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Comparison of Response Inhibition Ability and Spike-Receiving Performance between Skilled and Novice Volleyball Athletes

Chidapha Siriwan, Benjapol Benjapalakorn

Faculty of Sports Science, Chulalongkorn University, Bangkok, Thailand

ABSTRACT

Siriwan C, Benjapalakorn B. Comparison of Response Inhibition Ability and Spike-Receiving Performance between Skilled and Novice Volleyball Athletes. Response inhibition is a cognitive ability that enables individuals to suppress automatic, yet potentially inappropriate, actions. It plays a crucial role in executing open motor skills and is essential for athletes. In volleyball, response inhibition affects reaction time and decision-making, particularly during spike reception, where it facilitates the transition from defense to offense and enhances scoring opportunities. This study investigated and compared response inhibition in spike-receiving performance of skilled and novice volleyball athletes. Thirteen skilled and novice volleyball players participated in the study. The participants were examined for inhibition capabilities using Spatial Stroop Tests and a Motor Go/No-Go Task with FitLight™. The participants were also tested for their spike-receiving performance, specifically designed based on the spatial Stroop protocol. Although no difference was found between the Groups in Flanker or spatial Stroop tasks, skilled volleyball athletes exhibited faster reaction times in both congruent (P = 0.001) and incongruent conditions (P = 0.002), greater spike reception accuracy (P = 0.019), and higher scores (P = 0.005) compared to the novice athletes. These findings suggest that the faster reaction times of skilled athletes enhance spike reception success, supporting the idea that greater competitive experience may improve inhibitory control in managing complex, fast-paced game situations.

Key Words: Response Inhibition, Reaction Time, Spike-Receiving Performance

INTRODUCTION

Inhibitory control (IC) refers to the ability to focus on relevant information while suppressing inappropriate stimuli and response patterns (3,4). It is considered an important component of executive brain function, as it prevents the execution of inappropriate or unnecessary responses (3,4,8). Inhibitory control comprises two primary components: cognitive inhibition and behavioral inhibition. Cognitive inhibition pertains to the regulation of memory, thought processes, perception, and emotional responses, whereas behavioral inhibition refers to the ability to suppress actions in response to stimuli or situations deemed inappropriate for engagement. Failure to exert behavioral inhibition in such contexts may result in impulsive actions.

The ability to inhibit responses allows individuals to exhibit flexible behavior in dynamic environments, especially when an initial response to a stimulus is no longer appropriate or effective (9,33,34). In sports, inhibitory control has been suggested to be important in tasks that require rapid decision-making and motor execution, for example. Several studies also suggested that high-level and open-skill athletes should possess superior response inhibition and attentional shifting abilities compared to non-athletes or athletes of closed-skill sports (1,2,6,10,14,17,19,24,31,37). This enhanced inhibitory control is suggested to contribute to faster decision-making and more efficient responses in competitive settings (32,39,40).

Spike receiving is a fundamental skill in volleyball, playing a crucial role in both defensive and offensive strategies. It is a key determinant of game dynamics, as effective spike reception not only prevents the opposing team from scoring but also initiates the rally phase, ultimately setting the stage for successful offensive plays (21,22,23,26,27). Successfully executing a spike reception requires a complex combination of perceptual processing, rapid decision-making, swift motor responses, and efficient inhibitory control that contribute to an athlete's ability to respond effectively in fast-paced and swiftly changing game situations. Despite the recognized importance of response inhibition, research on its role in sport skills such as volleyball spike reception remains limited and requires further investigation.

Despite the recognized importance of response inhibition, research on its role in sport skills such as volleyball spike reception remains limited and requires further investigation. Therefore, the purpose of this study was to determine the impact of response inhibition on both inhibitory control ability and spike-receiving performance, comparing skilled volleyball athletes with novice athletes. By examining the relationship between inhibitory control and spike reception skills, the findings from this study will contribute to the growing body of knowledge on cognitive-motor interactions in volleyball, specifically regarding how response inhibition affects athletes' spike-receiving performance.

METHODS

Subjects

Thirteen skilled volleyball athletes (age: 20.15 ± 1.5 years) and an equal number of novice volleyball athletes (age: 21.15 ± 1.6 years) participated in the study. The study's methods were approved by the Research Ethics Committee of Chulalongkorn University, and informed consent was obtained from all the participants prior to data collection.

Procedures

The experiment was conducted on 2 consecutive days for each participant. On day 1, assessments for response inhibition on the spatial Stroop Test and the Motor Go/No-Go Task with FitLight™ were conducted in the computer laboratory at Chulalongkorn University.

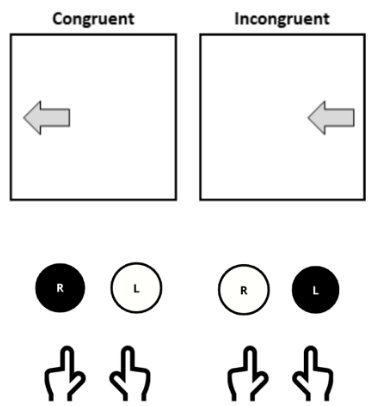

Figure 1. The Spatial Stroop Test.

Figure 1 illustrates the Spatial Stroop Test in which the participants were instructed to respond to the arrow appearing on the screen by pressing the "<" button when the arrow on the screen pointed to the left and the ">" button when the arrow pointed to the right. Reaction times and accuracy rates were recorded for 2 test conditions:

- Congruent: The position and direction of the arrow were aligned (e.g., a left-pointing arrow appearing on the left side of the screen).

- Incongruent: The position and direction of the arrow were misaligned (e.g., a left-pointing arrow appearing on the right side of the screen).

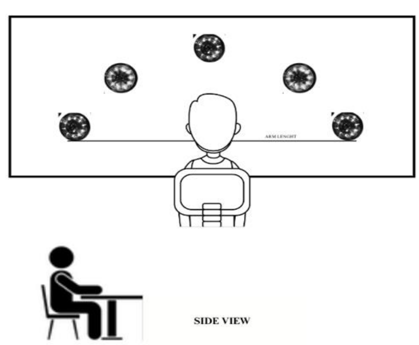

Figure 2. The Motor Go/No-Go Task with FitLight™.

Figure 2 illustrates the Motor Go/No-Go Task with FitLight™ in which the participants' distance from the FitLight™ was measured from the acromion to the third metacarpophalangeal joint to set the blanking distance. The test instructions were as follows: (a) when a blue light appeared, participants were instructed to slap the light (Go trail); and (b) when a yellow light appeared, they were instructed not to slap the light (No-Go trail). The participants were required to respond as quickly and accurately as possible until the end of the test series (7,28). The Go trial and No-Go trial appeared randomly in a total of 32 trials, with an equal number of each type of trial.

On day two, the participants were tested for their spike-receiving performance based on the Spatial Stroop Protocol. This experiment measured response inhibition, reaction time, and response accuracy. It was conducted at the Thailand Volleyball Association and the biomechanics laboratory of the Sport Authority of Thailand. Eight Qualisys Oqus motion capture cameras (Sweden) were installed to record movement in three dimensions, and two video cameras were positioned to capture behavioral data.

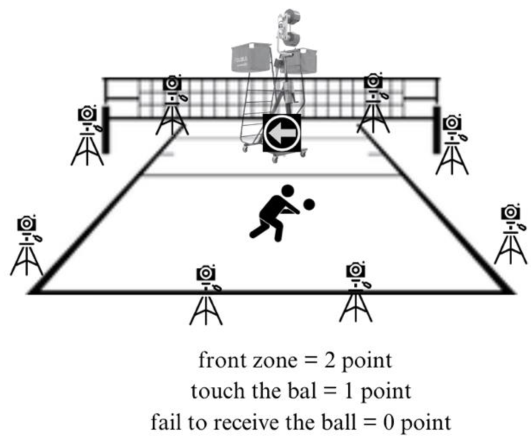

Figure 3. Spike-Receiving Performance Based on the Spatial Stroop Protocol.

Figure 3 illustrates the spike-receiving performance based on the Spatial Stroop Protocol. Each participant had a reflective marker placed on their C7 vertebra (5) and stood at the center of the backcourt as the starting position. A volleyball shooting machine was positioned at the center of the net, 2.5 meters high, 7 meters away from the participant, randomly launching spike balls to the left or right. The participants were instructed to respond to the ball only after it was launched and were not allowed to move beforehand. The volleyballs were fitted with 6 flat reflective markers, each 1.5 cm in size, to facilitate tracking. The ball’s speed was constantly set at 60 km/h.

For the Spatial Stroop Test, an experiment assistant held an arrow sign that randomly pointed left or right. The sign was displayed before the ball was launched, with the ball’s direction being randomly determined. If the arrow direction matched the ball’s trajectory (e.g., the arrow pointed right, and the ball was launched to the participant’s right), this was classified as a stimulus-response compatible (S-R com) condition. Conversely, if the arrow direction and the ball trajectory were opposite (e.g., the arrow pointed left, but the ball was launched to the participant’s right), this was classified as a stimulus-response incompatible (S-R incom) condition. The time delay between the arrow display and the ball launch was randomized between 5 and 10 seconds during the 3-second trial (since the machine could make perfect shots every 2 seconds). The participants were instructed to receive the ball and send it to the frontcourt (18).

Scoring System:

- 2 points: The received ball successfully landed in the frontcourt.
- 1 point: The ball was received but did not reach the frontcourt, was merely touched, or was sent over the net to the opposing side.
- 0 points: The ball was not received at all (i.e., no contact with the ball).

Each set consisted of 10 trials with a maximum possible score of 20 points per set. The participants completed 3 sets with a 5-minute rest period between the sets.

Statistical Analyses

The data analysis included reaction time, movement time, directional accuracy, mean time, and errors in the Spatial Stroop Test, flanker task, and Spike Reception Test based on the Spatial Stroop Protocol. Additionally, inhibitory control and automaticity in the Spatial Stroop Test were analyzed and presented as means and standard deviations. An independent *t*-test was used for statistical analysis.

