

## Original Article

# Paeonol protects H9C2 cardiomyocytes from ischemia/reperfusion injury by activating Notch1 signaling pathway in vitro

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**Abstract:** Objective: To investigate the protective effects of paeonol on simulated ischemia/reperfusion treated cardiomyocytes in vitro. Methods: In this research, the rat cardiomyocyte line, H9c2, was treated with hypoxia/reoxygenation as an I/R model in vitro. Cell viability was assayed by CCK-8 kit; cell apoptosis was detected by flow cytometry and protein expression was assayed by western blot. Results: SIR injury can decrease the viability of the H9c2 cells and significantly increase the apoptosis-related protein bax, caspase-3 and down regulation of the anti-apoptosis-related protein bcl-2. Paeonol can down regulate the expression of apoptosis-related protein following SIR injury and restore the viability of the H9c2 cells. A significant increase in Notch1 protein levels were observed in the H9c2 cells treated with both paeonol and SIR injury. However, the anti-apoptotic effect conferred by paeonol was blocked by DAPT (the specific inhibitor of Notch1 signaling) in the cultured H9c2 cells. Conclusion: The findings of our study suggest that paeonol protects the H9c2 cells against SIR injury-induced injury through the activation of the Notch1 signaling. These results provide new evidence for the potential protective effects of paeonol.

**Keywords:** Paeonol, ischemia/reperfusion injury, simulated ischemia/reperfusion, Notch1 signaling pathway

## Introduction

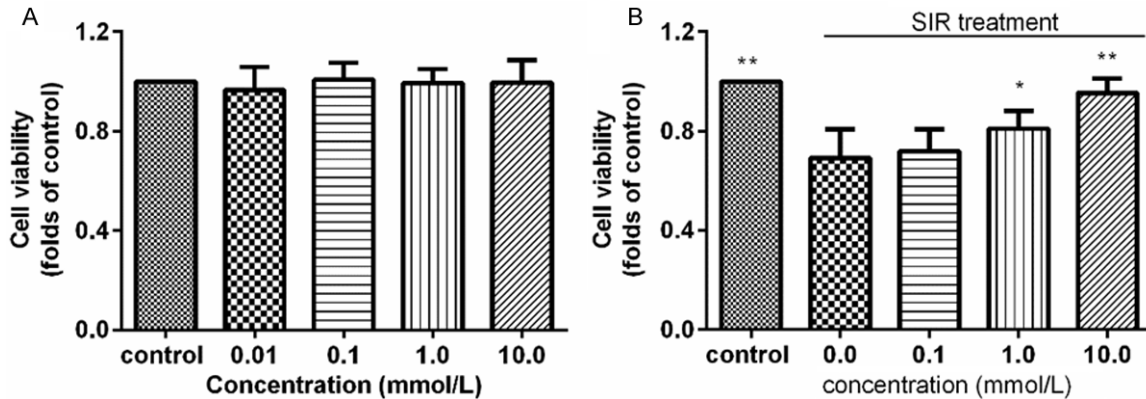
Cardiovascular diseases are the major contributor to mortality both in developed and developing countries today and myocardial ischemia is one of the main results of cardiovascular diseases. Because of lacking effective therapies, myocardial ischaemia/reperfusion (I/R) injury remains an unsolved medical problem [1]. Timely reperfusion is essential for recovery of the ischemic myocardium; however, reperfusion itself can result in major cardiac injury [2]. Although the underlying mechanism regulating myocardial injury induced by I/R remains to be fully elucidated, numerous evidences indicated that cellular apoptosis is an essential form in I/R injury [3].

The Notch1 signaling pathway involves in multiple cellular processes, including cell fate determination, development, differentiation, proliferation, apoptosis, and regeneration [4-7]. In heart, Notch1 signaling not only relates to embryonic cardiac development and differentiation, but also stimulates proliferation of immature cardiomyocytes and promotes quiescent

cardiomyocytes to reenter the cell cycle [8-11]. All these effects promote regeneration and repair of the injured myocardium. Expression levels for Notch1, decline in cardiomyocytes during cardiac postnatal development, are activated and restored in the adult injured myocardium.

