Sevoflurane preconditioning attenuates hypoxia/reoxygenation injury of H9c2 cardiomyocytes by activation of the HIF-1/PDK-1 pathway

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Background: Sevoflurane preconditioning (SPC) can provide myocardial protective effects similar to ischemic preconditioning(IPC). However, the underlying molecular mechanism of SPC remains unclear. Studies confirm that hypoxia-inducible factor-1 (HIF-1) can transform cells from aerobic oxidation to anaerobic glycolysis by activating the switch protein pyruvate dehydrogenase kinase-1 (PDK-1), thus providing energy for the normal life activities of cells under hypoxic conditions. The purpose of this study was to investigate whether the cardioprotective effects of SPC are associated with activation of the HIF-1a/PDK-1 signal pathway. **Methods**: The H9c2 cardiomyocytes hypoxia/reoxygenation model was established and treated with 2.4% sevoflurane at the end of equilibration. Lactate dehydrogenase (LDH) level, cell viability, cell apoptosis, mitochondrial membrane potential, key enzymes of glycolysis, ATP concentration of glycolysis were assessed after the intervention. Apoptosis related protein(Bcl-2, Bax), HIF-1a protein, and PDK-1 protein were assessed by western blot.**Results**: Compared with the H/R group, SPC significantly increased the expression of HIF-1a, PDK-1, and Bcl-2 and reduced the protein expression of Bax, which markedly decreased the apoptosis ratio and Lactate dehydrogenase (LDH) level, increasing the cell viability, content of key enzymes of glycolysis, ATP concentration of glycolysis and stabilizing the mitochondrial membrane potential. However, the cardioprotective effects of SPC were disappeared by treatment with a HIF-1a selective inhibitor.**Conclusion**: This study demonstrates that the cardioprotective effects of SPC are associated with the activation of the HIF-1a/PDK-1 signaling pathway. The mechanism may be related to increasing the content of key enzymes and ATP of glycolysis in the early stage of hypoxia.**Keywords**: Sevoflurane preconditioning, hypoxia/reoxygenation injury, myocardial protective effect, hypoxia-inducible factor-1, pyruvate dehydrogenase

kinase-1, glycolysis

1 **Sevoflurane preconditioning attenuates hypoxia/reoxygenation injury of H9c2**

2 **cardiomyocytes by activation of the HIF-1/PDK-1 pathway**

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Abstract

15 **Background**: Sevoflurane preconditioning (SPC) can provide myocardial protective effects similar to ischemic preconditioning

16 (IPC). However, the underlying molecular mechanism of SPC remains unclear. Studies confirm that hypoxia-inducible factor-1

17 (HIF-1) can transform cells from aerobic oxidation to anaerobic glycolysis by activating the switch protein pyruvate dehydrogenase

18 kinase-1 (PDK-1), thus providing energy for the normal life activities of cells under hypoxic conditions. The purpose of this study

19 was to investigate whether the cardioprotective effects of SPC are associated with activation of the HIF-1a/PDK-1 signal pathway.

20 **Methods**: The H9c2 cardiomyocytes hypoxia/reoxygenation model was established and treated with 2.4% sevoflurane at the end

21 of equilibration. Lactate dehydrogenase (LDH) level, cell viability, cell apoptosis, mitochondrial membrane potential, key enzymes

22 of glycolysis, ATP concentration of glycolysis were assessed after the intervention. Apoptosis related protein (Bcl-2, Bax), HIF-

23 1a protein, and PDK-1 protein were assessed by western blot.

24 **Results**: Compared with the H/R group, SPC significantly increased the expression of HIF-1a, PDK-1, and Bcl-2 and reduced the

25 protein expression of Bax, which markedly decreased the apoptosis ratio and Lactate dehydrogenase (LDH) level, increasing the

26 cell viability, content of key enzymes of glycolysis, ATP concentration of glycolysis and stabilizing the mitochondrial membrane

27 potential. However, the cardioprotective effects of SPC were disappeared by treatment with a HIF-1a selective inhibitor.

28   **Conclusion**: This study demonstrates that the cardioprotective effects of SPC are associated with the activation of the HIF-

29   1a/PDK-1 signaling pathway. The mechanism may be related to increasing the content of key enzymes and ATP of glycolysis in

30   the early stage of hypoxia.

31   **Keywords**: Sevoflurane preconditioning, hypoxia/reoxygenation injury, myocardial protective effect, hypoxia-inducible factor-

32   1, pyruvate dehydrogenase kinase-1, glycolysis

33

Introduction

35   Despite substantial progress in prevention and treatment, ischemic heart disease (IHD) remains the main cause

36   of morbidity and mortality worldwide (Devereaux et al. 2017). At present reperfusion therapy is the most

37   effective treatment for IHD. However, it is also inevitable that ischemia/reperfusion (I/R) injury will occur to

38   cause greater injury for tissues (Heusch 2013). Accumulated evidence has indicated that preconditioning with

39   sevoflurane could attenuate the I/R injury both in vitro and in vivo (Guerrero-Orriach et al. 2017; Kunst & Klein

40   2015; Obal et al. 2005), and there are multiple mechanisms involved in the cardioprotective effect of sevoflurane

41   preconditioning (SPC), such as activation of KATP channel, to improve ion transport in the myocardial cell

42   membrane, mitochondrial membrane and relieve Ca^{2+} overload (Zhang et al. 2012), activation of Adenosine A1

43   receptor as to reduce the production of reactive oxygen species (Lucchinetti et al. 2018), downregulation of

44   apoptosis (Wei et al. 2017). However, the potential molecular mechanisms of SPC in myocardial protection still

45   have not been fully elucidated.

