDP, left ventricular developed pressure.

higher than those in the picoside II-10 group ($P<0.05$). However, no significant differences in the values of cardiac function parameters were observed in the picoside II-1 group compared with the control group ($P>0.05$).

Effect of picoside II on infarct size

As shown in Figure 3, the infarct size was significantly reduced in the picoside II-10 group and picoside II-100 group as compared with that in the control group ($36.3\%\pm 8.9\%$ and $26.0\%\pm 6.4\%$, respectively, versus $46.5\%\pm 7.6\%$; $P<0.05$), but no significant reduction of infarct size was observed in the picoside II-1 group as compared with the control group ($44.4\%\pm 7.9\%$ versus $46.5\%\pm 7.6\%$; $P>0.05$). Meanwhile, the infarct size was further reduced in the picoside II-100 group compared with the picoside II-10 group ($26.0\%\pm 6.4\%$ versus $36.3\%\pm 8.9\%$; $P<0.05$). These results suggested that picoside II reduced infarct size in a dose-dependent manner.

Effect of picoside II on apoptosis

The percentage of cardiomyocyte apoptosis in all experimental groups is shown in Figure 4. As compared with the control group, the percentage of cardiomyocyte apoptosis was significantly reduced in the picoside II-10 group and picoside II-100 group ($29.3\%\pm 5.9\%$ and $21.5\%\pm 4.8\%$, respectively, versus $38.6\%\pm 3.7\%$; $P<0.05$), but no significant decrease was observed in the picoside II-1 group ($37.5\%\pm 3.8\%$ versus $38.6\%\pm 3.7\%$; $P>0.05$). Moreover, the antiapoptosis effect of picoside II was also in a dose-dependent manner.

by a lower percentage of cardiomyocyte apoptosis in the picoside II-100 group compared with the picoside II-10 group ($21.5\%\pm 4.8\%$ versus $29.3\%\pm 5.9\%$; $P<0.05$).

Effect of picoside II on NO content in rat myocardium

As shown in Figure 5, the content of NO in rat myocardium significantly increased in the picoside II-10 group and picoside II-100 group compared with the control group ($4.40\pm 1.08\ \mu\text{mol/g}$ and $6.52\pm 1.53\ \mu\text{mol/g}$, respectively, versus $2.62\pm 0.64\ \mu\text{mol/g}$; $P<0.05$), however, the content of NO did not increase in the picoside II-1 group ($2.65\pm 1.19\ \mu\text{mol/g}$ versus $2.62\pm 0.64\ \mu\text{mol/g}$; $P>0.05$). Besides, the content of NO in the picoside II-100 group was remarkably higher compared with the picoside II-10 group ($6.52\pm 1.53\ \mu\text{mol/g}$ versus $4.40\pm 1.08\ \mu\text{mol/g}$; $P<0.05$), which suggests that picoside II could also increase the content of NO in ischemic myocardium in a dose-dependent manner.

Expression of Bcl-2 and Bax proteins

In order to elucidate the underlying mechanism of the antiapoptosis effect of picoside II, the expression of apoptosis-related proteins Bcl-2 and Bax was further examined (Figure 6). As compared with the control group, there was a significant increase in the expression of Bcl-2 in the picoside II-10 group and picoside II-100 group (0.446 ± 0.022 and 0.584 ± 0.023 , respectively, versus 0.140 ± 0.015 ; $P<0.05$) (Figure 6B), whereas a remarkable decrease in the expression