Paeonol, 2'-hydroxy-4'-methoxyacetophenone is a major active component extracted from Moutan Cortex, a Chinese medicine prepared from the root bark of *Paeonia suffruticosa* Andrews and *Cynanchum paniculatum* (Bunge) Kitagawa [12]. Traditional Chinese medicine literature has documented that paeonol possesses abundant therapeutic effects including anti-oxidation, anti-tumor, anti-inflammation, anti-atherosclerosis and anti-proliferation of vascular smooth muscle cells [13-17]. Despite these pharmacological findings, whether paeonol protects cardiomyocytes against I/R-induced injury through a Notch1-dependent mechanism is not yet known. To examine this hypothesis, in this study, we investigated the effects of paeonol on Notch1 activity as a means of modulating apoptosis in vitro. Our data demonstrated

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**Figure 1.** The effect of paeonol treatment on cell viability in SIR-treated cardiomyocyte cells. A: The cells were incubated with the different concentrations of paeonol for 12 h; B: Cells were subjected to SIR treatment in the absence or presence of paeonol (0.1, 1.0 or 10.0 mmol/L). Then, the cell viability was assayed by the MTT method. Results were expressed as mean  $\pm$  S.E.M. from six independent experiments, \* $P < 0.05$  or \*\* $P < 0.01$  vs. SIR treatment.

that the treatment of H9c2 cells with paeonol attenuated SIR-induced cell apoptosis, upregulated Notch expression.

### Materials and methods

#### Reagents

Paeonol was purchased from the National Food and Drug Testing Institute (Beijing, China). The DAPT were purchased from Sigma-Aldrich (St. Louis, MO, USA); Dulbecco's modified Eagle's medium (DMEM) and fetal bovine serum (FBS) were purchased from Gibco Thermo Fisher Scientific, Inc. (Waltham, MA, USA). Penicillin and streptomycin were purchased from Beijing Solarbio Science & Technology Co., Ltd. (Beijing, China). The Cell Counting kit-8 (CCK-8) was purchased from Boster biotech Co., Ltd. (Wuhan, China). Protein quantification kit was purchased from Bio-Rad (Hercules, CA, USA). Primary antibodies against Notch1 were obtained from Abcam (Cambridge, MA, USA); cleaved-caspase-3, bax, bcl-2, and GAPDH were obtained from Santa Cruz Biotechnology (Santa Cruz, CA, USA). Secondary antibodies were purchased from the Zhongshan Company (Beijing, China).

#### Cell culture

H9c2 embryonic rat myocardium-derived cells, a well-characterized and widely used cell line to study myocardial cell ischemia, were cultured in Dulbecco's modified Eagle's medium (DMEM) supplemented with 10% fetal bovine serum (FBS) and 1% antibiotic-antimycotic. The H9c2 cells were maintained at 37°C with 5% CO<sub>2</sub>.

#### Simulated ischemia/reperfusion treatment

The SIR treatment was performed by physiological concentrations of potassium, hydrogen, and lactate. The procedure was performed as described previously [18]. Briefly, the H9c2 cells were exposed to an ischemic buffer containing (in mmol/L) 137 NaCl, 12 KCl, 0.49 MgCl<sub>2</sub>, 0.9 CaCl<sub>2</sub>, and 4.0 HEPES. This buffer was also supplemented with (in mmol/L) 10.0 deoxyglucose, 0.75 sodium dithionite, and 20.0 lactate. The buffer pH was 6.5, and the cells were incubated for 50 min in a humidified cell culture incubator (21% oxygen, 5% CO<sub>2</sub>, 37°C). Reperfusion was initiated by returning the cells to normal culture medium for 4 h in a humidified cell culture incubator (21% oxygen, 5% CO<sub>2</sub>, 37°C).