RESULTS

Table 1. Mean and Standard Deviation (SD) of the Physical Characteristics of the Skilled Athletes and the Novice Athletes.

Physical Characteristics	Skilled Athletes (Mean ± SD)	Novice Athletes (Mean ± SD)	*t*	P-Value
Age (yr)	20.15 ± 1.51	21.15 ± 1.67	-1.594	.124
Weight (kg)	74.46 ± 10.68	70.92 ± 12.17	.788	.439
Height (cm)	180.00 ± 7.83	177.15 ± 6.40	1.050	.304
Playing Experience (yr)	9.54 ± 3.68	7.23 ± 3.81	1.569	.130
Training Frequency (days/wk)	6.00 ± .00	4.15 ± .98	6.743	<.001*
Training Time (hr/day)	3.00 ± .00	3.15 ± .55	-1.000	.337

The participants were entirely right-handed.

The Skilled and the Novice Volleyball Athlete Groups showed similar mean values for age, weight, height, years of sports experience, and daily training duration (i.e., hours per day). However, a significant difference was found in training frequency (days per week) ($P < 0.001$).

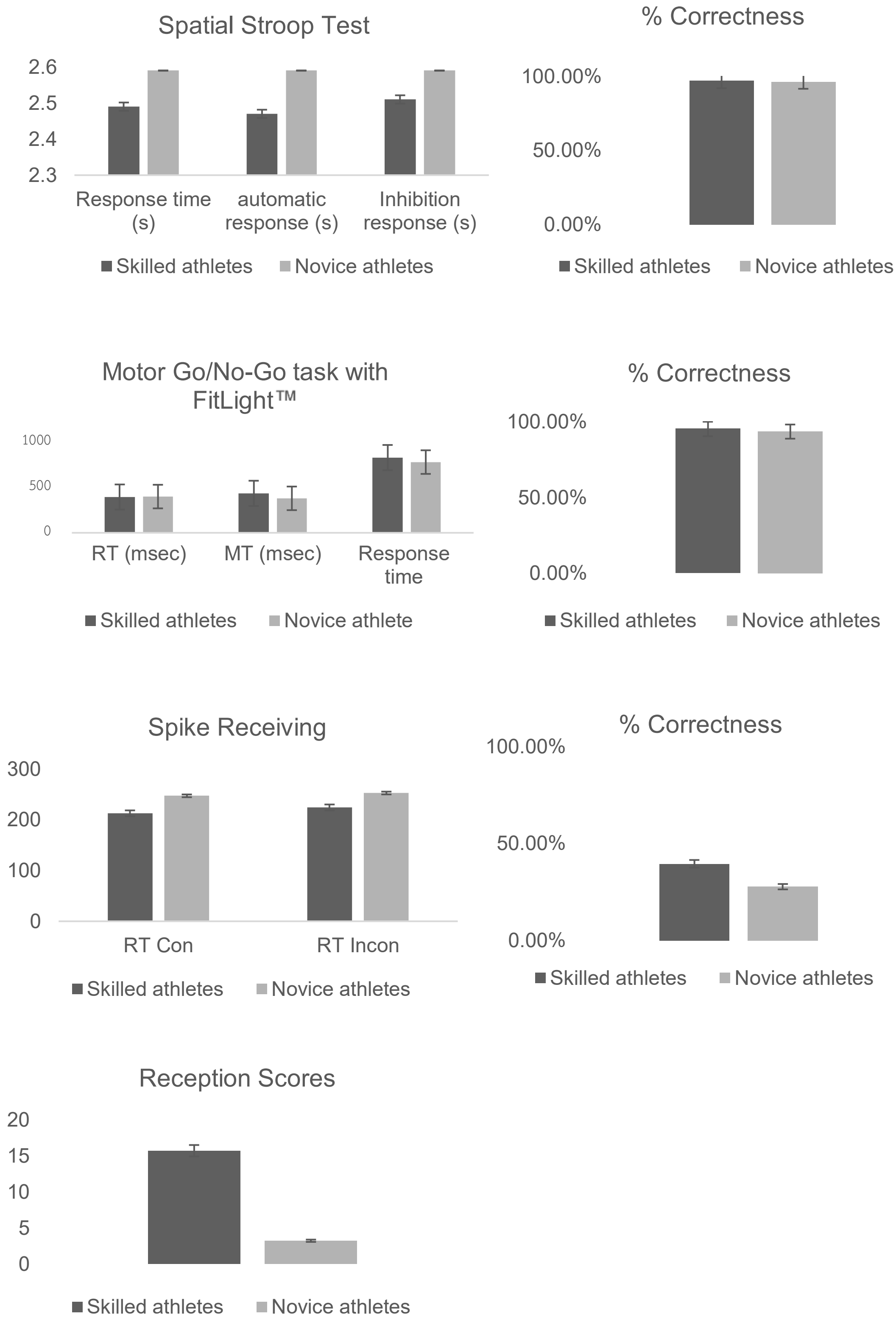

Figure 4. Comparative Analysis of Immediate Test Results for the Spatial Stroop Test, Motor Go/No-Go Task with FitLight™, and Spike-Receiving Performance, Specifically Designed Based on the Spatial Stroop Protocol.

The Spatial Stroop Test and Motor Go/No-Go Task with FitLight™ showed no significant differences between the Groups. Similarly, no significant difference was found in the spike-receiving performance for MT Congruent, MT Incongruent, RS Congruent, RS Incongruent, and inconsistent reception times between the skilled and the novice volleyball athletes. However, significant differences were observed only in RT Congruent, RT Incongruent, reception scores, congruent reception times, and percentage of spike reception correctness, with P-values of .001, .002, .005, .008, and .019, respectively.

DISCUSSION

This study found no significant differences between the skilled volleyball athletes and the novice volleyball athletes in the Spatial Stroop Test and the Motor Go/No-Go Task with FitLight™. This might suggest that both Groups exhibited similar levels of ability to regulate inhibitory responses in the cognitive and motor cortices during the small movement tasks, such as the check-in response and slapping the light. Both Groups of athletes demonstrated comparable levels of cognitive and inhibitory control that may be attributed to their similar educational background and the prolonged, continuous nature of their volleyball training.

However, differences in spike reception were observed, specifically in reaction time (RT) for both congruent (S-R con) and incongruent (S-R incon) conditions, as well as in reception accuracy. These findings indicate that the skilled volleyball athletes demonstrated faster reactions and greater reception accuracy compared to the novice athletes. This supports the idea that effective response inhibition may influence motor skills and visual perception in high-speed sports, particularly in reception accuracy.

Consistent with the findings by Wang et al. (37), athletes engaged in open-skill sports have been shown to possess enhanced response inhibition. Moreover, improved response performance has been associated with success in sports that demand rapid and precise reactions. Verburgh et al. (32) also suggested that high-level athletes exhibited superior response inhibition and attentional shifting abilities compared to a Control Group (35,37).

The present study indicates that the skilled athletes could demonstrate superior performance in receiving spike shots compared to the novice athletes, despite no significant differences in the cognitive test results. This discrepancy may have been attributed to the differences in information processing speed, particularly in motor execution.

The information that is processed in motor tasks consists of 3 key stages: (a) stimulus identification; (b) response selection; and (c) response programming (25). In the stimulus identification stage, athletes would detect and recognize incoming stimuli influenced by the characteristics of the stimulus. The response selection stage involves decision-making based on stimulus-response (S-R) alternatives, where a higher level of S-R compatibility facilitates faster decision-making. The final stage, response programming, translates the selected response into motor execution with reaction time (RT) varying depending on the movement complexity. Generally, RT increases as the response becomes more complicated, which highlights the role of motor execution in response efficiency. This suggests that movements requiring more intricate coordination and decision-making take longer to initiate, emphasizing the importance of well-developed motor planning and execution skills in optimizing response speed and correctness (12).

As skilled athletes generally have extensive training in sport-specific motor tasks, it is likely that their neural transmission from the brain to the spinal cord and motor units is more efficient, allowing for faster and more precise movements compared to beginners. This suggests that their advantage lies not in the differences in cognitive inhibition, but in a more refined and rapid motor response system. These findings align with previous research indicating that elite athletes exhibit superior motor preparation and execution, which leads to shorter response times and enhanced movement efficiency under game-like conditions (25,36).

Finally, another key factor contributing to the superior performance of skilled athletes may be due to their enhanced corticospinal excitability and intracortical inhibition. Several studies have suggested that stronger intracortical inhibition could modulate excitatory and topographic differences that allow for more refined motor control (11,16,30,39). This mechanism is critical in movement execution and inhibition, where thalamocortical drive facilitates motor activation, while inhibitory circuits such as the fronto-subthalamic pathway, involving the pre-SMA, dlPFC, and rIFG that regulate motor inhibition. These cognitive inhibition processes extend beyond movement control to influencing decision-making and perceptual functions through the mediodorsal thalamocortical drive to the PFC and pulvinar nuclei. This regulation further supports corticospinal excitability and enhances signal transmission from the brain to the muscles (20,29).

Empirical evidence supports the notion that skilled athletes exhibit heightened corticospinal excitability, which correlates with faster reaction times and improved movement efficiency (11). Additionally, a review by Kidgell et al. (13) states that athletes possess superior corticospinal activation compared to non-athletes, which is likely due to a higher training intensity and frequency (13). The increased neural drive observed in the skilled athletes could be attributed to long-term motor learning and repeated exposure to high-intensity neuromuscular demands that lead to greater motor unit recruitment and improved neural transmission efficiency.

Moreover, since the participants in this study were engaged in open-skill sports, it is plausible that their frequent interaction with the dynamic and unpredictable environments further facilitated more rapid and efficient neural signaling. This aligns with previous findings that open-skill athletes demonstrate superior sensorimotor processing and corticospinal responsiveness due to the adaptive demands of their sport (15,38).

Overall, these findings suggested that the enhanced response inhibition might contribute to the faster decision-making and reaction times in competitive settings, which ultimately improves reception skills in volleyball.