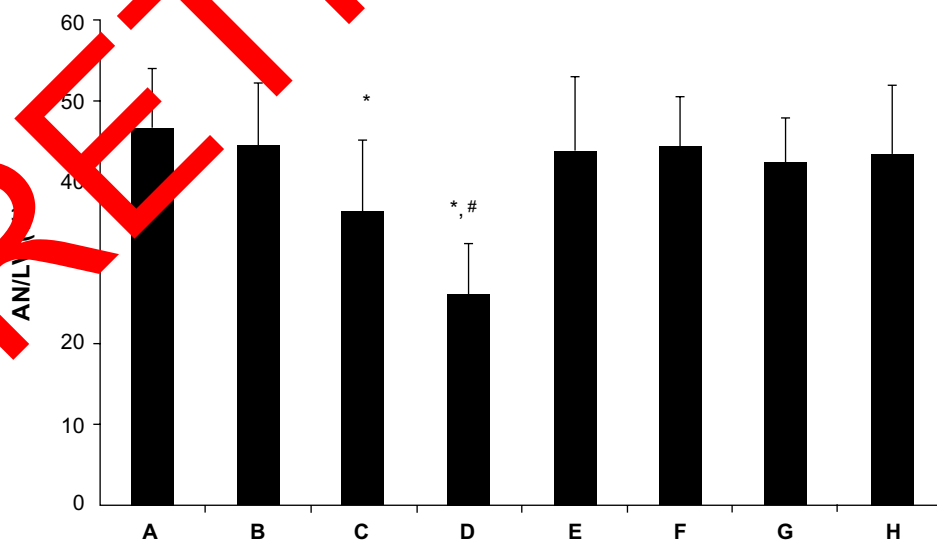


Figure 3 AN expressed as a percentage of LV area. (A) Control group; (B) 1 μM picoside II pretreatment group; (C) 10 μM picoside II pretreatment group; (D) 100 μM picoside II pretreatment group; (E) 100 μM picoside II pretreatment+wortmannin group; (F) 100 μM picoside II pretreatment+L-NAME group; (G) wortmannin control group; and (H) L-NAME control group.

Notes: Values represent mean $\pm$ standard deviation; $n=8$; * $P<0.05$ versus control; # $P<0.05$ versus 10 μM picoside II pretreatment group.

Abbreviations: AN, area of necrosis; LNAME, L-N^G-nitroarginine methyl ester; LV, left ventricle.

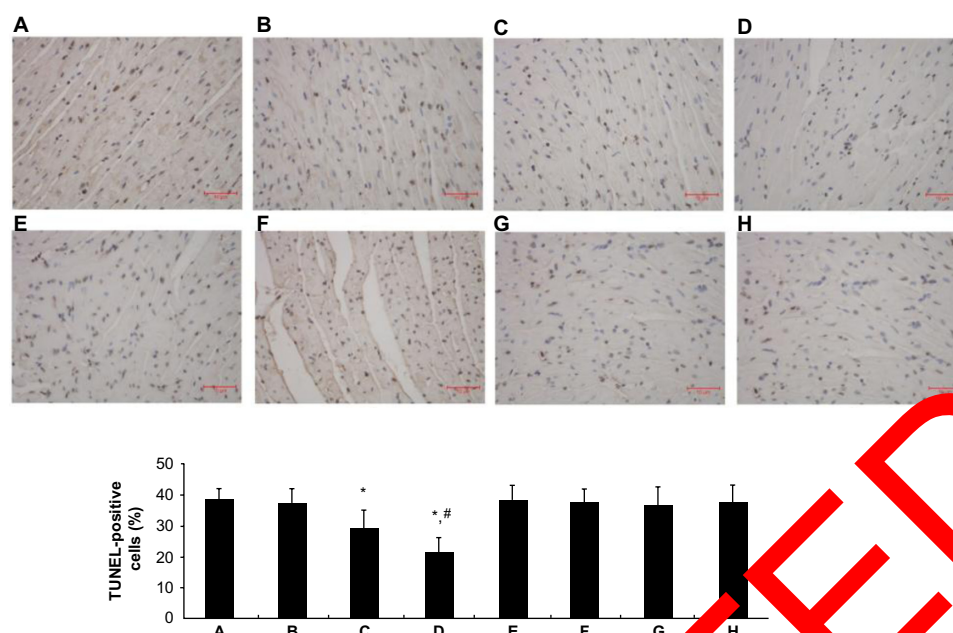


Figure 4 Apoptosis after myocardial infarction. Photomicrographs were taken at 400× magnification. Apoptotic cardiomyocyte nuclei appear brown stained whereas TUNEL-negative nuclei appear blue. Histogram shows the percentage of TUNEL-positive cells (brown staining). (A) Control group; (B) 1 μM picoside II pretreatment group; (C) 10 μM picoside II pretreatment group; (D) 100 μM picoside II pretreatment group; (E) 100 μM picoside II pretreatment+wortmannin group; (F) 100 μM picoside II pretreatment+L-NAME group; (G) wortmannin control group; and (H) L-NAME control group.

