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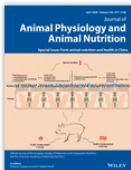
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He Ma, Yufei Zhang, Jiaxin Wang, Wenjin Guo, Guiqiu Hu, Shengnan Xie, Zhanqing Yang, Juxiong Liu, Shoupeng Fu

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Yellow mealworm, *Tenebrio molitor* (Col: Tenebrionidae), larvae powder as dietary protein sources for broiler chickens: Effects on growth performance, carcass traits, selected intestinal microbiota and blood parameters

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Biochemical and molecular investigation of oxidative stress associated with urolithiasis induced by increased dietary calcium or protein in chickens

Mahmoud G. El Sebaei, Nagah Arafat, Reham A. El-Shafei, Mohamed A. El-Adl, Amany Farag, Abeer E. Aziza, Abdelfattah H. Eladl

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Effects of dietary supplementation with herbal extract mixture on growth performance, organ weight and intestinal morphology in weaning piglets

Meiwei Wang, Huijun Huang, Yangping Hu, Yiting Liu, Xiao Zeng, Yu Zhuang, Huansheng Yang, Lei Wang, Shuai Chen, Lanmei Yin, Shengwen He, Shuo Zhang, Xiaozhen Li, Shanping He

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Impact of an anti-*Salmonella*. *Typhimurium* Bacteriophage on intestinal microbiota and immunity status of laying hens

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Blood mineral profile of the critically endangered Western Derby eland (*Taurotragus derbianus derbianus*) in two conservation breeding reserves in Senegal

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Effects of transport stress on pathological injury and main heat shock protein expression in the respiratory system of goats

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Effects of silymarin supplementation during transition and lactation on reproductive performance, milk composition and haematological parameters in sows

XiaoJun Jiang, Sen Lin, Yan Lin, ZhengFeng Fang, ShengYu Xu, Bin Feng, Yong Zhuo, Jian Li, LianQiang Che, XueMei Jiang, De Wu

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Effect of dietary pomegranate peel (*Punica granatum* L.) and Aloe vera gel (*Aloe barbadensis miller*) supplementation on testicular antioxidant biomarkers and spermatogenesis enzymes in mature V-Line rabbit bucks

Manal R. Bakeer Ph.D., Mahmoud M. El-Attrouny Ph.D., Alzahraa M. Abdelatty Ph.D.

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Effects of dietary fibres on gut microbial metabolites and liver lipid metabolism in growing pigs

Yaolian Hu, Daiwen Chen, Bing Yu, Hui Yan, Ping Zheng, Xiangbing Mao, Jie Yu, Jun He, Zhiqing Huang, Yuheng Luo, Junqiu Luo, Xianghui Zhang, Luhong Luo

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Beneficial effects of curcumin as a native or nanoparticles form on productive efficiency, liver and kidney functions, antioxidative status and immunity of heat-stressed growing rabbits

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Effects of *Opuntia ficus-indica* in the diet of primiparous sows on the metabolic profile during late gestation and lactation and feed intake during lactation

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Supplementation of diets with tannins from Chestnut wood or an extract from *Stevia rebaudiana* Bertoni and effects on in vitro rumen fermentation, protozoa count and methane production

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Expression of selected genes encoding mechanistic pathways, nutrient and amino acid transporters in jejunum and ileum of broiler chickens fed a reduced protein diet supplemented with arginine, glutamine and glycine under stress stimulated by dexamethasone

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Blastodermal development, hatchability and chick quality of Marshall® broiler breeders of different flock ages during egg storage

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In vitro degradability of corn silage and *Leymus chinensis* silage and evaluation of their mixed ratios on performance, digestion and serum parameters in beef cattle

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The possibility of using citric phosphate dextrose in chilling ram semen instead of egg yolk and soybean lecithin to improve fertility

Mahmoud Yassin Mohamed, Tarek M. M. Mahdy, Ezz I. Khalifa

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Dietary cold-pressed red and black pepper oil mixture enhances growth, carcass, blood chemistry, antioxidant, immunity and caecal pathogens of quails

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Changes in long-chain fatty acid composition of milk fat globule membrane and expression of mammary lipogenic genes in dairy cows fed sunflower seeds and rumen-protected choline

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Zhi-min Chen, Wen-huan Chang, Ai-juan Zheng, Hui-yi Cai, Guo-hua Liu

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The effect of Rosemary (*Rosmarinus officinalis* L.) distillation residues and linseed supply on fatty acid profile, meat colour, lipid oxidation and sensorial and hygienic quality of cull Barbarine ewes' meat

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The effect of crude protein content of the diet on renal energy losses in horses

Marleen Kuchler, Annette Zeyner, Andreas Susenbeth, Ellen Kienzle

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***Chlorella vulgaris* microalgae and/or copper supplementation enhanced feed intake, nutrient digestibility, ruminal fermentation, blood metabolites and lactational performance of Boer goat**

Ahmed E. Kholif, Hatem A. Hamdon, Ayman Y. Kassab, Eman S. A. Farahat, Hossam H. Azzaz, Osama H. Matloup, Ashraf G. Mohamed, Uchenna Y. Anele

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Ruminal degradation and estimated energy and protein values for ruminants of Durum wheat varieties grown in three locations

Jochen Krieg, Natascha Titze, Herbert Steingass, C. Friedrich H. Longin, Markus Rodehutsord

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Comparative study of adaptation in three chicken genotypes under humid tropical conditions of Nigeria

Monsuru O. Abioja, Olufemi P. Omotara, Oluwaseun S. Iyasere, John A. Abiona, Lawrence T. Egbeyale, Obafemi F. Akinjute

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Effects of reducing crude protein concentration in starter feed containing constant rumen undegradable protein on dairy calves performance

Mohammad Boorboor, Ali A. Alamouti, Nasser Karimi, Mohsen Sahraei Belverdy

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Effects of feeding extruded flaxseed on layer performance, total tract nutrient digestibility, and fatty acid concentrations of egg yolk, plasma and liver

Siyuan Huang, Bushansingh Baurhoo, Arif Mustafa

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The effect of dietary supplementation with globin and spray-dried porcine plasma on performance, digestibility and histomorphological traits in broiler chickens

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Effects of dietary amino acid levels and ambient temperature on mixed muscle protein turnover in *Pectoralis major* during finisher feeding period in two broiler lines

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Fibrolytic enzymes improving in vitro rumen degradability of tropical forages

Gabriel Zanuto Sakita, Thiago Francisco Ventoso Bompadre, Dhanasekaran Dineshkumar, Paulo de Mello Tavares Lima, Adibe Luiz Abdalla Filho, Tania Sila Campioni, Pedro de Oliva Neto, Herman Bremer Neto, Helder Louvandini, Adibe Luiz Abdalla

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Effects of maternal dietary vitamin E on the egg characteristics, hatchability and offspring quality of prolonged storage eggs of broiler breeder hens

Jun Yang, Xuemei Ding, Shiping Bai, Jianping Wang, Qiufeng Zeng, Huanwei Peng, Zhuowei Su, Yue Xuan, Gregory Scott Fraley, Keying Zhang

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
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Julia Windi Gunadi✉, Vita Murniati Tarawan, Iwan Setiawan, Hanna Goenawan, Hana Ratnawati, Yenni Limyati, Oeij Anindita Adhika, Andreas Wardono Santoso, Ronny Lesmana, Unang Supratman

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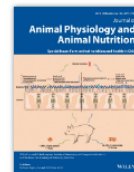


