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Effect of Gallic Acid Pretreatment and SGK1 Enzyme Inhibition on Cardiac Function and Inflammation in a Rat Model of Ischemia-Reperfusion Injury

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Abstract

Background: Serum and glucocorticoid-induced kinase 1 (SGK1) is an enzyme that may play an important role in ischemic-reperfusion (I/R) injury and myocardial dysfunction. Although many studies have been conducted on individual antioxidants, little attention has been paid to the effects of co-administration of an antioxidant with an SGK1 inhibitor on cardiac function after I/R.

Methods: This study aimed to determine the effects of gallic acid (as an antioxidant) combined with an SGK1 inhibitor on I/R-induced cardiac dysfunction and inflammation. Sixty male Wistar rats were randomized into 6 groups, pretreated with gallic acid or vehicle for 10 days. Subsequently, the heart was isolated and exposed to I/R. In groups that received the SGK1 inhibitor, the heart was perfused with the SGK1 inhibitor GSK650394, 5 min before induction of ischemia. After that, cardiac function, inflammatory factors, and myocardial damage were evaluated.

Results: The combination of these two compounds improved cardiac contractility, heart rate, rate pressure product, left ventricular developed pressure, left ventricular systolic pressure, perfusion pressure, and QRS voltage significantly ($P < 0.05$). In addition, concomitant therapy of these two agents reduced tumor necrosis factor-alpha and interleukin-6, and the activity of creatine kinase-MB, lactate dehydrogenase, and troponin-I ($P < 0.05$).

Conclusions: The results indicated that administration of gallic acid with the SGK1 inhibitor may have a potentiating effect on the improvement of cardiac dysfunction and I/R-induced inflammation.

Keywords: Gallic Acid, Inflammation, Ischemic-Reperfusion Injury, Rat, Serum-glucocorticoid regulated kinase 1 (SGK1).

Introduction

Myocardial ischemia is the leading cause of death worldwide and has many destructive consequences for the cardiomyocytes, which left untreated, can lead to cell death (1). Damage to cardiomyocytes or disruption of their functions can lead to osmotic imbalance and leakage of cellular metabolites into the extracellular space. In addition, lysosomes' membrane damage could result in the release of destructive enzymes that can digest cellular elements and lead to cell necrosis (2).

Inflammatory reactions induced by ischemia-reperfusion (I/R) lead to release of cytokines that are important components of I/R-induced injury to the myocardium. In this process, the production of potential proinflammatory cytokines including interleukin 6 (IL-6) and tumor necrosis factor-

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alpha (TNF-α) (3) lead to inflammation and immune cell activation (4).

Myocardial injury in acute coronary syndrome is a primary and direct cause of hemodynamic changes that can result in elevated cardiac biomarkers and the electrocardiogram (ECG) changes (5). Elevated cardiac biomarkers, particularly cardiac troponin-I (cTnI) and creatine kinase-MB (CK-MB), indicate myocardial cell damage and necrosis (6, 7), and ECG changes in PR interval, QRS complex voltage, and ST-segment potentially reflect myocardial ischemia (8). However, cardiac biomarkers and ECG changes alone are not sufficient to diagnose acute myocardial infarction (9).

Serum and glucocorticoid-induced kinase 1 (SGK1) is an important enzyme that plays a role in ischemic-reperfusion injury and myocardial infarction. This enzyme belongs to a subfamily of serine/threonine kinases (10). SGK1 expression is high in the heart (11). Recent research has shown that SGK1 performs a vital function in cardiac apoptosis, inflammatory cytokine expression, and vascular remodeling. In addition, SGK1 is dynamically regulated during acute biological stress in the heart and controls the survival and hypertrophic response of cardiomyocytes (12). Stress-induced stimuli have been shown to activate SGK1 (13). Thus, SGK1 is an important factor involved in the pathophysiological features of various cardiovascular diseases (14), including inflammatory response regulation (15).

Gallic acid is found in numerous plants and commonly used in medicine as an antioxidant (16) and anti-inflammatory factor and can also protect against those changes (17). Furthermore, SGK1 may be involved in inflammation and cardiac dysfunction in the isolated heart due to ischemic-reperfusion injury. Therefore, the present study aimed to co-administer gallic acid and SGK1 inhibitor to investigate their possible protective and potentiating effect on inflammation and cardiac dysfunction due to ischemic-reperfusion injury.

Materials and Methods

Materials

Xylazine (2%) and ketamine HCl (10%) were received from Alfasan Co. (Netherlands). Krebs salts were obtained from Merck Co. (Germany). Gallic acid was obtained from Sigma (St. Louis, MO USA). GSK650394 (GSK) was obtained from MedChemExpress (USA). Creatine kinase-MB isoenzyme and lactate dehydrogenase (LDH) were received from the Pars Azmoon Co. (Iran). Cardiac troponin-I is a selected biomarker of cardiac damage as measured with a specific kit obtained from Monobind Inc. (Lake Forest, California, USA).

Animal grouping

Sixty male adult Wistar rats (250-300 g) were received from the animal house of Ahvaz Jundishapur University of Medical Sciences one week before initiation of the experiments and had free access to water and food during the 12:12 hour light-dark cycles under controlled temperature conditions (22 ± 2 ºC). The protocols of the experiments were approved by the Research Ethics Committee of the Center of Research & Laboratory Animal at Ahvaz Jundishapur University of Medical Sciences (ID: IR.AJUMS.ABHC.REC.1400.032, dated: 2021-05-25). The rats were randomized into six groups with 10 in each group (Table 1). Gallic acid was dissolved in normal saline and administered (30 mg/kg by gavage) once daily for 10 days (18). In the groups that received GSK, five min before the onset of an ischemic attack, the isolated hearts were perfused with Krebs-Henseleit solution containing 1 μmol of GSK (19) prepared in DMSO (18). For the groups that did not receive gallic acid or GSK, the medication vehicles were given instead. Ischemia induction was performed by complete closure of the infusion flow for 30 min followed by reperfusion for 60 min (18).

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Table 1. Animal treatments used in the present study.

Groups*	Gallic acid(mg/kg)	GSK# (µmol)
Sham	0	0
Gallic acid	30	0
Isc**	0	0
Isc + G	30	0
Isc + GSK	0	1
Isc + G + GSK	30	1

*, 10 animals per group; **, ischemic/reperfusion groups; #, GSK650394 (SGK1 inhibitor).

Cardiac isolation and ischemia induction

The animals were anesthetized by injecting HCl ketamine (50 mg/kg) and xylazine (5 mg/kg) intraperitoneally. To prevent blood clots, heparin was injected intraperitoneally (1000 U/kg) (18). The trachea was then cannulated and attached to the rodent's ventilator (UGO BASILE, model 7025), to allow artificial breathing to ambient air after opening the chest and removing the ribs. The aorta was cannulated by inserting a stainless-steel cannula through an incision in its wall and secured by a suture. The heart was immediately infused with Krebs-Henseleit solution which consisted of glucose, MgSO4, KH2PO4, NaCl, KCl, NaHCO3, and CaCl2 (11.1 mM, 1.2 mM, 1.18 mM, 118 mM, 4.75 mM, 25 mM, and 1.75 mM, respectively) equilibrated by 5% CO2 and 95% O2 at pH of 7.4. Subsequently, hearts were excised and transferred into the Langendorff device containing Krebs-Henseleit solution. The isolated heart was continuously perfused with the solution by a peristaltic pump at a constant flow rate of 7 $ml.min^{-1}$ at 37 °C (20). During the experiment, the buffer was bubbled with carbogen (95% O2-5% CO2) to maintain a pH of 7.4. The ischemia was induced by the no flow method for 30 min as described in the previous section and then re-perfused for 60 min (18).

