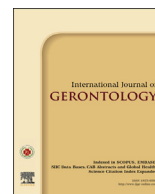




Contents lists available at SciVerse ScienceDirect

## International Journal of Gerontology

journal homepage: www.ijge-online.com



## Original Article

Treadmill Exercise Alleviates Aging-induced Apoptosis in Rat Cardiac Myocytes<sup>☆</sup>Il-Gyu Ko<sup>1,2</sup>, Sung-Eun Kim<sup>2</sup>, Chang-Ju Kim<sup>2</sup>, Yong-Seok Jee<sup>1\*</sup><sup>1</sup> Department of Exercise Physiology Prescription, Graduate School of Health Promotion, Hanseo University, Chungcheongnam-do 356-706 <sup>2</sup> Department of Physiology, College of Medicine, Kyung Hee University, Seoul 130-701, Republic of Korea

## ARTICLE INFO

## Article history:

Received 30 July 2012

Received in revised form

6 November 2012

Accepted 30 November 2012

Available online 15 February 2013

## Keywords:

aging,  
apoptosis,  
cardiomyocyte,  
heat shock protein 70 (HSP70),  
treadmill exercise

## SUMMARY

**Background:** The incidence and prevalence of heart failure increases with age. Cardiomyocyte apoptosis contributes to the pathogenesis of heart failure. In the end-stage of human heart failure, increased cardiomyocyte apoptosis is observed. Exercise training is one of the nonpharmacological treatments for chronic heart failure.**Methods:** In the present study, we investigated the effect of treadmill exercise on the aging-induced apoptosis within cardiac myocytes in relation to the expression of heat shock protein 70 (HSP70) using rats. Terminal deoxynucleotidyl transferase-mediated dUTP nick end labeling (TUNEL) staining and Western blotting for the expression of Bcl-2, Bax, HSP70, and phosphorylated p38 (p-p38) in the cardiac myocardium were conducted.**Results:** Aging induced apoptosis in the myocardium, which was confirmed by increased TUNEL-positive cells and the enhancement of Bax. Expression of HSP70 was suppressed and p-p38 expression was enhanced by aging. Treadmill exercise alleviated aging-induced apoptosis with enhancing HSP70 expression and suppressing p-p38 expression in the cardiac myocytes.**Conclusion:** Based on the present results, it can be inferred that treadmill exercise can provide a cardioprotective effect on aging-induced apoptosis through the enhancement of HSP70 expression in the heart. Thus, regular exercise may be a useful strategy for preventing heart problems in the elderly.

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## 1. Introduction

Aging is a complicated physiological process caused by the progressive decline of multiple biological functions and disrupted homeostasis. These alterations to homeostasis cause various diseases, including stroke, dementia, and heart disease. The incidence and prevalence of heart attacks such as myocardial infarction increases with age, and developed countries are increasingly faced with an aging population. Aging is associated with a dramatic increase in the incidence and prevalence of heart failure: heart failure is four times more common in those over 85 years compared to those aged 65–75 years<sup>1</sup>. It can thus be concluded that as our

population continues to age, the burden of heart failure will continue to rise.

In normal aging of both humans and animals, postmitotic heart tissue has been associated with a decrease in the total number of cells<sup>2,3</sup>. Therefore, a reduction in the total number of viable cells may lead to an accelerated decline in heart function. Cardiomyocyte apoptosis has been shown to contribute to the pathogenesis of heart failure. In the end stage of human heart failure, increased cardiomyocyte apoptosis is observed<sup>4</sup>.

Apoptosis is known as programmed cell death, and it is distinct from necrosis in terms of a type of cell death involved in cellular development. Apoptosis plays a crucial role in normal development and tissue homeostasis<sup>5</sup>. In addition to cell loss via necrosis, apoptosis may be a major factor contributing to the loss of post-mitotic cells with age<sup>6</sup>. The morphological characteristics of apoptotic cell death are cell shrinkage, chromatin condensation, membrane blebbing, and DNA fragmentation. Terminal deoxynucleotidyl transferase-mediated dUTP nick end labeling (TUNEL) staining is an assay that detects DNA fragmentation, which is characteristic of apoptotic cell death<sup>7,8</sup>. Cardiomyocyte dysfunction

<sup>☆</sup> All contributing authors declare no conflicts of interest.