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Abstract

Information about the role of moderate acute treadmill training in modulating autophagy and mitochondrial markers that might be correlated with alteration of muscle fibre gene expression in rat cardiac muscles is very limited. In this present study, the researchers divided twenty male Wistar rats into four groups: sedentary control, 3, 6 and 15 days and subjected them to treadmill training with moderate intensity (20 m/min), 30 min each day. RNA was extracted from cardiac muscles and stored in temperature of -80°C . Specific primers were utilized for semi-quantitative PCR. Treadmill training decreased autophagy-related gene expression (LC3, p62) and upper stream signalling of autophagy (PIK3CA, Akt and mTOR) in 3 and 6 d, but stimulated gene expression of mitochondrial markers (PGC1 α , Cox1, Cox2 and Cox4) in 15 days. α MHC gene expression increased while β MHC gene expression decreased in 15 days. In line with this, autophagy-related genes increased in 3 and 6 days and returned to baseline in 15 days. The increment in mitochondrial gene expression might be correlated with shifting gene expression of α MHC and β MHC in 15 days. Taken together, acute adaptation in cardiac muscles is stimulated by genetic modulation of autophagy, mitochondrial marker and muscle fibre that may explain physiological cardiac adaptation after training. This study can be used as a reference for optimizing performance in period of cardiac muscle adaptation stimulated by treadmill training.

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Adaptation of aerobic training essentially involved autophagy, mitochondrial marker and muscle fibre genetic modulation in rat cardiac muscles

Julia Windi Gunadi^{1,2}  | Vita Murniati Tarawan³  | Iwan Setiawan³ |
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KEYWORDS

adaptation, autophagy, cardiac, mitochondria, myosin heavy chain, training

1 | INTRODUCTION

Regular exercise improves physical health especially the cardiovascular system that protects the heart from injury (Platt, Houstis, & Rosenzweig, 2015; Wei, Liu, & Rosenzweig, 2015). During aerobic exercise, such as treadmill training, there are several phases of cardiac adaptation. It starts with immediate improvement of the cardiac function, increasing the heart rate and stroke volume that augments the cardiac output (Fulghum & Hill, 2018; Weiner & Baggish, 2012), and then followed by an increase in the vascular function together with cardiac output to increase blood flow to skeletal muscles (Fulghum & Hill, 2018). However, the molecular mechanism that explains mitochondria and muscle fibre genetic modulation correlated with autophagy in cardiac muscles during early treadmill training adaptation remains unclear.

In order to cope with cellular stress induced by training, cardiac adaptation might involve cell death that occurs in several ways, such as apoptosis, necrosis and potentially autophagy (Bernardo, Ooi, Weeks, Patterson, & McMullen, 2018). Autophagy may play an important role to enhance optimal adaptation to damage due to cellular stress since cardiomyocyte does not have a regenerative capacity (Lee et al., 2017). Autophagy is a generic term for all pathways by which cytoplasmic materials are delivered to the lysosome in animal cells (Mizushima & Komatsu, 2011). Autophagy is divided into macroautophagy, microautophagy and chaperone-mediated autophagy. In macroautophagy, initiation of autophagy is carried out by a phagophore, a non-selective sequestering cytosolic substrate within a double membrane, and then conjugated with ubiquitination-linked proteins, together with light chain 3 (LC3) and p62/sequestosome 1 in a structure called autophagosome. Then, autophagosome will be fused to lysosome, where the

TABLE 1 Primers used for semi-quantitative PCR analysis

Gene symbol	Primer Sequence (5'-3') Upper strand: sense Lower strand: antisense	Product size (bp)	Annealing (°C)	Cycle	Accession number	References
PIK3CA	ACCTCAGGCTTGAAGAGTGTCTG CCGTAAGTCGTCGCCATTTTAA	137	59	35	NM_133399.2	Krusen et al. (2016)
Akt	CTAAGTCTGAGCCGAGGAAC GCTTGCTCAGTTTGCTACCC	165	57	35	XM_008764918.2	Primer3
mTOR	CTGATGTCATTTATTGGCACAAA CAGGGACTCAGAACACAAATGC	170	57	35	NM_019906.1	Yin et al. (2013)
LC3	GGTCCAGTTGTGCCTTTATTGA GTGTGTGGGTTGTGTACGTCG	153	59.5	35	NM_022867.2	Yin et al. (2013)
p62	CTAGGCATCGAGGTTGACATT CTTGCTGAGTACCACTCTTATC	116	56	35	NM_175843.4	Kowalik et al. (2016)
PGC1 α	CGCACAACCTCAGCAAGTCTC CCTTGCTGGCCTCCAAAGTCTC	263	62	37	NM_031347.1	Sylviana et al. (2018)
Cox1	GGAGCAGTATTCGCCATCAT CGGCCGTAAGTGAGATGAAT	244	55.3	35	X14848	Javadov, Purdham, Zeidan, and Karmazyn (2006)
Cox2	ACTTGGCTTACAAGACGCTACA TCTTGGGCGTCTATTGTGCTT	162	56.7	35	S67722.1	Primer3
Cox4	CTCCCATCTTATGTTGATCG GTACAATTGGACTTTCTCATCC	144	57	35	NM_017202.1	Lesmana, Sinha, et al. (2016)
α MHC	GCCCTTTGACATCCGCACAGAGT TCTGCTGCATCACCTGGTCTCTCC	152	60	35	NM_017239.2	Radik, Doka, Malikova, Krenek, and Klimas (2016)
β MHC	GCGGACATTGCCGAGTCCCAG GCTCCAGGTCTCAGGGCTTCACA	133	59.5	35	NM_017240.2	Radik et al. (2016)
GAPDH	GTTACCAGGGCTGCCTTCTC GATGGTGATGGGTTTCCCGT	177	61	35	NM_017008.4	Wang et al. (2017)

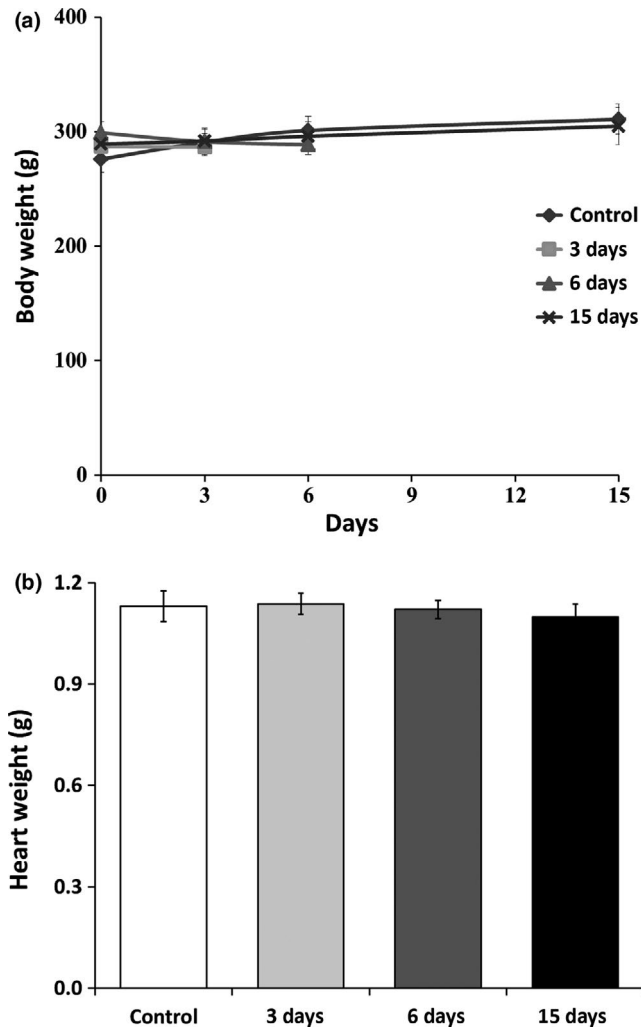


FIGURE 1 Rat body weight and heart weight during treadmill training after several periods of training. Baseline characteristics of the rats in each group. (a) Body weight of each group of the rats. (b) Heart weight of each group of the rats. Data are presented as average mean \pm standard error of the mean (SEM)

substrate is then degraded by enzymes (Mizushima & Komatsu, 2011; Pankiv et al., 2007).