Cardiac function parameters

The hearts were placed in a 37 °C coated glass chamber and left for 25–30 min to reach equilibrium before all experiments. A rubber balloon filled with water, connected to a pressure transducer with a stainless-steel needle, was inserted into the left ventricle through the left atrium to measure left ventricular pressure (LVP). The balloon volume was adjusted so the LV end-diastolic pressure (EDP) was 5-10 mm Hg. A Powerlab system (Powerlab, AD instrument, Australia) was used to record and analyze the signal from the pressure transducer. End-diastolic pressure, left ventricular developed pressure (LVDP), the maximum rates of LVP rising (+$dp.dt^{-1}$ max) and falling (-$dp.dt^{-1}$ max) as indices of myocardial contractility, the rate pressure product (RPP; the product of LVDP and heart rate), and lead II of ECG were recorded. All hearts were perfused for 25–30 min before ischemia to stabilize the LVP and coronary perfusion pressure (CPP) and then exposed to 30 min of no-flow global ischemia followed by 60 min of reperfusion (18).

Electrocardiogram parameters and heart rate

To record the electrical activity, hook electrodes were attached to the isolated heart. A lead II electrocardiogram was recorded to calculate the RR and QT intervals and QRS complex voltage. ECG recordings were performed using Bio Amp tools and a Powerlab system. Because the QT interval varies with heart rate changes, corrected QT (QTc) was reported according to Bazett's formula (21).

Bazett's formula: QTc (QT corrected for heart rate) = QT/square root of RR

In all groups, heart rate was also measured using the RR interval during the ECG measurement (22).

Inflammatory factors evaluation

Tissue TNF-α and IL-6 levels were used as inflammatory biomarkers. Cardiac tissues were homogenized and centrifuged. Inflammatory biomarker concentrations in the supernatants were measured according to the kits'

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instructions using an ELISA reader (Biotek, USA) (23).

Evaluation of myocardial injury

To evaluate ischemia-induced myocardial damage, perfusion solution samples were collected from hearts 20 min after reperfusion to measure cTnI, LDH, and CK-MB activity. The measurements were performed using an ELISA reader according to the kits' instructions (24).

Statistical analysis

Data were analyzed with SPSS version 22 and are expressed as means ± standard deviations. The normal distribution of the data was checked using the Kolmogorov-Smirnov goodness test. Groups were compared using one-way analysis of variance, followed by Tukey's multiple comparison test. P values less than 0.05 were considered statistically significant.

Results

Cardiac function parameters

The cardiac perfusion pressures did not differ significantly between the gallic acid-treated and sham groups but were significantly less in the Isc, Isc + G, and Isc + GSK groups than in the sham group (###). Perfusion pressures in the Isc + G, Isc + GSK, and Isc + G + GSK were significantly greater than that in the untreated ischemic group, and the differences between the treated groups were also significant (* vs. ** vs. ***.) Perfusion pressures in the Isc + G and Isc + GSK groups were significantly less than that in the Isc + G + GSK group ($$) (Fig. 1).

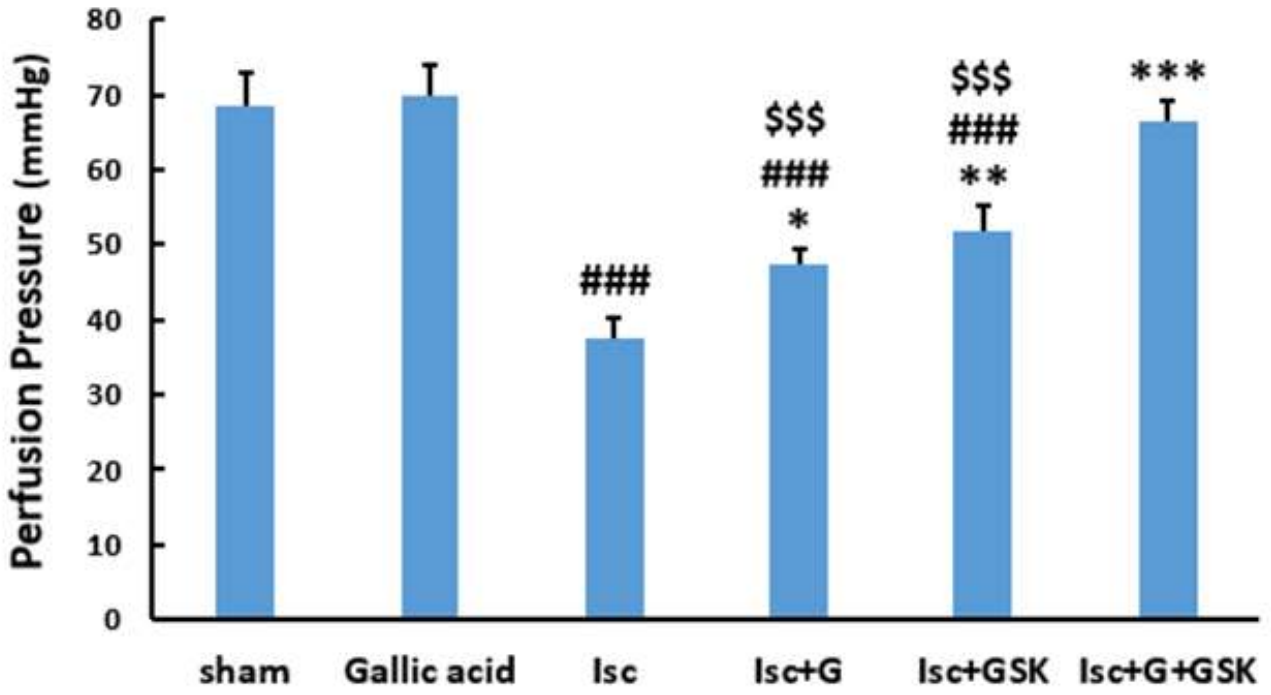

Fig. 1. The effects of gallic acid (G, 30 mg/kg/daily by gavage) and GSK (1 µmol) on perfusion pressure (mean ± SD, n = 10). ### P < 0.001 vs. sham. *** P < 0.001, ** P < 0.01, and * P < 0.05, vs. Isc. $$$ P < 0.001 vs. Isc + G + GSK (One way ANOVA followed by Tukey's post hoc test).

Cardiac contractility did not differ significantly between the gallic acid-treated and sham groups. Cardiac contractility maximum rising and falling rates (+dp. d t^{-1} and -dp. dt^{-1}, respectively) in LVP were significantly less in all the Isc groups than in the sham group (### and ##). Contractility was significantly greater in the Isc + G, Isc + GSK, and Isc + G + GSK groups than in in the Isc group and the differences between the groups were also significant (* vs. ** vs. ***). Contractility was significantly less in the Isc + G group than in the Isc + G + GSK group ($) (Figs. 2A and 2B).