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caused by apoptosis has been associated with various molecules, including heat shock protein 70 (HSP70), mitogen-activated protein (MAP) kinase, and the Bcl-2 family.

Heat shock proteins are known as “stress-induced proteins,” and they are ubiquitous, highly conserved chaperones that are involved in the folding of newly synthesized or damaged proteins<sup>9</sup>. HSP70 plays a critical role in maintaining cellular homeostasis and protecting cells during episodes of stress, damage, and aging<sup>10</sup>. An increase in the level of HSP70 counterbalances the age-related antioxidant system in the rat heart<sup>11</sup>. The rate of apoptosis increases and HSP70 expression decreases with age in rats<sup>12</sup>. Many studies have indicated that the heart survival promoting effect of HSP70 can be ascribed to the suppressive effect of HSP70 on apoptosis<sup>13,14</sup>.

MAP kinases, members of discrete signaling cascades, serve as a focal point in response to various extracellular stimuli, and are divided into four subtypes: extracellular signal-regulated kinase (ERK), c-jun N-terminal or stress-activated protein kinase (JNK/SAPK), ERK/big MAP kinase 1 (BMK1), and p38 MAP kinase (p38)<sup>15</sup>. Of these, p38 regulates a variety of cellular processes including cell growth processes, cell differentiation, apoptosis, and cellular response to inflammation. HSP70 is also involved in the inhibition of p38 within the myocardium<sup>16</sup>. Activation of p38 in cardiomyocytes was reported to lead to a rapid onset of lethal cardiomyopathy, including cardiomyocyte hypertrophy, interstitial fibrosis, and contractile dysfunction<sup>17</sup>. Activation of p38 was ascertained through the phosphorylated p38 (p-p38) that is involved in the initiation of apoptosis<sup>18</sup>.

The Bcl-2 family proteins also play an important role in the regulation of apoptosis. The Bcl-2 family proteins are classified into antiapoptotic proteins, including Bcl-2 and Bcl-xL, and proapoptotic proteins, such as Bax and Bid. Bcl-2 inhibits apoptosis by preventing the release of cytochrome-c from the mitochondria. The antiapoptotic Bcl-2 and the proapoptotic Bax are important regulators of mitochondrial function in cardiomyocyte apoptosis<sup>19</sup>. Bcl-2 and Bcl-xL form heterodimers with the main proapoptotic member, Bax, and can be incapacitated in their protective function<sup>20</sup>. The balance between Bcl-2 and Bax is one of the crucial factors determining whether the cells undergo apoptosis, and the Bcl-2 to Bax ratio can be changed during the aging process<sup>21–23</sup>.

Regular exercise is known to decrease cardiovascular morbidity and mortality in both adults and elderly<sup>11,24,25</sup>. Regular exercise training improves exercise capacity, endothelial function, and collateralization in patients with coronary artery disease and chronic heart failure<sup>26</sup>. In addition, exercise ameliorates the aging-induced decrease in the capillary density of the heart<sup>27</sup>. The exercise training-induced increase in the capillary density may be a beneficial adaptation for the aged heart because the capillary network is involved in maintaining the supply of oxygen and energy to the heart<sup>28</sup>. Exercise is one of the nonpharmacological treatments for chronic heart failure, and it improves the exercise capacity and quality of life in heart failure patients<sup>29</sup>.

Kwak et al<sup>30</sup> demonstrated the protective effect of exercise training against elevated apoptosis through reducing the caspase-9 level and the ratio of Bax to Bcl-2. However, the effect of exercise on age-induced apoptosis in cardiac myocytes in relation with the expression of HSP 70 and p-p38 has rarely been observed. In the present study, TUNEL staining and Western blotting for the expression of Bcl-2, Bax, HSP70, and p-p38 in the cardiac myocardium were conducted.