Notes: Values represent mean ± standard deviation; n=6; * $P<0.05$ versus control; # $P<0.05$ versus 10 μM picoside II pretreatment group.

Abbreviations: LNAME, L-N^G-nitroarginine methyl ester; TUNEL, terminal deoxynucleotidyl transferase deoxyuridine triphosphate nick end labeling.

of Bax was shown in these two groups (0.399 ± 0.019 and 0.193 ± 0.034 , respectively, versus 0.495 ± 0.026 ; $P<0.05$ versus control).

(Figure 6C) compared with the control group, which is consistent with previous data derived from the terminal deoxynucleotidyl transferase deoxyuridine triphosphate nick end labeling staining for apoptosis (Figure 4). These results reveal that picoside II could effectively upregulate

Expression of Akt and eNOS proteins

As shown in Figure 7, treatment with 10 μM and 100 μM picoside II resulted in a significant increase in the phosphorylation of Akt compared with the control group (0.316 ± 0.019

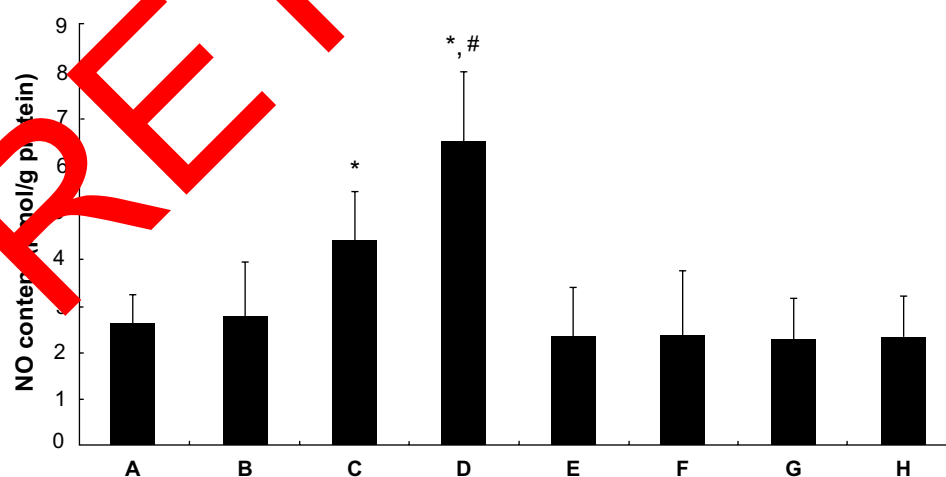


Figure 5 The content of NO in myocardium. (A) Control group; (B) 1 μM picoside II pretreatment group; (C) 10 μM picoside II pretreatment group; (D) 100 μM picoside II pretreatment group; (E) 100 μM picoside II pretreatment+wortmannin group; (F) 100 μM picoside II pretreatment+L-NAME group; (G) wortmannin control group; and (H) L-NAME control group.

Notes: Values represent mean ± standard deviation; n=6; * $P<0.05$ versus control; # $P<0.05$ versus 10 μM picoside II pretreatment group.

Abbreviations: NO, nitric oxide; LNAME, L-N^G-nitroarginine methyl ester.