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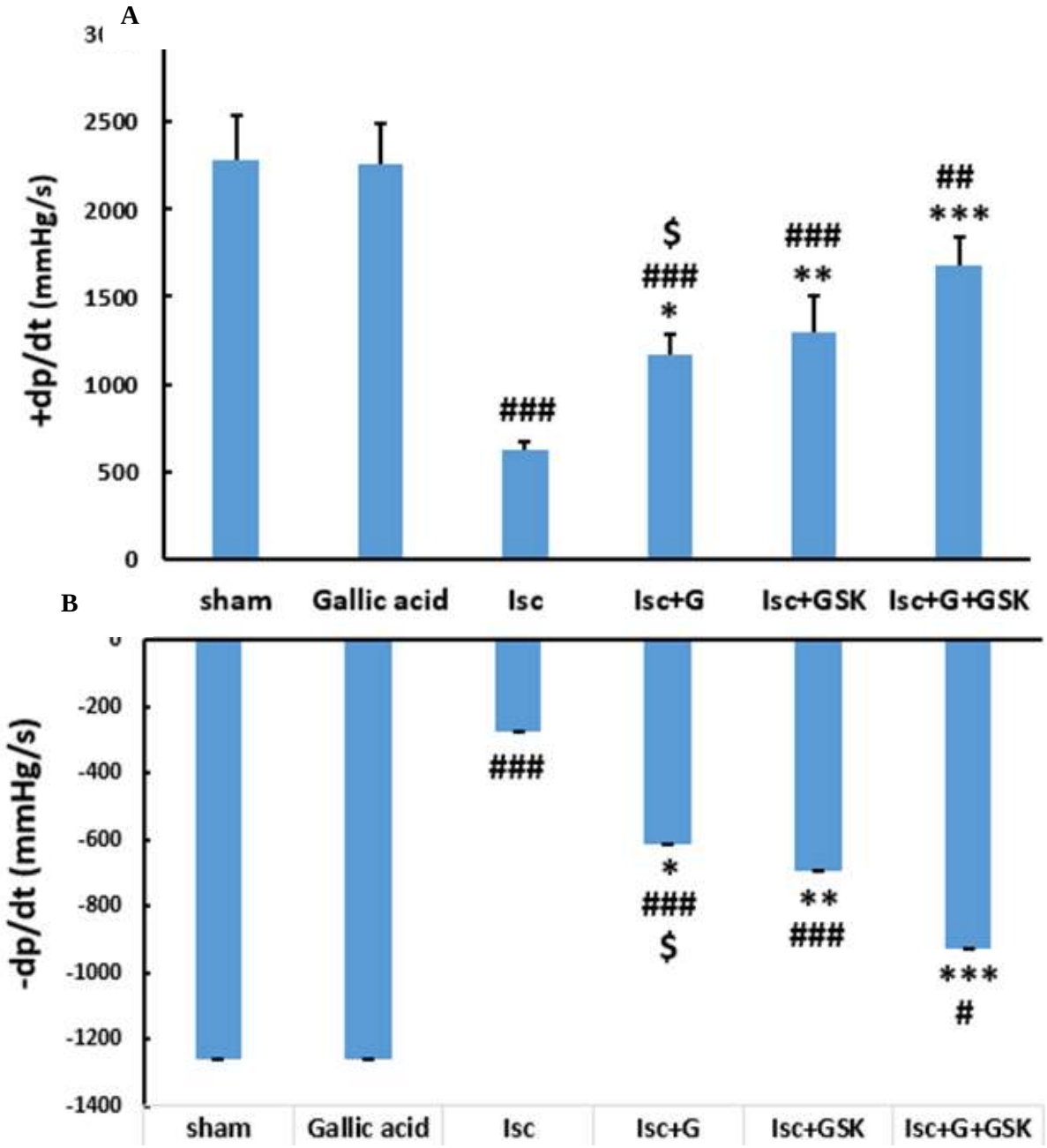

Fig. 2. The effects of gallic acid (G, 30 mg/kg/daily by gavage) and GSK (1 μmol) on myocardial contractility (mean ± SD, n = 10). ### P < 0.001, ## P < 0.01, and # P < 0.05, vs. sham. *** P < 0.001, ** P < 0.01, and * P < 0.05, vs. Isc. $ P < 0.05 vs. Isc + G + GSK (One way ANOVA followed by Tukey's post hoc test).

Heart rate did not differ significantly between the gallic acid-treated and sham groups, nor was it significantly affected by ischemia or ischemia plus treatment with gallic acid or GSK alone; however, it was significantly greater in the Isc + G + GSK than in the Isc group (*) (Fig. 3A).

LVDP and RPP did not differ significantly between the gallic acid-treated and sham groups but were significantly less in all the Isc groups than in the sham group (###). Treatment with gallic acid or GSK had no significant effect on LVDP or RPP relative to the Isc group, but both parameters were significantly greater in the groups treated with both drugs combined than in the Isc group (***), while those parameters in the Isc groups treated with either drug were significantly less than in the groups treated with both drugs combined ($$ and $) (Figs. 3B and 3C).

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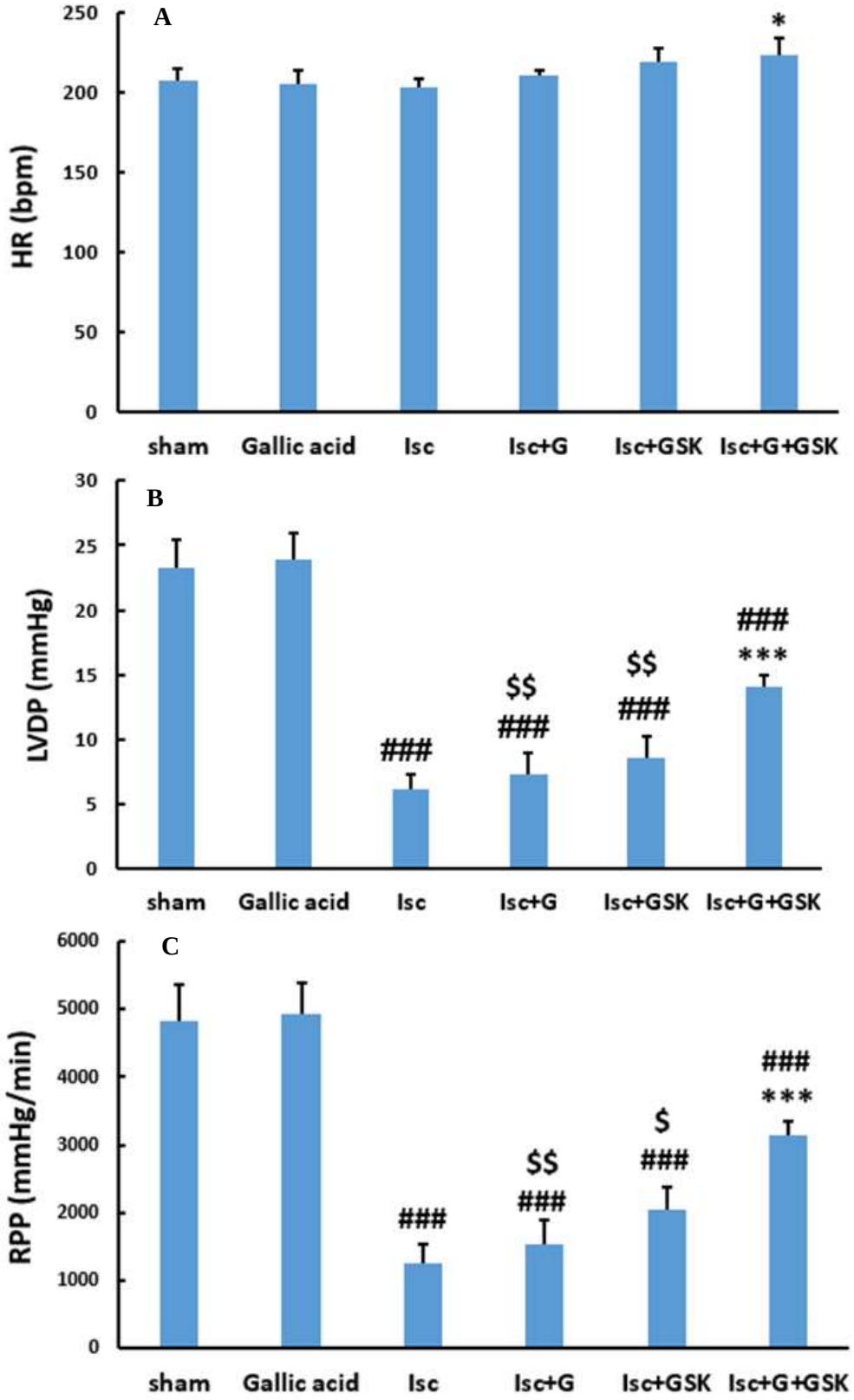