## 2. Materials and methods

### 2.1. Experimental animals

Ten-week-old Sprague-Dawley rats ( $n = 20$ ; weighing  $250 \pm 10$  g) were used as the young-aged group and 24-month-old rats ( $n = 20$ ; weighing  $420 \pm 20$  g) were used as the old-aged group. The

experimental procedures were performed in accordance with the animal care guidelines of the National Institutes of Health (NIH) and the Korean Academy of Medical Sciences. The rats were housed under controlled temperature ( $22 \pm 2^\circ\text{C}$ ) and lighting (08:00 to 20:00 hours) conditions with food and water available *ad libitum*. The rats were randomly divided into four groups ( $n = 10$  in each group): the young-aged sedentary group, the young-aged exercise group, the old-aged sedentary group, and the old-aged exercise group.

### 2.2. Treadmill exercise protocols

The rats in the exercise groups were forced to run on a motorized treadmill for 30 minutes once a day for 6 weeks. The exercise load consisted of running at a speed of 2 m/min for the first 5 minutes, 5 m/min for the next 5 minutes, and 8 m/min for the last 20 minutes, with no incline. The rats in the control groups were left on the treadmill without running for the same time period as the exercise groups.

### 2.3. Tissue preparation

The animals were sacrificed immediately after the last treadmill exercise performed. The animals were anesthetized using Zoletil 50 (10 mg/kg, i.p.; Vibac Laboratories, Carros, France), and the left ventricle area in the cardiac muscle was removed. Cardiac muscles were fixed in 4% paraformaldehyde, dehydrated in graded ethanol, treated in xylene, and infiltrated and embedded in paraffin. Coronal sections of 5- $\mu\text{m}$  thickness were made by a paraffin microtome (Thermo, Co, Cheshire, UK), mounted on coated slides, and then dried at  $37^\circ\text{C}$  overnight on a hot plate.

### 2.4. TUNEL staining

In order to visualize DNA fragmentation, a marker of apoptosis, TUNEL staining was performed using an In Situ Cell Death Detection Kit (Roche, Mannheim, Germany) according to the manufacturer's protocol<sup>8</sup>. The sections were postfixed in ethanol-acetic acid (2:1) and rinsed. The sections were then incubated with proteinase K (100  $\mu\text{g}/\text{mL}$ ), rinsed, and incubated in 3%  $\text{H}_2\text{O}_2$ , permeabilized with 0.5% Triton X-100, rinsed again, and incubated in the TUNEL reaction mixture. Then, the sections were rinsed and visualized using Converter-POD with 0.03% 3,3'-diaminobenzidine (DAB). Mayer's hematoxylin (DAKO, Glostrup, Denmark) was used as a counterstain, and the sections were mounted onto gelatin-coated slides. Slides were air-dried overnight at room temperature, and coverslips were mounted using Permount.

### 2.5. Western blot analysis

Western blotting was performed as the method described previously<sup>22</sup>. The left ventricle tissues in the cardiac muscle were collected and immediately frozen at  $-70^\circ\text{C}$ . The tissues were homogenized with a lysis buffer containing 50 mM Tris-HCl (pH 8.0), 150 mM NaCl, 10% glycerol, 1% Triton X-100, 1.5 mM  $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ , 1 mM EGTA, 1 mM PMSF, 1 mM  $\text{Na}_2\text{VO}_4$ , and 100 mM NaF, and then centrifuged at 14,000 rpm for 30 minutes. Protein content was measured using a Bio-Rad colorimetric protein assay kit (Bio-Rad). Forty micrograms of protein were separated on sodium dodecyl sulfate (SDS)-polyacrylamide gels and transferred onto a nitrocellulose membrane. A rabbit glyceraldehyde 3-phosphate dehydrogenase (GAPDH) antibody (1:5000; AbFrontier, Seoul, Korea), mouse Bax antibody (1:1000; Santa Cruz Biotechnology, Santa Cruz, CA, USA), mouse Bcl-2 antibody (1:1000; Santa Cruz Biotech.), rabbit p38 antibody (1:1000; Cell Signaling Technology, Beverly,

MA, USA), mouse phosphorylated p38 (p-p38) antibody (1:1000; Santa Cruz Biotech.), and mouse HSP70 antibody (1:1000; Santa Cruz Biotechnology, Santa Cruz, CA, USA) were used as the primary antibodies. Horseradish peroxidase-conjugated antimouse antibody (1:2000; Vector Laboratories, Burlingame, CA, USA) for Bax, Bcl-2, p-p38, and HSP70, and antirabbit antibody (1:3000; Vector Laboratories) for GAPDH were used as the secondary antibodies. The experiment was performed in normal laboratory conditions and at room temperature, except for membrane transfer. Membrane transfer was performed at 4°C with a cold pack and pre-chilled buffer. Band detection was performed using the enhanced chemiluminescence (ECL) detection kit (Santa Cruz Biotechnology, Santa Cruz, CA, USA). In order to compare the relative expression of proteins, detected bands were calculated densitometrically using Molecular Analyst version 1.4.1 (Bio-Rad, Hercules, CA, USA).