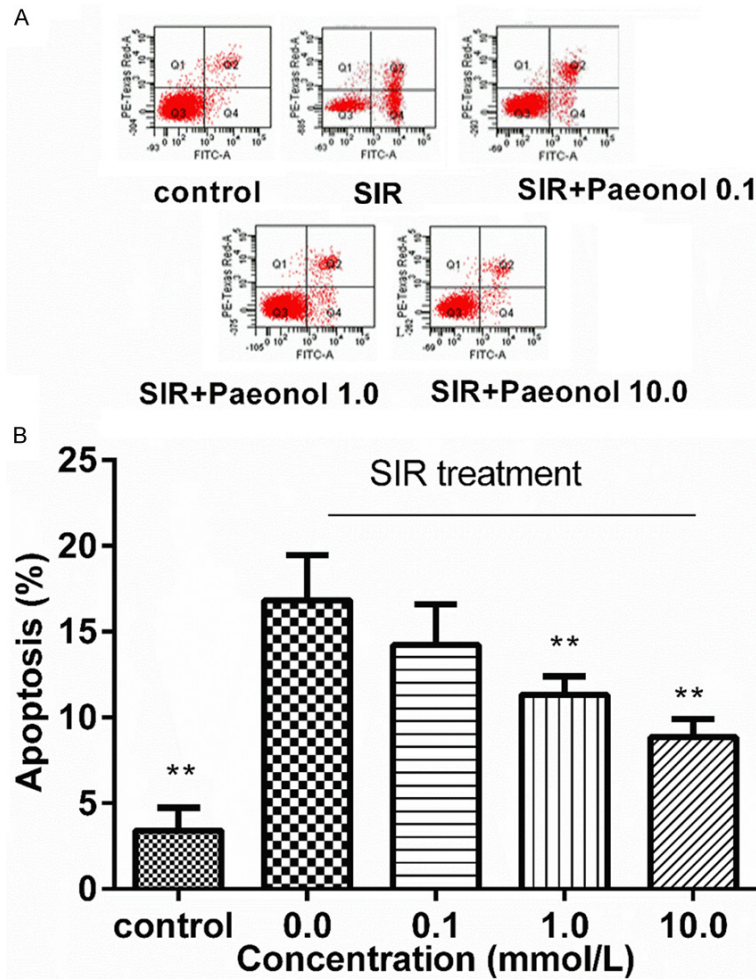
#### Cell viability assay

After the H9c2 cells were seeded in 96-well culture plates and received different treatments, 10  $\mu$ l CCK-8 solution was added to each well at a 1/10 dilution. After 3 h of incubation, the absorbance was measured using a microtiter plate reader Bio-Rad (Hercules, CA, USA) at a wavelength of 450 nm. The cell viability was calculated by dividing the optical density of samples with the optical density of control group.

#### Determination of cell apoptosis

Apoptotic cells were identified by an Annexin V/PI apoptosis kit (Keygen Biotech, Nanjing, China) and flow cytometry. After 12 h of culture

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**Figure 2.** Impacts of paeonol on SIR-induced cardiomyocytes apoptosis by annexin V/PI staining. Cardiomyocytes were pre-treated with paeonol (0.1, 1.0 or 10.0 mmol/L) for 1 h and then were stimulated with SIR for 12 h. At the end of the incubation period, the myocytes were then prepared for annexin V/PI staining. The data expressed as % apoptotic cardiac myocytes. Results were expressed as mean  $\pm$  S.E.M. from 3 independent experiments, \*\* $P < 0.01$  compared with SIR treatment.

under the different treatments,  $(1-2) \times 10^6$  cells were harvested and re-suspended in 500  $\mu$ l binding buffer. Next, the cells were incubated with 5  $\mu$ l Annexin V-fluorescein isothiocyanate (FITC) and 5  $\mu$ l PI (50 mg/ml) for 25 min in the dark and immediately analyzed by flow cytometry. Data from at least  $2 \times 10^5$  cells of each sample were acquired and analyzed using Cell Quest software, version 7.5.3 (Becton Dickinson). In the PI vs. FITC scatter plot, the percentage of cells in the lower right quadrant of (early apoptotic cells), upper right quadrant (late apoptotic cells), upper left quadrant (necrotic cells) and lower left quadrant (live cells) was calculated for comparison.

### Western blot analysis

The H9c2 cells were harvested and lysed after the indicated treatments. The lysates were clarified by centrifugation at 4°C for 15 min at 12,000 rpm. After quantitation of protein concentration, 40  $\mu$ g of total protein was separated by SDS-PAGE and then transferred to a polyvinylidene difluoride membrane Bio-Rad (Hercules, CA, USA). The membrane was blocked with 8% free-fat milk in TBST for 4 h at room temperature, then incubated with primary antibodies specific to Notch1, Caspase-3, Bcl-2, Bax and  $\beta$ -actin, at least 12 h at 4°C. After washing three times with TBST for 15 min, the membrane was incubated with the secondary antibodies for 4 h at room temperature, and then washed as above. The positive protein bands were developed using a chemiluminescent system, and the bands were scanned and quantified by densitometric analysis using an image analyzer Quantity One System (Bio-Rad, Richmond, CA, USA).