CONCLUSIONS

The findings suggest that skilled athletes exhibited faster reaction times, which allowed them to more quickly respond to the ball and achieve greater success in spike reception. These results support the idea that greater competitive experience in skilled athletes enhances inhibitory control that enables them to manage complex and fast-paced situations more effectively.

Limitations in this Study

One limitation of this study is the absence of neurophysiological assessments that would have provided valuable insights into potential differences in brain function related to inhibitory control between skilled and novice volleyball athletes.

Recommendations

Future studies should incorporate neurophysiological measures (e.g., EEG, fMRI) to explore the neural mechanisms underlying differences in inhibitory control. Additionally, including the physiological variable, abdominal strength, may provide additional evidence to support the interpretation of these results. To enhance the generalizability and applicability of the findings, future research could also include national-level athletes.

Address for correspondence: Benjapol Benjapalakorn, EdD, Faculty of Sports Science, Chulalongkorn University, Bangkok, Thailand, 10330, Email: Benjapol1978@gmail.com

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Effect of Two Types of Chinese Martial Arts on Functional Fitness in Middle-Aged and Older Adults

Meng Fan

Aichi University, 4-60-6 Hiraike-cho, Nakamura-ku, Nagoya 453-8777, Aichi, Japan

ABSTRACT

Fan M. The purpose of this study was to examine the effects of two types of Chinese martial arts on the physical fitness of middle-aged and older adults. Twenty-one individuals 50 to 70 years of age who participated in a health promotion exercise class took part in this study. The participants chose to join either the Kung Fu Gymnastics Group (Kung Fu Group, n = 11) or the Tai Chi Group (n = 10). Both Groups performed 60-minute exercise sessions twice a week for 6 weeks. Body weight, body fat percentage, and functional fitness were measured before and after the intervention. In the functional fitness tests, a two-way ANOVA revealed significant main effects (time effects) for functional reach, single-leg squat (right leg), single-leg squat (left leg), closed-eyes one-leg stand time (right leg), and closed-eyes one-leg stand time (left leg). Additionally, a significant interaction was observed for usual walking speed. This study consisted of a 6-week exercise program targeting middle-aged and older adults from the local community without prior exercise habits. It focused on Kung Fu Gymnastics and Tai Chi, which are two forms of Chinese martial arts. The results showed comparable improvements in several aspects of functional fitness for both interventions.

Key Words: Balance, Chinese Martial Arts, Kung Fu Gymnastics, Lower Extremity Muscle Strength, Tai Chi

INTRODUCTION

In modern society, maintaining health and improving the quality of life for middle-aged and elderly individuals has become an important issue. In Japan, which is facing a super-aging society, the average life expectancy in 2023 was 81.09 years for men and 87.14 years for women (13). However, the healthy life expectancy that is defined as the period in which individuals can live independently without relying on regular and continuous medical care or nursing was 72.68 years for men and 75.38 years for women in 2019 (12,22). Reducing the gap between average life expectancy and healthy life expectancy is a critical societal challenge.

As the population continues to age, the prevalence of chronic diseases and the decline in physical function are increasing. Hip fractures due to falls and vertebral compression fractures in elderly individuals are partly caused by a decrease in physical function, and these injuries can lead to bedridden states that significantly shorten healthy life expectancy (4,14). With the increase in age and the decrease in balance ability, muscle strength and flexibility, the resulting risk of falls becomes particularly pronounced in physically frail individuals (10). Therefore, maintaining health in middle-aged and elderly individuals is receiving increased attention.

Against this backdrop, various studies have examined training methods to improve the physical function of middle-aged and elderly adults. These studies suggest that appropriate exercise programs can enhance physical functions, such as balance ability that often deteriorates with age (1,15,21).

Chinese martial arts have long been recognized for emphasizing harmony between the body and mind, and are believed to contribute to improvements in flexibility, balance, muscle strength, and other aspects of physical function. Tai Chi, a well-known Chinese martial art, is particularly accessible for middle-aged and elderly adults due to its slow and gentle movements. As a form of exercise aimed at promoting health, Tai Chi is widely practiced not only in China but also across Asia, Europe, and the Americas. In Japan, there are approximately 1.5 million Tai Chi practitioners, with a significant proportion being middle-aged and elderly.

Tai Chi has become firmly established as a suitable form of exercise for this age group (6). Studies have reported that for the middle-aged and elderly adults who practice Tai Chi for at least 60 minutes per session, two or more times a week, over a period of 15 to 48 weeks can improve their balance and tendency to fall among other benefits (2,5,10,11,18,20). However, despite the many different types of Chinese martial arts, research comparing the effects of Tai Chi with other forms, as well as studies on the impact of these other martial arts on the health of middle-aged and elderly individuals remains limited. Kung Fu gymnastics has a higher intensity compared to Tai Chi (3), and it is possible that, given the same intervention period and frequency, Kung Fu may yield greater effects than Tai Chi.

Therefore, the purpose of this study was to examine the effects of two types of Chinese martial arts (Kung Fu Gymnastics and Tai Chi) on the functional physical fitness (muscle strength, flexibility, balance, etc.) of middle-aged and elderly adults with no prior exercise experience. Additionally, this study aims to clarify how Chinese martial arts can potentially be used for health promotion in this population.

METHODS

Participants

The participants in the study were individuals who took part in the "Health Promotion Exercise Classes for Local Residents" (hereafter referred to as the "Class"), which is an annual event organized by the Aichi University Physical Education Laboratory as part of its community outreach and efforts to promote and develop Chinese martial arts. The participants were recruited through the city's public newsletter. They agreed with the purpose of the study that included the measurements of functional physical fitness and other factors, which were conducted with their consent before and after the exercise period.

A total of 34 participants (56 to 84 years of age) enrolled in the Class and practiced one of two types of Chinese martial arts over a 6-week period. Among them, 22 participants were between 50 and 70 years of age. Of these, 21 middle-aged and elderly individuals (excluding one who could not participate in the fitness measurements due to personal reasons) were selected for this study. Before the Class began, the participants were divided into 2 Groups: (a) the Kung Fu Gymnastics Group; and (b) the Tai Chi Group. Each participant continued the assigned exercise as a health promotion activity throughout the Class duration. The Kung Fu Gymnastics Group consisted of 11 participants (age: 67.8 ± 4.4 years, height: 157.4 ± 6.9 cm, weight: 53.4 ± 7.5 kg), while the Tai Chi Group consisted of 10 participants (age: 65.3 ± 4.1 years, height: 157.1 ± 6.7 cm, weight: 53.4 ± 8.8 kg). There were no significant differences in age or physical characteristics between the 2 Groups before the intervention.

This study was approved by the Ethical Review Committee for Research Involving Human Subjects at the Graduate School of Physical Education, Chukyo University (Approval number: 2018-24). Before the study, the participants received a thorough explanation of its purpose, content, and any potential risks. Written informed consent was obtained from all the participants.

Procedures

The intervention lasted 6 weeks, with both Groups attending 60-minute sessions twice per week, totaling 12 sessions. The sessions were held in a multipurpose room at Aichi University. The Kung Fu Gymnastics Group practiced 2 routines, "Kung Fu Gymnastics 1" and "Kung Fu Gymnastics 2," developed by the Technical Committee of the Asian Martial Arts Federation. These routines (known as *taolu* in Chinese, where "tao" means a full set and "lu" refers to the direction and movement path very similar to *kata* in Japanese martial arts) were taught in a structured format. Each session included a 20-minute warm-up, 30 minutes of the main exercise (with brief rest breaks), and 10 minutes of cool-down. Sessions 1 through 6 focused on learning the routines, while sessions 7 through 12 emphasized performing the complete sets.

The Tai Chi Group practiced beginner-level movements that incorporated health-focused stretches with an emphasis on fluid and slow motions. Sessions 1 through 3 covered hand movements, sessions 4 through 6 covered footwork, and sessions 7 through 9 combined both into integrated sequences. Sessions 10 through 12 focused on performing the full Tai Chi routine. Repetitive practice was tailored to the participants' proficiency. Each session included 20 minutes of warm-up, 35 minutes of main exercise (with brief rest breaks), and 5 minutes of cool-down. The program was led by a Chinese instructor trained in martial arts since childhood.

Body weight, body fat percentage, and functional fitness tests were conducted before and after the intervention.

Strength Test

Functional physical fitness, defined as the physical ability necessary for independent living in daily life, was developed and later modified by Takeshima and Rogers (17,19). This modified functional physical fitness test was used to assess the effects of the exercise intervention. All functional physical fitness tests were conducted following a thorough explanation and practice beforehand in accordance with the procedures outlined below.

Grip Strength

Using the Smedley-type digital grip strength meter (T.K.K.5401, Takei Scientific Instruments Co., Ltd.), the participants were instructed to hold the meter with the pointer facing outward, adjusting the grip width so that the second joint of the index finger was approximately at a right angle. In a standing position with both feet naturally apart and arms hanging freely, the participants were asked to grip the meter as hard as possible without allowing it to touch their body or clothing. They were instructed not to swing the meter and to perform the test 4 times in succession (right → left → right → left). The average value automatically displayed by the instrument was calculated. This process was repeated for 2 sets, and the higher value from the 2 measurements was used as the final value.

Sit-and-Reach

Measurements were conducted twice using a digital long seat body anteflexion meter (T.K.K.5412, Takei Scientific Instruments Co., Ltd.), and the better value was adopted. With both legs positioned under the anteflexion meter, the participants sat with their backs against a wall and palms face down at each side. They extended their palms toward the front of the anteflexion meter, gently stretching their bodies and back muscles. Paying close attention not to bend their knees, the participants slowly extended their arms at the elbows and slid their upper torsos forward.

Functional Reach

The participants were asked to stand with their feet together, facing sideways in front of a wall. They extended both arms straight in front at shoulder height (shoulder joint flexed at a 90-degree angle). From this position, they were instructed to lean their upper body forward as far as possible. The distance their middle fingers reached (measured as the difference from the starting point) was recorded in 1 cm increments. If the participant was unable to return to the original position, it was considered a failed attempt. The measurement was performed twice. If the second measurement was greater than the first, a third measurement was taken, and the best value was used.