## 2.6. Data analysis

The number of TUNEL-positive cells in the cardiac muscle tissues was measured using the Image-Pro Plus computer-assisted image analysis system (Media Cybernetics Inc., Silver Spring, MD, USA) attached to a light microscope (Olympus, Tokyo, Japan). The percentage of TUNEL-positive cells was calculated by normalizing the number of TUNEL-positive nuclei to the total nuclei in the randomly selected four fields. In the Western blot analysis, to compare the relative expressions of proteins, the detected bands were calculated densitometrically using Molecular Analyst, version 1.4.1 (Bio-Rad). All data were reported as the mean  $\pm$  standard error of the mean (SEM). The Kolmogorov–Smirnov test was used to determine the distribution of normality of the examined variables. Differences in all the variables among the four groups were evaluated using one-way analysis of variance followed by the Duncan *post hoc* test. Statistical analysis was conducted using the SPSS statistical software (version 15.0). The level of statistical significance was set at  $p < 0.05$ .

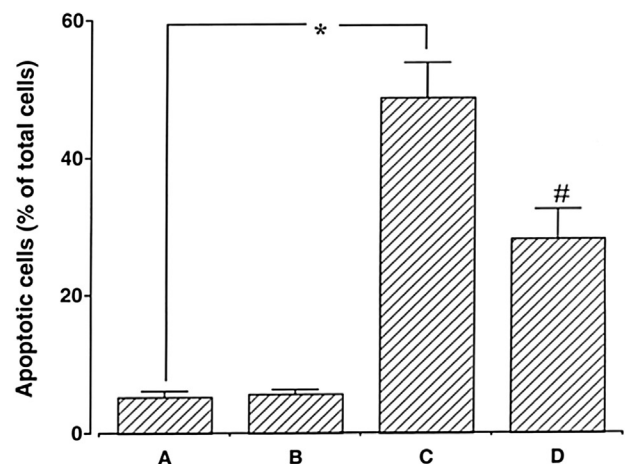
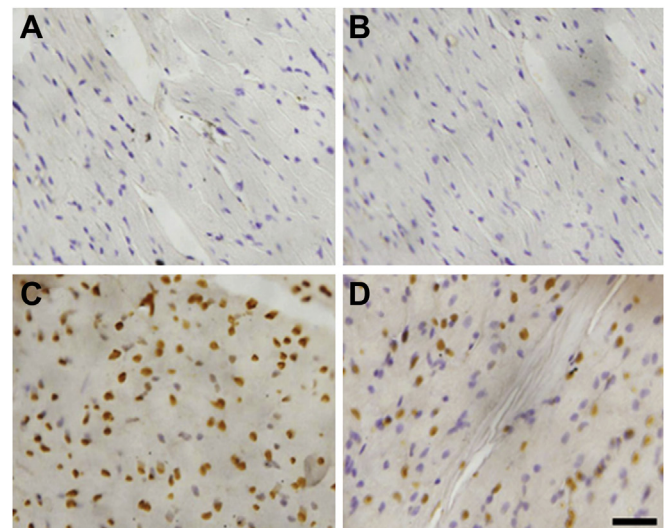
## 3. Results

### 3.1. Effect of treadmill exercise on the number of TUNEL-positive cells in the cardiac muscle

Photomicrographs of TUNEL-positive cells in the cardiac muscle are presented in Fig. 1. The percentage of TUNEL-positive cells was  $5.26 \pm 0.76\%$  in the young-aged sedentary group,  $5.59 \pm 0.62\%$  in the young-aged exercise group,  $48.75 \pm 5.05\%$  in the old-aged sedentary group, and  $28.21 \pm 4.31\%$  in the old-aged exercise group. The percentage of TUNEL-positive cells in the old-aged rats was higher than that in the young-aged rats ( $p < 0.05$ ). Furthermore, treadmill exercise suppressed the percentage of TUNEL-positive cells in the old-aged rats ( $p < 0.05$ ). In the young-aged rats, treadmill exercise exerted no significant effect on the percentage of TUNEL-positive cells.