Stimulation of autophagy is important and essential for mitochondrial biogenesis and activity in skeletal muscles. The role of autophagy in muscle adaptation is connected with autophagy-induced mitochondrial biogenesis in skeletal muscles (Lesmana, Sinha, et al., 2016). Autophagy in mitochondria (mitophagy) determines mitochondrial function and content in skeletal muscles (Chen, Erlich, & Hood, 2018). Mitophagy is a selective autophagy of mitochondria that eliminates damaged mitochondria, as part of quality control mechanism. There is an interplay between mitochondrial dynamics—their movements, fissions and fusions—and the progression of mitophagy; arrest and fragmentation of mitochondria after damage are likely to facilitate the selective clearance of damaged organelles (Ashrafi & Schwarz, 2013; Bloemberg & Quadri, 2019). Mitochondrial biogenesis is regulated by peroxisome proliferator-activated receptor gamma co-activator 1 α (PGC1 α) (Fernandez-Marcos & Auwerx, 2011; Puigserver

et al., 1998), while mitochondrial energy metabolism is assessed using Cytochrome c oxidase (Cox) enzyme activity (Kadenbach, Hüttemann, Arnold, Lee, & Bender, 2000). Another important process that plays a role in the adaptation to aerobic training in skeletal muscles is fibre type transformation (Farenia et al., 2019; Yan, Okutsu, Akhtar, & Lira, 2011). This study hypothesizes that adaptation of skeletal muscle by autophagy may also have a role in cardiac muscles adaptation.

Cardiac muscles fibres have myosin heavy chain (MHC) as a chemical and mechanical transducer to drive the sliding of myofilaments (Nadal-Ginard & Mahdavi, 1989). MHC provides structural integrity, and its isoform is a major determinant of contractile and functional properties. Cardiac MHC isoforms exist as homodimer or heterodimer, and a unique gene encodes each subunit. At the protein level, cardiac α or β MHC proteins have a high degree (94%) of sequence identity, and divergence only occurs in clusters, some of which are functionally important sites such as the adenosine triphosphatase (ATPase) catalytic site (Mcnelly, Kraft, Bravo-Zehnder, Taylor, & Leinwand, 1989; Rafalski, Abdourahman, & Edwards, 2007). α MHC has twofold to threefold higher actin-activated ATPase activity and actin filament sliding velocity than β MHC (Herron & McDonald, 2002; Krenz & Robbins, 2004).

Recent studies have shown that aerobic training induces autophagy gene expression in skeletal muscles (Tarawan et al., 2019) and in cardiac muscles (He et al., 2012; Lee et al., 2017). Aerobic training stimulated mitochondrial biogenesis markers and increased PGC1 α levels in cardiac muscles (Kim, Ahn, & Jung, 2018). Exercise increased α MHC while repressing β MHC genes in rats compared with sedentary control in infarcted heart (Hashimoto, Kambara, Nohara, Yazawa, & Taguchi, 2004; Wan, Xu, Zhao, Garza, & Zhang, 2014). Cardiac muscle fibres may shift MHC isoforms (from α MHC to β MHC) as a compensatory response to training, due to increased glycolytic demand and lack of functional capacity in the muscle fibre. This shift occurs in early period and might be responsible in increasing myocardial contractility and preserving cardiac functions (Rafalski et al., 2007). Taken together, modulation of autophagy, mitochondrial marker and muscle fibres may take part in cardiac muscles adaptation stimulated by training.

2 | MATERIALS AND METHODS

2.1 | Animals

Ten-week-old male Wistar rats were obtained from the Animal Breeding Centre of PT Biofarma in Bandung, Indonesia. The baseline characteristics for the rats were 10 ± 2 weeks in term of age and 287.8 ± 4.74 g in term of weight. In terms of environment, the rats were subjected to a dark light cycle (12 hr of light cycle and 12 hr of dark cycle) and a stable temperature ($\pm 22^\circ\text{C}$). The rats were fed a pellet rodent diet ad libitum and had free access to water. After one week of acclimatization, 20 male rats were divided into four groups, sedentary control group and three training groups (3, 6 and 15 days). All experimental procedures followed the guidelines for the care and use of laboratory animals (National Research Council, 2011)