### Data analysis

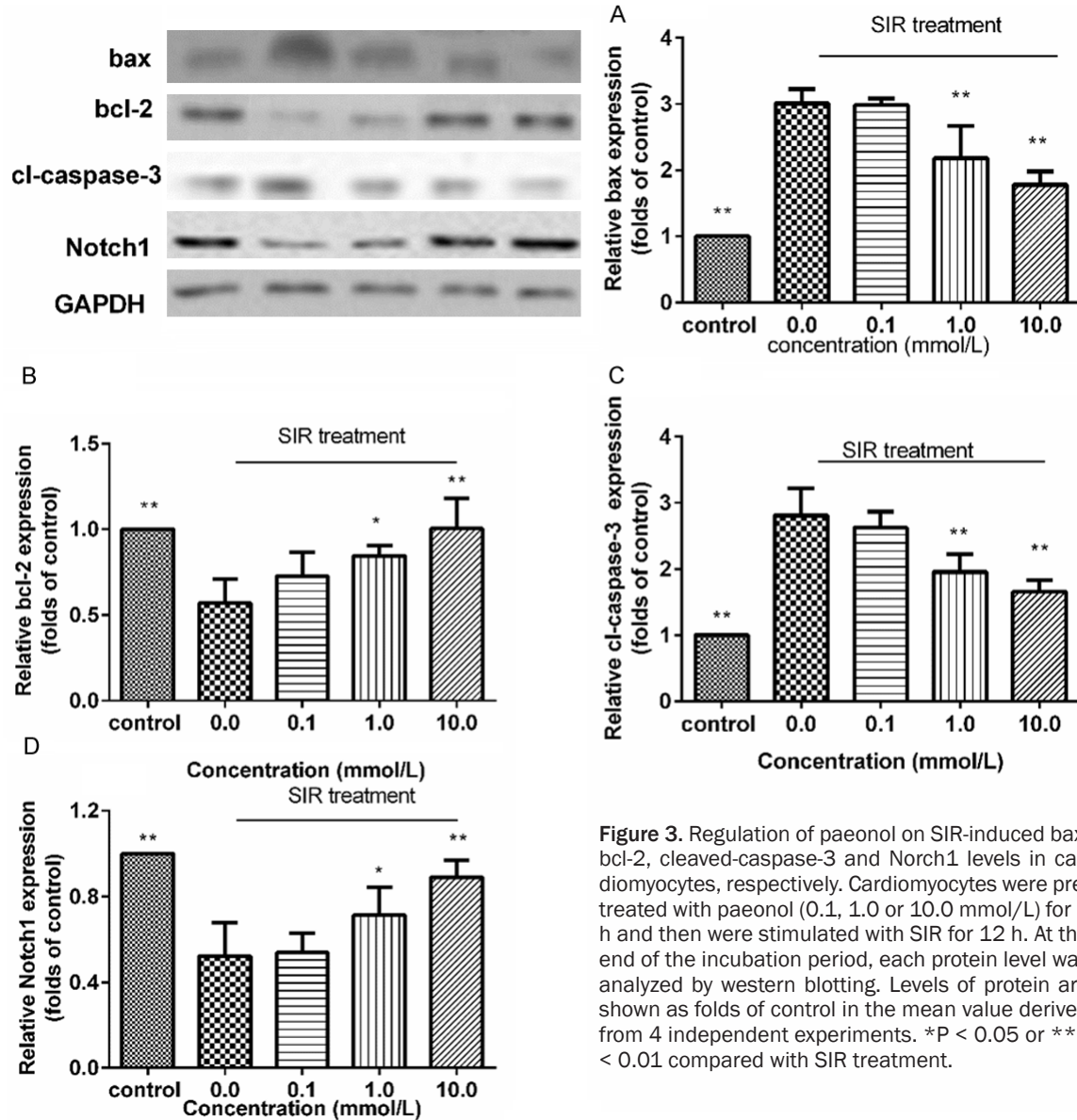
All values are presented as mean  $\pm$  S.E.M. Differences were compared by ANOVA followed by Bonferroni correction for post hoc t test, where appropriate.  $P < 0.05$  were considered to be statistically significant. All of the statistical tests were performed with the GraphPad Prism software version 6.0 (GraphPad Software, Inc., San Diego, CA).

### Results

#### *The effect of paeonol treatment on cell viability in SIR-treated H9C2 cells*

To explore whether paeonol was able to protect against cardiac injury induced by SIR in vitro.

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**Figure 3.** Regulation of paeonol on SIR-induced bax, bcl-2, cleaved-caspase-3 and Notch1 levels in cardiomyocytes, respectively. Cardiomyocytes were pre-treated with paeonol (0.1, 1.0 or 10.0 mmol/L) for 1 h and then were stimulated with SIR for 12 h. At the end of the incubation period, each protein level was analyzed by western blotting. Levels of protein are shown as folds of control in the mean value derived from 4 independent experiments. \*P < 0.05 or \*\*P < 0.01 compared with SIR treatment.