46   Hypoxia-inducible factor-1 (HIF-1) is a protein that regulates the expression of an arrangement of hypoxia-

47   sensitive proteins beneath hypoxic conditions to preserve the survival of tissues (Semenza 2011). Considers have

48   affirmed that HIF-1 is central to cardio-protection against I/R injury (Eckle et al. 2008). Pyruvate dehydrogenase

49   kinase (PDK) is a key protein downstream of HIF-1 regulating energy metabolism. Now four isozymes of PDK-

50   1, PDK-2, PDK-3, and PDK-4 have been identified in PDK, they are mainly located in the mitochondrial matrix,

51   in which PDK-1 is mainly expressed in the heart (Sugden & Holness 2003). When cells are in a state of hypoxia,

52   HIF-1 regulates the expression of downstream target protein PDK-1, which changes the energy metabolism of

53   cardiomyocytes from the tricarboxylic acid cycle to glycolysis (Holness & Sugden 2003). Although glycolysis

54   is an inefficient way of energy production compared with mitochondrial aerobic oxidation, it plays an important

55   role in sustaining basic life activities under the conditions of ischemia/hypoxia. Thus, we investigated whether

56   the myocardial protective effect of SPC was associated with the regulation of glycolysis activity by activating

57   the HIF-1a/PDK-1 signaling pathway in H9c2 cardiomyocytes.

58   In the present study, H9c2 cardiomyocytes were used to establish a hypoxia/reoxygenation (H/R) induced

59   myocardial cell injury model. To explore the molecular mechanism of SPC against H/R injury of cardiomyocytes

60   by studying the activities of key enzymes and energy metabolism of glycolysis.

Materials and methods

Reagent and antibodies

63   TRYPSIN 0.25% (1X) solution with EDTA, penicillin-streptomycin solution and DMEM/low glucose medium,

64   phosphate-buffered saline (PBS) were purchased from Hyclone (Cat#SH30042.01, SV30010, SH30021.01,

65   SH30256.01; Hyclone, US). Fetal Bovine Serum (Cat#10091148, GIBCO, New York, US). Dimethyl sulfoxide,

66   Tris base, Glycine were purchased from Sigma (Cat# V900090, V900483, V900144; Sigma, US).

67   Annexin V-PE apoptosis detection kit was purchased from Becton, Dickinson, and Company (Cat#559763,

68   US). Mitochondrial membrane potential detection kit (JC-1), 10◊TBST buffer, non-fat milk powder, sodium

69   dodecyl sulfate, SDS-page gel preparation kit, 4◊protein sample buffer (containing β-mercaptoethanol) were

70   purchased from Solarbio (Cat#M8650, T1081, S8010-100, P1200-2, P1016, Solarbio, Beijing, China). ATP

71   detection kit and BCA protein quantitative kit were purchased from Beyotime (Cat#s0026, P0012, Beyotime,

72   Shanghai, China). The lactate dehydrogenase (LDH) kit was purchased from Nanjing Jiancheng Biotech Co. Ltd

73   (Cat# A020-2).

74   Rabbit-anti-HIF-1 alpha monoclonal antibody [EPR16897] (ab179483), Rabbit-anti-GAPDH antibody

75   [EPR16891] (ab181602-100), Rabbit-anti-Bcl-2 monoclonal antibody (ab62557),   Rabbit-anti-Bax

76   monoclonal antibody (ab32503), horseradish peroxidase (HRP)-conjugated goat anti-rabbit immunoglobulin G

77   (IgG) (ab205718), 10◊RIPA lysate (ab156034), Protease Inhibitor Cocktail, (ab201111), ECL Substrate Kit

78   (High Sensitivity) (ab133406) were purchased from Abcam Cambridge, MA, US. Rainbow protein pre-staining

79   marker, 10 to 180 kDa (26616, thermo-fermentas, MA, US). Rabbit-anti-PDK-1 (Cat# BF0312, Affinity

80   Biosciences, Changzhou, China). Lificiguat (YC-1) was purchased from Selleck (Cat#S7958,Shanghai, China).

81

Cell culture and processing

83   The H9c2 rat embryonic cardiomyocyte cell line was obtained from Procell Life Science & Technology Co.,

84   Ltd., China. The cell culture conditions consisted of DMEM (low sugar, 5mM) medium+10% (v/v) FBS (Gibco,

85   USA) + 1% (v/v) Penicillin/Streptomycin solution (Gibco, USA) at 37℃, 5%CO2, and saturated humidity. The

86   H9c2 cells were passaged at the ratio of 1:4 when the cell confluence reached 90% (by visual estimate) in 55cm^2

87   culture plate. Cells were cultured for 48h at 37°C in a 5% CO2 incubator. The supernatant was discarded when

88   the cells grew to 90% confluency, After gently washing the adherent cells with PBS twice, the serum-free

89   DMEM (low sugar, 5mM) medium was added. Treatment with Lificiguat (YC-1, 10μM) was added before

90   sevoflurane preconditioning. Plates with H9c2 cardiomyocytes were then placed in a sealed chamber (Modular

91   Incubator Chamber, MIC1; Billups-Rothenberg, Inc., Del Mar, CA, USA; http://www.brincubator.com/) filled

92   with 95% N_2 and 5% CO_2 to achieve an oxygen-deficient environment. Ventilation at 5 L/min for 15 min was

93   used to achieve a 1% lower oxygen concentration in the chamber (The oxygen indicator card was used to reflect

94   the oxygen concentration. Its color will change from blue to red when the oxygen concentration is less than 0.1%

95   in the sealed chamber). Cells were incubated at 37℃ for 3 h, and the PBS was removed and replaced with fresh

96   medium containing 10% FBS. Longer 3 h incubation in 95% air and 5% CO2 at 37℃ was performed as

97   reoxygenation. The plates of the CON group were kept in normoxic conditions for the corresponding times.

98   **Experimental protocol**

99   The H9c2 cardiomyocytes were randomly divided into four groups(Fig.1).

100   (1) Control (CON) group: H9c2 cells were continuously cultured in DMEM low-glucose medium (5mM)

101   containing 10% FBS without any interventions but with inhalation of pure oxygen (100% oxygen) for 15 min at

102   the same time interval when the SPC group was exposed to sevoflurane.

