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Original Article

Post-workout supplementation with CoQ10 and sports drink on exercise performance and muscle recovery after exercise in normal and overweight males

Phyo Pyae Thar [a], Teerarat Likitwattanasade [b], Ratchakrit Srikuea [a,*]

[a] Department of Physiology, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand
[b] Department of Biotechnology, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand

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ABSTRACT

Background: Post-workout supplementation has been used in athletes and recreational exercisers; however, responses between normal and overweight individuals on exercise performance and muscle recovery are less known.

Methods: Normal and overweight young adult males (21 subjects/group) participated in resistance and fatiguing exercises before receiving post-workout supplements: placebo, coenzyme Q10 (CoQ10), or sports drink in a crossover design. Resistance exercises included upper body exercise (bench press, upright row, and standing shoulder press) and lower body exercise (dead lift, back squat, and front squat) at 75% of one-repetition maximum (1 RM). Fatiguing exercise was performed on a cycle ergometer with 3 min of all-out effort at 3.5% of body mass. Participants consumed post-workout supplements within 10 min of exercise completion and repeated-bout exercise was performed 1 h later, followed by cardiovascular responses, urinary biomarkers, and delayed onset muscle soreness (DOMS) assessments.

Results: There were effects of overweight on resistance exercise volume, critical power, fatigue index, and post-exercise diastolic blood pressure (DBP). However, no differences in urinary biomarkers of muscle damage (potassium and creatinine) or DOMS between normal and overweight individuals. After supplementation, CoQ10 and sports drink increased resistance exercise volume regardless of body mass and increased critical power in the normal group. Additionally, CoQ10 supplementation was associated with a reduction in urinary biomarkers and DOMS in both groups.

Conclusion: These findings are beneficial for sport scientists, nutritionists, and exercise physiologists in guiding post-workout supplementation with CoQ10 and sports drink to improve exercise performance and muscle recovery in normal and overweight individuals.

1. Introduction

Nutrition has been recognized as a primary contributing factor to athletic performance, the recovery process, and adaptation to metabolic responses during training sessions.[1] The response to nutrient supplementation strongly depends on the genetics, microbiome, and dietary patterns of individuals, and nutrient supplementation can affect nutritional requirements for training schedules.[2] Supplements for enhancing athletic performance have been previously reported (i.e., caffeine, creatine, nitrate, β-alanine, and bicarbonate).[3] Dietary supplement consumption is particularly popular among professional athletes and recreational exercisers. The main reasons for their use are to increase muscle mass, increase the rate of recovery, and improve exercise performance.[4,5]

Exercise-induced muscle damage (EIMD) involves mechanical stress to contracting muscle fibers (i.e., resistance exercise), which initiates inflammatory responses resulting in delayed onset muscle soreness (DOMS) and decreased muscle function.[6] Certain supplementary ingredients have been demonstrated to enhance muscle recovery after EIMD, i.e., branched-chain amino acids,[7] creatine-carbohydrate,[8] β-hydroxy-β-methylbutyrate,[9] L-glutamine,[10] and vitamin D.[11] However, the beneficial effects of these supplements were not associated with an alleviation of inflammatory responses or DOMS after exercise.

* Corresponding author. Department of Physiology, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand.
E-mail address: ratchakrit.sri@mahidol.ac.th (R. Srikuea).

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List of abbreviations

1 RM	One-repetition maximum
ANOVA	Analysis of variance
BMI	Body mass index
BMR	Basal metabolic rate
BP	Blood pressure
cm	Centimeter
CoQ10	Coenzyme Q10
dL	Deciliter
DBP	Diastolic blood pressure
DOMS	Delayed onset muscle soreness
EIMD	Exercise-induced muscle damage
g	Gram
GPO	Government Pharmaceutical Organization
h	Hour
HR	Heart rate
IGF-1	Insulin-like growth factor 1
IPAQ	International Physical Activity Questionnaire
kg	Kilogram
kJ	Kilojoule
L	Liter
MET	Metabolic equivalent
m	Meter
mg	Milligram
min	Minute
mL	Milliliter
mm	Millimeter
mmHg	Millimeter of mercury
mmol	Millimole
NADPH	Nicotinamide adenine dinucleotide phosphate
NSCA	National Strength and Conditioning Association
PAR-Q	Physical Activity Readiness Questionnaire
ROS	Reactive oxygen species
s	Second
SBP	Systolic blood pressure
SD	Standard deviation
SV	Stroke volume
W	Watt

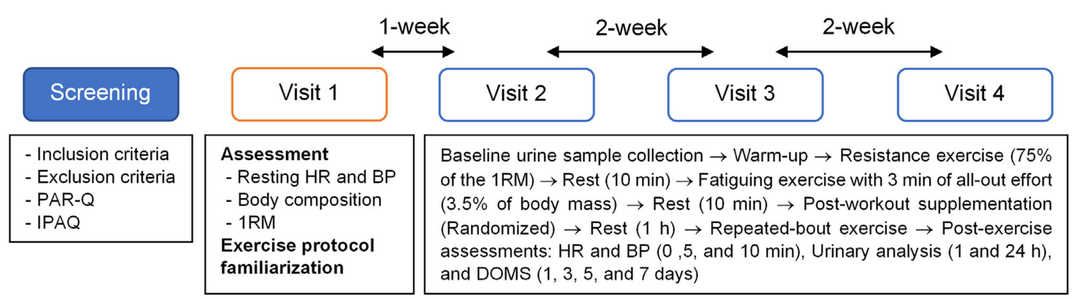

Fig. 1. Diagram of the experimental design and procedures. PAR-Q – Physical Activity Readiness Questionnaire, IPAQ – International Physical Activity Questionnaire, HR – Heart rate, BP – Blood pressure, 1RM – One-repetition maximum, min – Minute, h – Hour.

Alternatively, supplementation with the antioxidant coenzyme Q10 (CoQ10) significantly reduced muscle damage after strenuous exercise by decreasing exercise-induced oxidative stress and inflammatory cytokine levels.[12] To support this observation, CoQ10 could act as an antioxidant for scavenging reactive oxygen species (ROS) through its reduced form (ubiquinol) to protect against lipid and mitochondrial membrane damage due to free radicals.[13] This evidence suggests the potential use of CoQ10 for reducing inflammatory responses and DOMS after EIMD. Additionally, owing to its antioxidant properties, oral CoQ10 administration has also been reported to reduce fatigue during physical performance tests in healthy volunteers, supporting its beneficial effects on exercise performance.[14]

Table 1
Subject characteristics, BMI, resting HR, SBP, DBP, and total MET values.

Variables	Normal	Overweight	*p*
Age (years)	26.3 ± 2.7	26.6 ± 2.2	0.668
Height (cm)	168.1 ± 7.2	173.4 ± 5.9*	0.013
Body mass (kg)	58.8 ± 7.7	73.5 ± 5.5***	< 0.001
BMI ($kg \cdot m^{-2}$)	20.7 ± 1.5	24.4 ± 0.4***	< 0.001
Resting HR (beats/min)	76.1 ± 12.8	80.5 ± 10.1	0.975
Resting SBP (mmHg)	121.3 ± 8.6	126.2 ± 4.4*	0.026
Resting DBP (mmHg)	69.1 ± 9.7	73.5 ± 4.5	0.063
Total MET-value	870.9 ± 507.5	692.9 ± 383.0*	0.028

Metabolic equivalent (MET) is the rate of energy expenditure while sitting at rest and 1 MET is equal to 3.5 mL of oxygen/kg/min. *, ****p* < 0.05 and < 0.001, respectively.
BMI – Body mass index, HR – Heart rate, SBP – Systolic blood pressure, DBP – Diastolic blood pressure, cm – Centimeter, kg – Kilogram, m – Meter, min – Minute, mmHg – Millimeter of mercury.

Table 2
Body composition analysis.

Variables	Normal	Overweight	*p*
Extracellular water (kg)	13.3 ± 1.3	15.5 ± 0.9***	< 0.001
Intracellular water (kg)	21.4 ± 3.9	26.1 ± 2.5***	< 0.001
Body water (kg)	34.7 ± 5.1	41.6 ± 3.3***	< 0.001
Skeletal muscle mass (kg)	28.7 ± 5.2	35.0 ± 3.4***	< 0.001
Muscle mass (kg)	47.8 ± 5.9	56.8 ± 4.2***	< 0.001
Lower body muscle mass (kg)	17.9 ± 2.4	21.7 ± 1.7***	< 0.001
Upper body muscle mass (kg)	5.0 ± 0.7	5.9 ± 0.5***	< 0.001
Trunk muscle mass (kg)	24.9 ± 3.0	29.2 ± 2.2***	< 0.001
Fat range (%)	13.9 ± 4.3	18.5 ± 1.5***	< 0.001
Fat mass (kg)	8.3 ± 3.2	13.6 ± 1.7***	< 0.001
Fat-free mass (kg)	50.4 ± 6.3	59.9 ± 4.4***	< 0.001
Visceral fat	3.8 ± 1.8	7.7 ± 0.7***	< 0.001
Bone mass (kg)	2.6 ± 0.3	3.1 ± 0.2***	< 0.001
Impedance (Ohm)	620.8 ± 66.2	549.4 ± 32.0***	< 0.001
Basal metabolic rate (kJ)	5 957.0 ± 772.6	6 920.0 ± 1 338.0**	0.007

**, ****p* < 0.01 and < 0.001, respectively.
Skeletal muscle - Muscle that is attached to bone by tendon.
Muscle mass - Combination of 3 types of muscles which are skeletal, smooth and cardiac muscles.
Fat-free mass - Mass of body excluding fat mass.
kg – Kilogram, kJ – Kilojoule.