### 3.2. Effect of treadmill exercise on the expression of Bcl-2 and Bax in the cardiac muscle

We ascertained the relative expression of Bcl-2 and Bax (Fig. 2). When the level of Bcl-2 (26–29 kDa) in the young-aged sedentary group was set at 1.00, the levels of Bcl-2 were  $0.96 \pm 0.05$  in the young-aged exercise group,  $1.28 \pm 0.07$  in the old-aged sedentary group, and  $1.96 \pm 0.12$  in the old-aged exercise group. The expression of Bcl-2 in the old-aged rats was higher than that in the young-aged rats ( $p < 0.05$ ). Treadmill exercise further enhanced the expression of Bcl-2 in the old-aged rats ( $p < 0.05$ ). In the young-

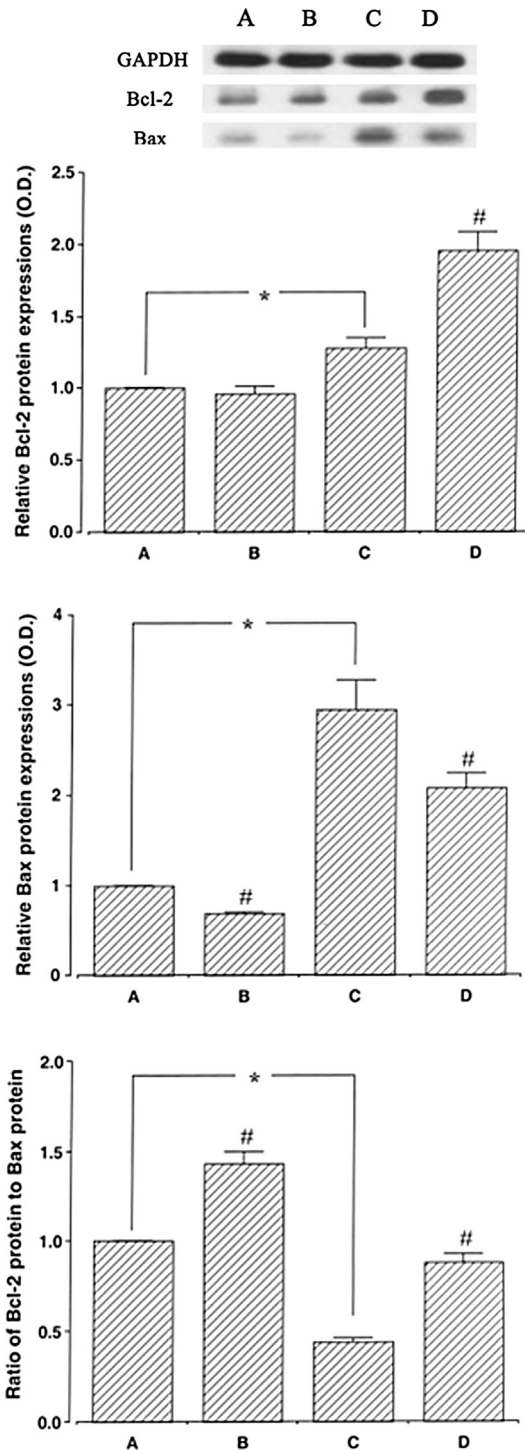


**Fig. 1.** Effect of aerobic exercise on DNA fragmentation in the myocardium. Upper: Photomicrographs of TUNEL-positive cells in the myocardium. (A) Young-aged sedentary group, (B) Young-aged exercise group, (C) Old-aged sedentary group, (D) Old-aged exercise group. The sections are stained for TUNEL. The scale bar represents 250  $\mu$ m. Lower: The percentage of TUNEL-positive cells in each group. \*  $p < 0.05$  compared to the young-aged sedentary group. #  $p < 0.05$  compared to each sedentary group. TUNEL = terminal deoxynucleotidyl transferase-mediated dUTP nick end labeling.

aged rats, treadmill exercise exerted no significant effect on the expression of Bcl-2.

