Morphine pretreatment reduces myocardial ischemia-reperfusion injury in heart failure rats via GSK-3β/Cx43 signaling proteins and apoptosis-related gene, Bcl-2/Bax

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Abstract

Purpose: To investigate the effect of morphine preconditioning on myocardial ischemia reperfusion injury in heart failure rats, and the mechanism(s) of action involved

Methods: Seventy-two healthy male Sprague-Dawley rats were assigned to 4 groups: sham, model, morphine-preconditioning and SB203580 inhibitor groups, each with 18 rats. The expressions of P-p38, p-glycogen synthetase kinase-3, and p-gap junction protein 43 in rat myocardial cells were assayed by Western blotting. The mRNA expression levels of Bcl-2 and Bax, and Bcl-2/Bax were determined using real-time fluorescence quantitative PCR.

Results: The expression levels of P-p38, p-glycogen synthetase kinase-3, p-gap junction protein 43, Bcl-2 mRNA and Bcl-2/Bax were significantly higher in the pretreatment group than in the model group, while Bax mRNA was significantly lower (p < 0.05). Moreover, the mRNA expression levels of P-p38, p-glycogen synthetase kinase-3, p-gap junction protein, Bcl-2, and Bcl-2/Bax in inhibitor-treated rats decreased significantly, when compared to the values for pretreatment rats; furthermore, Bax mRNA was markedly upregulated (p < 0.05).

Conclusion: Morphine preconditioning significantly inhibits the expressions of GSK-3β and Cx43 signaling proteins, as well as apoptosis-related gene, Bcl-2 and Bax. In addition, it inhibits the apoptosis of rat cardiomyocytes, and reduces myocardial injury, after ischemia reperfusion, via activation of the p38 MARK signaling pathway. This provides a new strategy for clinical reduction of myocardial injury after ischemia-reperfusion.

Keywords: Morphine, Pretreatment, GSK-3β/Cx43 signaling protein, Bcl-2/Bax, Heart failure, Ischemia-reperfusion injury

INTRODUCTION

Coronary artery disease is considered the main cause of morbidity and mortality globally. According to statistics, the incidence of coronary heart disease in China is gradually increasing and showing a trend towards younger people [1]. Heart failure is a serious stage in various heart diseases. With increase in the aging population, heart failure patients are prone to perioperative
myocardial ischemia and reperfusion injury during cardiac or non-cardiac surgery, with serious effect on the quality of life and safety of patients [2].

Studies have found that post-myocardial ischemia reperfusion increases myocardial infarction area and myocardial cell apoptosis, thereby seriously affecting cardiac function recovery and endangering the lives and safety of patients [3]. Therefore, there is a need to evolve effective methods for protecting the myocardium. Ischemic preconditioning, a traumatic stimulation, is the most classical and effective method for protecting the myocardium from ischemic perfusion injury [4]. Morphine is an opioid which significantly reduces myocardial suppression and the incidence of heart failure [5].

In the present study, the effect of morphine preconditioning on myocardial ischemia reperfusion injury in cardiac failure rats, and the mechanism involved, were investigated.

**EXPERIMENTAL**

**Animals**

A total of 72 healthy male SD rats [provided by Animal Experimental Center of Anhui Medical University; production license SCXK (Anhui) 2015-0001] weighing 211 ± 37 g, were used for the study. They were housed in a laboratory at a temperature of 26 ± 3°C, humidity of 47 ± 11%, and photoperiod of 12-h day/12-h night.

This research received approval from the Animal Ethical Committee of First Affiliated Hospital of Jiamusi University (approval no. 20195631, and was conducted according to "Principles of Laboratory Animal Care" (NIH publication no. 85-23, revised 1985) [6].