Table 3
Estimated 1 RM (kg).

Exercise Position	Normal	Overweight	*p*
Bench press	37.6 ± 7.7	37.1 ± 5.6	0.820
Deadlift	42.4 ± 6.2	44.8 ± 6.0	0.216
Upright row	25.7 ± 6.0	23.8 ± 5.0	0.268
Back squat	35.2 ± 6.8	37.1 ± 4.6	0.295
Shoulder press	22.9 ± 4.6	22.4 ± 4.4	0.733
Front squat	24.3 ± 6.0	27.6 ± 6.2	0.085

1 RM – One-repetition maximum, kg – Kilogram.

Endurance exercise elicits muscular fatigue and energy storage depletion, which subsequently affect exercise performance.[15] To restore exercise ability under these circumstances, the consumption of sports drinks during and after moderate exercise intensity enhances endurance capacity by replenishing losses in fluid, electrolytes, and energy.[16] Sports drinks contain water, electrolytes, and carbohydrates, which are necessary for energy replenishment,[17] prevent hyponatremia,[18] and enhance exercise performance by maintaining metabolism and optimizing water absorption.[19] Additionally, the ingestion of sports drinks that combine carbohydrate formulas during prolonged and exhaustive exercise could increase carbohydrate and fluid delivery, maintain exercise performance, and facilitate recovery after exercise.[20] Nevertheless, the effects of sports drinks on short-term exercise performance, which relies mainly on the glycolysis system and induces muscular fatigue, have never been reported. The glycolysis system utilizes energy substrates from blood glucose or glycogen storage in skeletal muscle, the former of which could be increased after acute carbohydrate supplementation. This raises the potential of post-workout supplementation of sports drinks containing carbohydrates to enhance repeated-bout exercise performance after exhaustive fatiguing exercise.

Currently, the responses of normal and overweight individuals to post-workout supplementation with CoQ10 and sports drinks after exercise have not yet been investigated. Notably, alterations in physiological factors, i.e., endocrine function, inflammatory responses, insulin sensitivity, and dyslipidemia, have been noted in overweight/obese people.[21] Moreover, obese individuals exhibit significantly lower levels of anabolic hormones, including IGF-1 and testosterone, in response to resistance exercise.[22] These conditions could affect the responses of energy replenishment and muscle recovery after exercise in overweight individuals. Therefore, the main objective of this study was to investigate the effects of body mass and post-workout supplementation with CoQ10 and sports drink consumption on exercise performance and muscle recovery after resistance and fatiguing exercise in normal and overweight individuals.

2. Materials and methods

2.1. Ethical approval

The experimental protocol used in this study was approved by the Mahidol University Central Institutional Review Board (MU-CIRB) with Certificate of Approval No. MU-CIRB 2021/165.1207. Informed consent was obtained from all the subjects involved in the study, and this study was implemented in accordance with the Declaration of Helsinki.

2.2. Subjects

The total sample size was calculated using G*Power software[23] to determine the mean differences between two independent groups (normal vs. overweight), and 21 subjects/group (total of 42 subjects) was determined. For calculation, the power (1- β error probability) was set at 0.8, and the effect size was 0.8, with an α error probability of 0.05. The inclusion criteria included male age between 18 and 30 years with normal BMI (18.5–22.9 $kg{\cdot}m^{-2}$) and overweight BMI (23.0–24.9 $kg{\cdot}m^{-2}$) according to the Asian BMI classification.[24] Exclusion criteria included individuals with musculoskeletal injuries and diseases (i.e., hypertension, depression, and kidney disease). Athletes and individuals who trained using resistance and endurance exercises in the past 6 months were also excluded. The subjects who volunteered to participate in this study had to undergo screening procedures according to the selection criteria and the Physical Activity Readiness Questionnaire (PAR-Q). In addition, the International Physical Activity Questionnaire (IPAQ)-Short Form was used to evaluate daily physical activity and calculate metabolic equivalent (MET) values. Informed consent was obtained from the subjects before the study was conducted.

2.3. Food and water control

The subjects were instructed to maintain a normal dietary pattern and avoid caffeine and alcohol 24 h prior to visiting the Exercise Physiology Laboratory (Department of Physiology, Faculty of Science, Mahidol University). They were asked not to consume food 90 min before starting the exercise protocol. The subjects were instructed to drink 500 mL of water at night before going to bed and 500 mL of water 90 min prior to visiting the laboratory.

2.4. Experimental design and procedures

In this study, each subject was randomized to receive all supplemental conditions (placebo, CoQ10, or sports drink) in a crossover study

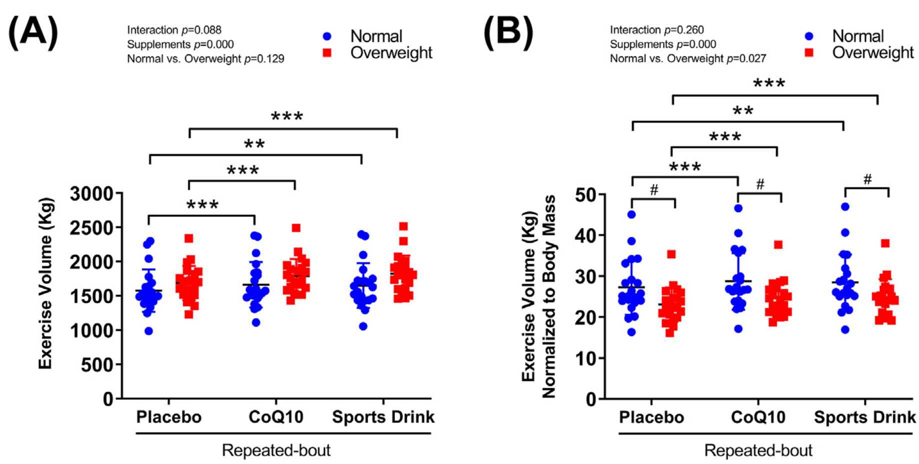

Fig. 2. Effects of body mass and post-workout supplementation on resistance exercise volume during repeated-bout exercise. (A) Absolute and (B) relative values after normalization to body mass. $^{\#}p < 0.05$ compared between the normal and overweight groups. $^{**}p < 0.01$ and $^{***}p < 0.001$ compared between supplemented conditions. CoQ10 – Coenzyme Q10, kg – Kilogram.