When the level of Bax (24 kDa) in the young-aged sedentary group was set at 1.00, the levels of Bax were  $0.68 \pm 0.02$  in the young-aged exercise group,  $2.95 \pm 0.33$  in the old-aged sedentary group, and  $2.08 \pm 0.16$  in the old-aged exercise group. The level of Bax in the old-aged rats was higher than that in the young-aged rats ( $p < 0.05$ ). Treadmill exercise conspicuously suppressed the expression of Bax in the old-aged rats ( $p < 0.05$ ). In the young-aged rats, treadmill exercise also inhibited the expression of Bax.

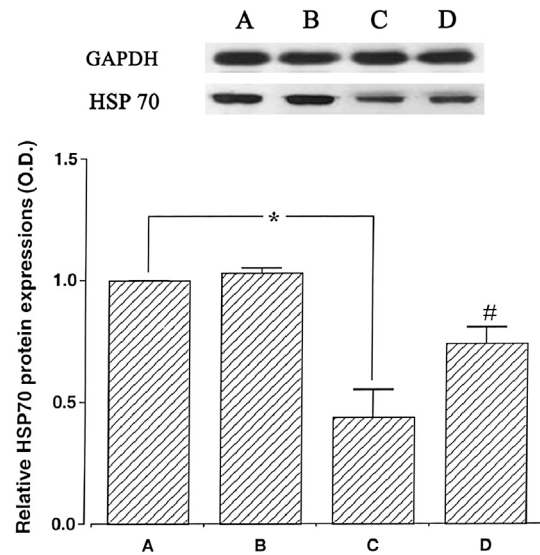
The ratio of Bcl-2 to Bax was calculated. When the ratio of Bcl-2 to Bax in the young-aged sedentary group was set at 1.00, the ratio of Bcl-2 to Bax was  $1.43 \pm 0.07$  in the young-aged exercise group,  $0.44 \pm 0.02$  in the old-aged sedentary group, and  $0.88 \pm 0.05$  in the old-aged exercise group. The ratio of Bcl-2 to Bax in the old-aged rats was lower than that in the young-aged rats ( $p < 0.05$ ). Moreover, treadmill exercise increased the ratio of Bcl-2 to Bax in the old-aged rats ( $p < 0.05$ ). In the young-aged rats, treadmill exercise also increased the ratio of Bcl-2 to Bax ( $p < 0.05$ ).



**Fig. 2.** Effect of aerobic exercise on the expression of Bax and Bcl-2 proteins. GAPDH is used as an internal control (46 kDa). (A) Young-aged sedentary group, (B) Young-aged exercise group, (C) Old-aged sedentary group, (D) Old-aged exercise group. Upper: The results of band detection using the ECL detection kit. Lower: (1) The relative expression of Bax protein. (2) The relative expression of Bcl-2 protein. (3) The ratio of Bax to Bcl-2. \*  $p < 0.05$  compared to the young-aged sedentary group. #  $p < 0.05$  compared to each sedentary group. ECL = enhanced chemiluminescence; GAPDH = glyceraldehyde 3-phosphate dehydrogenase; O.D. = optical density.

### 3.3. Effect of treadmill exercise on the expression of HSP70 in the cardiac muscle

We ascertained the relative expression of HSP70 (Fig. 3). When the level of HSP70 (70 kDa) in the young-aged sedentary group was



**Fig. 3.** Effect of aerobic exercise on the expressions of HSP70 protein. GAPDH was used as an internal control (46 kDa). (A) Young-aged sedentary group, (B) Young-aged exercise group, (C) Old-aged sedentary group, (D) Old-aged exercise group. Upper: The results of band detection using the enhanced chemiluminescence (ECL) detection kit. Lower: The relative expression of HSP70 protein. \*  $p < 0.05$  compared to the young-aged sedentary group. #  $p < 0.05$  compared to each sedentary group. ECL = enhanced chemiluminescence; GAPDH = glyceraldehyde 3-phosphate dehydrogenase; O.D. = optical density.

set at 1.00, the level of HSP70 was  $1.03 \pm 0.02$  in the young-aged exercise group,  $0.44 \pm 0.11$  in the old-aged sedentary group, and  $0.74 \pm 0.07$  in the old-aged exercise group. The expression of HSP70 in the old-aged rats was lower than that in the young-aged rats ( $p < 0.05$ ). Treadmill exercise enhanced the expression of HSP70 in the old-aged rats ( $p < 0.05$ ). In the young-aged rats, treadmill exercise exerted no significant effect on the expression of HSP70.