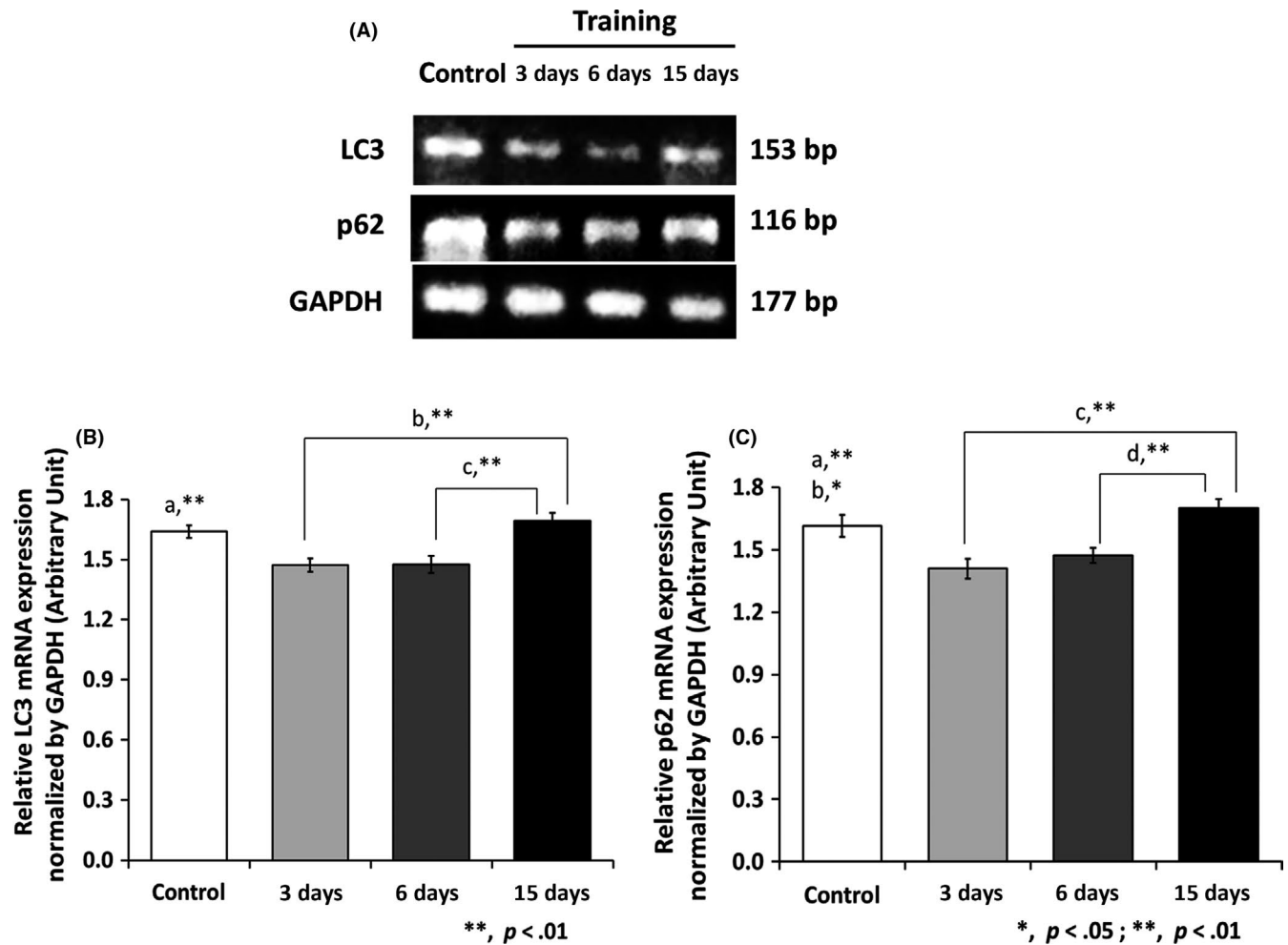


FIGURE 2 Aerobic training modulates autophagy-related gene expression in physiologic adaptation of rat cardiac muscles. (A) Representative electrophoresis result of autophagy-related gene expression in 3, 6 and 15 days after treadmill training. (B) Relative mRNA expression of LC3 was significantly decreased in 3 and 6 days (a) compared with control, and between 3 and 15 days (b), 6 and 15 days (c). (C) Relative mRNA expression of p62 was significantly decreased in 3 days (a) and 6 days (b) compared with control, and between 3 and 15 days (c), and 6 and 15 days (d). Data are presented as average mean \pm standard error of the mean (SEM); with $p < .05$ considered as significant (*), $p < .01$ considered as very significant (**)

and approved by Research Ethics Committee of Faculty of Medicine Universitas Kristen Maranatha-Rumah Sakit Immanuel Bandung No 013/KEP/V/2019.

2.2 | Treadmill training protocol

A moderate treadmill training protocol (20 m/min), 30 min a day was designed, for three different groups of male Wistar rats, divided into three periods: 3, 6 and 15 days. The study chose moderate treadmill training based on a previous study in rats (Gunadi et al., 2019; Lesmana, Iwasaki, et al., 2016). For the control group, the rats were put on the treadmill without training. After given one week to acclimatize, the rats were put on the treadmill for 3 days with increasing speed and time. The rats were subjected to the treadmill for 30 min a day and a speed of 20 m/min. They were then killed in 3, 6 and 15 days immediately after the last session of the training. All their body weights were monitored and recorded weekly. Control and training

groups were euthanized using isoflurane gas, and then, their cardiac muscles were removed, snap-frozen in liquid nitrogen and stored in temperature of -80°C until used. The researchers who analysed the tissues did not know to which group the rats belonged.

2.3 | RNA extraction and semi-quantitative PCR

RNA from cardiac muscles was extracted using TRIsure reagent (Bioline). Total RNA was measured using Multimode Microplate Reader at 268/280 nm absorbance spectrophotometry (M200 Pro; Tecan). Semi-quantitative PCR was performed using the One-Step RT-PCR Kit (Bioline, United Kingdom). Gene expression levels were normalized using GAPDH. BluePad Detection system was used to visualize electrophoresis gels. Visualization and quantification of PCR band were done using ImageJ 1.52 version (Schneider, Rasband, & Eliceiri, 2012). Primer sequences used in this study are presented in Table 1.

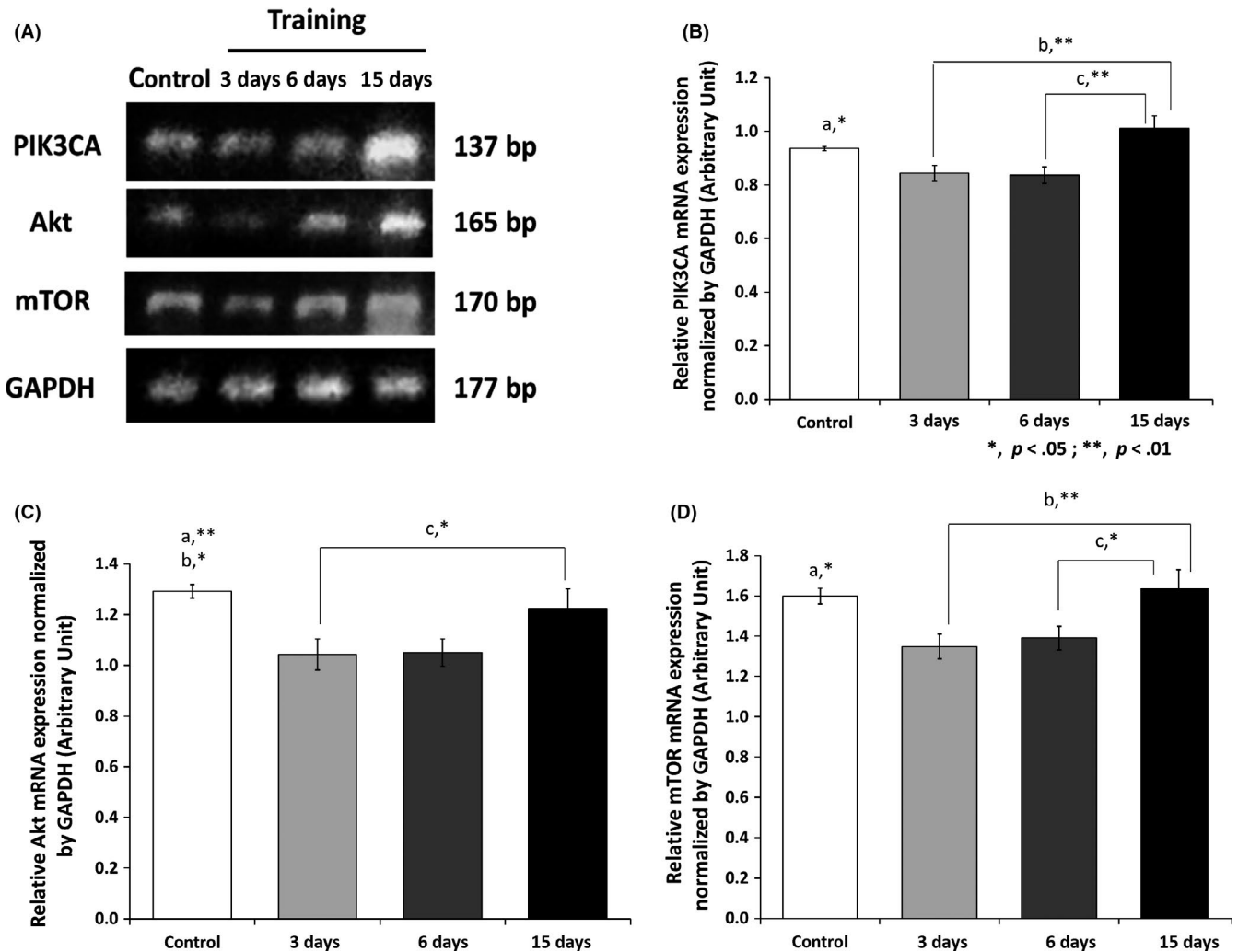


FIGURE 3 Aerobic training modulates PIK3CA, Akt and mTOR signalling gene expression that is involved in modulating autophagy.