Normal Walking Speed

A 10-meter flat walking path was marked with tape at the 3-meter and 8-meter points. After starting to walk, the time it took for the participant to walk the 5-meter distance between the 3-meter line (when any part of the body, such as the waist or shoulder, crossed the line) and the 8-meter line was measured using a manual stopwatch, precise to 0.01 seconds. The participants were instructed to walk at their usual pace and not to race. The measurement was performed twice, and the best value was used for the final result.

Vertical Jump

Using a digital vertical jump measuring device (T.K.K.5406, Takei Scientific Instruments Co., Ltd.), the participant stood on a mat with a measuring cord hanging down. A belt attached to one end of the cord was wrapped around the participant's waist. The cord was pulled tight and fixed at waist height before jumping, and the meter scale was set to 0 cm. The participant was instructed to jump vertically with maximum effort. They were also instructed not to catch the cord with their hands or feet during takeoff or landing and to avoid jumping at an angle. The measurement was performed twice, and the best value was used for the final result.

Repeated Side Jumps

With three parallel lines placed 1 m apart on the floor, the participants straddled the central line. At the start signal, they side-stepped (not jumped) over the line to the right, returned to the center, then side-stepped over the line to the left. In the warm-up before the test, flexibility of the ankles, Achilles tendons, knees, and other joints (including stretching) was assessed. This exercise was repeated for 20 seconds with each line crossing counting as one point. The measurement was performed twice, and the better value was adopted.

Sit-Ups

The participants laid on the floor face up with their hands gently clasped into fists in front of the chest while the knees were kept at a 90° angle. An assistant held down the knees, and at the start signal, the participants rose so that both elbows and thighs touched once, then quickly returned to the starting position. They repeated this as many times as possible in 30 seconds. Measurements were performed only once. The participants with subjective symptoms of back pain were instructed not to perform this test.

Single-Leg Squat

From a seated position, the participants were instructed to stand and sit repeatedly on one leg as quickly as possible, counting how many times they could stand in 30 seconds. Their hands were extended straight ahead, and the participants were instructed not to use momentum. The test was performed once for each leg.

One-Leg Standing Time with Eyes Closed

With the eyes closed, the participants placed their hands on their hips and stood still. At the recorder's signal, they slightly lifted one foot while bending the knee, and the time they could remain balanced on one leg was measured. Timing stopped when the supporting leg shifted, the lifted foot touched the supporting leg or floor, or the hands moved away from the hips. The test was conducted twice for each leg, and the best value from each leg was used for the final result.

Statistical Analyses

All values were expressed as means and standard deviations. An unpaired *t*-test was used to compare the functional fitness test results between the 2 Groups before the intervention. The effects of the exercise intervention were examined using a two-way repeated measures analysis of variance (ANOVA). When significant differences between the 2 Groups were observed in pre-intervention values, these values were treated as covariates. Main effects (Group), main effects (Time), and interaction effects (Group × Time) were analyzed. When statistical significance was detected, the Bonferroni's multiple comparison test was performed. Statistical analyses were conducted using statistical software (SPSS ver. 23.0 for Windows), and the significance level was set at $P < 0.05$.

RESULTS

Effects of Exercise Intervention and Differences Between the Two Groups

Table 1 shows the results of the physical characteristics and functional fitness tests before and after the exercise intervention for the Kung Fu Gymnastics Group and the Tai Chi Group. No significant main effects (Group or Time) or interactions were observed for body weight before and after the intervention.

In the functional fitness tests, two-way analysis of variance revealed significant main effects (time) for functional reach, single-leg squat (right leg), single-leg squat (left leg), one-leg standing time with eyes closed (right leg), and one-leg standing time with eyes closed (left leg). Additionally, a significant interaction effect was found for normal walking speed.

DISCUSSION

The purpose of this study was to examine the effects of two types of Chinese martial arts: (a) Kung Fu Gymnastics; and (b) Tai Chi on functional fitness in middle-aged and elderly adults 50 to 70 years of age who lived in the same region and had no prior structured exercise habits. The intervention lasted for 6 weeks (twice a week, 60 minutes per session). The results showed that the exercise intervention had an influence on functional reach, single-leg squat (right leg), single-leg squat (left leg), one-leg standing time with eyes closed (right leg), and one-leg standing time with eyes closed (left leg) in both Groups.

Additionally, a significant interaction was observed in the normal walking speed measurement that indicated differences in intervention effects between the 2 Groups. According to Fan et al. (3), differences in exercise intensity exist between Kung Fu and Tai Chi. However, the results of this study indicate that after 6 weeks of practice, both Kung Fu and Tai Chi had similar effects on improving functional fitness. Nonetheless, differences between the exercise styles were observed in the normal walking speed measurement, which suggest that further research is needed.

According to Oda et al. (16), a 12-week program of 8-Form Tai Chi was conducted for men and women aged 50 to 70 who participated in a Tai Chi class organized by the community. The sessions were held once a week for 90 minutes. Significant differences were observed at the 12th week in measures, such as one-leg standing with eyes closed, the number of single-leg squats, and the maximum step width test that was developed by Kamioka et al. (7) in which the participants stood with both feet together and then stepped out as far as possible with one foot, bringing the other foot together. The change rates for one-leg standing with eyes closed were 50.6% for the left foot and 88.5% for the right foot, and the change rate for the number of single-leg squats was 33.6% for the left foot only. In this study, the change rates for one-leg standing with eyes closed were approximately 54% for the right foot and 70% for the left foot in the Kung Fu Gymnastics Group, and approximately 63% for both feet in the Tai Chi Group.

Additionally, the change rates for the number of single-leg squats were approximately 32% for the right foot and 26% for the left foot in the Kung Fu gymnastics Group, and approximately 28% for the right foot and 23% for the left foot in the Tai Chi Group. These change rates were similar to those observed in previous studies. Despite the shorter total exercise time in this study compared to that of Oda et al. (16), the effects on one-leg standing with the eyes closed and the number of single-leg squats in both the Kung Fu Gymnastics Group and the Tai Chi Group were very similar to those observed with 8-Form Tai Chi. This suggests that even within a short period, functional fitness improvement can be expected if the exercise volume is sufficient.

This study showed an interaction (Group × Time effect) for normal walking speed, indicating differing effects between the 2 exercise styles. In the Tai Chi Group, the time to walk 5 meters slightly increased post-intervention; whereas, in the Kung Fu Gymnastics Group, it slightly decreased. This may be due to Kung Fu including postures not commonly used in daily life, such as standing on one leg while raising the arms (Figure 1) that may have contributed to improved lower limb balance and strength.

Jin et al. (9) conducted a study in which the participants practiced 24-Form Tai Chi for 90 minutes per session, once a week (with at least two additional self-practice sessions per week) for five months on a vibrating surface (NeuroCom Balance Master system). A significant improvement in 10-meter walking speed was observed in the Tai Chi Group compared to the non-exercise Control Group, with walking speed reduced by 10% post-intervention.

In this study, over the 6-week period, the Kung Fu Gymnastics Group showed a 6.5% reduction in normal walking speed, while the Tai Chi Group showed no significant change. Although this study had a much shorter duration than Jin et al.'s, the Kung Fu Gymnastics Group showed similar improvements. With a longer intervention period like Jin et al. used, further reductions in walking speed might have been observed in the Tai Chi Group as well, and the Kung Fu Gymnastics Group may have shown even greater improvement.

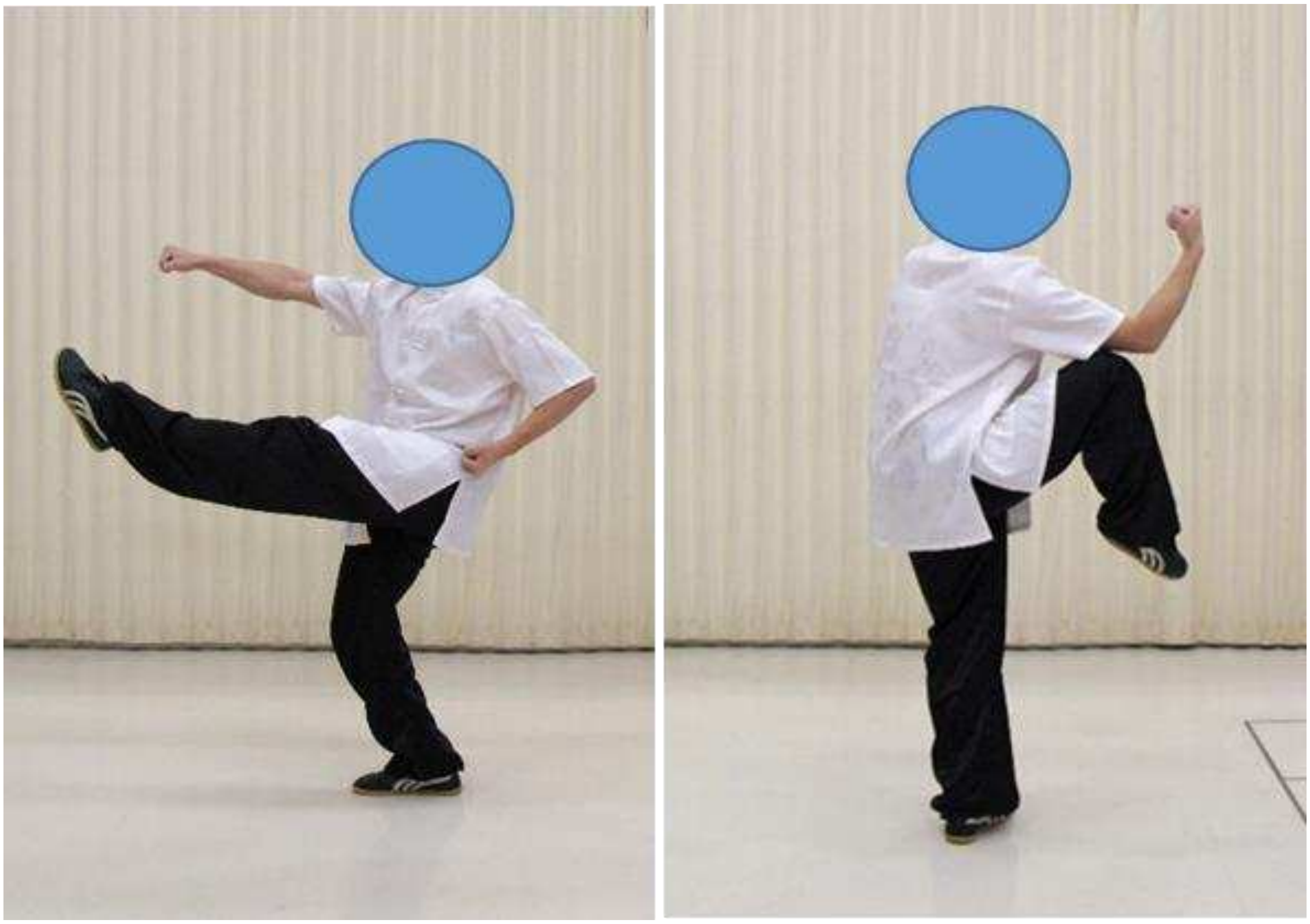

Figure 1. Example of One-Legged Balancing Movement in Kung Fu Gymnastics.