Fig. 3. The effects of gallic acid (G, 30 mg/kg/daily by gavage) and GSK (1 µmol) on cardiac function parameters: heart rate (HR, A), left ventricular developed pressure (LVDP, B), and rate pressure product (RPP, C) (mean ± SD, n = 10). ### P < 0.001 vs. sham. *** P < 0.001, and * P < 0.05, vs. Isc. $$ P < 0.01, and $ P < 0.05, vs. Isc + G + GSK (One way ANOVA followed by Tukey's post hoc test).

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QRS voltage did not differ significantly between the gallic acid-treated and sham groups but was significantly less in all the Isc groups than in the sham group (### and ##). Treatment with gallic acid or GSK alone had no significant effect; however, QRS voltage was significantly greater in the group treated with both drugs than in the Isc group (*). QRS voltage in the Isc + G group was significantly less than in the Isc + G + GSK group ($) (Fig. 4A).

QTc did not differ significantly between the gallic acid-treated and sham groups but was significantly greater in the Isc and Isc + G groups than in the sham group (### and ##). QTc was significantly less in the Isc + GSK and Isc + GSK + G groups than in the Isc group (* and **) (Fig. 4B).

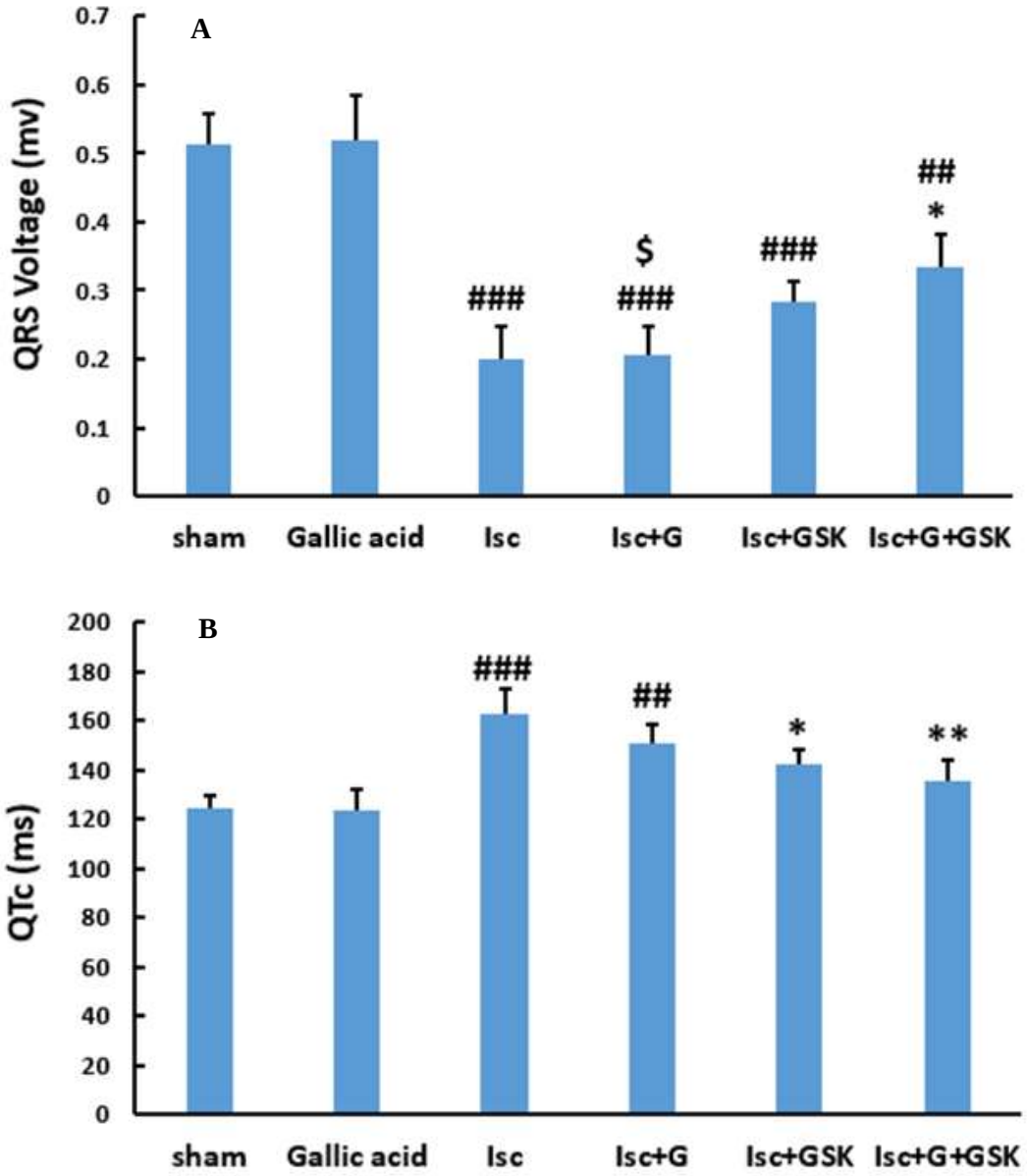

Fig. 4. The effects of gallic acid (G, 30 mg/kg/daily by gavage) and GSK (1 μmol) on the electrical parameters QRS voltage (A) and QTc (B) (mean ± SD, n = 10). ### $P < 0.001$, and ## $P < 0.01$, vs. sham. ** $P < 0.01$, and * $P < 0.05$, vs. Isc. $ $P < 0.05$ vs. Isc + G + GSK (One way ANOVA followed by Tukey's post hoc test).