**Major equipment and reagents**

The major instruments and reagents used, and their makers (in brackets) were: Animal Ventilator (Shanghai Yuyan Scientific Instrument Co. Ltd, model: SAR-1000); Low-temperature High-speed Centrifuge (Shanghai Hetian Scientific Instrument Co. Ltd, model: TG18G); Optical microscope (Shanghai Optical Instrument Factory, model: SG-51); CytoFLEX flow cytometer (Shanghai Murui Biotechnology Co. Ltd); phosphate buffer (Shanghai Thermo Fisher Technology Co. Ltd); fetal bovine serum (Shanghai Huiying Biotechnology Co. Ltd); Rabbit anti-rat Bax polyclonal antibody (Wuhan Aimejie Technology Co. Ltd); Rabbit anti-rat p38 MARK polyclonal antibody (Shanghai Xuanling Biotechnology Co. Ltd); Rabbit anti-mouse GSK-3β antibody polyclonal antibody (Aimekit Technology Co. Ltd); Mouse anti-Cx43 monoclonal antibody (Shanghai Huzhen Industrial Co. Ltd), and morphine (Shenyang First Pharmaceutical Co. Ltd, production batch no. 20173351, specification: 10 mg/mL).

**Animal groups**

A rat model of myocardial reperfusion injury was established, and the rats were randomly divided into sham group, model ischemic group, morphine pretreatment group (pretreatment group) and SB203580 inhibitor group i.e. inhibitor of p38 mitogen activated protein kinase (p38 MARK), with 18 rats in each group. Sham operation rats received 1mL physiological saline 10 min before perfusion without ligation. Rats in the model group were ligated at the coronary artery anterior descending arm for 35 minutes, and then released and ligated for 2 h after reperfusion. Normal saline (1 mL) was injected into the tail vein 10 min before perfusion. The rats in the pretreatment group were ligated at the coronary artery anterior descending arm for 35 minutes, and then released and ligated for 2 h for reperfusion. The rats were injected with 1 mol/L morphine 10 min before perfusion, while rats in the inhibitor group were given p38MARK inhibitor 5 min before morphine pretreatment.

**Treatment indicators**

The TCC staining was used to determine changes in myocardial infarction area in each group. After 2 h of myocardial reperfusion, the rat hearts were removed and injected with 0.5 mL of 0.25 % evanlan to expose the ischemic and non-ischemic areas: the ischemic areas were uncolored, while the non-ischemic areas were colored blue. The areas of myocardial infarction in the various groups were compared.

**Cell viability**

Changes in viability of cardiomyocytes were determined using CCK-8 method. The cardiomyocytes were seeded in 96-well plates at a density of 400000 cells/mL, followed by addition of 10 μL of CCK-8 and incubation for 2 h. The absorbance of each well was read at 450 nm.

**Evaluation of apoptosis**

Apoptosis of rat cardiomyocytes was measured with flow cytometry, while the expressions of P-p38, p-glycogen synthetase kinase-3 (p-GSK-3) and p-gap junction protein 43 (p-Cx43) were
determined with Western blotting assay. The mRNA expression levels of Bcl-2 and Bax, and Bcl-2/Bax ratio were determined using real-time fluorescence quantitative PCR.

**Statistical evaluation**

Measurement data are presented as mean ± standard deviation (SD), and were statistically compared with one-way ANOVA and LSD t-test using SPSS 22.0 software package. Values of $p < 0.05$ were taken as indicative of significant differences.

**RESULTS**

**Myocardial infarction area**

Myocardial infarction area was significantly higher in model rats than in sham rats. Myocardial infarction area in pretreatment rats was markedly decreased, relative to model rats, but it was markedly increased in inhibitor-treated rats. These results are shown in Figure 1 and Table 1.