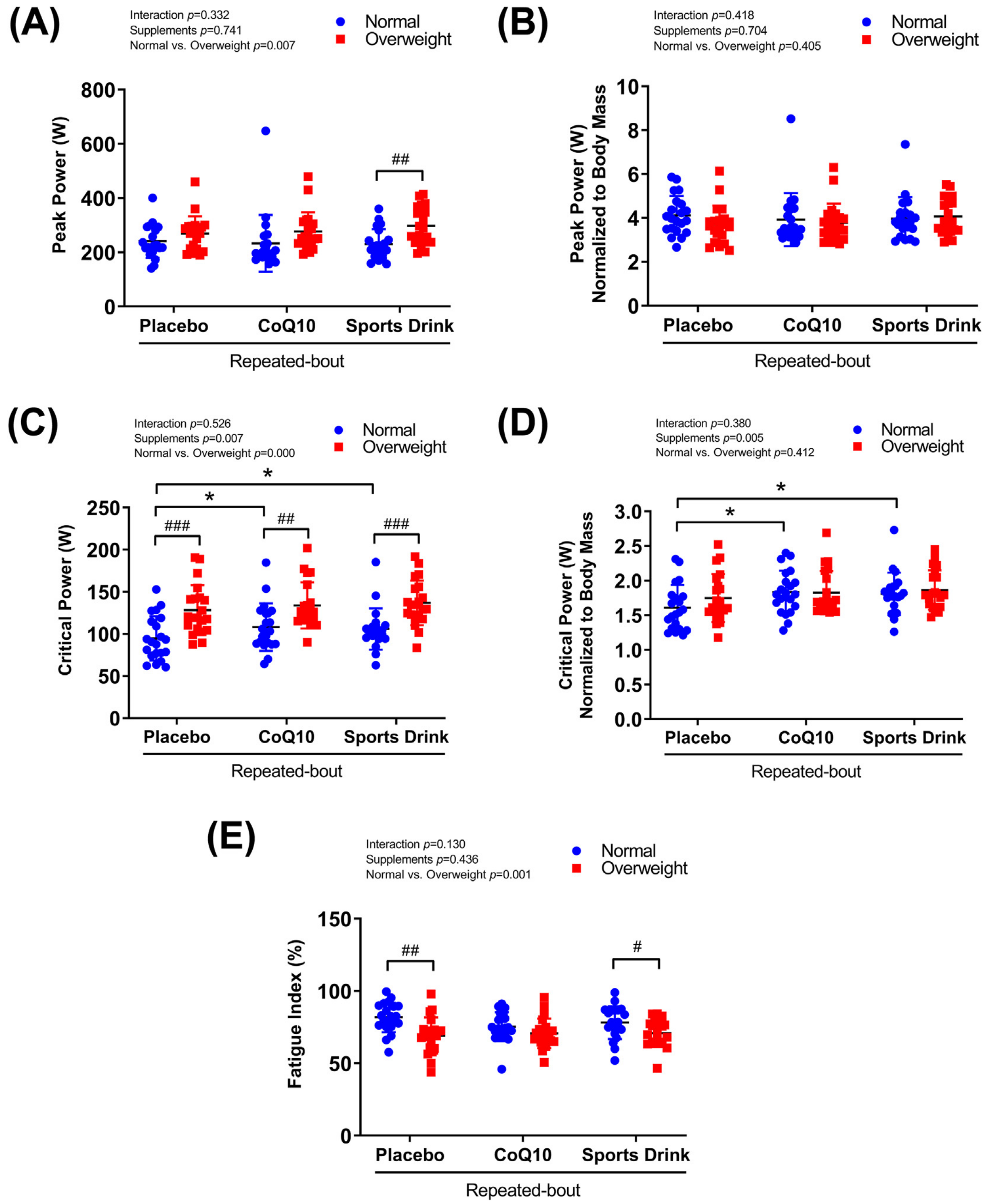

Fig. 3. Effects of body mass and post-workout supplementation on peak power, critical power, and the fatigue index during repeated-bout exercise. A) Absolute and (B) relative values after normalization to body mass (Peak power). (C) Absolute and (D) relative values after normalization to body mass (Critical power). (E) Fatigue index. $^{\#}p < 0.05$, $^{\#\#}p < 0.01$, and $^{\#\#\#}p < 0.001$ compared between the normal and overweight groups. $^{*}p < 0.05$ compared between supplemented conditions. CoQ10 – Coenzyme Q10, W – Watt.

design to determine the effects of supplementation on the primary outcomes (resistance exercise volume and fatiguing exercise performance) and the secondary outcomes (cardiovascular responses, urinary biomarkers, and DOMS). A diagram of the experimental design and procedures is shown in Fig. 1. Subject characteristics, resting heart rate (HR) and blood pressure (BP), body composition, and one-repetition maximum (1 RM) of all resistance exercise positions were assessed at visit 1. On the same day, the subjects were familiarized with the tests and assessments, including resistance and fatiguing exercise protocols, exercise techniques, and assessment procedures. There was one week of rest before the subjects started the experimental period on visits 2–4. On visits 2–4, baseline urine samples were collected prior to exercise after the subjects arrived at the laboratory. After warm-up, the exercise protocol started with resistance exercise at 75% of the 1 RM followed by fatiguing exercise performed on a cycle ergometer with a 3 min of all-out effort at 3.5% of body mass. Post-workout supplementation was provided after the exercise finished for 10 min according to a previous study.[25] Subjects were randomized to receive supplements (placebo, CoQ10, or sports drink) during visits 2–4. The repeated-bout exercise protocol was started after a 1 h resting period. The repeated-bout exercise protocol was performed as unlimited repetitions of resistance exercise at 75% of the 1 RM and exhaustive fatiguing exercise on a cycle ergometer at 3.5% of body mass. HR and BP were monitored immediately, 5 min, and 10 min after finishing repeated-bout exercise. Post-exercise urine samples were collected at 1 h and 24 h, and DOMS was assessed at 1, 3, 5, and 7 days after repeated-bout exercise. Thereafter, the subjects had a washout

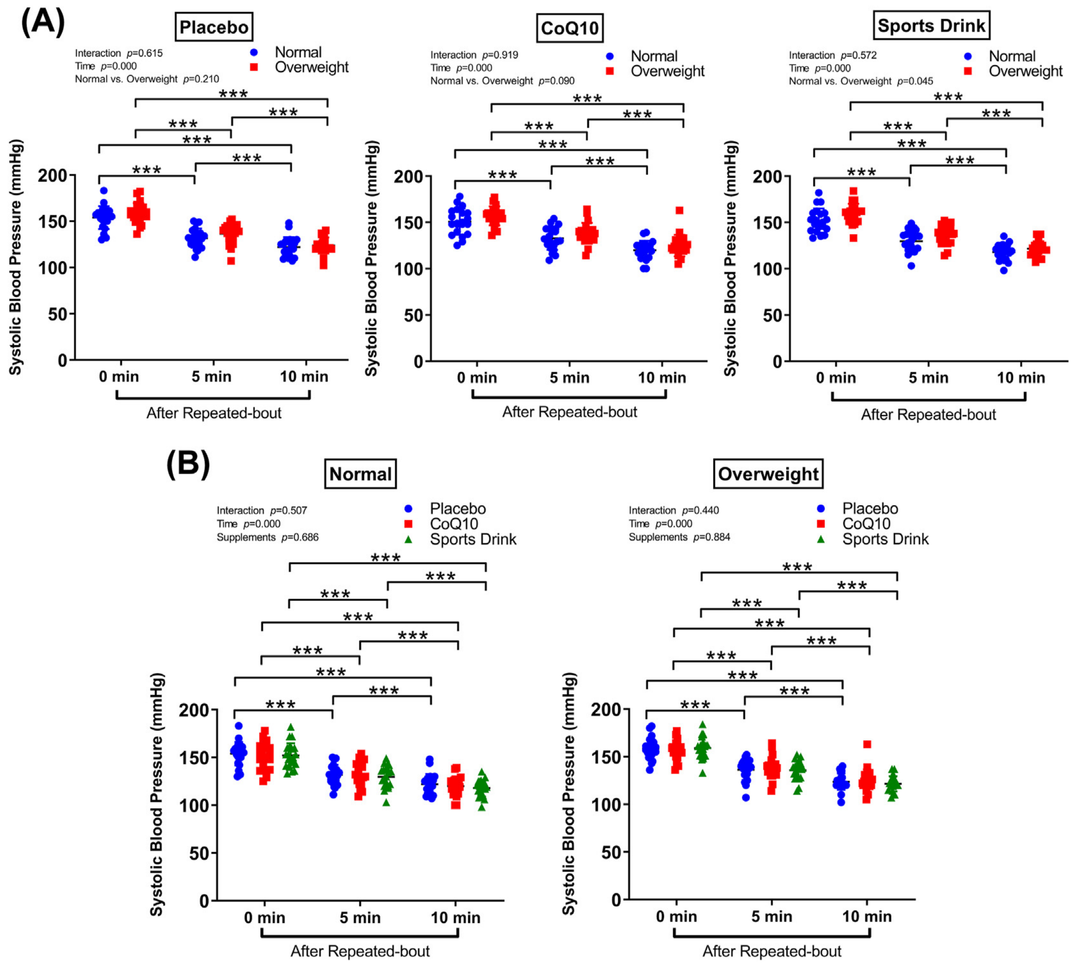

Fig. 4. Effects of body mass and post-workout supplementation on systolic blood pressure after repeated-bout exercise. (A) SBP between the normal and overweight groups. (B) SBP in the normal and overweight groups between supplemented conditions. (A and B) ***$p < 0.001$ compared within groups between specific time points. CoQ10 – Coenzyme Q10, SBP – Systolic blood pressure, mmHg – Millimeter of mercury, min – Minute.

period for 2 weeks before performing the exercise protocol, with the remaining interventions in a randomized order on visits 3 and 4. This washout period was used to eliminate carryover effects and allowed muscle recovery after exhaustive exercise to prevent deterioration of the exercise performance under the following supplementation conditions.

2.5. Body composition and basal metabolic rate assessments

Height was measured with a stadiometer. Body composition and the basal metabolic rate (BMR) were obtained from a bioelectrical impedance analysis instrument (TANITA MC-780MA) (Tanita Corp., Tokyo, Japan). Body mass index (BMI) was calculated and used to assess body mass status with the following formula: body mass (kg) divided by height squared (m^2).