103   (2) Hypoxia/reoxygenation (H/R) group: H9c2 cells were cultured in low glucose concentration medium for 48

104   h, removed, washed with PBS two times and inhaled pure oxygen (100% oxygen) for 15 min and placed in an

105   airtight container with 95% N2 and 5% CO2 for 3 h, then reoxygenation (95% air and 5% CO2) with the addition

106   of fresh low glucose DMEM with 10% FBS at 37 ℃, for a total 3 h of reoxygenation.

107   (3) Sevoflurane preconditioning group (SPC): H9c2 cells were exposed to 2.4% sevoflurane for 15 min before

108   hypoxia after incubation in the medium for 48h. the later steps are all same to the H/R group.

109   (4) Hypoxia-inducible factor-1a inhibitor YC-1 group (S+Y): Lificiguat (YC-1) was added before sevoflurane

110   preconditioning, after treatment with sevoflurane preconditioning, the later steps are all same to the SPC group.

111   **Measurement of lactate dehydrogenase(LDH)**

112   Data were collected as described previously (Yu et al. 2016). Cell supernatant (0.1ml) was collected from each

113   group's plate 1min after reoxygenation. The absorbance values were measured at 450 nm, and then put the

114   absorbance values into the formula (LDH (U/L)=[(Determination OD-Control OD)(Standard OD-Blank

115   OD)]×0.2 μmol/ml×1,000), LDH activity was expressed as international units per liter (IU/L).

116

117   **Measurement of cell viability**

118   Data were collected as described previously (Yang et al. 2019). Each experiment was repeated three times, and

119   each group was repeated twice.

120

121 **Flow cytometry assay**

122 The percentage of cells apoptosis was measured using the PE Annexin-V Apoptosis Detection Kit I (BD

123 Biosciences Pharmingen, US). In brief, cells were collected and stained with annexin-V and 7-AAD as per the

124 manufacturer's instrument. The apoptotic cells were identified by flow cytometry (Beckman Coulter, US).

125

126 **Detection of key enzymes in glycolysis**

127 The content of the key enzymes of glycolysis was detected by the Elisa High-end detection kits (Jianglai Biotech

128 Co. Ltd, China). The key enzymes of glycolysis, including that of Hexokinase (HK), 6-phosphofructokinase-1

129 (PFK-1), Pyruvate kinase (PK), were measured. Wash the cells twice with pre-cooled PBS. RIPA lysis buffer

130 was used to lyse the cells on ice for 30 min, then the cell lysate was collected by EP tube. Centrifugation: 16,000

131 rpm, 4℃, 10 min, collecting the supernatant, and waiting for the test. The standard curve was made on enzyme

132 coated plate with 50 μl different concentrations of a standard substance. 40 μl of sample diluent was added to

133 the enzyme coated plate, and then 10 μl of the sample to be tested was added. 100 μl of enzyme-labeled reagent

134 was added into each well. The mixture was incubated at 37℃ for 60 min, then washed 5 times and left to dry.

135 Chromogenic agent solutions A and B (50 μl each) were added and incubated at room temperature for 15 min in

136 the dark. After adding 50 μl of the termination solution, the OD values of each pore were measured by an Enzyme

137 labeling instrument at 450 nm.

138

139 **Detection of glycolysis energy**

140 The level of intracellular ATP was detected using the ATP Bioluminescence Assay Kit (Beyotime, Shanghai,

141 China). The cells lysate was added, fully lysed, and centrifuged at 15,000 rpm for 10 min at 4℃. The supernatant

142 was collected into an EP tube, waiting for the test. Take 200 μl ATP detection reagent and add 1800 μl ATP

143 detection reagent diluent to prepare a 2 ml ATP detection working solution. The ATP standard solution was

144 diluted into an appropriate concentration gradient with ATP detection lysate and made a standard curve using

145 concentrations of 0.01, 0.03, 0.1, 0.3, 1, 3 and10 μM. After adding 100 μl ATP detection working solution and

146 20 μl sample into the detection well, and then measured with multifunctional enzyme marker after two seconds

147 interval.

148

149 **Detection of mitochondrial membrane potential**

150 JC-1 (Millipore, USA) is used to assess the redistribution of mitochondrial membrane potential (ΔΨm).

151   According to the manufacturer's instruction, the H9c2 cells were incubated with 10 nmol/L JC-1 staining

152   solution at 37℃ free light for 10 min. The images were captured using a fluorescence inverted microscope

153   (LEICA-DMI4000B, Germany). Thirty randomly chosen cardiomyocytes per treatment group were analyzed

154   (n=3 independent experiments with 10 incubated cardiomyocytes per experiment). Red and green fluorescence

155   intensities were analyzed respectively using Image J software as described (Sun et al. 2019), and the ratio of the

156   red/green fluorescence was proportional to the $\Delta\Psi$m.

157

158   **Western blot analysis**

159   The HIF-1a, PDK-1, Bax, Bcl-2, and glyceraldehyde 3-phosphate dehydrogenase (GAPDH) proteins were

160   detected with the antibodies rabbit monoclonal anti-HIF-1a, rabbit monoclonal anti-GAPDH, rabbit monoclonal

161   anti-Bax, rabbit monoclonal anti-Bcl-2 (Abcam, US), rabbit monoclonal anti-PDK-1 (Affinity, USA), Proteins

162   were extracted with 100 µl Lysis Solution (Radioimmunoprecipitation assay buffer/Phenylmethanesulfonyl

163   fluoride (PMSF)=100:1) for each plate. The protein concentrations were measured using a BCA kit (Solarbio,

164   Beijing, China) and all the concentrations were adjusted to the lowest protein concentration with the RIPA lysate.

165   The supernatant was mixed with 5◊loading buffer and heated for 5 min at 100 ℃, and then 30 micrograms of

166   the sample were subjected to electrophoresis using an SDS-PAGE gel system, transferred to Polyvinylidene

167   fluoride (PVDF) Western blotting membranes (Roche, Germany) and blocked in 5% non-fat milk at 37℃ for 2