**Table 1: Size of myocardial infarction area (mean ± SD, n = 18)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Myocardial infarction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sham</td>
<td>0.02 ± 0.01</td>
</tr>
<tr>
<td>Model</td>
<td>0.15 ± 0.03$^a$</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.07 ± 0.03$^{ab}$</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>0.12 ± 0.02$^{ac}$</td>
</tr>
<tr>
<td>$F$</td>
<td>102.26</td>
</tr>
<tr>
<td>$P$-value</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

$^{a,b,c}P < 0.05$, where $^a$, $^b$, and $^c$ refer to comparison with sham, model and pretreatment rats, respectively

**Myocardial cell viability**

Table 2 shows that the viability of myocardial cells was markedly lower in model rats than in sham rats. Myocardial cell viability was significantly higher in pretreatment rats than in model rats, but was markedly less in inhibitor-treated rats than in pretreatment rats ($p < 0.05$).

**Table 2: Myocardial cell viability amongst the groups (mean ± SD, n = 18)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Cell viability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sham</td>
<td>1.01 ± 0.12</td>
</tr>
<tr>
<td>Model</td>
<td>0.62 ± 0.09$^a$</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>0.83 ± 0.03$^{ab}$</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>0.71 ± 0.05$^{ac}$</td>
</tr>
<tr>
<td>$F$</td>
<td>79.02</td>
</tr>
<tr>
<td>$P$-value</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

$^{a,b,c}P < 0.05$, where $^a$, $^b$, and $^c$ refer to comparison with sham, model and pretreatment rats, respectively

**Apoptosis of rat cardiomyocytes**

Apoptosis of myocardial cells was significantly higher in the model group than in sham group, but was markedly higher in pretreatment group than in the model group ($p < 0.05$). Compared with the pretreatment group, apoptosis of myocardial cells in the inhibitor group was significantly decreased ($p < 0.05$). These results are shown in Table 3.

**Table 3: Apoptosis of rat myocardial cells (mean ± SD, n = 18)**

<table>
<thead>
<tr>
<th>Group</th>
<th>Apoptosis of myocardial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sham</td>
<td>1.01 ± 0.07</td>
</tr>
<tr>
<td>Model</td>
<td>2.14 ± 0.73$^a$</td>
</tr>
<tr>
<td>Pretreatment</td>
<td>1.37 ± 0.11$^{ab}$</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>1.79 ± 0.75$^{ac}$</td>
</tr>
<tr>
<td>$F$</td>
<td>15.68</td>
</tr>
<tr>
<td>$P$-value</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

$^{a,b,c}P < 0.05$, where $^a$, $^b$, and $^c$ refer to comparison with sham, model and pretreatment rats, respectively

**Expression levels of P-p38, p-glycogen synthetase kinase-3 and p-gap junction protein 43 in rat myocardial cells**

The expression levels of P-p38, p-glycogen synthetase kinase-3 and p-gap junction protein 43 were markedly downregulated in model rats, relative to sham operation rats, but they were markedly higher in pretreatment rats than in model rats ($p < 0.05$). However, the expression levels of p-p38, p-GSK-3 and p-Cx43 in the inhibitor group were significantly lower than corresponding levels in pretreatment group ($p < 0.05$). These data are presented in Figure 2 and Table 4.

**Expression levels of Bcl-2 mRNA and Bax mRNA, and Bcl-2 /Bax ratio in rat muscle cells**

Table 5 shows that mRNA level of Bcl-2, and Bcl-2/Bax in rat myocardial cells in the model group were significantly lower than those in the sham group, while Bax mRNA was significantly higher ($p < 0.05$). In contrast, mRNA level of Bcl-2, and
Bcl-2/Bax ratio were markedly higher in pretreatment rats than in model rats, while Bax mRNA was significantly lower ($p < 0.05$). However, mRNA level of Bcl-2, and Bcl-2/Bax ratio were markedly downregulated, relative to pretreatment group, while Bax mRNA was significantly higher ($p < 0.05$).