(A) Representative electrophoresis result of PIK3CA, Akt and mTOR signalling gene expression in 3, 6 and 15 days after treadmill training. (B) Relative mRNA expression of PIK3CA was significantly decreased in 6 days compared with control (a), between 3 and 15 days (b), and between 6 and 15 days (c). (C) Relative mRNA expression of Akt was significantly decreased in 3 days (a), 6 days compared with control (b), and between 3 and 15 days (c). (D) Relative mRNA expression of mTOR was significantly decreased in 3, 6 days compared with control (a), and between 3 and 15 days (b), and 3 and 15 days (c). Data are presented as average mean \pm standard error of the mean (SEM), with $p < .05$ considered as significant (*), $p < .01$ considered as very significant (**)

2.4 | Statistics

SPSS 19.0 software was used to analyse the data obtained in this study. Results were presented as mean \pm standard error of mean (mean \pm SEM). Mean differences between groups were examined with one-way ANOVA and LSD post hoc test with 95% confidence interval with $p < .05$.

3 | RESULTS

3.1 | There were no significant differences in body weight and heart weight

The rats from the four experimental groups had similar initial body weight (287.8 ± 4.74 g). There were no significant differences found

in body weight (Figure 1a) and heart weight (Figure 1b) between 3, 6 and 15 days training groups and control after the rats were subjected to treadmill training for 30 min/day with speed of 20 m/minute.

3.2 | Training stimulated dynamic modulation of autophagy-related gene expressions in cardiac muscles of Wistar rats

There was modulation of autophagy-related gene expression in cardiac muscles of Wistar rats (Figure 2a). LC3 and p62 bands were normalized using GAPDH. Treadmill training decreased autophagy-related gene expression: LC3 by 0.897-fold in 3 days and 0.9 in 6 days (Figure 2b) and p62 by 0.874-fold in 3 days and 0.913 in 6 days (Figure 2c).

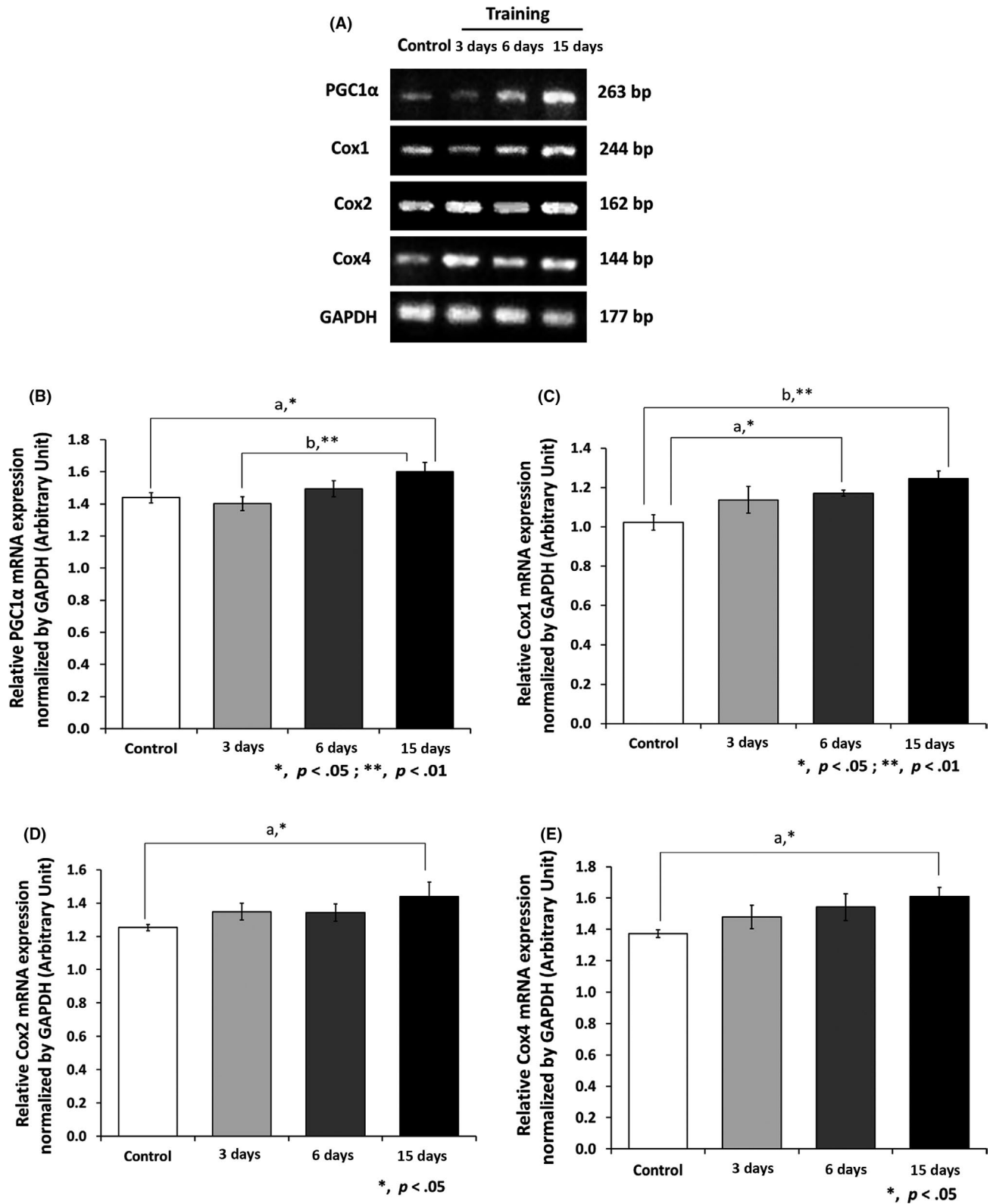


FIGURE 4 Modulation of mitochondrial marker gene expression during aerobic training adaptation in rat cardiac muscles. (A) Representative electrophoresis result of mitochondrial marker gene expression in 3, 6 and 15 days after treadmill training. (B) Relative mRNA expression of PGC1 α was significantly increased in 15 days compared with control (a), and between 3 and 15 days (b). (C) Relative mRNA expression of Cox1 was significantly increased in 6 days (a) and 15 days (b) compared with control. (D) Relative mRNA expression of Cox2 was significantly increased in 15 days compared with control (a). (E) Relative mRNA expression of Cox4 was significantly increased in 15 days compared with control (a). Data are presented as average mean \pm standard error of the mean (SEM); with $p < .05$ considered as significant (*), $p < .01$ considered as very significant (**)

3.3 | Upper stream signalling of autophagy was also modulated after training in cardiac muscles of Wistar rats

This study explored autophagy upper stream signalling and observed the modulation of PIK3CA-Akt-mTOR in cardiac muscles of Wistar rats (Figure 3a). PIK3CA, Akt and mTOR bands were normalized using GAPDH. Treadmill training decreased autophagy upper stream signalling gene expression in 3 and 6 days: PIK3CA by 0.894-fold in 6 days (Figure 3b), Akt by 0.807-fold in 3 days and 0.813-fold in 6 days (Figure 3c), and mTOR by 0.844-fold in 3 days and 0.870-fold in 6 days (Figure 3d).

3.4 | Training induced mitochondrial markers gene expressions in cardiac muscles of Wistar rats

Mitochondrial markers gene expressions were upregulated in rat cardiac muscles through training (Figure 4a). PGC1 α , Cox1, Cox2 and Cox4 bands were normalized using GAPDH. This study found increased gene expressions for mitochondrial markers in 15 days: PGC1 α increased by 1.111-fold in 15 days (Figure 4b), Cox1 increased by 1.218-fold in

15 days (Figure 4c), Cox2 increased by 1.148-fold in 15 days (Figure 4d) and Cox4 increased by 1.173-fold in 15 days (Figure 4e).

3.5 | Training increased α MHC and decreased β MHC gene expressions in cardiac muscles of Wistar rats

This study also examined muscle fibre gene expression in cardiac muscles of Wistar rats. α MHC and β MHC bands were normalized using GAPDH (Figure 5a). This study found increase in α MHC gene expression by 1.145-fold in 6 days and 1.314-fold in 15 days (Figure 5b) and decrease β MHC gene expression by 0.907-fold in 3 days and 0.887-fold in 15 days (Figure 5c).