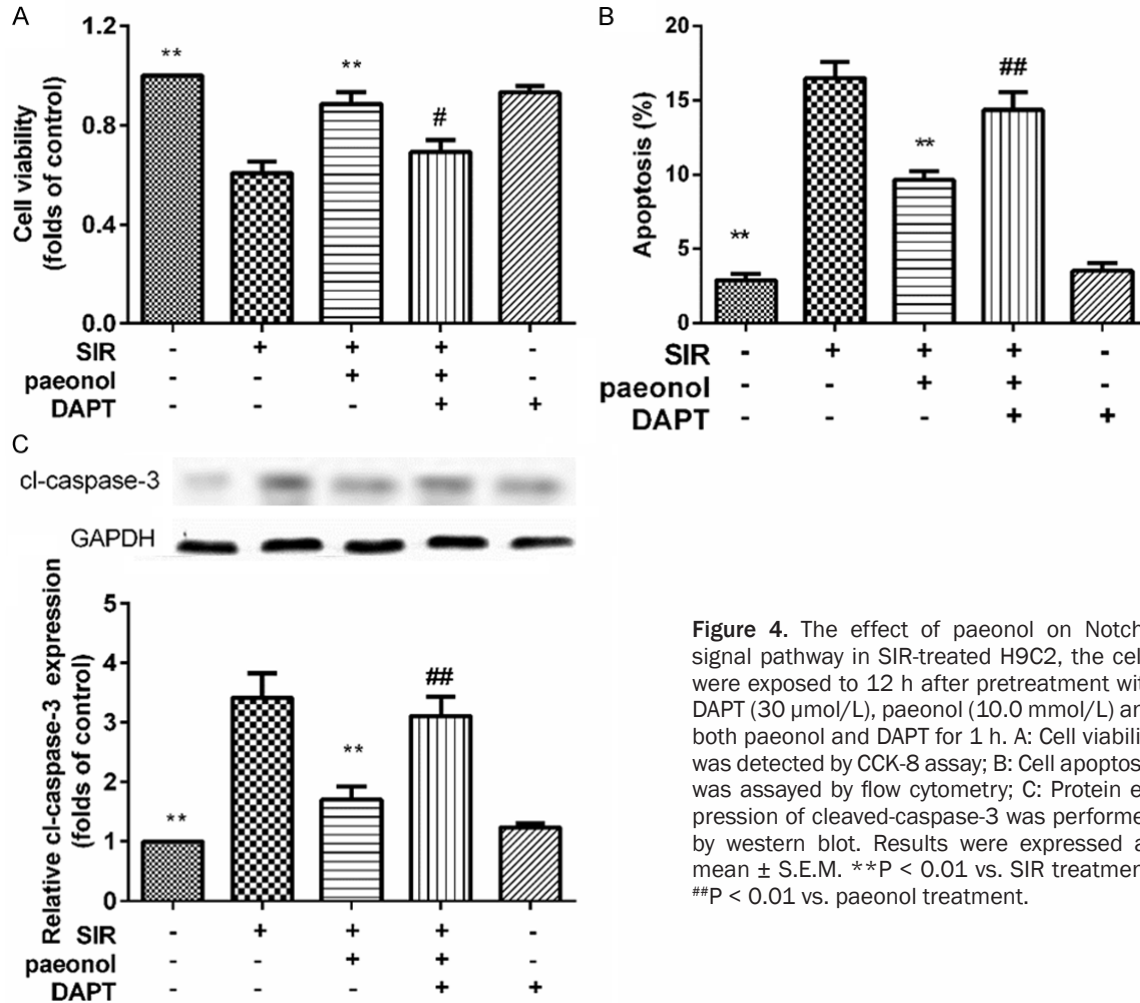
Firstly, determined the effects of paeonol on the viability of H9c2 cells. The H9c2 cells were exposed to paeonol (0.01, 0.1, 1.0 and 10.0 mmol/L) for 8 h. Then, cell viability was determined by CCK-8. As shown in **Figure 1A**, no significant cell viability changes were found compared with the control group ( $P > 0.05$ ). Next, the cells were subjected to SIR treatment in the absence or presence of paeonol (0.1, 1.0 and 10.0 mmol/L) treatment. SIR treatment significantly decreased cell viability (**Figure 1B**,  $P < 0.05$ , compared with the control group), while paeonol (1.0 and 10.0 mmol/L) treatment for 12 h resulted in a significant increase in cell viability, in a dose-dependent manner (**Figure 1B**,  $P < 0.05$ , compared with the SIR group).

However, 0.1 mmol/L paeonol had almost no effect on improving the cell viability (vs. IR group,  $P > 0.05$ ).

*Paeonol prevented the cell apoptosis induced by SIR treatment*

To examine whether paeonol has any effect on SIR-induced apoptosis in H9c2 cells, the present study performed by flow cytometry. Results showed that SIR treatment increased the percentage of apoptotic cells ( $P < 0.05$ , compared with control group, **Figure 2**). Compared with the SIR group, paeonol (1.0 and 10.0 mmol/L) treatment attenuated the H9c2 cells apoptosis, in a dose-dependent manner ( $P < 0.05$ , **Figure 2**), this result is identical with the CCK-8

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**Figure 4.** The effect of paeonol on Notch1 signal pathway in SIR-treated H9C2, the cells were exposed to 12 h after pretreatment with DAPT (30  $\mu$ mol/L), paeonol (10.0 mmol/L) and both paeonol and DAPT for 1 h. A: Cell viability was detected by CCK-8 assay; B: Cell apoptosis was assayed by flow cytometry; C: Protein expression of cleaved-caspase-3 was performed by western blot. Results were expressed as mean  $\pm$  S.E.M. \*\* $P < 0.01$  vs. SIR treatment; ## $P < 0.01$  vs. paeonol treatment.

results. In conclusion, these data confirmed that exposure of the H9c2 cells to SIR induced apoptotic cell death, however, pretreatment with paeonol reversed this effect and protected the H9c2 cells.