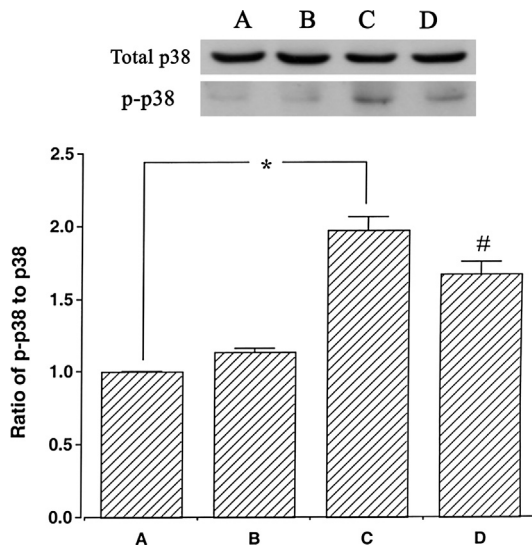
### 3.4. Effect of treadmill exercise on the expression of p-p38 in the cardiac muscle

We ascertained the relative expression of p-p38, and p-p38 was normalized to total p38 (Fig. 4). When the level of p-p38 (38 kDa) in the young-aged sedentary group was set at 1.00, the level of p-p38 was  $1.14 \pm 0.02$  in the young-aged exercise group,  $1.97 \pm 0.10$  in the old-aged sedentary group, and  $1.67 \pm 0.08$  in the old-aged exercise group. The expression of the p-p38 protein in the old-aged rats was higher than that in the young-aged rats ( $p < 0.05$ ). Treadmill exercise suppressed the expression of p-p38 in the old-aged group ( $p < 0.05$ ). In the young-aged rats, treadmill exercise exerted no significant effect on the expression of p-p38.

## 4. Discussion

Progressive loss of cardiac myocytes occurs during the aging process and heart failure, and both necrosis and apoptosis play an important role in these processes<sup>31</sup>. In particular, Kajstura et al<sup>32</sup> demonstrated that apoptosis in the left ventricles was increased by more than 200% in 24-month-old rats compared to 16-month-old rats, but there was no quantitative change in necrotic cell death. They strongly suggested that apoptosis might be more prevalent than necrosis in older rats<sup>32</sup>.

In the present study, the percentage of TUNEL-positive cells in the myocardium was increased in the old-aged rats. Treadmill exercise inhibited the percentage of TUNEL-positive cells in the old-aged rats (Fig. 1). TUNEL staining is used for the detection of



**Fig. 4.** Effect of aerobic exercise on the expressions of p-p38 protein that is normalized to total p38. (A) Young-aged sedentary group, (B) Young-aged exercise group, (C) Old-aged sedentary group, (D) Old-aged exercise group. Upper: The results of band detection using the ECL detection kit. Lower: The relative expression of p-p38 protein. \*  $p < 0.05$  compared to the young-aged sedentary group. #  $p < 0.05$  compared to each sedentary group. ECL = enhanced chemiluminescence; p-p38 = phosphorylated p38.

apoptotic cells as it exploits the generation of free 3'-hydroxyl termini on DNA via cleavage of chromatin into single and multiple oligonucleosome-length fragments, one of the biochemical hallmarks of apoptosis<sup>33</sup>.