3.6 | Summary of gene expression modulation after aerobic training in rat cardiac muscle

Adaptation to aerobic training essentially involved autophagy, mitochondrial marker and fibre shifting in rat cardiac muscles. Autophagy

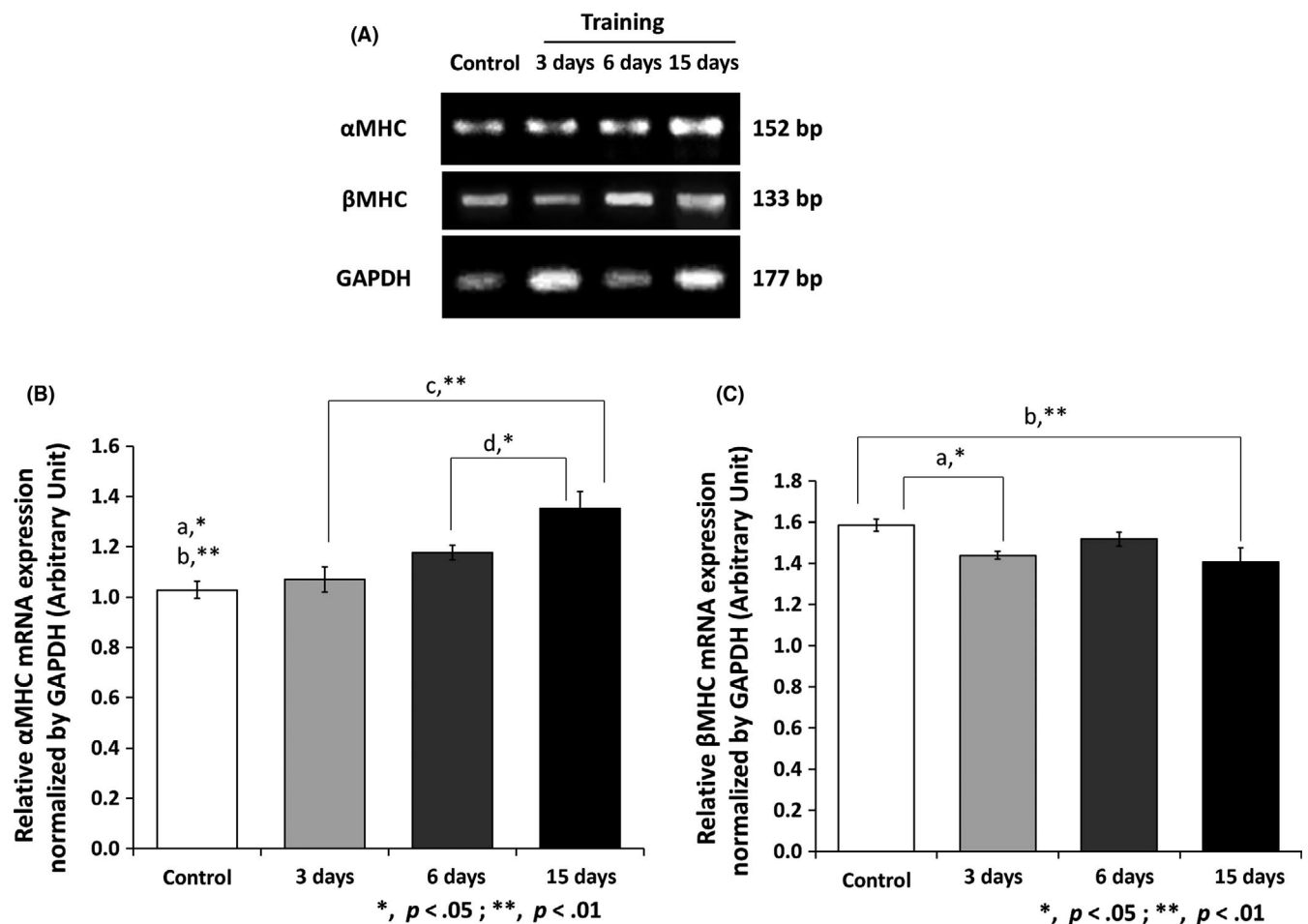


FIGURE 5 Modulation of muscle fibre gene expression after aerobic training in rat cardiac muscles. (A) α MHC gene expression increased while β MHC decreased in 15 days of treadmill training. (B) Relative mRNA expression of α MHC was significantly increased in 6 days (a) and 15 days (b) compared with control, and between 3 and 15 days (c), 6 and 15 days (d). (C) Relative mRNA expression of β MHC was significantly decreased in 3 days compared with control (a), and between 15 days compared with control (b). Data are presented as average mean \pm standard error of the mean (SEM); with $p < .05$ considered as significant (*), $p < .01$ considered as very significant (**)

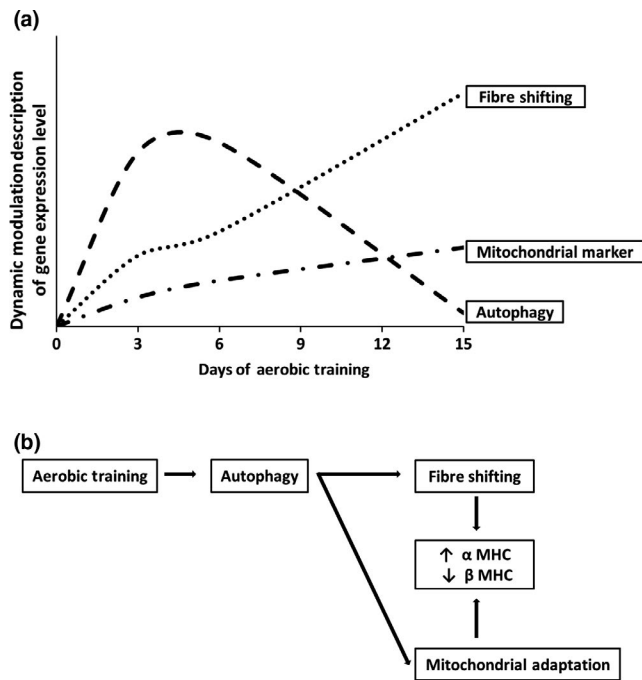


FIGURE 6 Summary of gene expression modulation after aerobic training in rat cardiac muscles. (a) Dynamic modulation description of autophagy, mitochondrial marker and muscle fibre gene expression in cardiac muscles during adaptation to aerobic training. (b) Proposed mechanism of autophagy, mitochondrial marker, and muscle fibre gene expression in cardiac muscles during adaptation to aerobic training

started to increase in 3 and 6 days, then back to baseline in 15 days, while mitochondrial marker and fibre shifting started to occur in 15 days (Figure 6a). The proposed mechanism for this modulation is described in Figure 6b.

4 | DISCUSSION

Cardiac myocytes in adult rat heart represent 70%–85% of the heart's volume, but possess extremely limited regenerative capacity. Thus, it is important to preserve the function of cardiac myocytes to maintain healthy living (Lee et al., 2017; Pinto et al., 2016). There are some key processes in adaptation of training in cardiac myocytes including cellular stress response (proteasome-ubiquitin system, autophagy and apoptosis), mitochondrial adaptation (energy metabolism and redox status) and fibre shifting (Bernardo et al., 2018; Yan et al., 2011). However, the understanding about coregulation of these systems during aerobic training adaptation remains unclear.