2.6. 1 RM testing

The 1 RM was determined using an estimated 1 RM table (National Strength and Conditioning Association, NSCA). The subjects were asked to lift a weight with their full range of motion, and repetitions were recorded within the range of 1–15 times. The 1 RM was subsequently estimated with a 1 RM table using the weight and the number of repetitions that the subject performed. The 1 RM was evaluated individually for each resistance exercise position according to the resistance exercise protocol.

2.7. Blood pressure and heart rate

Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using an OMRON digital blood pressure Model HEM-7121 (OMRON HEALTHCARE Co., Ltd., Kyoto, Japan). Heart rate was measured with a Polar M430 heart rate monitor (Polar Electro, Inc., Bethpage, NY, USA).

2.8. Resistance exercise protocol

The resistance exercise protocol in this study was applied to untrained subjects and was modified from the previously reported protocol in resistance-trained men.[26] There were six types of exercises, including three upper body exercises (bench press, upright row, and standing shoulder press) and three lower body exercises (dead lift, back squat, and front squat). One set of exercises included one upper body exercise and one lower body exercise. There were three sets of the exercise for resistance exercise protocol, including bench press and dead lift (set 1), upright row and back squat (set 2), and standing shoulder press and front squat (set 3). Each set was performed for 10 repetitions at 75% of the 1 RM. One minute of rest was given after each exercise, and 3 min of rest were given between each set of exercises. The resistance exercise volume was calculated by multiplying the number of repetitions with the weight lifted.

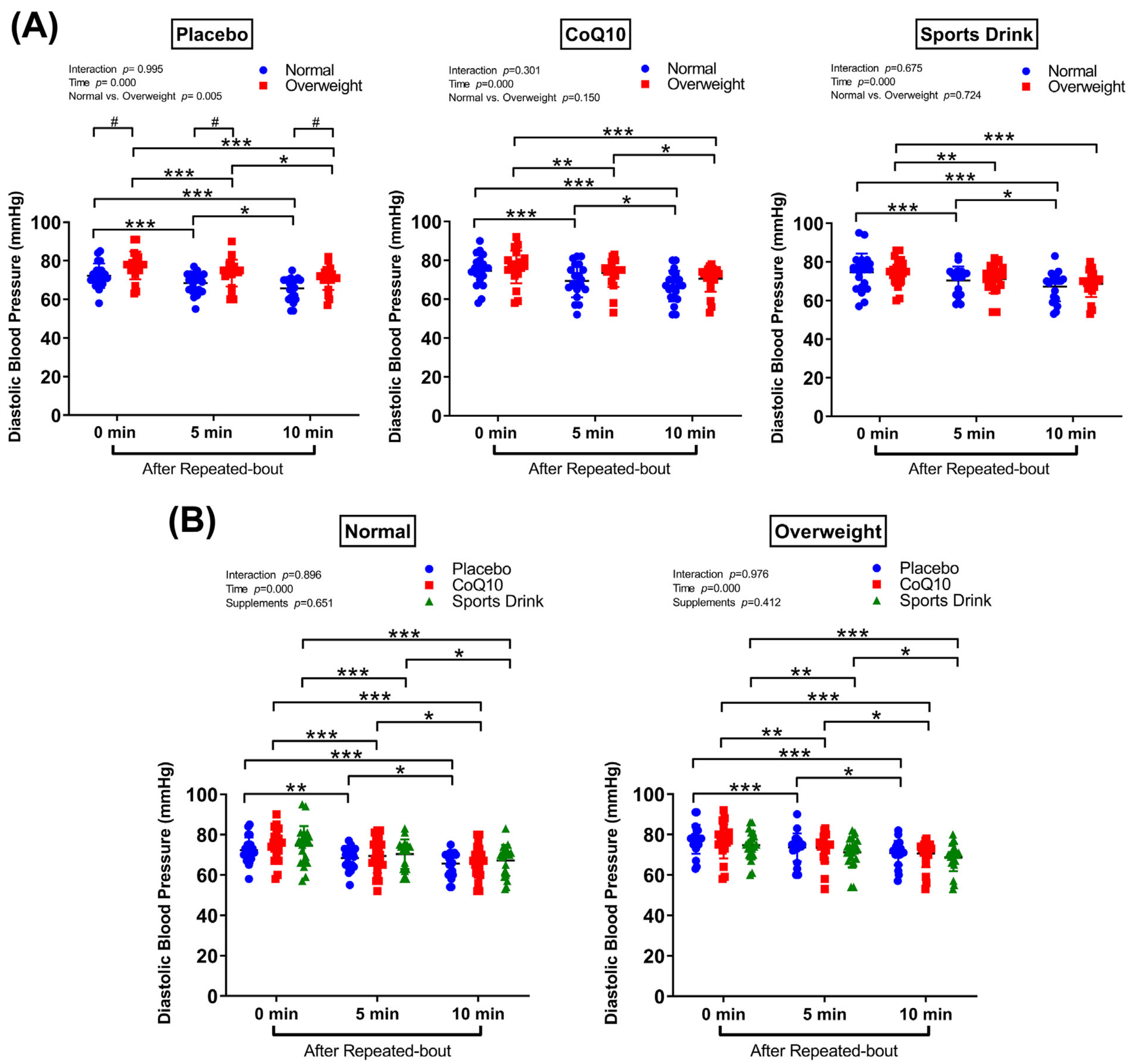

Fig. 5. Effects of body mass and post-workout supplementation on diastolic blood pressure after repeated-bout exercise. (A) DBP between the normal and overweight groups. (B) DBP in the normal and overweight groups between supplemented conditions. (A) *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ compared within groups between specific time points, $^{\#}p < 0.05$ compared between the normal and overweight groups. (B) *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ compared within groups between specific time points. CoQ10 – Coenzyme Q10, DBP – Diastolic blood pressure, mmHg – Millimeter of mercury, min – Minute.

2.9. Fatiguing exercise protocol

The subjects performed fatiguing exercise on a Monark cycle ergometer Model 894E (Monark, Varberg, Sweden). The seat height was adjusted according to the subject's waist to ensure that their legs could be fully extended when cycling. After warm-up for 1 min, fatiguing exercise was conducted using 3 min of all-out effort, with resistance set at 3.5% of body mass. The subjects were asked to maintain their cadence as high as possible throughout the exercise period. Data obtained during the test for analysis of the peak power (highest power output during the test), critical power (mean power output over the final 30 s of the test), and fatigue index (% drop in power output from the start to the end of the test) were recorded using Monark Anaerobic Test Software version 3.3.0.0 (Monark, Varberg, Sweden).

2.10. Post-workout supplementation

Post-workout supplementation was given 10 min after completion of the fatiguing exercise protocol. There were three groups for supplementation: placebo (flavored water and an empty capsule), CoQ10 (flavored water and a CoQ10 capsule), and sports drink (sports drink and an empty capsule). Flavored water was prepared by mixing synthetic lemon flavor (L-F10190) (Givaudan Singapore Pte Ltd.) and water, and the taste was comparable to that of a sports drink. The ingredients in the synthetic lemon flavor included 0 g of total fat, 0 g of protein, 0 g of total carbohydrates, 0 g of sugar, 0 g of sodium, and 0 g of potassium. Empty capsules were used in placebo and sports drink conditions to blind the subjects and mimic the CoQ10-supplemented condition in which the subjects received ubiquinol CoQ10 in the form of a capsule. Ubiquinol CoQ10 was purchased from the Government Pharmaceutical Organization (GPO), Bangkok, Thailand. The amount of ubiquinol CoQ10 given was 300 mg. The sports drink used was lemon-flavored Gatorade (Suntory PepsiCo Beverage (Thailand) Co., Ltd.), which contained 0 g of total fat, 0 g of protein, 16 g of total carbohydrates, 15 g of sugar, 113 g of sodium, and 31 g of potassium. All the supplements were served in an opaque mug at a cold temperature and volume approximately 250 mL.