The balance-related indicators that included the one-leg standing time with eyes closed, functional reach (dynamic balance), and single-leg squats (lower limb strength) improved after the intervention in both Groups, with similar levels of change across all items. Previous studies of Tai Chi training for individuals 50 to 70 years of age, with total exercise volumes (training time per session × total number of sessions) ranging from 1,080 to 11,923 minutes, reported improvements in strength, flexibility (2,11), muscular endurance (2,24), balance, walking ability, and fall prevention (5,10,11,18,20). The present study's findings in the Tai Chi Group align with those results, confirming the effectiveness of the training. Furthermore, similar effects were observed in the Kung Fu Gymnastics Group, suggesting that both exercise styles can improve balance and lower limb strength in this population.

Yamamoto (23) noted that postural sway tends to increase more laterally than anterior-posterior with age. Greenspan et al. (4) reported that lateral falls result in a higher incidence of femoral neck fractures, which are critical for walking. In this study, improvements in balance and lower limb strength were observed after both Kung Fu and Tai Chi interventions. Kung Fu, which emphasizes more lateral movements, may help prevent lateral falls and, thus reduce the risk of femoral fractures. In fact, this point makes Kung Fu an interesting focus for future research.

Table 1. Exercise Intervention Outcomes (Physical Characteristics and Functional Fitness Test) o Gymnastics Group and Tai Chi Chuan Group.

Conditions	Kung Fu Gymnastics (11)						Tai Chi Chuan (10)						Main Effect (Group)		Main Effect (Time)	
	Pre			Post			Pre			Post			F	P	F	P
Characteristics																
Height (cm)	157.4	±	6.9				157.1	±	6.7				n.s.			
Age (yr)	67.8	±	4.4				65.3	±	4.1				n.s.			
Weight (kg)	53.4	±	7.5	53.4	±	7.4	53.4	±	8.8	53.6	±	8.8	n.s.		n.s.	
Functional Fitness Test																
Grip Strength (kg)	25.1	±	7.7	25.7	±	6.2	23.2	±	4.5	23.8	±	5.3	n.s.		n.s.	
Sit-and-Reach (cm)	35.1	±	7.5	39.8	±	8.3	31.6	±	8.4	33.3	±	7	n.s.		n.s.	
Functional Reach (cm)	33	±	6	38.6	±	3.5*	35.4	±	2.4	37.2	±	2.4	n.s.		11.511	<0.05
Normal Walking Speed (sec)	3.1	±	0.4	2.9	±	0.3	3.1	±	0.3	3.3	±	0.3‡	n.s.		n.s.	
Vertical Jump (cm)	25.6	±	7.2	27.0	±	6.1	23.8	±	3.6	24.8	±	4.3	n.s.		n.s.	
Repeated Side Jumps (point)	33.3	±	2.8	34.7	±	5.4	33.1	±	3	34.9	±	2.4	n.s.		n.s.	
Sit Ups (times)	8.4	±	7.4	10.7	±	6.2	8.9	±	4.7	9.6	±	5.5	n.s.		n.s.	
Single-Leg Squat (right side) (times)	13.4	±	4.4	17.7	±	3.5*	10.9	±	4.6	13.9	±	5.7*	n.s.		17.345	<0.05
Single-Leg Squat (left side) (times)	13.1	±	5.2	16.5	±	4.1*	10.7	±	5.5	13.2	±	6.2*	n.s.		13.357	<0.05
OLST[1)] (right side) (sec)	7	±	4.9	10.8	±	8.1*	5.6	±	2.3	9.1	±	6.1*	n.s.		8.728	<0.05
OLST[1)] (left side) (sec)	4.7	±	3.4	8	±	3.5*	6.3	±	3.5	10.3	±	8.9	n.s.		5.072	<0.05

*Significant change between Pre and Post (P < 0.05), ‡Significance difference between Groups (P < 0.05), n.s.: Not Significan time with eyes closed.

Many previous studies have reported Tai Chi's effectiveness in improving balance. According to Kimura (8), among healthy adults engaged in various sports, those practicing Tai Chi or ballroom dancing had longer one-leg standing times with eyes closed. Kamioka et al. (7) and Takahashi et al. (18) reported that significant improvements in balance were more likely when the participants completed "at least 40 practice sessions" and were evaluated under "conditions where maintaining balance was difficult." In contrast, in the present study, Kung Fu Gymnastics with fewer than 40 practice sessions showed results very similar to those of Tai Chi. Hence, considering the time and cost efficiency of instruction, Kung Fu Gymnastics may improve physical fitness in a shorter period than Tai Chi.

Although no significant improvements were observed in grip strength, sit-and-reach flexibility, vertical jump, lateral jump, or sit-ups, both groups showed positive change rates. These results suggest that both Kung Fu and Tai Chi contributed to improvements in muscle strength, flexibility, and explosive power. The increase in sit-up performance was greater in the Kung Fu Gymnastics Group. Both styles incorporate breathing techniques and stretching, and both styles are known to improve functional fitness. Based on this study, both Kung Fu and Tai Chi may help improve functional fitness in middle-aged and elderly adults.

This study examined the intervention effects of Kung Fu Gymnastics and Tai Chi on community-dwelling middle-aged and elderly adults. Similar improvements were observed across many functional fitness indicators, suggesting that both forms of Chinese martial arts may positively influence functional fitness in this population. However, given that only a few studies have addressed this topic, further research is warranted.

CONCLUSIONS

In this study, an intervention using either Kung Fu Gymnastics or Tai Chi (both forms of Chinese martial arts) was conducted for 6 weeks (twice a week, 60 minutes per session) with middle-aged and elderly adults living in the community who had no prior regular exercise habits. The effects were assessed using functional fitness as an indicator. As a result, improvements were observed in 3 of the 9 functional fitness items: (a) functional reach; (b) single-leg squat; and (c) one-leg standing time with eyes closed. These findings suggest that both Kung Fu Gymnastics and Tai Chi, when performed for 6 weeks (twice a week, 60 minutes per session), can have a positive influence on improving functional fitness in middle-aged and elderly adults.

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Address for correspondence: Meng Fan, Aichi University, 4-60-6 Hiraike-cho, Nakamura-ku, Nagoya Zip Code: 453-8777, Aichi, Japan. Email: fan_meng1990@yahoo.co.jp

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Associations Between Renal Function Biomarkers, Body Composition, and Physical Fitness in Patients with Early-Stage Chronic Kidney Disease

Pattraphon Suvannarot[1], Piyapong Prasertsri[2], Tadsawiya Padkao[2]

[1]Department of Physical Therapy, Chamni Hospital, Chamni District, Buriram 31110, Thailand,
[2]Faculty of Allied Health Sciences, Burapha University, Chonburi 20131, Thailand

ABSTRACT

Suvannarot P, Prasertsri P, Padkao T. This study investigated the associations between renal function biomarkers (serum creatinine (Cr), Cr clearance (CrCl), and estimated glomerular filtration rate (eGFR)) and body composition and physical fitness in 67 adults with early-stage chronic kidney disease (CKD) (mean age 60.1 ± 11.2 years; 67.2% female). Body composition was assessed by bioelectrical impedance analysis, while physical fitness was evaluated with hand-grip strength dynamometry and the 60-second sit-to-stand test. Serum Cr correlated strongly and positively with muscle mass ($r = 0.712$), bone mass ($r = 0.539$) and right- ($r = 0.405$) and left-handgrip strength ($r = 0.403$) (all $P < 0.001$). It showed negative associations with fat mass ($r = -0.354$) and hip circumference ($r = -0.277$) (both $P < 0.05$). CrCl displayed positive relationships with fat mass ($r = 0.378$), body-mass index ($r = 0.346$), hip circumference ($r = 0.318$), and bone mass ($r = 0.251$), but only a weak associated with right-hand grip strength ($r = 0.222$) (all $P < 0.05$). Conversely, eGFR was inversely correlated with muscle mass ($r = -0.697$) and bone mass ($r = -0.504$) (both $P < 0.001$) and with no significant associations with adiposity or fitness measures. These findings suggest that serum Cr may indicate muscular and functional status; whereas, CrCl and eGFR reflect broader body composition influences. Integrating these biomarkers with body composition assessments may enhance early CKD evaluation.