### *The effect of paeonol treatment on caspase-3, bax, bcl-2 and notch1 proteins expression in SIR-treated H9C2 cells*

To investigate whether the protective effect of paeonol is associated with apoptosis related protein, the protein levels of pro-apoptotic cleaved-caspase-3, bax, and anti-apoptotic Bcl-2 were measured using Western blot analysis. As shown in **Figure 3**, the protein expression of cleaved-Caspase-3, and bax in the SIR group was significantly upregulated, compared with that in the control group ( $P < 0.05$ ). However, paeonol attenuated the SIR-induced upregulation in the expression of cleaved-caspase-3 and bax, compared with the SIR group

( $P < 0.05$ ). In addition, conversely, SIR produced a significant decrease in the expression of Bcl-2 ( $P < 0.05$ , compared with control group). While, paeonol treatment up-regulated the ratio of Bcl-2 ( $P < 0.05$ , compared with the SIR group). The results suggested that the protective effects of paeonol were associated with the down regulation of cleaved-caspase-3 and bax, and up regulation the expression of bcl-2. As shown in **Figure 3D**, SIR treatment can significantly down regulate the level of Noch1 in compared with control group. However, paeonol (1.0 and 10.0 mmol/L) can up regulate the expression of Notch 1 protein.

### *The effect of paeonol on Notch1 signal pathway in SIR-treated H9C2 cells*

The above experiments indicated that paeonol protected the H9c2 cells from SIR-induced cell death and this mechanism may be related to Notch1 signaling pathway. The following experi-

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ment was to explore the role of the Notch1 signaling pathway in paeonol's protective effect on SIR-treated H9c2 cells. We determined whether treatment with DAPT, a specific inhibitor of the Notch1 signaling pathway, affected cell viability in SIR-treated H9c2 cells. The cells were subjected to SIR treatment in the absence or presence of paeonol (1.0 mmol/L). SIR treatment significantly decreased cell viability, similar to our previous experiments ( $P < 0.05$ , compared with the control group), while paeonol treatment for 12 h resulted in a significant increase in cell viability ( $P < 0.05$ , compared with the SIR group). However, paeonol-induced cardioprotective effect was significantly blunted by co-administration of DAPT (**Figure 4A**,  $P < 0.05$ , compared with the SIR+ paeonol group). As assayed by flow cytometry, paeonol (1.0 mmol/L) treatment significantly attenuated SIR-induced cell apoptosis. However, this protective effect was partially blunted by co-administration of DAPT (**Figure 4B**). As shown in **Figure 4C**, paeonol (1.0 mmol/L) treatment also reduced the apoptotic protein cleavage-caspase-3, while DAPT co-administration significantly blocked this protective effect ( $P < 0.05$ , compared with the SIR+ paeonol group). These findings indicated that paeonol had direct anti-apoptotic effect against SIR injury and Notch1 signaling might play a key role in this protective action.

### Discussion

Recent years, increasing attentions have been focused on the potential various pharmacological properties of paeonol, including sedation, antipyresis, analgesic, anti-tumor, anti-oxidation, anti-inflammation and immunoregulation and so on [19-23]. The present study was carried out to further elucidate the underlying mechanisms of paeonol's cardioprotective action. In this study, the vitro model was used to investigate the protective effect of paeonol against SIR-induced cardiac damage. We found that paeonol markedly ameliorated the SIR injury by activating Notch1 signal pathway.

Notch1 signaling has indispensable functional to control tissue formation in cardiogenesis [24, 25]. Intriguingly, the modulation effect of Notch1 signaling on cardioprotection attracted increasing attention recently. Notch1 signaling played a cardio protective role following cardiac injury and the activation of Notch1 signaling in the H9c2 cells contributed to the cardio protection provided by ischemic preconditioning and

postconditioning [9, 26, 27]. However, the relationship between paeonol and Notch1 signaling in myocardium has not been elucidated. In this study, we found that the expression of Notch1 was significantly up-regulated by paeonol treatment in SIR-treated H9c2 cells, which indicated the critical role of Notch1 signaling in paeonol's protective action.

To further discover the role of Notch1 signaling in paeonol's cardio protective action, DAPT was added in the H9c2 cells. DAPT, a potent and specific inhibitor of  $\gamma$ -secretase, has been widely used to specifically block the Notch1 signal pathway. In the present study, DAPT significantly attenuated paeonol's protective effect against SIR treatment on the H9c2 cells. This finding indicated that the potential relevance of Notch1 signaling. In this study, we provided direct in vitro evidence that Notch1 signaling activation by paeonol reduced the SIR-treated H9c2 cells and that blocking this signaling significantly reverse this effect.