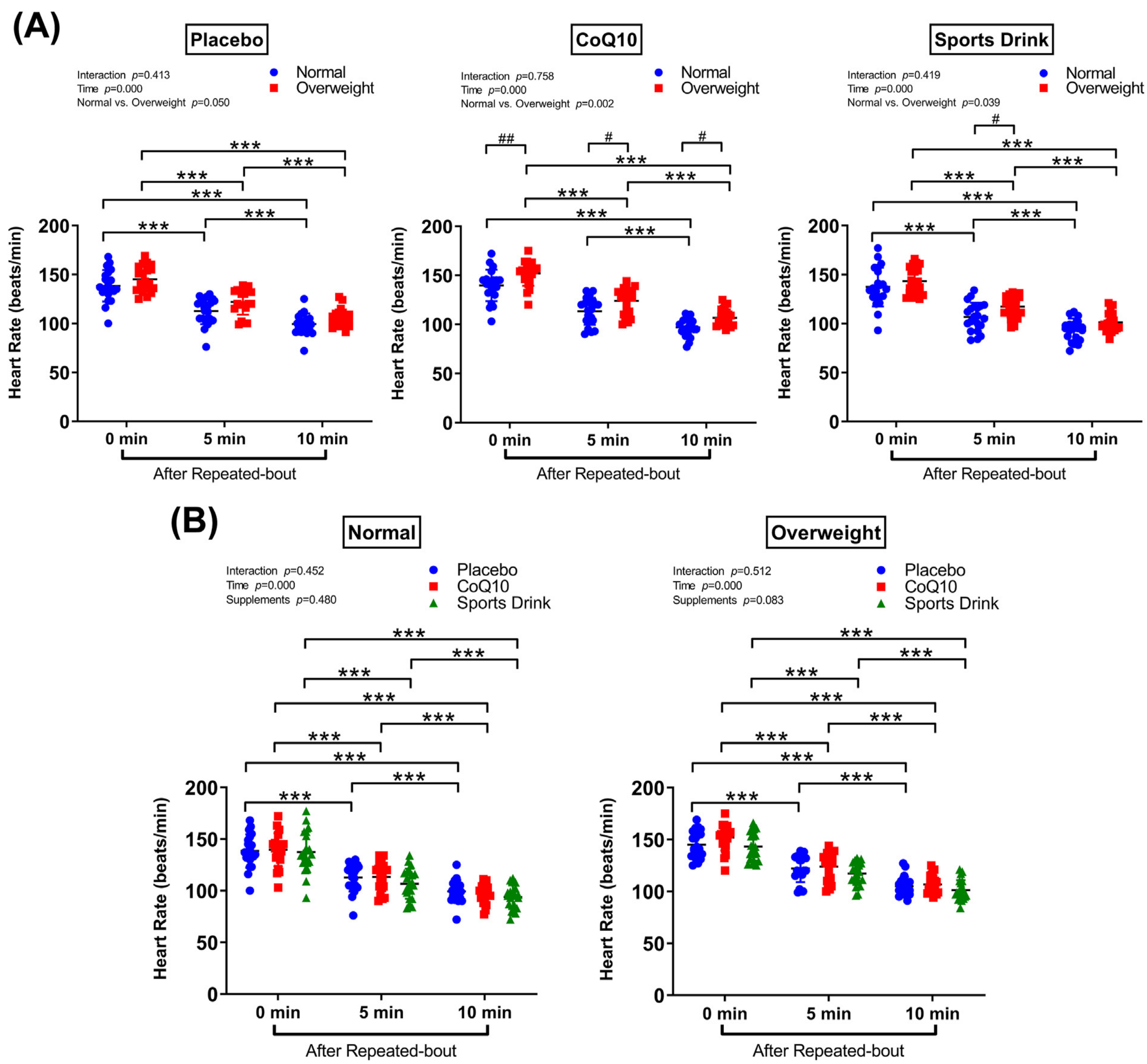

Fig. 6. Effects of body mass and post-workout supplementation on heart rate after repeated-bout exercise. (A) HR between the normal and overweight groups. (B) HR in the normal and overweight groups between supplemented conditions. (A) ***$p < 0.001$ compared within groups between specific time points, $^{\#}p < 0.05$ and $^{\#\#}p < 0.01$ compared between the normal and overweight groups. (B) ***$p < 0.001$ compared within groups between specific time points. CoQ10 – Coenzyme Q10, HR – Heart rate, min – Minute.

2.11. Urine sample collection and analysis

Urine was collected in a sterile bottle at baseline and then at 1 h and 24 h after the end of the repeated-bout exercise session. Urine samples were sent to the clinical laboratory to measure urinary potassium and creatinine levels. Abbott Alinity (Abbott Laboratories, Abbott Park, IL, USA) was used to measure urinary potassium and creatinine levels with ion-selective electrode and enzymatic technologies, respectively.

2.12. DOMS

DOMS was evaluated using a visual analog scale from 0 mm (no pain) to 100 mm (worst pain) after 1, 3, 5, and 7 days of the repeated-bout exercise session.

2.13. Statistical analyses

Subject characteristics, resting HR and BP, BMI, body composition, total MET value, BMR, and estimated 1 RM between the normal and overweight groups were analyzed using independent *t*-tests. Two-way ANOVA with repeated measures and post hoc tests were used to determine the differences in resistance exercise volume, fatiguing exercise performance, cardiovascular responses, urinary biomarkers, and DOMS between two independent variables (i.e., body mass × post-workout supplements or body mass/post-workout supplements × time). The data are presented as the means ± standard deviation (*SD*) and were analyzed with GraphPad Prism software (GraphPad Software Inc., San Diego, CA, USA). $p < 0.05$ indicates statistical significance.

3. Results

3.1. Subject characteristics

The subjects in this study had a moderate physical activity level according to a total MET value > 600 MET-minutes/week. There were no significant differences in age, resting HR, or resting DBP between the normal and overweight groups ($p > 0.05$). Nevertheless, statistically significant differences among groups in height ($p < 0.05$), body mass ($p < 0.001$), BMI ($p < 0.001$), resting SBP ($p < 0.05$), and total MET values ($p < 0.05$) were detected between the groups (Table 1). Additionally,

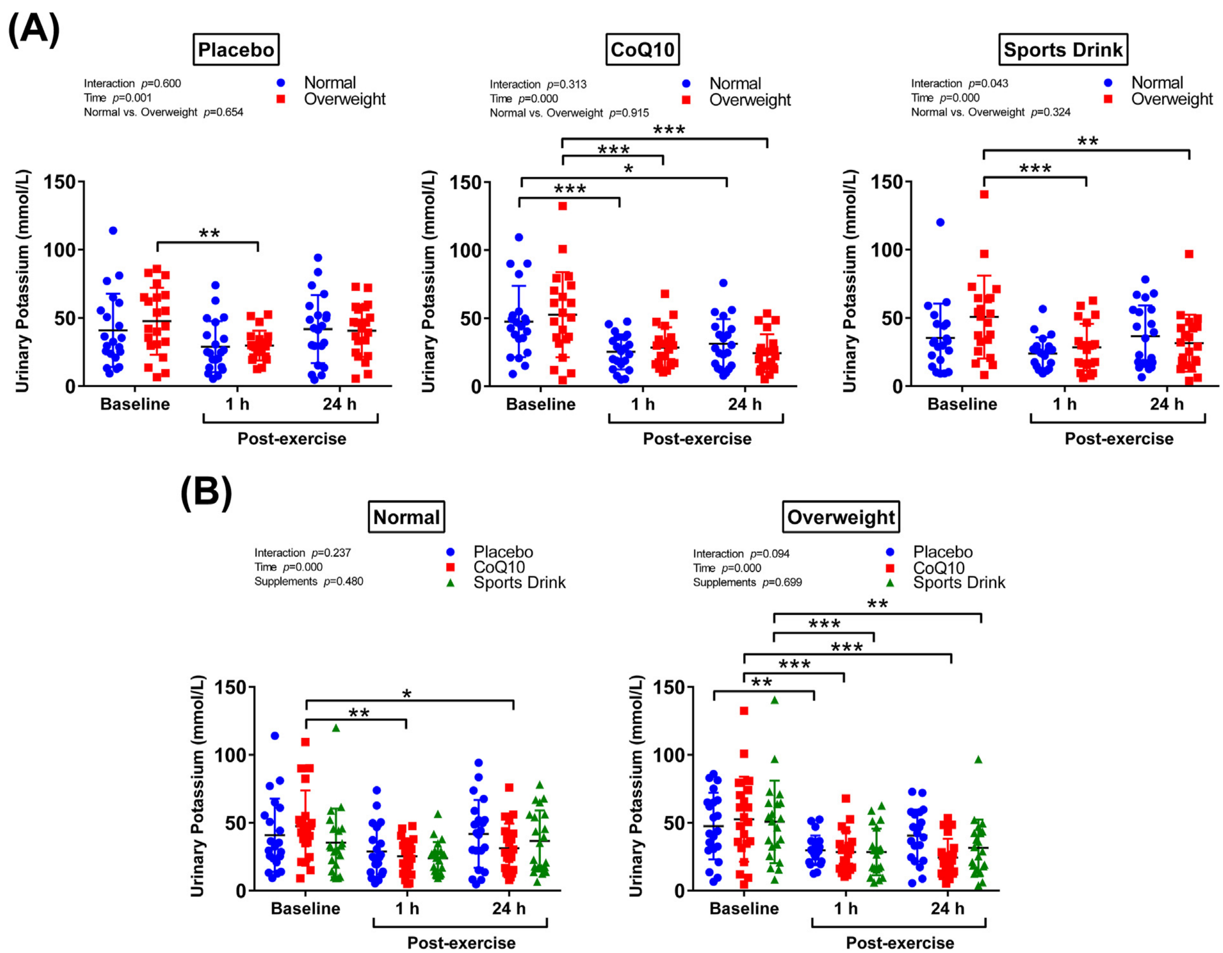

Fig. 7. Effects of body mass and post-workout supplementation on urinary potassium levels during post-exercise recovery. (A) Urinary potassium levels between the normal and overweight groups. (B) Urinary potassium levels in the normal and overweight groups between supplemented conditions. (A–B) *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$ compared within groups between specific time points. CoQ10 – Coenzyme Q10, h – Hour, mmol – Millimole, L – Liter.