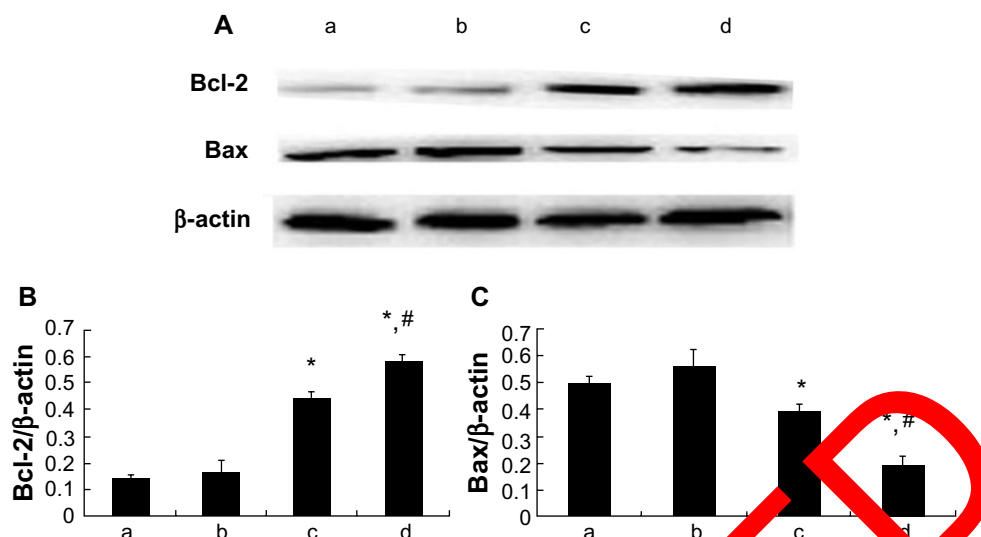


Figure 6 Myocardial Bcl-2 and Bax expression. (A) Bcl-2 and Bax protein expressions detected by Western blotting; (B) Relative protein expression level of Bcl-2; (C) Relative protein expression level of Bax; (a) control group; (b) 1 μM picoside II pretreatment group; (c) 10 μM picoside II pretreatment group; and (d) 100 μM picoside II pretreatment group.

Notes: Values represent mean ± standard deviation; n=3; * $P<0.05$ versus control; # $P<0.05$ versus 10 μM picoside II pretreatment group.

and 0.414 ± 0.020 , respectively, versus 0.186 ± 0.011 ; $P<0.05$). Figure 8 shows a similar increase in the phosphorylation of eNOS (0.342 ± 0.037 and 0.503 ± 0.021 , respectively, versus 0.253 ± 0.021 ; $P<0.05$). However, there was no significant change in total expressions of Akt and eNOS in the picoside II-10 group and picoside II-100 group (Figures 7C and 8C). Moreover, the levels of phosphorylated Akt and eNOS were higher in the picoside II-100 group as compared with those in the picoside II-10 group. These results were parallel

with the results obtained with measurement of NO content in the myocardium, indicating that picoside II increases NO production by upregulating the PI3K/Akt/eNOS pathway.

Effects of wortmannin and L-NAME on the cardioprotection of picoside II

To further assess the role of PI3K/Akt/eNOS pathway in the protective effect of picoside II, a PI3K specific inhibitor (wortmannin) and an NOS specific inhibitor (L-NAME)