Key Words: Body Composition, Chronic Kidney Disease, Creatinine, Physical fitness

INTRODUCTION

Chronic kidney disease (CKD) is a progressive disorder characterized by a gradual decline in kidney function, affecting an estimated 10% to 14% of the global population (36). While clinical management often focuses on advanced CKD stages (stages 4 and 5) requiring dialysis or transplantation, the earlier stages (particularly stages 2 and 3) represent a crucial window for early intervention and prevention of disease progression (22). Despite being largely asymptomatic, patients in these early stages may already show physiological disturbances such as reduced glomerular filtration rate (GFR), low-grade systemic inflammation, and early muscle wasting (35,36). Detecting these changes early is vital to prevent disease progression, limit complications, and maintain quality of life.

Importantly, early-stage CKD is not confined to renal impairment alone. As the disease progresses, it is increasingly associated with systemic complications, such as cardiovascular dysfunction, sarcopenia, and decreased physical performance that contribute to frailty, disability, and increased mortality risk (9,33,40). These functional consequences highlight the need for a broader clinical perspective beyond traditional renal parameters.

In routine clinical practice, renal function is primarily evaluated using biomarkers such as serum creatinine (Cr), reatinine clearance (CrCl), and estimated glomerular filtration rate (eGFR) (36). While these indicators are valuable for diagnosing and staging CKD, they may also offer insight into the patient's overall physiological state. For example, creatinine levels are influenced not only by renal excretion but also by muscle metabolism, while eGFR can be biased by body composition. As such, they provide insights not only into renal function but also into the broader health status of patients. Given the physiological interplay between kidney function and musculoskeletal health, there is increasing interest in exploring how renal function biomarkers in clinical practice are associated with physical characteristics such as body composition and physical fitness (7,9,20,29). As such, these biomarkers may indirectly reflect systemic physiological alterations, including inflammation, metabolic dysfunction, or muscle loss (40,41).

Growing evidence suggests a bidirectional link between kidney and musculoskeletal health. In CKD, metabolic acidosis, hormonal alterations, chronic inflammation, and protein-energy wasting contribute to loss of muscle mass, increased fat accumulation, and reduced bone mineral content (20). This altered body composition, especially low muscle and bone mass, can increase the risk of falls, fractures, frailty, and mortality (20,23,46). Although body mass index (BMI) is commonly used to assess nutritional status, its interpretation in CKD is often confounded by fluid shifts and altered lean-to-fat ratios (6,32). Therefore, a comprehensive understanding of body composition in CKD is essential for identifying individuals at risk of functional decline and for informing targeted nutritional and rehabilitative strategies.

Equally important is the assessment of physical fitness. Functional tests such as handgrip strength and the 60-second sit-to-stand test are simple yet reliable indicators of muscular performance and overall physical capacity (15,21). Impaired fitness in CKD patients has been linked to poor health outcomes, including reduced independence, increased hospitalizations, and elevated mortality (3,16,43). However, the complex interrelationships between renal biomarkers, body composition, and physical function remain underexplored.

Emerging evidence suggests that serum Cr may serve as a surrogate for muscle mass and physical function; whereas, CrCl and eGFR may be more reflective of overall body composition.

Integrating these renal biomarkers with measures of body composition and fitness could enhance early detection of functional decline in CKD.

Therefore, the purpose of this study was to examine the associations between renal function biomarkers, body composition parameters, and physical fitness in individuals with stage 2 to 3 CKD. A deeper understanding of these relationships may support early, targeted interventions to slow progression, reduce disability, and improve quality of life in this high-risk population.

METHODS

Study Design and Subjects

This cross-sectional study was conducted between August 2024 and January 2025 at Chamani Hospital, Buriram Province, Thailand. A total of 67 adults with stage 2 to 3 CKD were recruited through purposive sampling from local health service units. All the participants provided written informed consent prior to enrollment. The study protocol was approved by the Institutional Ethics Review Board of the Buriram Provincial Public Health Office (Protocol No. BRO2024-074; approval date: 7/16/2024), and it was registered at ClinicalTrials.gov (ID: NCT07059559).

Inclusion Criteria included males and females who were 18 to 70 years of age with a confirmed diagnosis of CKD stage 2 to 3, defined by an eGFR between 30 and 89 $mL \cdot min^{-1} \cdot 1.73\ m^{-2}$, sustained for at least 3 months. ***Exclusion Criteria*** included the presence of musculoskeletal disorders impairing mobility (e.g., osteoarthritis), regular engagement in structured physical exercise (defined as more than 3 sessions or more than 150 minutes per week), the use of antioxidant-containing medications and/or supplements, a diagnosis of schizophrenia, or the inability to communicate in Thai.

Procedures and Data Collection

All the data were collected following IRB approval and standardized protocols. Prior to participation, each subject received a detailed explanation of the study objectives, procedures, potential risks, and data confidentiality. The assessments included the following components.

Renal Function Biomarkers

Renal function was evaluated using 3 standard clinical biomarkers: (a) serum Cr; (b) CrCl; and (c) eGFR from venous blood. Serum Cr levels were analyzed using the VITROS CREA slide method, as per laboratory procedure (RIA Laboratory, Co., Ltd., Nakhon Ratchasima, Thailand). The eGFR was calculated using the Modification of Diet in Renal Disease (MDRD) equation (19), depending on standard clinical practice, while CrCl was estimated using the Cockcroft–Gault formula that incorporates serum Cr, age, sex, and body weight (8). All biomarker analyses were performed by licensed medical technologists according to standard clinical procedures.

Body Composition Assessment

Body composition was evaluated using bioelectrical impedance analysis (BIA) (Tanita UM076, Tokyo, Japan), which provided values for BMI, muscle mass, fat mass, and bone mass. The participants were instructed to fast for at least 4 hours and avoid vigorous physical activity for 12 hours before testing. BMI was calculated as weight (kg) divided by height squared (m^2). Waist and hip circumferences were measured using a non-elastic tape, and waist-to-hip ratio (WHR) was calculated as waist circumference divided by hip circumference. Waist circumference was measured at the midpoint between the lowest rib and iliac crest, while hip circumference was measured at the widest part of the hips (femoral head level). All anthropometric data were collected by a licensed physical therapist.

Physical Fitness Assessment

Physical fitness was assessed across 2 domains: (a) muscle strength; and (b) functional performance. Grip strength was measured using a calibrated hand-held dynamometer (Takei TKK5001, Tokyo, Japan). The participants performed 3 maximal-effort trials with each hand. The highest value for each hand was recorded in kilograms (kg) (34). The 60-second Sit-to-stand test *(*60s-STS*)* was used to evaluate lower-limb endurance and functional capacity. The participants were instructed to repeatedly stand up and sit down from a standard chair for 60 seconds without using their arms. The total number of full stands was recorded (24).

Statistical Analyses

Descriptive statistics were used to summarize the participant characteristics. Continuous variables were expressed as mean ± standard deviation (SD) or median (range), depending on data distribution assessed by the Kolmogorov-Smirnov test. Categorical variables were presented as frequency and percentage. Associations between renal function biomarkers and body composition or physical fitness parameters were using Pearson correlation coefficients for normally distributed variables and Spearman's rho for non-normally distributed or ordinal variables. Correlation strength was interpreted as weak ($r < 0.30$), moderate ($r = 0.30 - 0.50$), and strong ($r > 0.50$) (25). A P-value < 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Participant Characteristics

The physiological characteristics of the 67 participants are summarized in Table 1. The sample included a higher proportion of females (67.2%) with a mean age of 68.04 ± 6.95 years. Most participants (85.1%) had stage 2 CKD, while the remainder were classified as stage 3. The mean systolic blood pressure (SBP) was 150.96 ± 15.85 mmHg, consistent with stage 2 hypertension classification (42). Basal metabolic rate (BMR), reported in both kilocalories (kcal) and kilojoules (kJ), demonstrated wide inter-individual variability, indicating diverse metabolic demands.

Table 1. Physiological Characteristic of the Participants (n = 67).

Conditions	Mean ± SD
Sex (Male: Female, n (%))	22 (32.80%): 45 (67.20%)
Age (years)	68.04 ± 6.95
Stage of CKD	
Stage 2 (number (%))	57 (85.10%)
Stage 3 (number (%))	10 (14.9%)
HR (beats/minute)	80.60 ± 12.79
SBP (mmHg)	150.96 ± 15.85
DBP (mmHg)	70.60 ± 12.36

Conditions	Mean ± SD
Basal Metabolic Rate (kcal)	4,811.58 ± 960.77
Basal Metabolic Rate (kJ)	1,149.19 ± 229.58

Note: All the data are presented as mean ± standard deviation (SD), except for sex and CKD stage, which are presented as n (%). **Abbreviations: CKD** = Chronic Kidney Disease, **HR** = Heart Rate, **SBP** = Systolic Blood Pressure, **DBP** = Diastolic Blood Pressure.

Renal Function Biomarkers, Body Composition, and Physical Fitness

Descriptive data for renal function biomarkers, body composition, and physical fitness measures are provided in Table 2. Overall, renal function indicated preserved kidney performance with a mean eGFR of 73.56 ± 11.56 $mL \cdot min^{-1} \cdot 1.73\ m^{-2}$ and a mean serum Cr of 1.01 ± 0.21 mg/dL. Body composition analysis showed BMI values within the normal to overweight range (mean = 24.72 ± 4.39 $kg \cdot m^{-2}$), with moderate levels of fat and muscle mass. Bone mass and waist-to-hip ratio (WHR) reflected relatively stable skeletal and central adiposity profiles.

Regarding physical fitness, grip strength values suggested reduced upper-body strength, as typically observed in aging populations. Performance on the 60-second sit-to-stand test (median 21 repetitions, range 9-34) reflected moderate lower-body functional capacity.

Table 2. Renal Function Biomarkers, Body Compositions and Physical Fitness Parameters (n = 67).