In summary, our findings suggested that paeonol exerted a profound cardio protective effect against apoptosis of the H9c2 cells induced by SIR treatment. This protection appeared to be largely due to the modulation of Notch1 signaling pathway. These results indicated that paeonol may be a promising candidate for the treatment of ischemic heart diseases.

### Disclosure of conflict of interest

None.

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### References

- [1] Ibanez B, Heusch G, Ovize M and Van de Werf F. Evolving therapies for myocardial ischemia/reperfusion injury. *J Am Coll Cardiol* 2015; 65: 1454-1471.
- [2] Heusch G. Treatment of myocardial ischemia/reperfusion injury by ischemic and pharmacological postconditioning. *Compr Physiol* 2015; 5: 1123-1145.
- [3] von Elverfeldt D, Maier A, Duerschmied D, Braig M, Witsch T, Wang X, Mauler M, Neudorfer I, Menza M, Idzko M, Zirlík A, Heidt T, Bronsert P, Bode C, Peter K and von Zur Muhlen C. Dual-contrast molecular imaging allows noninvasive

## Paeonol protects cardiomyocytes from ischemia/reperfusion injury

- characterization of myocardial ischemia/reperfusion injury after coronary vessel occlusion in mice by magnetic resonance imaging. *Circulation* 2014; 130: 676-687.
- [4] Ann EJ, Kim MY, Yoon JH, Ahn JS, Jo EH, Lee HJ, Lee HW, Kang HG, Choi DW, Chun KH, Lee JS, Choi CY, Ferrando AA, Lee K and Park HS. Tumor suppressor HIPK2 regulates malignant growth via phosphorylation of Notch1. *Cancer Res* 2016; 76: 4728-4740.
- [5] Panaccione A, Chang MT, Carbone BE, Guo Y, Moskaluk CA, Virk RK, Chiriboga L, Prasad ML, Judson B, Mehra S, Yarbrough WG and Ivanov SV. NOTCH1 and SOX10 are essential for proliferation and radiation resistance of cancer stem-like cells in adenoid cystic carcinoma. *Clin Cancer Res* 2016; 22: 2083-2095.
- [6] Yu XM, Jaskula-Sztul R, Georgen MR, Aburjania Z, Somnay YR, Levenson G, Sippel RS, Lloyd RV, Johnson BP and Chen H. Notch1 signaling regulates the aggressiveness of differentiated thyroid cancer and inhibits SERPINE1 expression. *Clin Cancer Res* 2016; 22: 3582-3592.
- [7] Adamowicz M, Vermezovic J and d'Adda di Fagagna F. NOTCH1 inhibits activation of ATM by impairing the formation of an ATM-FOXO3a-KAT5/Tip60 complex. *Cell Rep* 2016; 16: 2068-2076.
- [8] Rasi S, Khiabani H, Ciardullo C, Terzi-di-Bergamo L, Monti S, Spina V, Brusca A, Cerri M, Deambrogi C, Martuscelli L, Biasi A, Spaccarotella E, De Paoli L, Gattei V, Foa R, Rabadan R, Gaidano G and Rossi D. Clinical impact of small subclones harboring NOTCH1, SF3B1 or BIRC3 mutations in chronic lymphocytic leukemia. *Haematologica* 2016; 101: e135-138.
- [9] Pei H, Du J, Song X, He L, Zhang Y, Li X, Qiu C, Zhang Y, Hou J, Feng J, Gao E, Li D and Yang Y. Melatonin prevents adverse myocardial infarction remodeling via Notch1/Mfn2 pathway. *Free Radic Biol Med* 2016; 97: 408-417.
- [10] Liu X, Luo Q, Zheng Y, Liu X, Hu Y, Liu W, Luo M, Tao H, Wu D, Zhao Y and Zou L. Notch1 impairs endothelial progenitor cell bioactivity in pre-eclampsia. *Reprod Sci* 2016; [Epub ahead of print].
- [11] Zhou XL, Fang YH, Zhao Y, Zou B, Xu QR, Xu H, Rao CX and Liu JC. [The effect of Notch1 on myocardial ischemia reperfusion injury]. *Zhonghua Yi Xue Za Zhi* 2016; 96: 1591-1596.
- [12] Deng C, Yao N, Wang B and Zhang X. Development of microwave-assisted extraction followed by headspace single-drop microextraction for fast determination of paeonol in traditional Chinese medicines. *J Chromatogr A* 2006; 1103: 15-21.