168   h. Diluted primary antibodies to HIF-1a [EPR16897] (1:1000, Abcam, ab179483), Bax (1:500, Abcam,

169   ab32503), GAPDH (1:1000, Abcam, ab181602-100), PDK-1 (1:1000, Affinity Biosciences Cat#BF0312) and

170   Bcl-2 (1:500, Abcam, ab62557) were added, and the membrane was incubated overnight (4℃). The membrane

171   was washed with TBST solution for 3 times and incubated with HRP-conjugated secondary antibody (1:10,000,

172   Abcam, ab205718) for 2 h at room temperature. High Sensitivity ECL Substrate Kit (Abcam, ab133406) was

173   used for visualization and imaging. Signals were detected and quantified with Image Lab 4.0 software (Bio-Rad

174   Laboratories, US).

175

176   **Statistical analysis**

177   SPSS 20.0 statistical software was used for the data analysis. All values were expressed as the mean ± standard

178   deviation. The within-group comparisons were performed using the analysis of variance of repeated

179   measurement design. Pairwise comparison in multiple groups was conducted with SNK method. $P<0.05$ was

180   considered significant. GraphPad Prism 5.0 was used to prepare graphs.

181

182 RESULTS

183 SPC reduced LDH level, cell death and expression of protein Bax, increased cell viability and
184 expression of protein Bcl-2 following simulated Hypoxia/Reoxygenation (H/R)

185 To observe the effect of SPC on H/R induced cell injury, the H9c2 cells were subjected to LDH level, cell
186 viability, flow cytometry, and western blot analysis. In this study, The cell viability of the H/R group was
187 significantly lower than the CON group ($P<0.05$), while the cell viability of the SPC group was increased
188 compared to the H/R group ($P<0.05$, Fig.2A). The LDH assay showed that compared to the H/R group, the LDH
189 activity of the SPC group was decreased ($P<0.05$), while the LDH activity did not significantly differ between
190 the H/R and S+Y groups ($P>0.05$, Fig.2B). Compared to the CON group, the cells apoptotic rate of H/R and
191 S+Y groups were significantly increased ($P<0.05$), while the cells apoptotic rate of the SPC group was decreased
192 compared to the H/R group ($P<0.05$, Fig.2C). Flow cytometry to measure apoptosis distribution graphs were
193 shown in Fig.D-G. The expression levels of apoptosis-related proteins were measured by using western blot
194 analysis. Western blot images of Bcl-2 protein and Bax protein were shown in Fig.H-I. Compared to the CON
195 group, the ratio of Bcl-2/GAPDH of H/R and S+Y groups did not have a significant difference ($P>0.05$),
196 however,the ratio of Bcl-2/GAPDH of SPC group was significantly increase ($P<0.05$, Fig.2J). Compared to
197 the CON group, the ratio of Bax/GAPDH of H/R and S+Y groups were significantly increased, but the ratio of
198 Bax/GAPDH of SPC was decreased ($P<0.05$, Fig.2K).

199

200 Sevoflurane preconditioning increases the activity of key enzymes and ATP production in
201 glycolysis

202 The HK, PFK-1, and PK activities at the end of equilibration did not significantly differ among groups ($P>0.05$).
203 The HK, PFK-1, and PK activities at the end of reoxygenation were significantly increased in all groups
204 compared to the activities at the end of equilibration ($P<0.05$). The comparison of all groups at the end of
205 reoxygenation showed that the HK, PFK-1, and PK activities in the SPC group were significantly increased
206 compared to those in the H/R group ($P<0.05$, Fig. 3A, 3B and 3C).

207 The concentration of ATP at the end of equilibration did not significantly differ among groups ($P>0.05$). The
208 ATP assay showed that compared with the Con group, the ATP concentration of H/R, SPC and S+Y groups
209 were significantly decreased ($P<0.05$). Compared to the H/R group, the ATP concentration of the SPC group
210 was increased, while the S+Y group was decreased ($P<0.05$, Fig. 3D).

211

212 Protective effects of SPC on H/R injury of H9c2 cells

213   ΔΨm, a sign of early-stage apoptosis (Marchetti et al. 1996) was evaluated in H9c2 using JC-1 staining.

214   Representative images of JC-1 in H9c2 cells were shown in Fig.4A. The result showed that the ratio of red to

215   green fluorescence intensity in the SPC group was higher than the H/R group (*P*<0.05). However, After the

216   application of hypoxia-inducible factor-1α inhibitor YC-1, there was no significant difference in the ratio of red

217   to green fluorescence intensity between H/R group and S+Y group (*P*<0.05, Fig. 4B)

218

219   **SPC increases the levels of HIF-1a and PDK-1 in the simulation of H/R injury**

220   At the end of reoxygenation, the expression of HIF-1a of SPC and H/R groups were all increased compared to

221   the Con group (*P*<0.05). Western blot images of HIF-1a protein and PDK-1 protein were shown in Fig.A-B.

222   Compared to the H/R group, the expression of HIF-1a of the SPC group was increased, while the S+Y group

223   was decreased (*P*<0.05, Fig. 5C). Compared to the CON group, the expression of PDK-1 of SPC and H/R groups

224   were all increased (*P*<0.05), while the S+Y group did not have statistical significance (*P*>0.05). Compared to

225   the SPC group, the expression of PDK-1 of the S+Y group was decreased (*P*<0.05)when the inhibitor YC-1 was

226   added into the culture medium (Fig. 5D).

227

228   # Discussion

229   The results of our study confirmed that sevoflurane preconditioning (SPC) can effectively attenuate the

230   Hypoxia/Reoxygenation (H/R) injury in H9c2 cardiomyocytes. This finding is in line with the proven SPC

231   cardiac protective effects reported in a related study (Wenlan et al. 2018). It is suggested that the cardioprotective

232   effect of SPC may be related to the activation of the HIF-1a/PDk-1 pathway.