This study suggests a time-dependent modulation of autophagy, mitochondrial biogenesis and fibre shifting gene expression during treadmill as an adaptation processes in cardiac muscles of Wistar rats. We try to understand how cardiac muscle autophagy related to and signalling gene expression via PI3KCA-Akt-mTOR are altered by aerobic training at certain periods (3, 6 and 15 days). The results indicate that autophagy increased significantly in 3 and 6 days and then returned to baseline in 15 days supported by decreased gene expression

of LC3, p62, PI3KCA, Akt and mTOR in 3 and 6 days (Figures 2 and 3). Other studies have also shown that endurance exercise training induces autophagy in cardiac muscles (He et al., 2012; Lee et al., 2017).

Autophagy plays a role in regulating mitochondrial markers such as PGC1 α and Cox enzyme activity (Lesmana, Sinha, et al., 2016). These markers increased due to aerobic training in 15 days (Figure 4). The previous study conducted by Kim et al. have also shown that during chronic aerobic training, mitochondrial biogenesis markers were upregulated in the cardiac muscle (Kim et al., 2018).

An interesting physiological transition of cardiac muscle gene expression stimulated by aerobic training was observed, proved by an increase of α MHC and decrease of β MHC in 15 days (Figure 5). Other studies showed that exercise significantly increased α MHC while repressing β MHC gene expression in exercise rats compared with sedentary control, and this shift occurred in early period (Hashimoto et al., 2004; Rafalski et al., 2007; Wan et al., 2014).

This study showed that autophagy, mitochondrial biogenesis and fibre shifting might be correlated and jointly regulated by aerobic training. Autophagy genes increased in 3 and 6 days (Figures 2 and 3), while genes responsible for mitochondrial function (Figure 4) and fibre shifting (Figure 5) were stimulated in 15 days. A summary of this modulation and its proposed mechanism is presented in Figure 6. However, other factors may also regulate these processes and need to be investigated, such as temperature (Puigserver et al., 1998) and nitric oxide (Tengan, Rodrigues, & Godinho, 2011). We had sacrificed all the rats immediately after the last session of the training and reduce all confounding factors by using rats with the same age, standardized food, controlled environment and same intensity of training induction. However, gene expression might be altered by other factors due to post-transcriptional modifications. Thus, it may be beneficial to measure the protein levels in future studies.

5 | CONCLUSION

This study suggests a time-dependent modulation of autophagy, mitochondrial biogenesis and fibre shifting during treadmill adaptation in cardiac muscles of Wistar rats. Autophagy increased in 3 and 6 days and returned to baseline after 15 days of treadmill training. Mitochondrial biogenesis increased after 15 days of treadmill training, along with shift of β MHC to α MHC in cardiac muscles of Wistar rats. The study believes that the adaptation period needs a specific genetic modulation, protein and tissue rearrangements, to improve functional capability improvement. An athlete's performance can be optimized through a time structured training programme by understanding the physiological adaptation period in cardiac muscles.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

- Ashrafi, G., & Schwarz, T. L. (2013). The pathways of mitophagy for quality control and clearance of mitochondria. *Cell Death and Differentiation*, 20, 31–42. <https://doi.org/10.1038/cdd.2012.81>
- Bernardo, B. C., Ooi, J. Y. Y., Weeks, K. L., Patterson, N. L., & McMullen, J. R. (2018). Understanding key mechanisms of exercise-induced cardiac protection to mitigate disease: Current knowledge and emerging concepts. *Physiological Reviews*, 98, 419–475. <https://doi.org/10.1152/physrev.00043.2016>
- Bloemberg, D., & Quadrilatero, J. (2019). Autophagy, apoptosis, and mitochondria: Molecular integration and physiological relevance in skeletal muscle. *American Journal of Physiology-Cell Physiology*, 317(1), C111–C130. <https://doi.org/10.1152/ajpcell.00261.2018>
- Chen, C. C. W., Erlich, A. T., & Hood, D. A. (2018). Role of Parkin and endurance training on mitochondrial turnover in skeletal muscle. *Skeletal Muscle*, 8(1), 10. <https://doi.org/10.1186/s13395-018-0157-y>
- Farenia, R., Lesmana, R., Uchida, K., Iwasaki, T., Koibuchi, N., & Shimokawa, N. (2019). Changes in biomarker levels and myofiber constitution in rat soleus muscle at different exercise intensities. *Molecular and Cellular Biochemistry*, 458(1–2), 79–87. <https://doi.org/10.1007/s11010-019-03532-9>
- Fernandez-Marcos, P. J., & Auwerx, J. (2011). Regulation of PGC-1 α , a nodal regulator of mitochondrial biogenesis. *The American Journal of Clinical Nutrition*, 93, 884S–S890. <https://doi.org/10.3945/ajcn.110.001917>
- Fulghum, K., & Hill, B. G. (2018). Metabolic mechanisms of exercise-induced cardiac remodeling. *Frontiers in Cardiovascular Medicine*, 5, 127. <https://doi.org/10.3389/fcvm.2018.00127>
- Gunadi, J. W., Tarawan, V. M., Setiawan, I., Lesmana, R., Wahyudianingsih, R., & Supratman, U. (2019). Cardiac hypertrophy is stimulated by altered training intensity and correlates with autophagy modulation in male Wistar rats. *BMC Sports Science, Medicine & Rehabilitation*, 11, 9. <https://doi.org/10.1186/s13102-019-0121-0>
- Hashimoto, T., Kambara, N., Nohara, R., Yazawa, M., & Taguchi, S. (2004). Expression of MHC-beta and MCT1 in cardiac muscle after exercise training in myocardial-infarcted rats. *Journal of Applied Physiology (Bethesda, Md., 1985)*, 97, 843–851. <https://doi.org/10.1152/japplphysiol.01193.2003>
- He, C., Bassik, M. C., Moresi, V., Sun, K., Wei, Y., Zou, Z., ... Levine, B. (2012). Exercise-induced BCL2-regulated autophagy is required for muscle glucose homeostasis. *Nature*, 481(7382), 511–515. <https://doi.org/10.1038/nature10758>
- Herron, T. J., & McDonald, K. S. (2002). Small amounts of alpha-myosin heavy chain isoform expression significantly increase power output of rat cardiac myocyte fragments. *Circulation Research*, 90, 1150–1152.
- Javadov, S., Purdham, D. M., Zeidan, A., & Karmazyn, M. (2006). NHE-1 inhibition improves cardiac mitochondrial function through regulation of mitochondrial biogenesis during postinfarction remodeling. *American Journal of Physiology-Heart and Circulatory Physiology*, 291, H1722–H1730. <https://doi.org/10.1152/ajpheart.00159.2006>
- Kadenbach, B., Hüttemann, M., Arnold, S., Lee, I., & Bender, E. (2000). Mitochondrial energy metabolism is regulated via nuclear-coded subunits of cytochrome c oxidase. *Free Radical Biology and Medicine*, 29, 211–221.
- Kim, K., Ahn, N., & Jung, S. (2018). Comparison of endoplasmic reticulum stress and mitochondrial biogenesis responses after 12 weeks of treadmill running and ladder climbing exercises in the cardiac muscle of middle-aged obese rats. *Brazilian Journal of Medical and Biological Research*, 51, e7508. <https://doi.org/10.1590/1414-431X20187508>
- Kowalik, M. A., Perra, A., Ledda-Columbano, G. M., Ippolito, G., Piacentini, M., Columbano, A., & Falasca, L. (2016). Induction of autophagy promotes the growth of early preneoplastic rat liver nodules. *Oncotarget*, 7, 5788–5799. <https://doi.org/10.18632/oncotarget.6810>
- Krenz, M., & Robbins, J. (2004). Impact of beta-myosin heavy chain expression on cardiac function during stress. *Journal of the American College of Cardiology*, 44, 2390–2397. <https://doi.org/10.1016/j.jacc.2004.09.044>
- Kruse, M., Keyhani-Nejad, F., Isken, F., Nitz, B., Kretschmer, A., Reischl, E., ... Pfeiffer, A. F. H. (2016). High-fat diet during mouse pregnancy and lactation targets gip-regulated metabolic pathways in adult male offspring. *Diabetes*, 65, 574–584. <https://doi.org/10.2337/db15-0478>
- Lee, Y., Kwon, I., Jang, Y., Song, W., Cosio-Lima, L. M., & Roltsch, M. H. (2017). Potential signaling pathways of acute endurance exercise-induced cardiac autophagy and mitophagy and its possible role in cardioprotection. *The Journal of Physiological Science: JPS*, 67, 639–654. <https://doi.org/10.1007/s12576-017-0555-7>
- Lesmana, R., Iwasaki, T., Iizuka, Y., Amano, I., Shimokawa, N., & Koibuchi, N. (2016). The change in thyroid hormone signaling by altered training intensity in male rat skeletal muscle. *Endocrine Journal*, 63(8), 727–738. <https://doi.org/10.1507/endocrj.EJ16-0126>
- Lesmana, R., Sinha, R. A., Singh, B. K., Zhou, J., Ohba, K., Wu, Y., ... Yen, P. M. (2016). Thyroid hormone stimulation of autophagy is essential for mitochondrial biogenesis and activity in skeletal muscle. *Endocrinology*, 157, 23–38. <https://doi.org/10.1210/en.2015-1632>
- McNally, E. M., Kraft, R., Bravo-Zehnder, M., Taylor, D. A., & Leinwand, L. A. (1989). Full-length rat alpha and beta cardiac myosin heavy chain sequences. Comparisons suggest a molecular basis for functional differences. *Journal of Molecular Biology*, 210, 665–671. [https://doi.org/10.1016/0022-2836\(89\)90141-1](https://doi.org/10.1016/0022-2836(89)90141-1)
- Mizushima, N., & Komatsu, M. (2011). Autophagy: Renovation of cells and tissues. *Cell*, 147, 728–741. <https://doi.org/10.1016/j.cell.2011.10.026>
- Nadal-Ginard, B., & Mahdavi, V. (1989). Molecular basis of cardiac performance. Plasticity of the myocardium generated through protein isoform switches. *The Journal of Clinical Investigation*, 84, 1693–1700. <https://doi.org/10.1172/JCI114351>
- National Research Council (2011). *Guide for the Care and Use of Laboratory Animals* (8th ed.). Washington, DC: National Academies Press.
- Pankiv, S., Clausen, T. H., Lamark, T., Brech, A., Bruun, J.-A., Outzen, H., ... Johansen, T. (2007). p62/SQSTM1 binds directly to Atg8/LC3 to facilitate degradation of ubiquitinated protein aggregates by autophagy. *The Journal of Biological Chemistry*, 282, 24131–24145. <https://doi.org/10.1074/jbc.M702824200>
- Pinto, A. R., Ilinykh, A., Ivey, M. J., Kuwabara, J. T., D'Antoni, M. L., Debuque, R., ... Tallquist, M. D. (2016). Revisiting cardiac