In the present study, the expression of Bax, the proapoptotic protein, in the myocardium was found to increase in old-aged rats. Although the expression of Bcl-2 also increased with aging, the enhancement of Bax was much greater than the increase of Bcl-2, and consequently, the ratio of Bcl-2 to Bax in the old-aged rats was suppressed (Fig. 2). From these results, it can be inferred that apoptosis in the myocardium may be increased through the aging process. Treadmill exercise significantly suppressed the expression of Bax, and considerably enhanced the expression of Bcl-2 in old-aged rats. Thus, treadmill exercise significantly enhanced the ratio of Bcl-2 to Bax through the suppression of the Bax expression and enhancement of the Bcl-2 expression (Fig. 2). Zhang et al<sup>34</sup> reported that low-level mitochondrial DNA mutations observed in aging increased apoptosis in the mouse heart. Phaneuf and Leewenburgh<sup>35</sup> reported that Bax and Bcl-2 play important roles in age-related myocardial apoptosis. The Bcl-2 member inhibits apoptosis by preventing the release of cytochrome c from the mitochondria. However, Bcl-2 or Bcl-xL forms heterodimers with the main proapoptotic member Bax, and they are incapacitated from their protective function<sup>20</sup>. Cell death was inhibited by increasing the ratio of the Bcl-2 to Bax<sup>21</sup>, and the increased Bcl-2/Bax ratio inhibited cytochrome c release and caspase-3 activation and consequently decreased apoptosis<sup>36</sup>. Interestingly, our study showed that the expression of Bcl-2 was found to increase in old-aged rats. Zhang et al<sup>37</sup> proposed that a programmed cell survival response was activated in the failing and aging heart. In their study, mitochondrial DNA mutation in the mouse heart induced a prosurvival response, including the upregulation of Bcl-2. Both the activation of programmed cell survival and death may occur in the aging myocardium<sup>37,38</sup>. The beneficial effects of exercise on the myocardium in the old-aged rats, suppression of Bax expression, and enhancement of Bcl-2 expression induced by exercise are also found in other studies<sup>30</sup>.

In the present study, the expression of HSP70 in the myocardium of the old-aged rats was significantly decreased compared to

that in the young-aged rats. Treadmill exercise enhanced the expression of HSP70 in the old-aged rats (Fig. 3). Overexpression of HSP70 in the heart exerted a cardioprotective effect<sup>39,40</sup>. In contrast, HSP70 expression in the heart was reduced with aging<sup>12</sup>. HSP70 works as a molecular chaperone and plays an important role in the adaptive response<sup>41</sup>. HSP70 is also involved in antiapoptotic mechanisms. Rinaldi et al<sup>11</sup> reported that exercise training decreased the occurrence of heart failure and coronary artery disease linked to aging and suppressed apoptotic cell death in the myocardium through the enhancement of the HSP70 expression. Zhao et al<sup>41</sup> reported that HSP70 might protect the cardiomyocyte from stress-induced injury by inhibiting Fas-mediated apoptosis. An increase in the level of myocardial HSP70 was observed following long-term aerobic training in aged rats<sup>42</sup>. Long-term regular exercise suppressed age-induced apoptosis through enhancement of the HSP70 expression<sup>12</sup>.

In the present study, the expression of p-p38 in the myocardium of the old-aged rats was significantly increased compared to the young-aged rats. However, treadmill exercise suppressed the expression of p-p38 in the myocardium of the old-aged rats (Fig. 4). HSP70 has been widely reported to be involved in the inhibition of p38 within the myocardium<sup>16,18</sup>. Decreased expression of HSP70 in the aged myocardium was linked with an increased expression of p-p38<sup>18</sup>. Sun et al<sup>43</sup> reported that inhibition of p38 exerted a protective effect on cardiomyocytes. The inhibition of p38 in the myocardium suppressed apoptosis and conversely the activation of p38 induced apoptosis in the cardiomyocyte<sup>44,45</sup>.

Exercise training is an inexpensive and effective intervention for elderly patients suffering from chronic heart failure<sup>29</sup>. In this study, we evaluated the effect of treadmill exercise on apoptotic cell death in the myocardium of aged rats. Aging-induced apoptosis in the myocardium was confirmed by the increase in TUNEL-positive cells and enhancement of Bax. HSP70 expression was suppressed and p-p38 expression was enhanced through aging. Treadmill exercise alleviated aging-induced apoptosis with the enhancement of the HSP70 expression and suppression of the p-p38 expression in cardiac myocytes. Based on the present results, it can be inferred that treadmill exercise can provide a cardioprotective effect on aging-induced apoptosis through the enhancement of the HSP70 expression in the heart. Thus, regular exercise may be a useful strategy for the prevention of heart problems in the elderly.

## Acknowledgments

The authors acknowledge the contributions of the grant from Hanseo University in 2010 (101 Social Science 01).

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