there were significant differences in extracellular and intracellular water, body water, skeletal muscle mass, muscle mass, % fat range, fat mass, fat-free mass, visceral fat, bone mass, and impedance between the groups ($p < 0.001$) (Table 2). These differences were associated with an increased BMR in the overweight group compared with the normal group ($p < 0.01$). In contrast to the differences in body composition, the estimated 1 RM values between the normal and overweight groups were not significantly different at all resistance exercise positions ($p > 0.05$) (Table 3).

3.2. Effects of body mass and post-workout supplementation on resistance exercise

There was no significant difference in the absolute resistance exercise volume during repeated-bout exercise under all supplemented conditions (placebo, CoQ10, and sports drink) between the normal and overweight groups ($p > 0.05$) (Fig. 2A). However, compared with the normal group, the overweight group presented significantly decreased relative values of resistance exercise volume normalized to body mass under all supplemented conditions ($p < 0.05$) (Fig. 2B). Compared with the placebo group, supplementation with CoQ10 or sports drink consumption significantly increased the absolute and relative values of resistance exercise volume in both groups (Fig. 2A–B). These results suggest that post-workout supplementation with CoQ10 and sports drink effectively increased the resistance exercise volume regardless of body mass.

3.3. Effects of body mass and post-workout supplementation on fatiguing exercise

3.3.1. Peak power

The absolute and relative peak powers did not significantly differ among the placebo- and CoQ10-supplemented groups ($p > 0.05$) (Fig. 3A–B). In contrast, the overweight group had greater absolute peak power than the normal group did after sports drink supplementation ($p < 0.01$) (Fig. 3A), but this difference between the groups disappeared after body mass normalization ($p > 0.05$) (Fig. 3B). Additionally, there were no significant differences in either absolute or relative peak power after normalization to body mass in the normal and overweight groups when compared CoQ10 and sports drink supplementations with the placebo ($p > 0.05$) (Fig. 3A–B). These findings suggest that neither CoQ10 nor sports drink supplementation improved peak power during fatiguing exercise in both normal and overweight groups.

3.3.2. Critical power

Compared with the normal group, the overweight group had greater critical power in terms of the placebo ($p < 0.001$), CoQ10 ($p < 0.01$) and sports drink ($p < 0.001$) supplementation conditions (Fig. 3C). After normalization to body mass, critical power was not significantly different among the groups under all supplemented conditions ($p > 0.05$) (Fig. 3D). However, critical power significantly increased in the normal group ($p < 0.05$) after supplementation with CoQ10 or sports drink consumption (Fig. 3C). After normalization to body mass, CoQ10 or

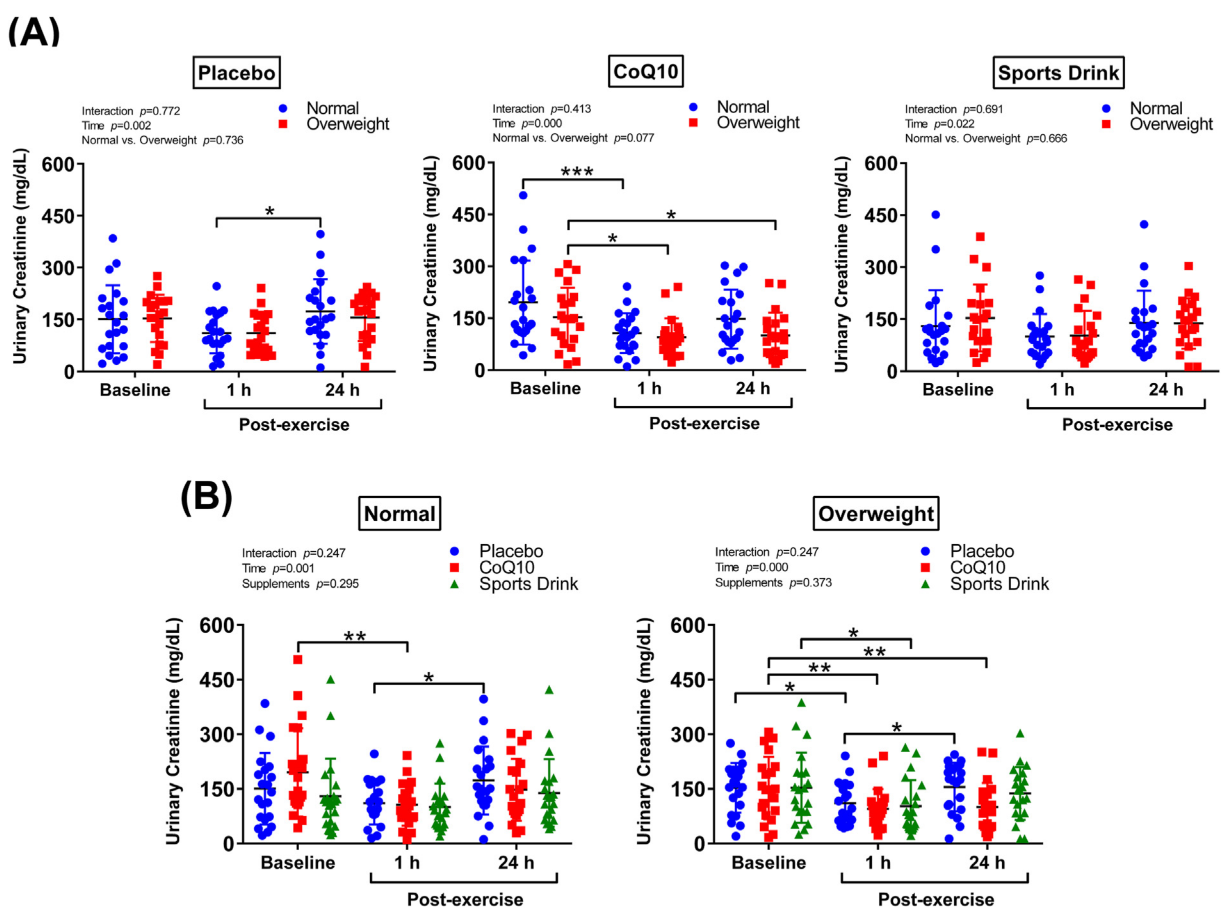

Fig. 8. Effects of body mass and post-workout supplementation on urinary creatinine levels during post-exercise recovery. (A) Urinary creatinine levels between the normal and overweight groups. (B) Urinary creatinine levels in the normal and overweight groups between supplemented conditions. (A–B) *$p < 0.05$, **$p < 0.01$, and ***$p < 0.001$ compared within groups between specific time points. CoQ10 – Coenzyme Q10, h – Hour, mg – Milligram, dL – Deciliter.

sports drink supplementation also significantly increased critical power in the normal group ($p < 0.05$) (Fig. 3D). In contrast, the critical power of the overweight group did not change under any of the supplemented conditions ($p > 0.05$) (Fig. 3C–D). Taken together, these data demonstrate that body mass is a determining factor affecting critical power. In addition, post-workout supplementation with CoQ10 or sports drink consumption effectively increased critical power among in the normal group but not in the overweight group during fatiguing exercise.

3.3.3. Fatigue index

Fatigue indices were significantly different between the normal and overweight groups in the placebo ($p < 0.001$) and sports drink ($p < 0.05$) supplementation groups. However, there was no significant difference between the groups after supplementation with CoQ10 ($p > 0.05$; Fig. 3E). Compared with the placebo group, neither CoQ10 nor sports drink supplementation reduced fatigue index during repeated-bout exercise in normal and overweight groups (Fig. 3E). These findings suggest that overweight affects the fatigue index during fatiguing exercise and CoQ10 could reduce the fatigue index between groups by lowering fatigue in the normal group.