233   Sevoflurane is widely used in all types of clinical cardiac surgery as a representative inhalation anesthetic

234   drug and is considered by the majority of scholars to be a landmark inhalation anesthesia drug. Some studies

235   have found that the protective effect of sevoflurane on ischemic myocardium, such as sevoflurane

236   preconditioning (SPC) or sevoflurane postconditioning (SPostC), is closely related to its mode of administration

237   (De Hert et al. 2004; Qian et al. 2018; Wu et al. 2017). Ischemic preconditioning (IPC) is the most effective

238   myocardial protection strategy found so far (Cai et al. 2003), and SPC can produce myocardial protective effects

239   similar to IPC (Qian et al. 2018) and has stronger clinical maneuverability. In the study, H9c2 cardiomyocytes

240   were used as the research object to simulate the H/R model to explore the molecular mechanism of myocardial

241   protection of SPC, to provide a theoretical basis for scientific and clinic research.

242   A member of the hypoxia-inducible factor family (HIFs) is HIF-1. Due to the inhibition of the activity of

243   prolyl-4-hydroxylase domain-containing enzymes (BHD) under anoxia situations, the ubiquitination of HIF-1 is

244   reduced. In the nucleus, it binds to the target gene promoter's hypoxia response element and regulates the
245   transcription of a series of downstream target genes which contribute to cell survival under hypoxic conditions
246   (Prabhakar & Semenza 2015). PDK-1 is a switch protein that regulates energy metabolism downstream of HIF-1
247   (Semenza 2011). Glucose will form pyruvate under aerobic conditions and then enter into the tricarboxylic acid
248   cycle to be oxidized to carbon dioxide and water, while in the anaerobic condition, pyruvate undergoes glycolysis
249   under the action of PDK-1 to produce lactic acid (Akram 2013). In this study, SPC and HIF-1a inhibitor YC-1
250   were used as intervention methods for grouping study. Western Blot protein detection technique was used to
251   quantify the contents of target protein HIF-1a and PDK-1. The results showed that the contents of HIF-1a and
252   PDK-1 were significantly increased in the SPC group, while the contents were significantly decreased after using
253   the inhibitor of HIF-1a. It is suggested that the myocardial protective effect of SPC may be related to activation
254   of the HIF-1a/PDK-1 signal pathway.

255   ATP is the direct energy for all kinds of life activities. The myocardium has a high energy demand, but there
256   is basically no energy reserve (Lopaschuk et al. 2010). Therefore, the heart must continuously produce a large
257   amount of ATP to maintain muscle contraction and ion homeostasis. Most of the ATP production (about 90-
258   95%) comes from oxidative phosphorylation of mitochondria and the rest from glycolysis. Mitochondria can use
259   a variety of energy substrates to produce ATP, including fatty acids, carbohydrates, ketones and amino acids,
260   among which fatty acid oxidation is the main source of ATP in the heart (Itoi & Lopaschuk 1993). What's more,
261   normal myocardium has a lot of "metabolic flexibility" (Kolwicz et al. 2013; Ritterhoff & Tian 2017), allowing
262   it to switch back and forth between fatty acid and carbohydrate oxidation, depending on the load of the heart,
263   the energy substrate provided to the heart, and the hormonal and nutritional status (Taegtmeyer et al. 2004). The
264   contribution for myocardial ATP production by glycolysis was increased under the condition of myocardial
265   ischemia/hypoxia (Akram 2013). Glycolysis is a dynamic process, which provides ATP for the body in the early
266   stage of hypoxia. However, with the extension of time, glycolysis will produce excessive acid metabolites, which
267   will lead to acidosis and aggravate the apoptosis and damage of the body (Dang et al. 2005). The study confirmed
268   that the glycolytic pathway content of key rate-limiting enzymes (HK, PFK-1, and PK) in cardiomyocytes may
269   indirectly reflect the state of energy metabolism of cardiomyocytes (Volker et al. 1995). And after hypoxia
270   injury, the levels of HK, PFK-1, and PK increased and the glycolytic activity of cardiomyocytes was significantly
271   increased in early hypoxia (Guo et al. 2017; Teng et al. 2010) and cardiomyocyte glycolysis activity reached its
272   peak at 1-3 hours of hypoxia, Since then, and has been decreasing (Dang et al. 2005). In our experiment, the
273   time limit of cell hypoxia damage was set as 3 hours and the results showed that activity of the key enzymes of
274   glycolysis of H/R, SPC and Y+S groups were significantly increased compared to CON group, and the activity
275   of the key glycolytic enzymes was the highest in the SPC group. The ATP concentration of SPC was also higher
276   than the H/R group. There are evidences that HIF-1a is also the main regulator of glycolytic enzyme expression
277   and the key transcription factor that drives glycolysis under anoxic conditions (Semenza 2010; Xie et al. 2015).
278   These evidences led us to hypothesize that SPC could optimize the glycolysis in early hypoxia by activating the

279   HIF-1a/PDK-1 signal pathway.

280   Mitochondria are not only the main place of energy metabolism in eukaryotes but also the main target of
281   ischemic/hypoxic injury (Halestrap & Richardson 2015). The level of mitochondrial membrane potential is an
282   index of early cardiomyocyte apoptosis (Marchetti et al. 1996). In this study, JC-1 was used for cell staining,
283   and the levels of mitochondrial membrane potential in different experimental groups were compared and the
284   apoptosis-related proteins Bcl-2 and Bax were detected by WB. The results showed that the levels of anti-
285   apoptotic protein Bcl-2 and mitochondrial membrane potential in the SPC group were higher than those in H/R
286   and Y+S groups, indicating that SPC could stabilize cardiomyocyte mitochondrial membrane potential and
287   reduce the rate of apoptosis induced by H/R injury in H9c2 cardiomyocytes.

288

Limitations

290   Several limitations of this study should be noted. Firstly, we only tested the hypothesis of the cardioprotective
291   effect of SPC at the cardiomyocyte level, and it should be further verified at the animal level in the future.
292   Secondly, the concentration of SPC used in this study was 2.4%, and the effect of other concentrations on the
293   results should also be investigated. Thirdly, we only observed the potential HIF-1a/PDK-1 signaling pathways
294   mechanisms in the myocardial protective function of SPC, further investigation is needed to identify essential
295   components in these complex signal transduction cascades that mediate SPC.