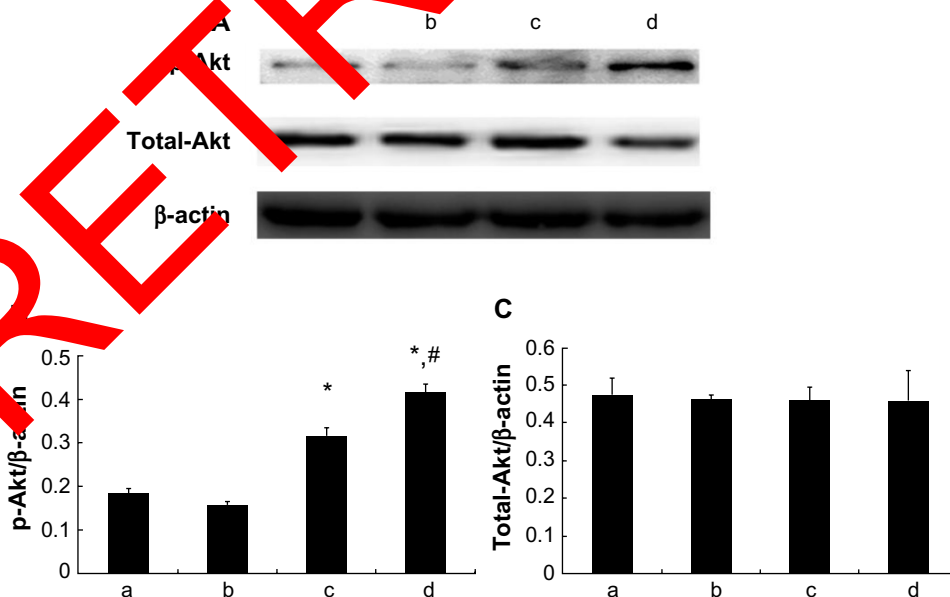


Figure 7 Myocardial total-Akt and p-Akt expression. (A) p-Akt and total-Akt protein expressions detected by Western blotting; (B) Relative protein expression level of p-Akt; (C) Relative protein expression level of total-Akt; (a) control group; (b) 1 μM picoside II pretreatment group; (c) 10 μM picoside II pretreatment group; and (d) 100 μM picoside II pretreatment group.

Notes: Values represent mean ± standard deviation; n=3; * $P<0.05$ versus control; # $P<0.05$ versus 10 μM picoside II pretreatment group.

Abbreviation: p-Akt, phospho-Akt.

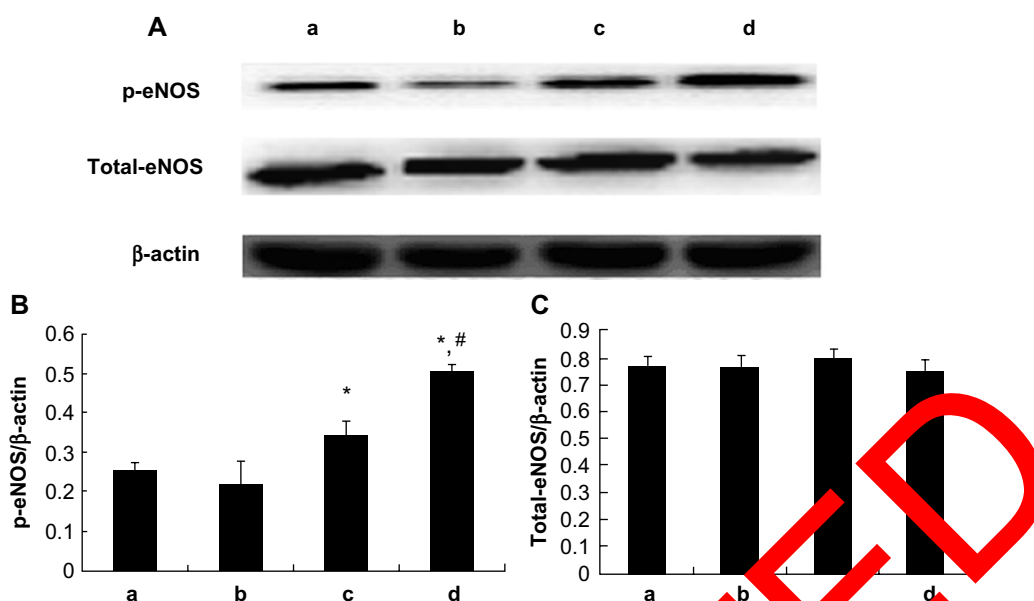


Figure 8 Myocardial total-eNOS and p-eNOS expression. **(A)** p-eNOS and total-eNOS protein expressions detected by Western blotting; **(B)** Relative protein expression level of p-eNOS; **(C)** Relative protein expression level of total-eNOS; **(a)** control group; **(b)** 1 μM picoside II pretreatment group; **(c)** 10 μM picoside II pretreatment group; and **(d)** 100 μM picoside II pretreatment group.

Notes: Values represent mean $\pm$ standard deviation; $n=3$; * $P<0.05$ versus control; # $P<0.05$ versus 10 μM picoside II pretreatment group.