Enzyme activity

Creatine kinase-MB activity did not differ significantly between the gallic acid-treated and sham groups but was significantly greater in all the Isc groups than in the sham group (### and ##). Treatment of the Isc group with gallic acid

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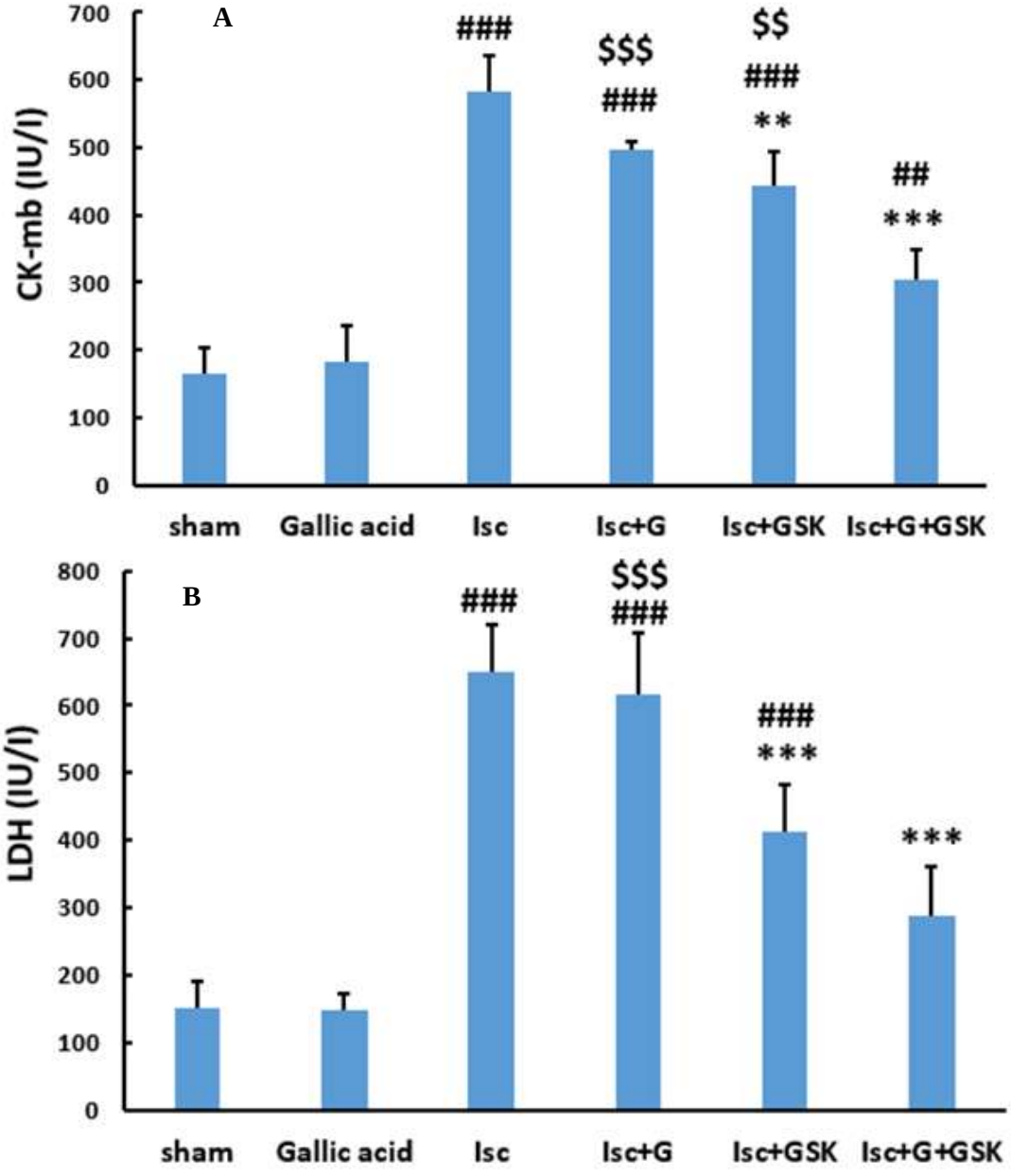
alone had no significant effect on CK-MB activity relative to Isc; however, CK-MB activity was significantly less in the Isc + GSK and Isc + G + GSK groups than in the Isc group (** and ***). Creatine kinase-MB activity was significantly greater in the Isc + G and Isc + GSK groups than in the Isc + G + GSK group ($$$ and $$) (Fig. 5A).

LDH activity in the gallic acid group did not differ significantly from that in the sham group but was significantly greater in the Isc, Isc + G, and Isc + GSK groups than in the sham group (###). LDH activity was significantly less in the Isc + GSK and Isc + G + GSK groups than in the Isc group (*), and was significantly greater in the Isc + G group than in the Isc + G + GSK group ($$$) (Fig 5B).

Cardiac troponin-I activity in the gallic acid group did not differ significantly from that in the sham group but was significantly greater in the Isc and Isc + G groups than in the sham group (###). Cardiac troponin-I activity was significantly less in the Isc + GSK and Isc + G + GSK groups than in the Isc group (***), and significantly greater in the Isc + G group than in the Isc + G + GSK group ($$$) (Fig. 5C).