3.4. Effects of body mass and post-workout supplementation on cardiovascular responses

3.4.1. Systolic blood pressure

SBP decreased significantly over time, starting at 5 min ($p < 0.001$), and decreased further until 10 min ($p < 0.001$) compared with 0 min after finishing repeated-bout exercise in both groups under any of the supplemented conditions (Fig. 4A). Nevertheless, there were no differences in SBP responses after repeated-bout exercise between the groups and supplemented conditions (Fig. 4A–B). These results indicate that neither body mass nor post-workout supplementation had an effect on SBP during recovery from the exercise workouts.

3.4.2. Diastolic blood pressure

DBP decreased significantly over time, starting at 5 min ($p < 0.001$) and dropping further until 10 min ($p < 0.001$) compared with 0 min after finishing repeated-bout exercise in both the normal and overweight groups (Fig. 5A), and no significant differences between supplemented conditions were observed (Fig. 5B). Nevertheless, the overweight group presented a greater DBP than did the normal group after repeated-bout exercise at all time points in the placebo condition ($p < 0.05$). After receiving CoQ10 or sports drink supplementation, there were no significant differences in post-exercise DBP between the groups ($p > 0.05$) (Fig. 5A). These data suggest that body mass affects the DBP response after exercise in overweight individuals.

3.4.3. Heart rate

HR decreased significantly over time similar to SBP, and DBP, after repeated-bout exercise in both groups (Fig. 6A). No significant differences between the supplemented conditions were observed (Fig. 6B). However, the post-exercise HR responses at 0 min ($p < 0.01$), 5 min ($p < 0.05$), and 10 min ($p < 0.05$) in the CoQ10 group and at 5 min ($p < 0.05$) in the sports drink-supplemented group were significantly different between the normal and overweight groups (Fig. 6A). These findings demonstrate that CoQ10 and sports drink supplementations affect heart rate responses between the normal and overweight groups during recovery from exercise.

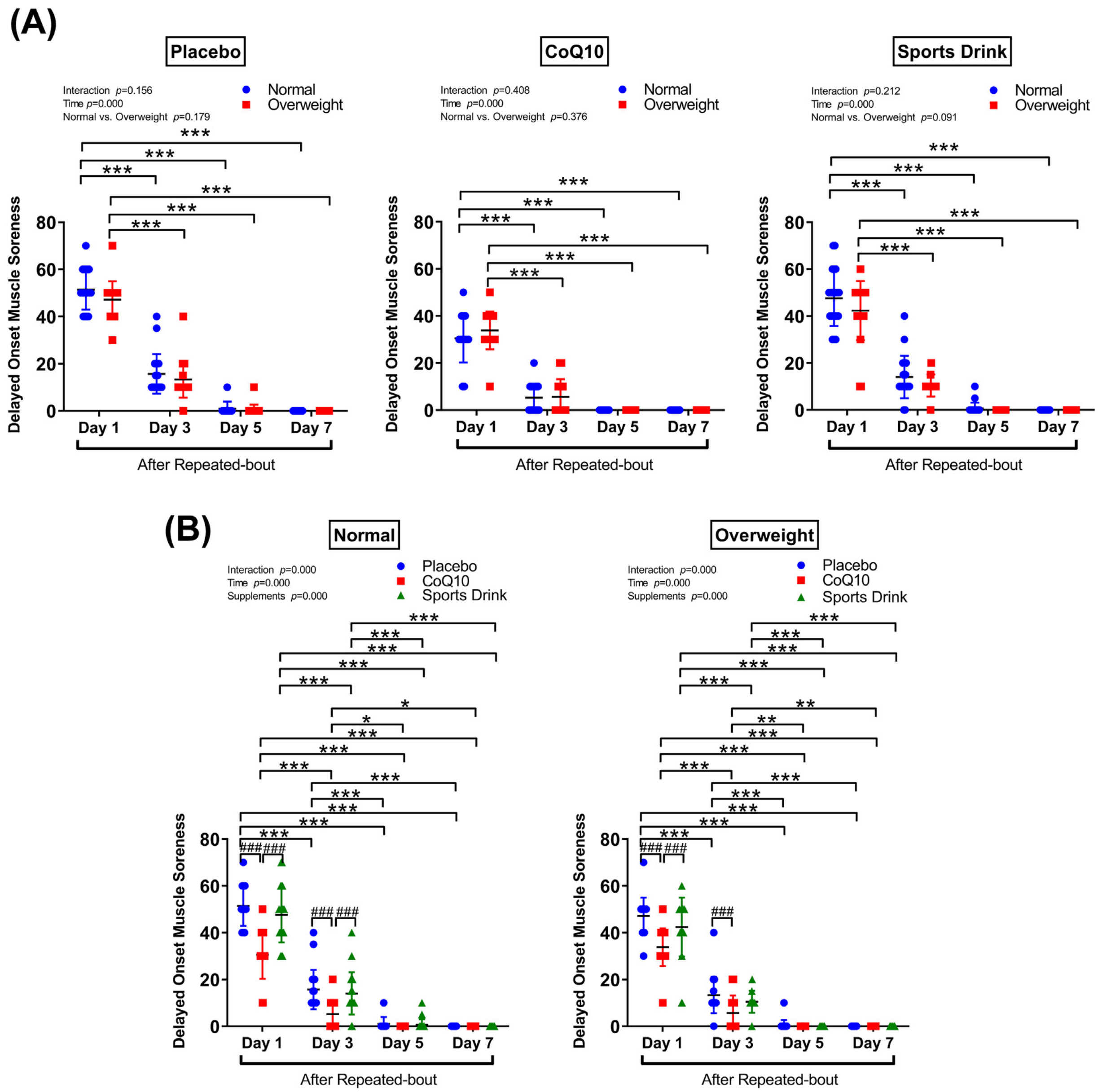

Fig. 9. Effects of body mass and post-workout supplementation on DOMS during post-exercise recovery. (A) DOMS between the normal and overweight groups. (B) DOMS in the normal and overweight groups between supplemented conditions. (A) ***$p < 0.001$ compared within groups between specific time points. (B) *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$ compared within groups between specific time points. $^{###}p < 0.001$ compared between groups at specific time points. DOMS – Delayed onset muscle soreness, CoQ10 – Coenzyme Q10.

3.5. Effects of body mass and post-workout supplementation on urinary biomarkers

3.5.1. Urinary potassium level

There were no significant differences in urinary potassium levels between the normal and overweight groups under any of the supplemented conditions at any of the investigated time points ($p > 0.05$) (Fig. 7A). However, the urinary potassium level decreased significantly compared with that at baseline in both groups after CoQ10 was given for 1 h ($p < 0.001$), and this effect was more pronounced in the overweight group at 24 h after repeated-bout exercise. The urinary potassium levels decreased significantly after 1 h ($p < 0.001$) and 24 h ($p < 0.001$) compared with the baseline level in the overweight group. In the normal group, the urinary potassium levels decreased significantly at 1 h ($p < 0.001$) and 24 h ($p < 0.05$) after being supplemented with CoQ10 (Fig. 7A). In addition, the urinary potassium levels were significantly lower at 1 h ($p < 0.001$) and 24 h ($p < 0.001$ or $p < 0.01$) than at baseline in the overweight group after supplementation with CoQ10 or sports drink consumption (Fig. 7B). These results suggest that post-workout supplementation with CoQ10 is associated with lowering urinary potassium levels during post-exercise recovery in both groups.

3.5.2. Urinary creatinine level

There was no significant difference between the groups under all supplemented conditions ($p > 0.05$) (Fig. 8A). In addition, there was no significant difference between each time point after giving sports drink in the normal and overweight groups ($p > 0.05$). However, the urinary creatinine level significantly decreased at 1 h post-exercise ($p < 0.001$) in the normal group after the administration of CoQ10. The overweight group had significantly lower urinary creatinine levels at 1 h ($p < 0.05$) and 24 h ($p < 0.05$) than at baseline after supplementation with CoQ10 (Fig. 8A). Compared with that in the normal group, the urinary creatinine level was significantly lower at 1 h after supplementation with CoQ10 ($p < 0.01$). However, the urinary creatinine levels were significantly lower at 1 h ($p < 0.01$) and 24 h ($p < 0.01$) than at baseline among the overweight group after supplementation with CoQ10 (Fig. 8B). These results indicate that CoQ10 supplementation is associated with a decrease in the levels of urinary creatinine in both groups during post-exercise recovery.

3.6. Effects of body mass and post-workout supplementation on DOMS

DOMS decreased significantly over time, starting from Day 3 ($p < 0.001$), and decreased further until Day 5 ($p < 0.001$) and Day 7 ($p < 0.001$) compared with Day 1 after finishing repeated-bout exercise in all supplemented conditions among normal and overweight groups (Fig. 9A). Additionally, DOMS was significantly reduced in both the normal and overweight groups from Day 3 ($p < 0.001$) until Day 7 ($p < 0.001$) compared with Day 1 under all supplemented conditions (Fig. 9B). Nevertheless, interaction effects of post-exercise recovery time and supplement type on DOMS were observed in both groups. In support of this observation, DOMS was significantly lower after supplementation with CoQ10 than after placebo during Day 1 ($p < 0.001$) and Day 3 ($p < 0.001$) in both the normal and overweight groups (Fig. 9B). These results suggest that the degree of DOMS after exercise was not dependent on body mass. Moreover, post-workout supplementation with CoQ10 effectively alleviated DOMS during the early phase of muscle recovery after exercise in both groups.