Abbreviations: eNOS, endothelial nitric oxide synthase; p-eNOS, phospho-eNOS.

was given to the 100 μM picoside II treatment group. The results show that the cardioprotection of picoside II was abrogated by treatment with wortmannin or L-NAME alone, as evidenced by no significant differences in hemodynamic parameters (Figure 2), myocardial infarct size (Figure 3), the percentage of cardiomyocyte apoptosis (Figure 4), and the content of NO (Figure 5) in the picoside II-100+wortmannin group and picoside II-100+L-NAME group compared with the control group.

Discussion

Picoside II, one of the effective components extracted from the traditional Chinese medicine rhizoma coptidis hu, has already been demonstrated to have multiple protective effects, including alleviating hepatocyte oxidative stress damage, inhibiting cerebral ischemic reperfusion injury, and reducing the expression of related inflammatory factors.^{9–13} Moreover, a recent study has also shown that picoside II could protect cardiomyocytes against oxidative stress and apoptosis induced by hypoxia/reoxygenation injury.¹⁵ However, the cardioprotection of picoside II has still not been demonstrated in animal models. In the present study, it was found that picoside II pretreatment significantly increased the values of LVDP, +dp/dt, -dp/dt, and CF, and decreased the size of infarction, which suggests that picoside II could produce a protective effect on MIRI in rats.

The new finding of this study is that picoside II remarkably increased the content of NO in ischemic myocardium. Therefore, it is speculated that picoside II improves postischemic cardiac functional recovery as a result of an increase in NO production because NO can reinforce myocardial contractility.^{16,17} The main source of cardiac NO is generated through eNOS, which is expressed by coronary endothelial cells and cardiomyocytes and regulated by PI3K/Akt.¹⁸ Consequently, the influence of picoside II on the activation of the PI3K/Akt/eNOS signal pathway was further explored. As expected, the levels of Akt and eNOS phosphorylation in the picoside II treatment group were remarkably higher than in the picoside II untreated group. The results suggest that picoside II increased the synthesis of NO in an ischemic rat heart through upregulation of the PI3K/Akt/eNOS signal pathway. Meanwhile, this speculation was further confirmed as evidenced by the beneficial protection of picoside II being abolished by the administration of wortmannin and L-NAME. According to these results, it can be concluded that picoside II protects the heart against MIRI through activating the PI3K/Akt/eNOS signal pathway, leading to an increase in the synthesis of NO.

In addition, over-apoptosis is believed to be a key factor contributing to the process of MIRI, and one important molecular mechanism for cell apoptosis might be the modulation of the expression of the *bcl-2* gene family, which plays a critical role for the common pathway of apoptosis.^{19,20}

Thus, the rate of apoptosis and the expressions of Bcl-2 and Bax was detected in all experimental groups. The results show that picoside II significantly inhibited cardiomyocyte apoptosis induced by ischemia reperfusion injury, upregulated the expression of Bcl-2, and downregulated the expression of Bax, which agrees with the previous founding of Meng et al in a myocardium hypoxia/reoxygenation model.²¹ Therefore, it is speculated that Bcl-2 and Bax are involved in mediating the anti-apoptotic effects of picoside II on MIRI.

Consistent with most previous studies, the cardioprotection of picoside II is also in a dose-dependent manner.²² In the present study, the results revealed that the 1 μ M picoside II treatment group did not show any beneficial effects in postischemic cardiac functional recovery, the size of infarction, the rate of apoptosis, and the content of NO, but the 10 μ M and 100 μ M picoside II treatment groups displayed a protective effect to a certain extent. Moreover, cardioprotection in the 100 μ M picoside II treatment group is superior to the 10 μ M picoside II treatment group as evidenced by the smaller size of infarction, less apoptosis, and greater NO production in the 100 μ M picoside II treatment group compared with the 10 μ M picoside II treatment group. Despite the fact that 100 μ M picoside II achieved the maximum protective effect in the present study, the optimal dose of picoside II for preventing MIRI still needs to be further determined.

Conclusion

This study demonstrated that picoside II has a significant protective effect on MIRI in isolated rat heart, which was mediated by upregulating the PI3K/Akt/eNOS pathway to increase NO production on the one hand and regulating the expression of Bcl-2 and Bax to inhibit apoptosis on the other.

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Disclosure

The authors report no conflict of interests in this work.

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