- [13] Fan HY, Qi D, Yu C, Zhao F, Liu T, Zhang ZK, Yang MY, Zhang LM, Chen DQ and Du Y. Paeonol protects endotoxin-induced acute kidney injury: potential mechanism of inhibiting TLR4-NF-kappaB signal pathway. *Oncotarget* 2016; 7: 39497-39510.
- [14] Li H, Song F, Duan LR, Sheng JJ, Xie YH, Yang Q, Chen Y, Dong QQ, Zhang BL and Wang SW. Paeonol and danshensu combination attenuates apoptosis in myocardial infarcted rats by inhibiting oxidative stress: roles of Nrf2/HO-1 and PI3K/Akt pathway. *Sci Rep* 2016; 6: 23693.
- [15] Choy KW, Mustafa MR, Lau YS, Liu J, Murugan D, Lau CW, Wang L, Zhao L and Huang Y. Paeonol protects against endoplasmic reticulum stress-induced endothelial dysfunction via AMPK/PPARdelta signaling pathway. *Biochem Pharmacol* 2016; 116: 51-62.
- [16] Ishiguro K, Ando T, Maeda O, Hasegawa M, Kadomatsu K, Ohmiya N, Niwa Y, Xavier R and Goto H. Paeonol attenuates TNBS-induced colitis by inhibiting NF-kappaB and STAT1 transactivation. *Toxicol Appl Pharmacol* 2006; 217: 35-42.
- [17] Wu J, Xue X, Zhang B, Cao H, Kong F, Jiang W, Li J, Sun D and Guo R. Enhanced antitumor activity and attenuated cardiotoxicity of Epirubicin combined with Paeonol against breast cancer. *Tumour Biol* 2016; 37: 12301-12313.
- [18] Yang Y, Duan W, Jin Z, Yi W, Yan J, Zhang S, Wang N, Liang Z, Li Y, Chen W, Yi D and Yu S. JAK2/STAT3 activation by melatonin attenuates the mitochondrial oxidative damage induced by myocardial ischemia/reperfusion injury. *J Pineal Res* 2013; 55: 275-286.
- [19] Huang TJ, Chuang H, Liang YC, Lin HH, Horng JC, Kuo YC, Chen CW, Tsai FY, Yen SC, Chou SC and Hsu MH. Design, synthesis, and bioevaluation of paeonol derivatives as potential anti-HBV agents. *Eur J Med Chem* 2015; 90: 428-435.
- [20] Liu MH, Lin AH, Lee HF, Ko HK, Lee TS and Kou YR. Paeonol attenuates cigarette smoke-induced lung inflammation by inhibiting ROS-sensitive inflammatory signaling. *Mediators Inflamm* 2014; 2014: 651890.
- [21] Ding Y, Li Q, Xu Y, Chen Y, Deng Y, Zhi F and Qian K. Attenuating oxidative stress by paeonol protected against acetaminophen-induced hepatotoxicity in mice. *PLoS One* 2016; 11: e0154375.
- [22] Li H, Xie YH, Yang Q, Wang SW, Zhang BL, Wang JB, Cao W, Bi LL, Sun JY, Miao S, Hu J, Zhou XX and Qiu PC. Cardioprotective effect of paeonol and danshensu combination on isoproterenol-induced myocardial injury in rats. *PLoS One* 2012; 7: e48872.
- [23] Jung EH, Hwang JS, Kwon MY, Kim KH, Cho H, Lyoo IK, Shin S, Park JH and Han IO. A tryptamine-paeonol hybridization compound inhibits LPS-mediated inflammation in BV2 cells. *Neurochem Int* 2016; 100: 35-43.
- [24] Yang H, Sun W, Quan N, Wang L, Chu D, Cates C, Liu Q, Zheng Y and Li J. Cardioprotective ac-

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- tions of Notch1 against myocardial infarction via LKB1-dependent AMPK signaling pathway. *Biochem Pharmacol* 2016; 108: 47-57.
- [25] Kumar D, Kumar S, Gorain M, Tomar D, Patil HS, Radharani NN, Kumar TV, Patil TV, Thulasiram HV and Kundu GC. Notch1-MAPK signaling axis regulates CD133+ Cancer stem cell-mediated melanoma growth and angiogenesis. *J Invest Dermatol* 2016; 136: 2462-2474.
- [26] Cai W, Yang X, Han S, Guo H, Zheng Z, Wang H, Guan H, Jia Y, Gao J, Yang T, Zhu X and Hu D. Notch1 pathway protects against burn-induced myocardial injury by repressing reactive oxygen species production through JAK2/STAT3 signaling. *Oxid Med Cell Longev* 2016; 2016: 5638943.
- [27] Xu H, Jin L, Chen Y and Li J. Downregulation of microRNA-429 protects cardiomyocytes against hypoxia-induced apoptosis by increasing Notch1 expression. *Int J Mol Med* 2016; 37: 1677-1685.