Parameters	Mean ± SD
Renal Function Biomarkers	
Cr (mg/dL)	1.01 ± 0.21
eGFR ($mL \cdot min^{-1} \cdot 1.73\ m^{-2}$)	73.56 ± 11.56
CrCl	53.14 ± 14.73
Body Composition	
BMI ($kg \cdot m^{-2}$)	24.72 ± 4.39
Fat Mass (kg)	18.29 ± 8.73
Muscle Mass (kg)	38.10 ± 8.35
Bone Mass (kg)	2.17 ± 0.49
Waist Circumference (cm)	87.61 ± 10.25
Hip Circumference (cm)	96.56 ± 8.80
Waist-to-Hip Ratio	0.90 ± 0.05
Physical Fitness	
Right Grip Strength (kg)	18.97 ± 8.30
Left Grip Strength (kg)	19.92 ± 7.45

Parameters	Mean ± SD
60-Second Sit-to-Stand Test (times) (median (range))	21 (9-34)

All parameters are presented as mean ± standard deviation (SD), except the 60-second sit-to-stand test, which is ordinal data and presented as median (range). **Abbreviations: Cr** = Creatinine, **CrCl** = Creatinine Clearance, **Egfr** = estimated Glomerular Filtration Rate, **BMI** = Body Mass Index.

Correlation Analyses

Creatinine and Physical Fitness

As shown in Figure 1, serum Cr was positively correlated with both right-hand grip strength (r = 0.243, P = 0.047) and left-hand grip strength (r = 0.365, P = 0.002), suggesting that higher Cr levels may be associated with greater upper-limb strength. A similar but non-significant trend was observed for the sit-to-stand test (r = 0.220, P = 0.073), suggesting a possible link with lower-limb endurance.

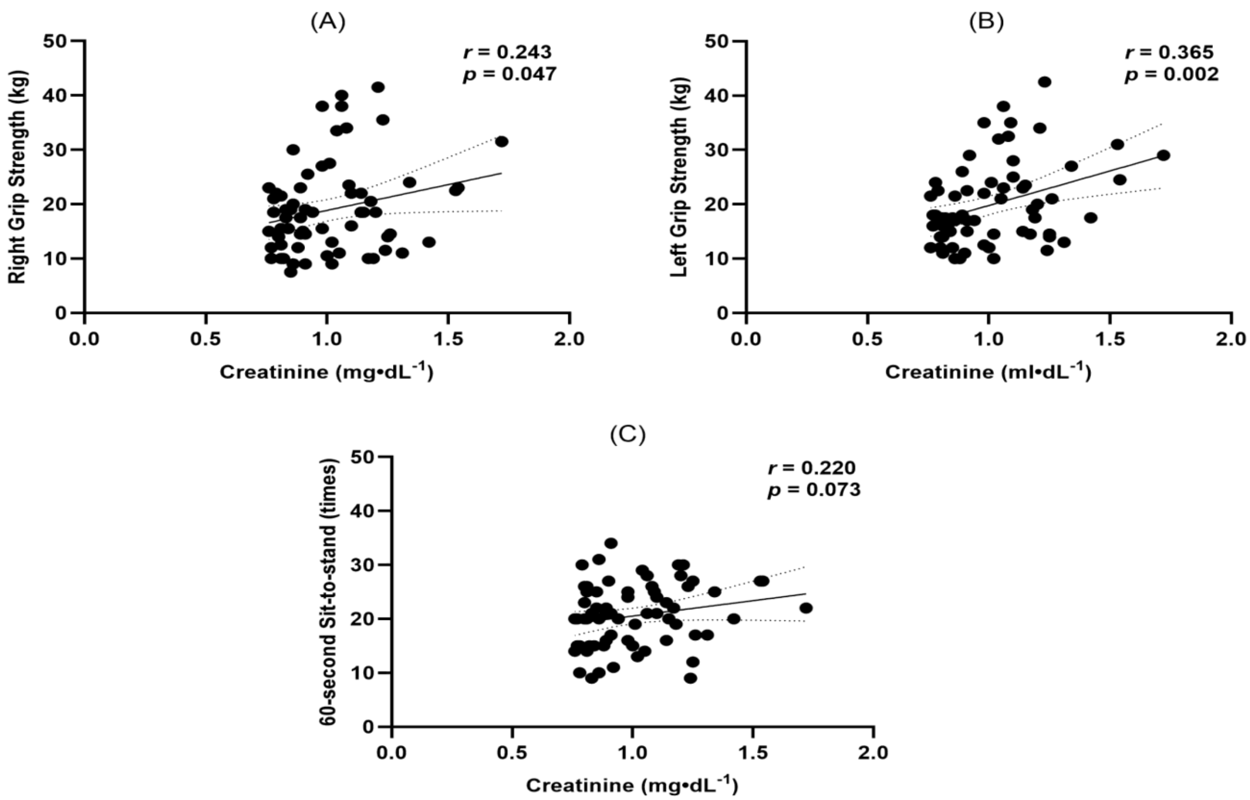

Figure 1. Correlation Coefficients (r) between Creatinine and Right-hand Grip Strength (A), Left-hand Grip Strength (B), analyzed using Pearson correlation, and the 60-second Sit-to-stand test (C), analyzed using Spearman's rho correlation. Data Points Represent the Mean Value of Each Individual. The Solid Black Line Indicates the Simple Linear Regression Line, and the Dashed Lines Represent the 95% Confidence Interval Bands (n = 67).

Creatinine Clearance and Physical Fitness

As shown in Figure 2, CrCl was weakly but significantly correlated with right-hand grip strength (r = 0.257, P = 0.035). However, the association with left-hand grip strength was not significant (r = 0.183, P = 0.139). No correlation was observed between CrCl and the 60-second sit-to-stand test (r = 0.000, P = 0.999).

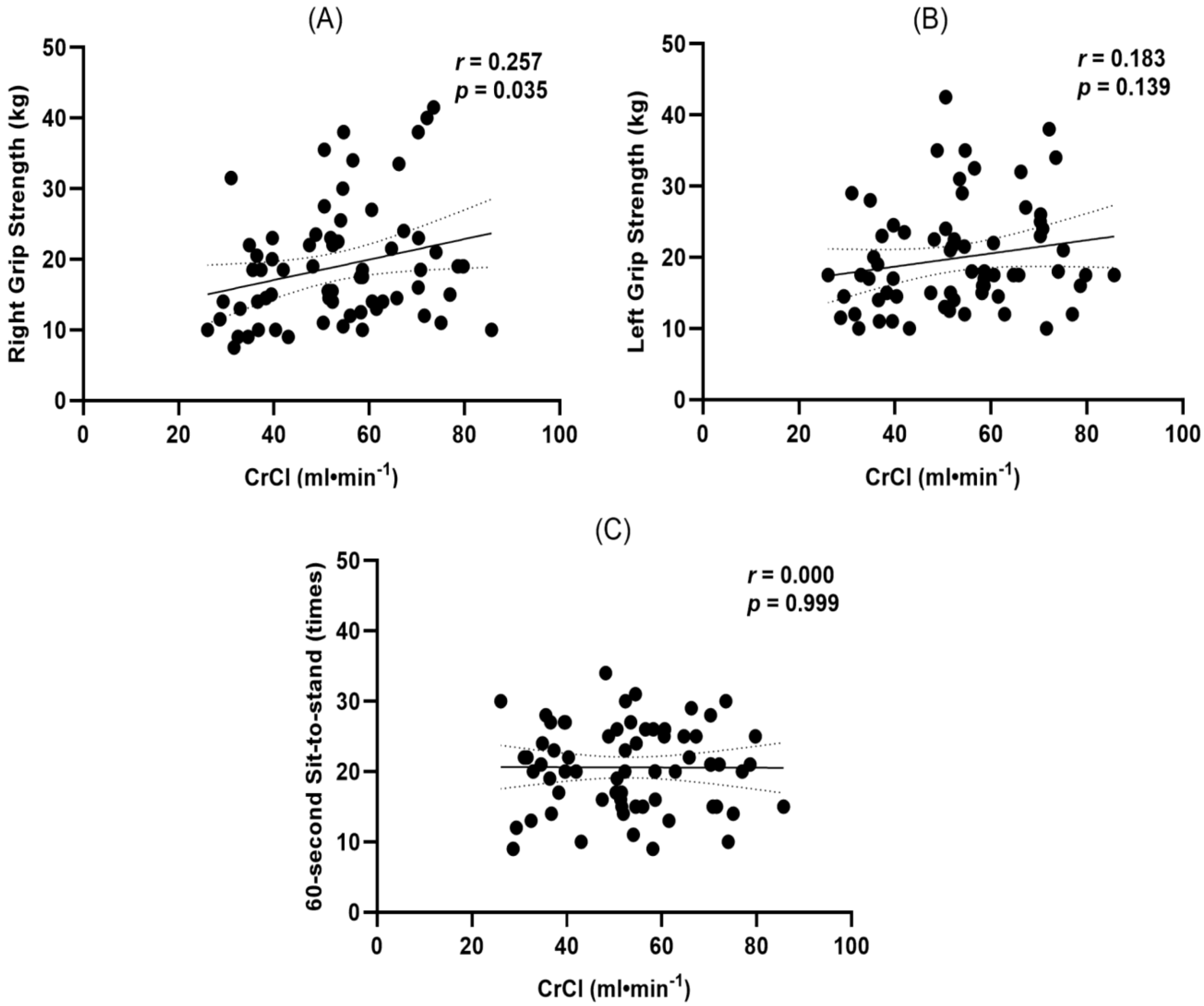

Figure 2. Correlation Coefficients (*r*) between Creatinine Clearance (CrCl) and Right Grip Strength (A), Left Grip Strength (B), analyzed using Pearson correlation, and the 60-second Sit-to-stand test (C), analyzed using Spearman's rho correlation. Data Points Represent the Mean Value of Each Individual. The Solid Black Line Indicates the Simple Linear Regression Line, and the Dashed Lines Represent the 95% Confidence Interval Bands (n = 67).

eGFR and Physical Fitness

As illustrated in Figure 3, eGFR was not significantly correlated with any physical fitness measures. The associations with right grip strength (r = -0.010, P = 0.934), left grip strength (r = -0.088, P = 0.481), and sit-to-stand performance (r = -0.036, P = 0.769) were all negligible.