**DISCUSSION**

Heart failure is a clinical syndrome associated with progressive dysfunction and circulatory failure. The stimulation of hypertension and coronary heart disease leads to hypertrophy, fibrosis and apoptosis of cardiomyocytes. At the same time, the expressions of marker genes also change, resulting in decreased contractility and enlargement of the myocardium, which eventually lead to heart failure [7]. The prevention and treatment of ischemia reperfusion injury (one of the postoperative complications of coronary artery treatment in clinical practice) has received extensive attention, with continuous development of various clinically-difficult cardiac techniques [8]. It has been reported that ischemic preconditioning of myocardial tissue before perfusion significantly reduces myocardial ischemia reperfusion injury for a long time thereafter, thereby playing a protective role [9]. Morphine is an important opioid. It is known that opioids are frequently used as analgesics during surgery. Studies have confirmed that opioid receptors are involved in the myocardial protective effect of opioid preconditioning against heart ischemia [10]. Morphine activates G-protein through cardiac opioid receptors, and then activates protein kinase C, thus playing a role in alleviating myocardial ischemia [11].

Myocardial infarction refers to the occlusion of coronary arteries, interruption of blood flow, and partial myocardial necrosis due to severe and persistent ischemia. Some studies have found that the myocardial infarction area is an important index for evaluating myocardial injury [12]. Apoptosis refers to the orderly death of cells, which is also the most significant feature in ischemia-reperfusion injury. Studies have revealed that the more severe the myocardial cell apoptosis, the more severe the myocardial infarction [13]. The results of this study showed that morphine preconditioning significantly improved the viability of myocardial cells, inhibited the apoptosis of myocardial cells, and reduced the area of myocardial infarction.

Studies on rabbit myocardial ischemia reperfusion injury have shown that p38 MAPK expression significantly changed due to the mitigating influence of morphine preconditioning on ischemia reperfusion-induced injury on rabbit myocardium [14]. The p38 MAPK signaling pathway may be involved in morphine preconditioning-induced protection against myocardial ischemia-reperfusion injury. A member of the MAPK family, P38 phosphorylates transcription factors and effector proteins, a process which is important for initiation of...
apoptosis and quiescence of cell cycle. The GSK-3β is a serine/threonine kinase found mainly in mammalian eukaryotic cells. Studies have revealed that GSK-3β beta affects blood glucose concentration and regulates Bax/hexokinase (HK II) ratio, the proportion of which is involved in regulating cell apoptosis [15]. Increased levels of p-gsk-3 morphine constitute an important link in the myocardial protective effect of morphine.

An important connexin, Cx43 is widely found in human tissues and cells, and is considered a unique component of cardiac gap junction [16]. Tania et al [17] found that the expression level of Cx43 plays an important role in maintaining normal heart function. It is known that Bcl-2 is a tumor suppressor gene which significantly inhibits apoptosis, while Bax is an apoptotic gene which inhibits Bcl-2. It has been reported that the Bcl-2/Bax ratio is a key factor that determines the degree of apoptosis [18]. The results of this study showed that morphine pretreatment significantly raised mRNA levels of p-p38, p-GSK-3β, p-Cx43, Bcl-2 and Bcl-2/Bax, while Bax mRNA levels were decreased.

CONCLUSION

The findings obtained in this study suggest that morphine preconditioning may significantly influence the expressions of p-glycogen synthetase kinase-3 and p-gap junction protein 43 signaling proteins, and the expressions of the apoptosis-related genes, Bcl-2 and Bax, by activating p38 MARK signaling pathway, inhibiting apoptosis of rat cardiomyocytes, and reducing myocardial injury after ischemia reperfusion. Thus, this research provides a new strategy for clinical reduction of myocardial injury after ischemia-reperfusion.

DECLARATIONS

Acknowledgement

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Conflict of interest

No conflict of interest is associated with this work.

Authors’ contributions

This study was done by the authors named in this article, and the authors accept all liabilities resulting from claims which relate to this article and its contents. The study was conceived and designed by Xuelian Zhu; Xuelian Zhu, Zhihai Geng, Xi Han, Xianfeng Xin collected and analyzed the data; Xianfeng Xin wrote the text. All authors read and approved the manuscript for publication.

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