296

Conclusions

298   In summary, this study demonstrated that the cardioprotective effect of SPC are associated with the activation
299   of the HIF-1a/PDk-1 pathway. The mechanism may be related to an increase in the expression of HIF-1a, PDK-1
300   and Bcl-2 after SPC, which leads to increasing the contents of key enzymes and ATP concentration of glycolysis,
301   thereby stabling mitochondrial membrane potential and reducing apoptosis.

302

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307

308 **Competing Interests**

309 The authors declare that they have no competing interests.

310

311 **Author Contributions**

312 Tianliang Hou conceived and designed the experiments, performed the experiments, analyzed the data,
313 contributed reagents/materials/analysis tools, prepared figures and/or tables, approved the final draft.

314 Haixia Wang, Haiping Ma conceived and designed the experiments, performed the experiments.

315 Chunling Chen performed the experiments, contributed reagents/materials/analysis tools.

316 Ahmed Mohamed Ahmed modify grammar and English language usage of this article

317 Jianrong Ye analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper.

318 Hong Zheng conceived and designed the experiments, wrote the paper and reviewed drafts of the paper.

319

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412

Figure 1

A schematic representation of the experiment protocol

H9c2 cardiomyocytes were randomly divided into control (CON), hypoxia/reoxygenation (H/R), sevoflurane preconditioning (SPC) and sevoflurane preconditioning+HIF-1a inhibitor(S+Y) groups.
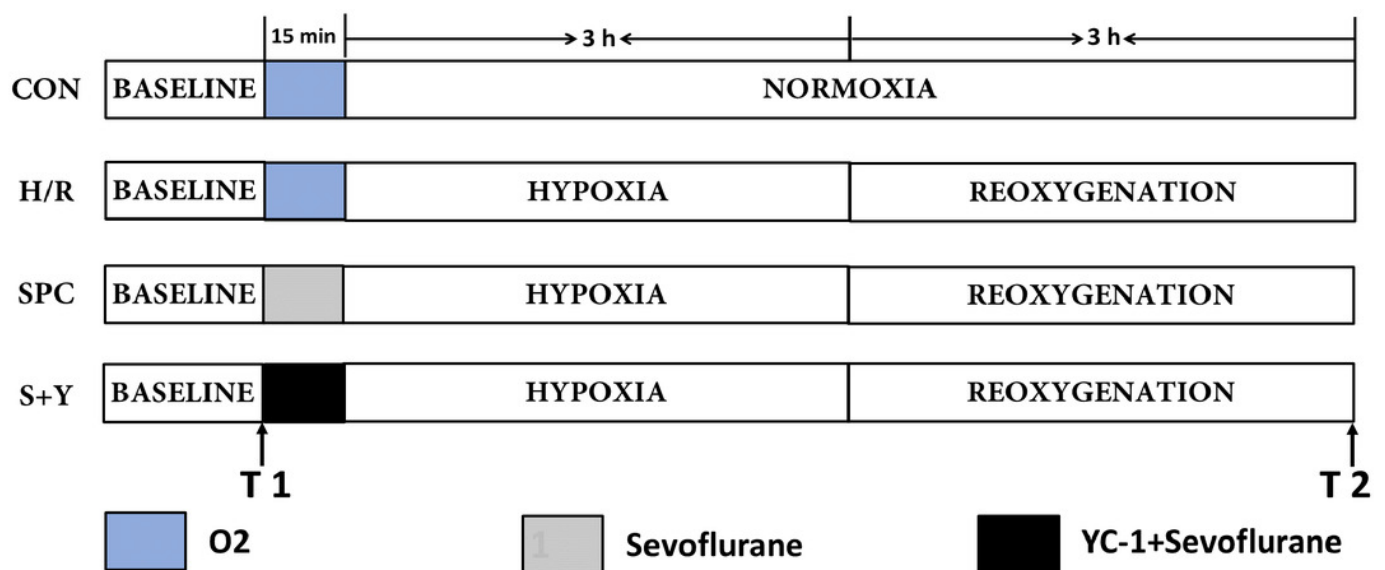
Figure 2