- cellular composition. *Circulation Research*, 118(3), 400–409. <https://doi.org/10.1161/CIRCRESAHA.115.307778>
- Platt, C., Houstis, N., & Rosenzweig, A. (2015). Using exercise to measure and modify cardiac function. *Cell Metabolism*, 31, 227–236. <https://doi.org/10.1016/j.cmet.2015.01.014>
- Puigserver, P., Wu, Z., Park, C. W., Graves, R., Wright, M., & Spiegelman, B. M. (1998). A cold-inducible coactivator of nuclear receptors linked to adaptive thermogenesis. *Cell*, 92, 829–839. [https://doi.org/10.1016/S0092-8674\(00\)81410-5](https://doi.org/10.1016/S0092-8674(00)81410-5)
- Radik, M., Doka, G., Malikova, E., Krenek, P., & Klimas, J. (2016). Voluntary exercise and testosterone therapy caused increase in percentage of Myh6 and expression of oxidative stress marker Cybb in left ventricles of rats. *European Pharmaceutical Journal*, 1, 12–15. <https://doi.org/10.1515/afpuc-2016-0007>
- Rafalski, K., Abdourahman, A., & Edwards, J. G. (2007). Early adaptations to training: Upregulation of alpha-myosin heavy chain gene expression. *Medicine and Science in Sports and Exercise*, 39, 75–82. <https://doi.org/10.1249/01.mss.0000240324.08406.3d>
- Schneider, C. A., Rasband, W. S., & Eliceiri, K. W. (2012). NIH Image to ImageJ: 25 years of image analysis. *Nature methods*, 9, 671–675.
- Sylviana, N., Helja, N., Qolbi, H. H., Goenawan, H., Lesmana, R., Syamsunarno, M. R. A. A., ... Purba, A. (2018). Effect of swimming exercise to cardiac PGC-1 α and HIF-1 α gene expression in mice. *Asian Journal of Sports Medicine*, 9, 1–7. <https://doi.org/10.5812/asjms.65079>
- Tarawan, V. M., Gunadi, J. W., Setiawan, R. L., Goenawan, H., Meilina, D. E., ... Supratman, U. (2019). Alteration of autophagy gene expression by different intensity of exercise in gastrocnemius and soleus muscles of Wistar rats. *Journal of Sports Science and Medicine*, 18, 146–154.
- Tengan, C. H., Rodrigues, G. S., & Godinho, R. O. (2011). Nitric oxide in skeletal muscle: Role on mitochondrial biogenesis and function. *International Journal of Molecular Sciences*, 13, 17160–17184. <https://doi.org/10.3390/ijms131217160>
- Wan, W., Xu, X., Zhao, W., Garza, M. A., & Zhang, J. Q. (2014). Exercise training induced myosin heavy chain isoform alteration in the infarcted heart. *Applied Physiology, Nutrition, and Metabolism*, 39, 226–232. <https://doi.org/10.1139/apnm-2013-0268>
- Wang, K., Wang, F., Bao, J. P., Xie, Z. Y., Chen, L., Zhou, B. Y., ... Wu, X. T. (2017). Tumor necrosis factor α modulates sodium-activated potassium channel SLICK in rat dorsal horn neurons via p38 MAPK activation pathway. *Journal of Pain Research*, 10, 1265–1271. <https://doi.org/10.2147/JPR.S132185>
- Wei, X., Liu, X., & Rosenzweig, A. (2015). What do we know about the cardiac benefits of exercise? *Trends in Cardiovascular Medicine*, 25, 529–536. <https://doi.org/10.1016/j.tcm.2014.12.014>
- Weiner, R. B., & Baggish, A. L. (2012). Exercise-induced cardiac remodeling. *Progress in Cardiovascular Diseases*, 54, 380–386. <https://doi.org/10.1016/j.pcad.2012.01.006>
- Yan, Z., Okutsu, M., Akhtar, Y. N., & Lira, V. A. (2011). Regulation of exercise-induced fiber type transformation, mitochondrial biogenesis, and angiogenesis in skeletal muscle. *Journal of Applied Physiology (Bethesda, Md., 1985)*, 110, 264–274. <https://doi.org/10.1152/japplphysiol.00993.2010>
- Yin, P., Wan, C., He, S., Xu, X., Liu, M., Song, S., ... Xu, J. (2013). Transport stress causes damage in rats' liver and triggers liver autophagy. *Bio Technology: an Indian Journal*, 8, 1561–1566.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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