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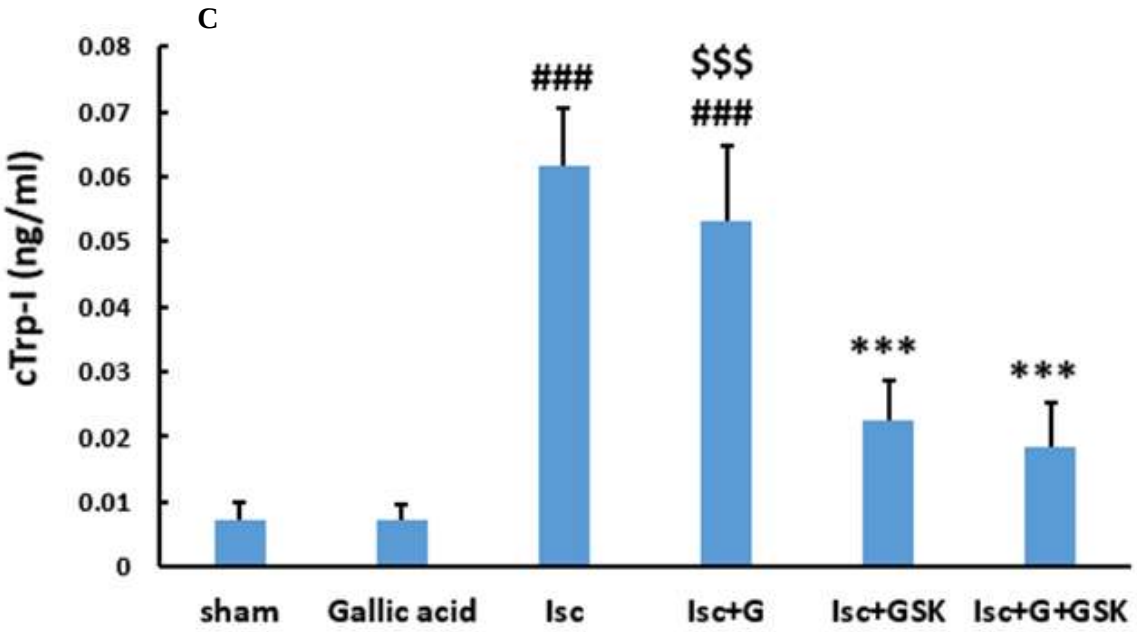
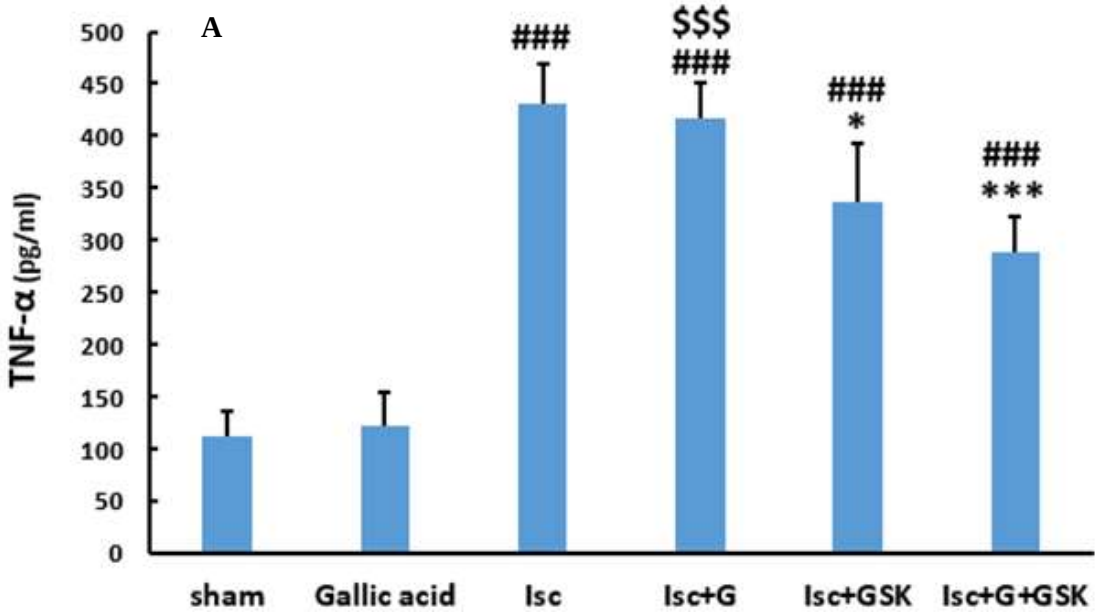


Fig. 5. The effects of gallic acid (G, 30 mg/kg/daily by gavage) and GSK (1 μmol) on creatine kinase-MB (CK-MB), lactate dehydrogenase (LDH), and cardiac troponin-I (cTnI), markers of myocardial injury (mean ± SD, n=10). ### P < 0.001, and ## P < 0.01, vs. sham. *** P < 0.001, and ** P < 0.01, vs. Isc. $$$ P < 0.001, and $$ P < 0.01, vs. Isc + G + GSK (One way ANOVA followed by Tukey's post hoc test).

Inflammation factors in the heart

TNF-α concentration did not differ significantly between the gallic acid-treated and sham groups but was significantly greater in all the Isc groups than in the sham group (###), and significantly less in the Isc + GSK and Isc + G + GSK groups than in the Isc group (* and ***). TNF-α was greater in the Isc + G group than in the Isc + G + GSK group ($$$) (Fig. 6A).

The IL-6 concentration did not differ significantly between the gallic acid-treated and sham groups but was significantly greater in all the Isc groups than in the sham group, although less so in the Isc + G + GSK group than in the other groups (# vs. ###). IL-6 was also significantly less in the Isc + G + GSK group than in the Isc group (*) (Fig. 6B).



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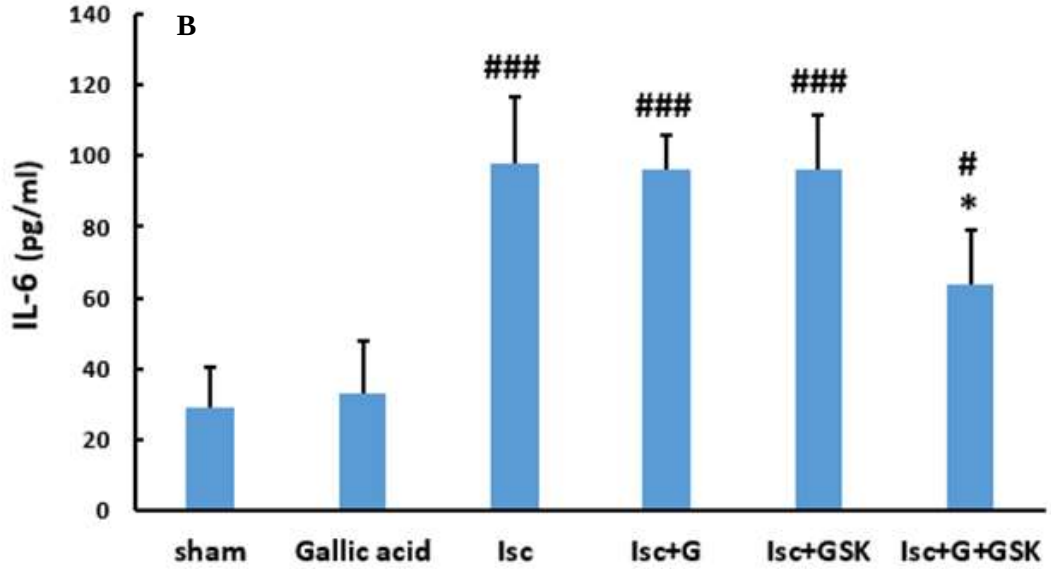

Fig. 6. The effects of gallic acid (G, 30 mg/kg/daily by gavage) and GSK (1 μmol) on the pro-inflammatory cytokines tumor necrosis factor-alpha (TNF-α) and interleukin 6 (IL-6) (mean ± SD, n=10). ### P < 0.001, and # P < 0.05, vs. sham. *** P < 0.001, and * P < 0.05, vs. Isc. $$$ P < 0.001 vs. Isc + G + GSK (One way ANOVA followed by Tukey's post hoc test).

Discussion

In this study, we examined gallic acid and the SGK1 inhibitor GSK alone or combined as a strategy to better manage I/R-induced myocardial injury. The results revealed the protective effects of gallic acid and GSK on myocardial injuries. Gallic acid and GSK significantly protected ventricular functions. This was indicated by the increase in myocardial contractility, inflammatory cytokines TNF-α and IL-6, cardiac enzyme markers CK-MB, LDH, and cTnI, and other cardiac parameters. In addition, the most important result was that the two drugs combined improved heart function more than either medication alone.

Consistent with these findings, other studies have shown that gallic acid, as a potent natural antioxidant, has useful and strong anti-inflammatory, immune, antioxidant, and antiatherogenic properties (25, 26). In vitro studies have shown that gallic acid interacts with multinucleated leukocytes to produce its effects. Gallic acid may inhibit inflammation through the removal of superoxide anions, inhibition of myeloperoxidase release and activity, and participation in the accumulation of active NADPH-oxidase (27, 28).