4. Discussion

The main findings of this study suggest that body mass is a crucial factor affecting resistance exercise volume, fatiguing exercise performance, and post-exercise DBP between normal and overweight individuals. Post-workout supplementation with CoQ10 or sports drink consumption increased the resistance exercise volume regardless of body mass, and increased critical power during fatiguing exercise in the normal group. Notably, CoQ10 supplementation effectively reduced DOMS after exercise in both groups. The ability of CoQ10 to alleviate DOMS was associated with decreased levels of urinary biomarkers of muscle damage (potassium and creatinine).

Resistance exercise is commonly used for training to increase skeletal muscle mass and strength. Its success requires muscle contractions over the full range of motion and completion of a number of repetitions specific to the training goals. In this study, body mass was a key factor influencing the ability of normal and overweight individuals to perform resistance exercise. In support of this notion, the resistance exercise volume in overweight individuals significantly decreased after normalization to body mass, suggesting that extra fat mass, which is not involved in force generation, affects resistance exercise performance. A previous study reported comparable findings among obese subjects and indicated that overweight and obese individuals had deficits in resistance exercise performance that could be associated with increased fat mass.[27]

To improve resistance exercise performance, the beneficial effects of post-workout supplements using protein–carbohydrate[28] and multi-ingredient[29] supplements have been reported. In addition to these supplements, this study demonstrated that CoQ10 supplementation and sports drink consumption are effective supplements for improving resistance exercise performance regardless of body mass. The ingestion of CoQ10 might exert an acute effect on exercise performance[30] associated with its antioxidant action[31] to attenuate ROS production during an acute bout of resistance exercise.[32] Alternatively, the ingestion of sports drink could enhance faster recovery and accelerate repeated-bout resistance exercise performance by increasing available fuel sources and the blood glucose concentration.[33]

Body fat is a passive tissue during exercise and negatively affects fatiguing exercise performance.[34] Intriguingly, post-workout supplementation with CoQ10 increased critical power during repeated-bout fatiguing exercise in normal but not overweight individuals. This effect of CoQ10 on improving exercise performance in untrained men during repeated-bout exercise is in accordance with previous reports.[35] Nevertheless, the diminished response to CoQ10 supplementation in overweight individuals might be explained by an impairment in antioxidant capacity[36] that limits an increase in fatiguing exercise performance. This finding is in accordance with a previous report that demonstrated no effect of CoQ10 on muscular fatigue in obese individuals compared with nonobese individuals.[37] In this study, sports drink consumption increased critical power in the normal group similar to CoQ10 supplementation; however, it had no effect on the reduction of the fatigue index after 3 min all-out effort exercise between groups. Although the blood glucose concentration could increase after sports drink supplementation, high-intensity exercise for less than 1 h might subsequently make the effects of sports drink consumption negligible.[38] Additionally, the order of fatiguing exercise that was performed following resistance exercise during repeated-bout exercise in this study might hinder the ability of sports drink to improve fatigability during exhaustive exercise. To support this notion, sports drink supplementation was associated with greater exercise performance in a previous study,[39] in which the exercise protocol, timing, and frequency differed from those in the current study.

During exercise, cardiac output is elevated to meet the requirements of working skeletal muscle through increases in HR and stroke volume (SV).[40] The increase in SBP was due to an increase in cardiac output during exercise, which decreased over time after exercise stopped.[41] This was due to an increase in parasympathetic reactivation and a decrease in sympathetic outflow in response to the deactivation of exercise effectors, which subsequently decreased HR and SV.[42] However, no significant difference in post-exercise SBP after finishing repeated-bout exercise was observed between the normal and overweight groups. This could suggest that body mass status had no effect on autonomic nervous system regulation during recovery from exhaustive exercise. In contrast to SBP, the reduction of post-exercise DBP could be explained by a decrease in vascular resistance and an increase in vasodilator substances.[43] Nevertheless, overweight individuals in this study demonstrated a slower reduction in post-exercise DBP after exercise than did normal individuals. This impairment in overweight individuals might involve increased arterial stiffness or endothelial dysfunction, which influence the post-exercise DBP response. Although a difference in post-exercise DBP was evident, no group difference in post-exercise HR in the placebo condition was observed, suggesting that body mass had no effect on parasympathetic reactivation after exercise.[44] Taken together, alterations in the post-exercise cardiovascular response in overweight individuals could be attributed to arterial stiffness or endothelial dysfunction but not to autonomic nervous system regulation.

Metabolic profiling of urinary metabolites due to exercise-induced muscle damage has been previously reported.[45] However, none of the previous studies investigated urinary metabolites that can be excreted into the urine by the kidneys and are mainly found in skeletal muscle (i.e., potassium[46] and creatine[47]). In this study, urinary potassium decreased at 1 h in both groups and increased to nearly baseline levels at 24 h after repeated-bout exercise. The increase in urinary potassium at 24 h might be related to resistance exercise-induced muscle damage, which causes disturbance of the plasma membranes in the cells and leakage of potassium into the blood. Notably, urinary potassium was significantly decreased at 24 h post-exercise in both groups after CoQ10 administration, supporting its ability to alleviate exercise-induced muscle cell damage.[48]

Creatine can be obtained from both de novo biosynthesis and dietary sources. It can be converted to creatinine in skeletal muscle cells when there are changes in temperature and pH caused by exercise.[47] Creatinine, which accumulates as a byproduct of creatine from the metabolism of skeletal muscle cells, may leak into the blood after exercise due to distortion of the plasma membrane and be excreted by the kidneys. In this study, urinary creatinine was decreased at 1 h post-exercise after CoQ10 supplementation in both groups. The effect of CoQ10 could be associated with a reduction in creatinine production after strenuous exercise.[12] Additionally, the suppression of inflammatory signaling which in turn reduces muscle damage[12] and prevents cell membrane deterioration after CoQ10 supplementation has been reported.[49]

Resistance exercise with a resistance load involving muscle contractions is associated with pain.[50] DOMS is a sensation of pain associated with cell membrane deterioration in damaged muscle fibers, activation of calcium-dependent proteases, infiltration of macrophages, and stimulation of group IV pain receptors.[51] Here, DOMS was used as a measure to evaluate muscle pain; it peaked at 24 h and then returned to baseline within 7 days in both normal and overweight individuals, similar to previous reports.[52] CoQ10 reduced DOMS in both groups after repeated-bout exercise, and its effect might be related to decreasing peroxidation of cell membrane lipids[53] by acting as an inhibitor of oxidative damage.[54] This oxidative stress in exercise-induced muscle damage involves the production of ROS and largely contributes to an increase in the activities of radical-generating enzymes (e.g., xanthine oxidase and nicotinamide adenine dinucleotide phosphate [NADPH] oxidase), which can be initiated with an acute bout of resistance exercise.[55] Therefore, the antioxidative effect of CoQ10 could oppose oxidative stress and improve antioxidant action, which in turn preventing muscle damage and subsequently reducing DOMS after an acute bout of resistance exercise.

5. Conclusion

This study provides practical implications for the effect of body mass and its impact on response to post-workout supplementation with CoQ10 and sports drink consumption to enhance exercise performance and muscle recovery after resistance and fatiguing exercise. Overweight is a crucial factor affecting resistance exercise volume, fatiguing exercise performance, and DBP during recovery from exercise workout. Post-workout supplementation with CoQ10 and sports drink enhanced resistance exercise volume regardless of body mass; however, an improvement in critical power during fatiguing exercise was limited to the normal group. Additionally, DOMS and urinary biomarkers of muscle damage during post-exercise recovery could be reduced in both groups after CoQ10 supplementation. Altogether, these findings are beneficial for sport scientists, nutritionists, and exercise physiologists in guiding post-workout supplementation, which is associated with inter-individual differences between normal and overweight individuals.

CRediT authorship contribution statement

Phyo Pyae Thar: Writing – original draft, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Teerarat Likitwattanasade:** Supervision, Methodology. **Ratchakrit Srikuea:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Data statement

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethical approval statement

The experimental protocol used in this study was approved by the Mahidol University Central Institutional Review Board (MU-CIRB) with Certificate of Approval No. MU-CIRB 2021/165.1207. Informed consent was obtained from all the subjects involved in the study, and this study was implemented in accordance with the Declaration of Helsinki.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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