SPC alleviated H9c2 cardiomyocytes hypoxia/reoxygenation injury

(A) Cell viability: Compared to the H/R group, the SPC group exhibited improved cell viability (n=6). (B) LDH activity: The LDH activity was reduced in the SPC group compared to the H/R group (n=6). (C) Apoptosis rate: The apoptosis rate of the SPC group was lower than that of the H/R group. While the protective effects of SPC were inhibited after administration of YC-1 (n=6). (D–G) Flow cytometry to measure apoptosis distribution graph. (H) Western blot image of Bcl-2 protein. (I) Western blot image of Bax protein. (J) Bcl-2 protein expression. (K) Bax protein expression. Protein content was normalized to GAPDH(n = 3/group). Data represent mean ± SD(*P < 0.05 vs C group, #P < 0.05 vs H/R group, &P < 0.05 vs SPC group)
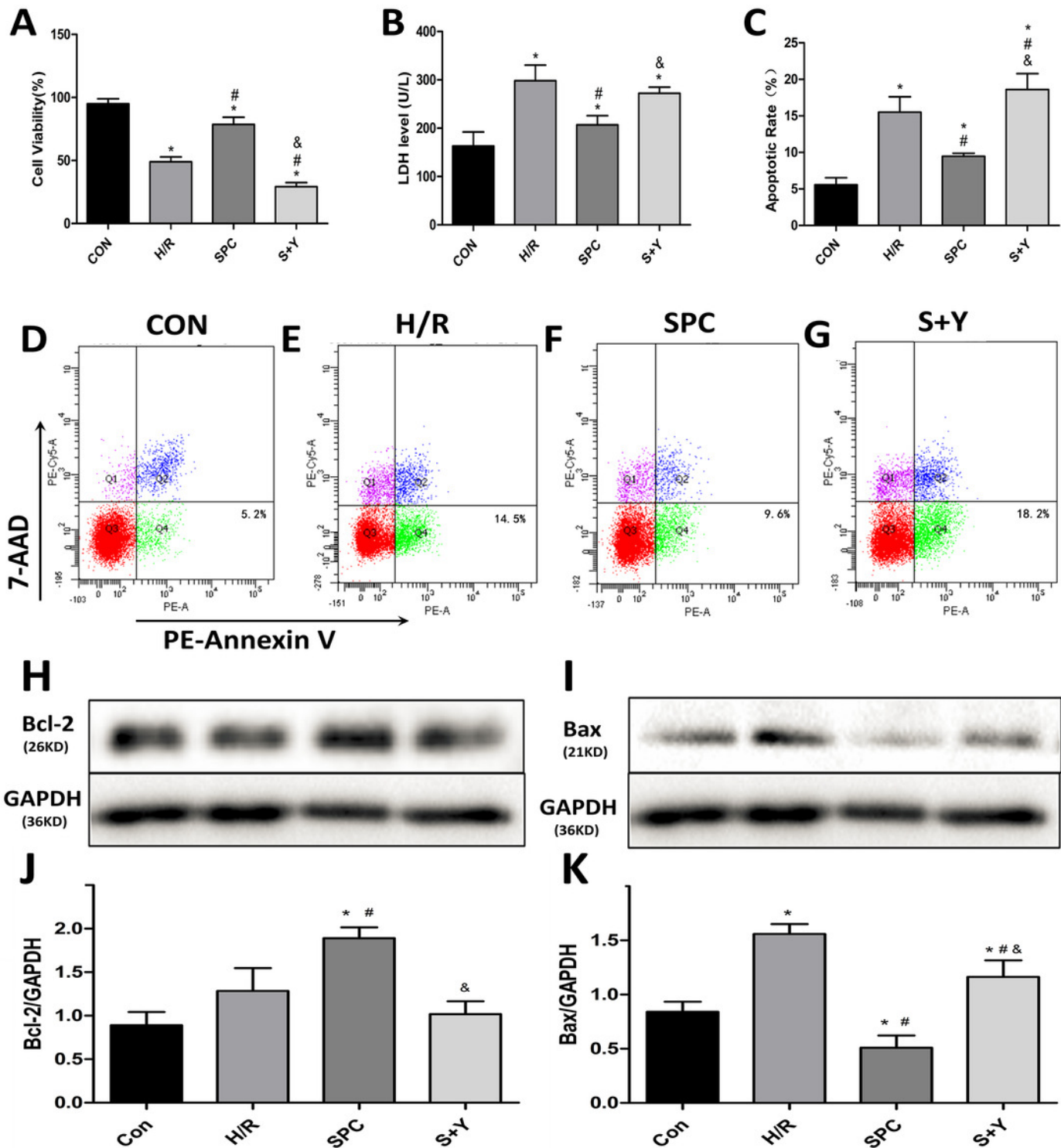
Figure 3

SPC improve glycolysis energy metabolism and key enzymes activity.

The end of equilibration (T1) and the end of reoxygenation (T2). (A)HK concentration. (B)PFK-1 concentration. (C)PK concentration. (D)ATP concentration. Data are presented as the mean ± SD (n=6). *P<0.05 vs T1; T2 time point: ^P<0.05 vs CON, #P<0.05 vs H/R, &P<0.05 vs SPC.
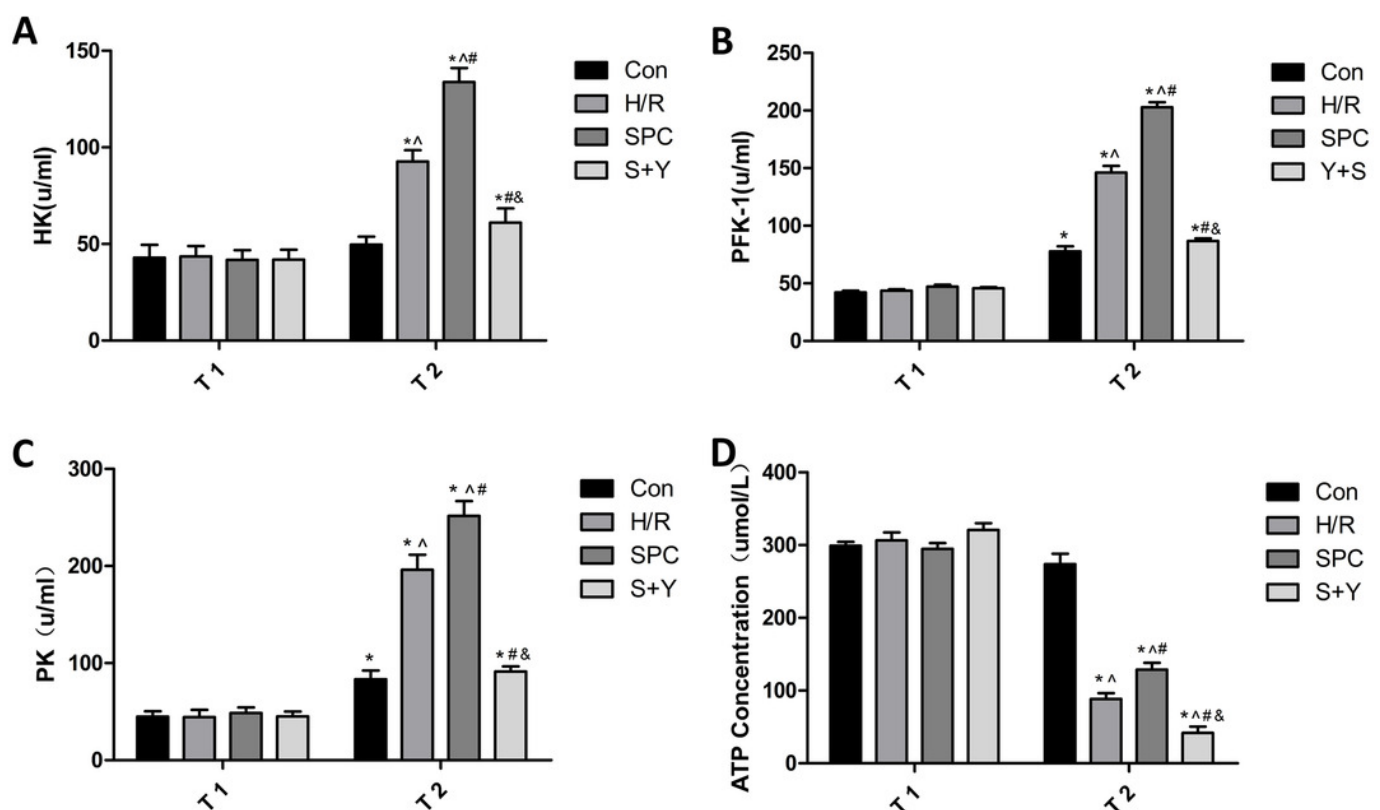
Figure 4