The present work found also that SGK1 inhibition, mediated by GSK, not only improved almost all cardiac functions, but also enhanced the protective effect of gallic acid, and that the coadministration of gallic acid and GSK was more protective than the administration of either compound alone. These protective effects are indicated by restoring reduced ventricular functions such as perfusion pressure, LVDP, RPP, and myocardial contractility. Consistent with our results, gallic acid has been reported to have a protective effect on left ventricular (LV) dysfunction in a rat diabetes model (17).

It has been shown that SGK1, by activating the STAT3 pathway, may play an essential role in the recruitment and activation of macrophages, leading to angiotensin II-induced cardiac fibrosis (29). Furthermore, SGK1 has been reported to have a key pressure-related role in regulating inflammatory response and cell fate in re-perfused ischemic myocardium (19).

In this study gallic acid and GSK administration, either alone or combined, restored the QT interval. It has also been shown that SGK1 affects the cardiac electrical cycle QT interval. Because the QT interval

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indicates left and right ventricular electrical depolarization and repolarization, perhaps SGK1 is not necessary to maintain normal QT, but could potentially shorten the QT interval (30). Additionally, an increase in body mass index (31) and a shortening of the QT interval, as well as an increase in blood pressure, were observed (32, 33). The increase in body mass index could be partly attributed to increased activation of the intestinal glucose transporter SGLT1 (31) and increased cardiac repolarization rate due to increased cardiac K+ channel activation KCNE1 (34). Therefore, the regulation of transporters and channels by SGK1 may explain the coincidence of hypertension, obesity, and heart action potential depletion (35).

Our results also showed that I/R increased IL-6 and TNF-α concentrations in heart tissue. GSK and gallic acid + GSK reduced TNF-α, while gallic acid + GSK reduced IL-6 (Figs. 6A and 6B). These results are consistent with other data that showed inhibition of SGK1 by EMD638683 may improve angiotensin II-induced myocardial inflammation and fibrosis by inhibiting the activation of inflammasome NLRP3 (15). Activation of the proinflammatory cytokine pathway in myocardial injury has been established in several studies (36-38). The expression of proinflammatory factors including IL-1β, TNF-α, and IL-6 is greatly enhanced in experimental models of myocardial infarction. It is widely accepted that proinflammatory factors such as TNF-α initiate irreversible loss of large numbers of cardiomyocytes after myocardial I/R injury (39).

In this study, 30 min of ischemia followed by 60 min of reperfusion induced myocardial damage, as demonstrated by elevated CK-MB, LDH, and cTnI concentrations in coronary perfusion samples 20 min after reperfusion (Figs. 5A, 5B, and 5C, respectively), consistent with previous reports (40, 41). The data also demonstrate that gallic acid and GSK are effective at reducing enzyme levels after I/R and their combined effect is greater than either alone, which means they provide increased protection against heart muscle damage when combined. Previous studies have shown that the CK-MB increase is strongly correlated with infarct size, and the LDH increase in myocardial infarction may be due to prolonged ischemic injury (41, 42). Our results agree with other studies demonstrating that cardiac enzymes are increased in I/R injury (40, 41). In our hands, administration of GSK and GSK + gallic acid reduced this increase.

In summary, this study demonstrated that gallic acid and GSK can act as potent anti-inflammatory and protective agents in a rat model of cardiac I/R injury. In addition to improving cardiac function, they reduced the myocardial injury markers CK-MB, LDH, and cTnI, and the proinflammatory cytokines TNF-α and IL-6. Generally, our results showed that gallic acid and GSK as an SGK1 inhibitor could have anti-inflammatory effects and improve cardiac function in I/R injury. Furthermore, the simultaneous use of both compounds may significantly increase and potentiate these curative effects.

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Conflicts of interest

The authors have no relevant financial or non-financial interests to disclose.

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Ethics Approval

The protocols of the experiments were approved by the research ethics committee of the Research Center & Experimental Animal House at Ahvaz Jundishapur University of Medical Sciences according to the ethical principles and national norms and standards for conducting Medical Research in Iran (ID: IR.AJUMS.ABHC.REC.1400.032, dated: 2021-05-25).

References

1. Smit M, Coetzee A, Lochner A. The pathophysiology of myocardial ischemia and perioperative myocardial infarction. J Cardiothorac Vasc Anesth. 2020;34(9):2501-12.
2. D'Arcy MS. Cell death: a review of the major forms of apoptosis, necrosis and autophagy. Cell Biol Int. 2019;43(6):582-92.
3. Mohammadi A, Karami ARB, Mashtani VD, Sahraei T, Tarashoki ZB, Khattavian E, et al. Evaluation of oxidative stress, apoptosis, and expression of microRNA-208a and microRNA-1 in cardiovascular patients. Rep Biochem Mol Biol. 2021;10(2):183.
4. Algoet M, Janssens S, Himmelreich U, Gsell W, Pusovnik M, Van den Eynde J, et al. Myocardial ischemia-reperfusion injury and the influence of inflammation. Trends Cardiovasc Med. 2022.
5. Garg P, Morris P, Fazlanie AL, Vijayan S, Dancso B, Dastidar AG, et al. Cardiac biomarkers of acute coronary syndrome: from history to high-sensitivity cardiac troponin. Intern Emerg Med. 2017;12(2):147-55.
6. Rashid S, Malik A, Khurshid R, Faryal U, Qazi S. The Diagnostic Value of Biochemical Cardiac Markers in Acute Myocardial Infarction. [Internet]. Myocardial Infarction. IntechOpen; 2019. Available from: http://dx.doi.org/10.5772/intechopen.76150
7. Naseroleslami M, Rakhshan K, Aboutaleb N, Souri F. Lavender Oil Attenuates Myocardial Ischemia/Reperfusion Injury Through Inhibition of Autophagy and Stimulation of Angiogenesis. Iran J Sci Technol Trans Sci. 2021;45(4):1201-9.
8. Baloglu UB, Talo M, Yildirim O, San Tan R, Acharya UR. Classification of myocardial infarction with multi-lead ECG signals and deep CNN. Pattern Recognit Lett. 2019;122:23-30.
9. Christenson E, Christenson RH. The role of cardiac biomarkers in the diagnosis and management of patients presenting with suspected acute coronary syndrome. Ann Lab Med. 2013;33(5):309-318.
10. Lang F, Shumilina E. Regulation of ion channels by the serum-and glucocorticoid-inducible kinase SGK1. FASEB J. 2013;27(1):3-12.
11. Lang F, Shumilina E. Regulation of ion channels by the serum- and glucocorticoid-inducible kinase SGK1. FASEB J. 2013;27(1):3-12.
12. Yang M, Zheng J, Miao Y, Wang Y, Cui W, Guo J, et al. Serum-Glucocorticoid Regulated Kinase 1 Regulates Alternatively Activated Macrophage Polarization Contributing to Angiotensin II–Induced Inflammation and Cardiac Fibrosis. Arterioscler Thromb Vasc Biol. 2012;32(7):1675-86.
13. Lang F, Stournaras C, Alesutan I. Regulation of transport across cell membranes by the serum- and glucocorticoid-inducible kinase SGK1. Mol Membr Biol. 2014;31(1):29-36.
14. Souri F, Badavi M, Dianat M, Mard SA, Sarkaki A. Protective effects of gallic acid and SGK1 inhibitor on oxidative stress and cardiac damage in an isolated heart model of ischemia/reperfusion injury in rats. Iran J Basic Med Sci. 2023, 26(3):308-315.
15. Gan W, Ren J, Li T, Lv S, Li C, Liu Z, Yang M. The SGK1 inhibitor EMD638683, prevents Angiotensin II–induced cardiac inflammation and fibrosis by blocking NLRP3 inflammasome activation. Biochim Biophys Acta Mol Basis Dis. 2018;1864(1):1-10.
16. Ahmadvand H, Yalameha B, Adibhesami G, Nasri M, Naderi N, Babaeenezhad E, Nouryazdan, N. The protective role of gallic acid pretreatment on renal ischemia-reperfusion

[DOI: 10.61186/rbmb.12.1.159]

injury in rats. Rep Biochem Mol Biol. 2019;8(1):42-48.
17. Ramezani-Aliakbari F, Badavi M, Dianat M, Mard SA, Ahangarpour A. Effects of gallic acid on hemodynamic parameters and infarct size after ischemia-reperfusion in isolated rat hearts with alloxan-induced diabetes. Biomed Pharmacother. 2017;96:612-8.
18. Badavi M, Sadeghi N, Dianat M, Samarbafzadeh A. Effects of gallic Acid and cyclosporine a on antioxidant capacity and cardiac markers of rat isolated heart after ischemia/reperfusion. Iran Red Crescent Med J. 2014;16(6):e16424.
19. Baban B, Liu JY, Mozaffari MS. SGK-1 regulates inflammation and cell death in the ischemic-reperfused heart: pressure-related effects. Am J Hypertens. 2014;27(6):846-56.
20. Javidanpour S, Dianat M, Badavi M, Mard SA. The inhibitory effect of rosmarinic acid on overexpression of NCX1 and stretch-induced arrhythmias after acute myocardial infarction in rats. Biomed Pharmacother. 2018;102:884-93.
21. Kalantari H, Mombeyni M, Dianat M, Badavi M, Goudarzi M. The effect of Prunus cerasus (sour cherry) kernel seed extract on QT interval of heart and its histopathology in biliary cirrhosis induced by bile duct ligation in rats. Jundishapur Journal of Natural Pharmaceutical Products. 2015;10(4).
22. Dianat M, Amini N, Badavi M, Farbood Y. Ellagic acid improved arrhythmias induced by CaCL2 in the rat stress model. Avicenna J Phytomed. 2015;5(2):120-7.
23. Sameri MJ, Savari F, Hoseinynejad K, Danyaei A, Mard SA. The hepato-protective effect of H2S-modified and non-modified mesenchymal stem cell exosomes on liver ischemia-reperfusion injury in mice: The role of MALAT1. Biochem Biophys Res Commun. 2022;635:194-202.
24. Aldous SJ. Cardiac biomarkers in acute myocardial infarction. Int J Cardiol. 2013;164(3):282-94.
25. Dludla PV, Nkambule BB, Jack B, Mkandla Z, Mutize T, Silvestri S, et al. Inflammation and Oxidative Stress in an Obese State and the Protective Effects of Gallic Acid. Nutrients. 2018;11(1):23.
26. Nouri A, Salehi-Vanani N, Heidarian E. Antioxidant, anti-inflammatory and protective potential of gallic acid against paraquat-induced liver toxicity in male rats. Avicenna J Phytomed. 2021;11(6):633-44.
27. Kroes Bv, Van den Berg A, Van Ufford HQ, Van Dijk H, Labadie R. Anti-inflammatory activity of gallic acid. Planta Med. 1992;58(06):499-504.
28. Kongpichitchoke T, Chiu MT, Huang TC, Hsu JL. Gallic acid content in Taiwanese teas at different degrees of fermentation and its antioxidant activity by inhibiting PKCδ activation: in vitro and in silico studies. Molecules. 2016;21(10):1346.
29. Yang M, Zheng J, Miao Y, Wang Y, Cui W, Guo J, et al. Serum-glucocorticoid regulated kinase 1 regulates alternatively activated macrophage polarization contributing to angiotensin II-induced inflammation and cardiac fibrosis. Arterioscler Thromb Vasc Biol. 2012;32(7):1675-86.
30. Lang F, Böhmer C, Palmada M, Seebohm G, Strutz-Seebohm N, Vallon V. (Patho)physiological significance of the serum- and glucocorticoid-inducible kinase isoforms. Physiol Rev. 2006;86(4):1151-78.
31. Dieter M, Palmada M, Rajamanickam J, Aydin A, Busjahn A, Boehmer C, et al. Regulation of glucose transporter SGLT1 by ubiquitin ligase Nedd4-2 and kinases SGK1, SGK3, and PKB. Obes Res. 2004;12(5):862-70.
32. Busjahn A, Aydin A, Uhlmann R, Krasko C, Bahring S, Szelestei T, et al. Serum- and glucocorticoid-regulated kinase (SGK1) gene and blood pressure. Hypertension. 2002;40(3):256-60.
33. Busjahn A, Luft F. Twin studies in the analysis of minor physiological differences between individuals. Cell Physiol Biochem. 2003;13(1):51-8.
34. Busjahn A, Seebohm G, Maier G, Toliat M, Nürnberg P, Aydin A, et al. Association of the serum and glucocorticoid regulated kinase (sgk1) gene with QT interval. Cell Physiol Biochem. 2004;14(3):135-42.
35. Lang F, Henke G, Embark H, Waldegger S, Palmada M, Böhmer C, et al. Regulation of

[DOI: 10.61186/rbmb.12.1.159]

channels by the serum and glucocorticoid-inducible kinase-implications for transport, excitability and cell proliferation. Cell Physiol Biochem. 2003;13(1):41-50.
36. Nah D-Y, Rhee M-Y. The inflammatory response and cardiac repair after myocardial infarction. Korean Circ J. 2009;39(10):393-8.
37. Hartman MH, Vreeswijk-Baudoin I, Groot HE, van de Kolk KW, de Boer RA, Mateo Leach I, et al. Inhibition of interleukin-6 receptor in a murine model of myocardial ischemia-reperfusion. PloS one. 2016;11(12):e0167195.
38. Radmehr V, Ahangarpour A, Mard SA, Khorsandi L. Crocin ameliorates MicroRNAs-associated ER stress in type 2 diabetes induced by methylglyoxal. Iran J Basic Med Sci. 2022;25(2):179.
39. Souri F, Rakhshan K, Erfani S, Azizi Y, Nasseri Maleki S, Aboutaleb N. Natural lavender oil (Lavandula angustifolia) exerts cardioprotective effects against myocardial infarction by targeting inflammation and oxidative stress. Inflammopharmacology. 2019;27(4):799-807.
40. Asdaq SM, Inamdar MN. Pharmacodynamic interaction of garlic with hydrochlorothiazide in rats. Indian J Physiol Pharmacol. 2009;53(2):127-36.
41. Asdaq SM, Inamdar MN, Asad M. Pharmacodynamic interaction of garlic with propranolol in ischemia-reperfusion induced myocardial damage. Pak J Pharm Sci. 2010;23(1):42-7.
42. Singh G, Rohilla A, Singh M, Balakumar P. Possible role of JAK-2 in attenuated cardioprotective effect of ischemic preconditioning in hyperhomocysteinemic rat hearts. Yakugaku Zasshi. 2009;129(5):523-35.

[DOI: 10.61186/rbmb.12.1.159]