SPC stabilize the mitochondrial membrane potential($\Delta\Psi$m)

(A) Representative images of JC-1 were capture using fluorescence inverted microscope in H9c2 cells. (B)The results showed that SPC increased the ratio of red to green fluorescence intensity. Data represent mean ± SD (n = 3/group). *P < 0.05 vs Con, #P < 0.05 vs H/R, &P <0.05 vs SPC.
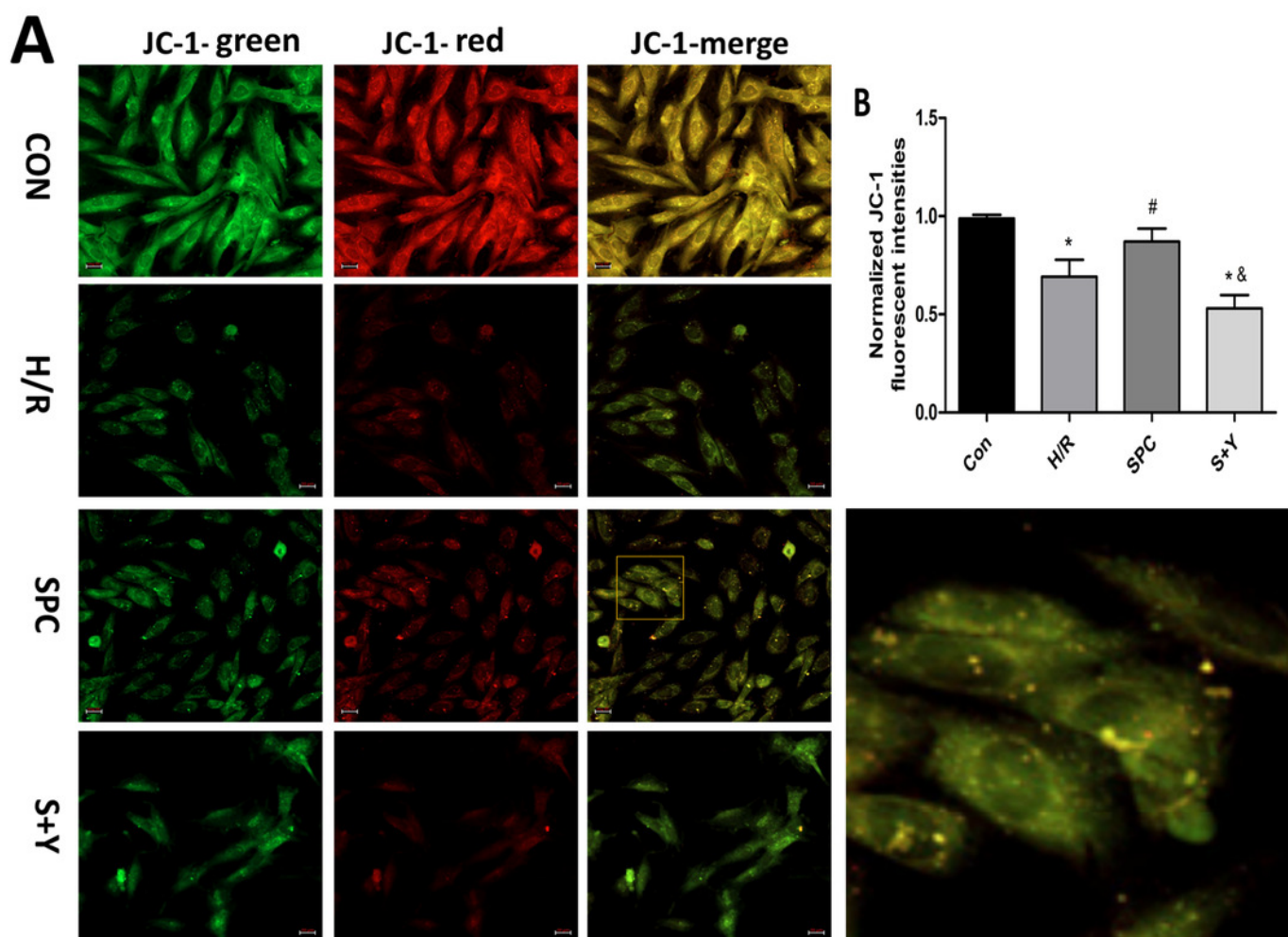
Figure 5

SPC upregulate the protein expression of HIF-1a and PDK-1.

(A) Western blot image of HIF-1a protein. (B) Western blot image of PDK-1 protein. (C)HIF-1a protein expression. (D)PDK-1 protein expression. Protein content was normalized to GAPDH. Data represent mean ± SD (n = 3/group). *P < 0.05 vs Con, #P < 0.05 vs H/R, &P <0.05 vs SPC.