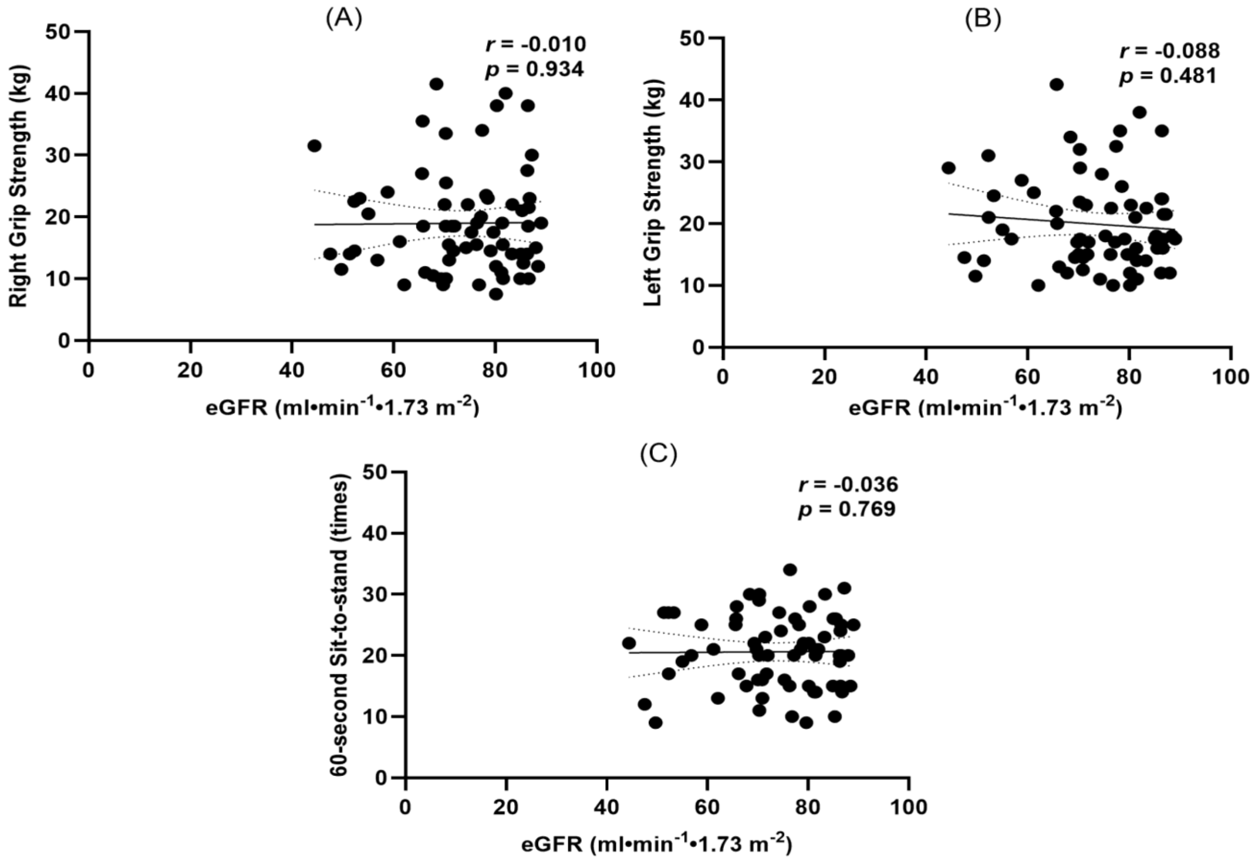

Figure 3. Correlation Coefficients (*r*) between estimated Glomerular Filtration Rate (eGFR) and Right Grip Strength (A), Left Grip Strength (B), analyzed using Pearson correlation, and the 60-second Sit-to-stand test (C), analyzed using Spearman's rho correlation. Data Points Represent the Mean Value of Each Individual. The Solid Black Line Indicates the Simple Linear Regression Line, and the Dashed Lines Represent the 95% Confidence Interval Bands (n = 67).

Correlations with Body Composition and Physical Fitness

The correlations between renal biomarkers and variables of body composition and physical fitness are summarized in Table 3. Serum Cr showed strong positive correlations with muscle mass (r = 0.604, P < 0.001) and bone mass (r = 0.587, P < 0.001), and a moderate negative correlation with fat mass (r = -0.294, P~~P~~ = 0.016). Cr was also inversely correlated with hip circumference (r = -0.211, P = 0.046).

CrCl demonstrated strong positive correlations with fat mass (r = 0.759, P < 0.001), BMI (P = 0.727, P < 0.001), and hip circumference (*r* = 0.694, *p* < 0.001), and moderate associations with bone mass (r = 0.330, P = 0.006), muscle mass (*r* = 0.262, P = 0.032), and waist circumference (r = 0.581, P < 0.001). Conversely, eGFR was negatively associated with muscle mass (r = -0.281, P = 0.021) and bone mass (r = -0.329, P= 0.006), but not with other body composition variables. Regarding physical fitness, muscle mass and bone mass showed moderate to strong correlations with both right and left grip strength (all P < 0.01). No significant correlations were observed between renal function biomarkers and the 60-second sit-to-stand test.

Table 3. Correlation Coefficient (*r*) Between Renal Function Biomarkers, Physical Fitness and Body Composition (n = 67).

	Cr [1]	CrCl [1]	eGFR [1]	Right Grip Strength [1]	Left Grip Strength [1]	60-Second Sit-to-Stand [2]
BMI	-0.181	0.727**	0.074	0.014	-0.018	-0.126
Fat Mass	-0.294*	0.759**	0.170	-0.004	-0.025	-0.132
Muscle Mass	0.604**	0.262*	-0.281*	0.509**	0.588**	0.140
Bone Mass	0.587**	0.330**	-0.329**	0.485**	0.564**	0.058
Waist Circumference	-0.004	0.581**	-0.013	0.167	0.136	0.086
Hip Circumference	-0.211*	0.694**	0.127	0.067	0.039	-0.228
Waist-to-Hip Ratio	0.288	0.075	-0.202	0.193	0.184	0.115

[1]Variable analyzed using the Pearson correlation, [2]Variable analyzed Using Spearman's rho correlation, *P value < 0.05, **P value < 0.001. **Abbreviations: Cr** = Creatinine, **CrCl** = Creatinine Clearance, **Egfr** = Estimated Glomerular Filtration Rate, **BMI** = Body Mass Index.

DISCUSSION

This study investigated the associations between renal function biomarkers (Cr, CrCl, and eGFR) with body composition and physical fitness in patients with stage 2 to 3 CKD. The findings demonstrate distinct relationships between each biomarker and various physiological parameters, including muscle, bone, adiposity, and functional performance with relevant clinical implications.

Serum Creatinine and Its Relationship with Physical Fitness and Body Composition

Although serum Cr is widely used as an indicator of kidney function, its interpretation is complicated by the fact that it is also a byproduct of skeletal muscle metabolism (2). In this study, serum Cr was strongly and positively correlated with muscle mass and bone mass. This is physiologically plausible, as individuals with greater lean mass typically produce more creatinine (45,47). Prior studies similarly suggest that serum Cr reflects muscle mass and may even obscure early CKD detection in muscular individuals (12,18). For example, among patients with stage 4–5 CKD undergoing dialysis, Cr levels closely mirrored muscle mass as measured by dual-energy X-ray absorptiometry (DEXA) (31). The observed positive association between Cr and bone mass may also reflect shared anabolic signaling pathways, such as the growth hormone/insulin-like growth factor-1 (GH/IGF-1) axis and vitamin D metabolism, both of which are altered in CKD (13). Additionally, this association may be secondary to the mechanical loading provided by muscle mass, which supports bone integrity. In contrast, serum Cr showed moderate negative correlations with fat mass and hip circumference, suggesting that increased adiposity is associated with lower serum Cr levels. This may be relevant in individuals with sarcopenic obesity, where increased fat mass masks reductions in muscle mass that potentially leads to underestimation of CKD severity (38,48).

Regarding physical fitness, serum Cr was moderately and positively associated with handgrip strength in both hands, which is consistent with the links observed between muscle mass, bone mass, and upper-body strength. Previous research has similarly shown modest correlations between serum Cr and handgrip strength among CKD patients (15). For instance, in patients undergoing maintenance hemodialysis, serum Cr correlated significantly with grip strength (r =

0.26, P = 0.018) (4). Also, in a cohort of 134 non-dialysis CKD patients, the creatinine-to-cystatin C ratio was more strongly correlated with grip strength (r = 0.49, P < 0.001) and lean mass by BIA that further supports its utility as a marker of muscle quality (5,44). A systematic review of 129 CKD studies further endorsed handgrip strength as a functional and nutritional biomarker (44). These findings support the potential of Cr and Cr-based indices to reflect upper-body muscle strength in CKD populations.

However, serum Cr was not significantly associated with lower-limb performance as assessed by the 60-second sit-to-stand test. This suggests that while Cr may reflect upper-limb strength and muscle mass, it does not adequately capture lower-body function or endurance. Previous studies have similarly reported limited associations between Cr and dynamic functional tests (39). For example, although sit-to-stand performance was not directly examined, Shiomi et al. (39) reported that the creatinine-to-cystatin C ratio was independently related to knee extensor strength in pre-dialysis CKD patients.

In summary, serum Cr appears to be a reliable indicator of muscle and bone mass and a moderate marker of upper-limb strength. However, it should not be relied upon as a standalone measure of functional capacity. Serum Cr should be interpreted alongside additional biomarkers, such as cystatin C, and direct physical assessments for a more comprehensive evaluation of musculoskeletal health in CKD (15,44).

Creatinine Clearance and Its Association with Body Composition and Physical Fitness

CrCl, an estimate of renal excretory function based on serum and urinary Cr, is influenced by body size and composition, making it potentially misleading in CKD patients with altered muscle-to-fat ratios (2,37). In this study, CrCl was strongly and positively correlated with fat mass, BMI, and hip circumference that suggest an overestimation of renal function in individuals with greater adiposity. This may reflect the influence of weight in the Cockcroft-Gault formula, which can overestimate CrCl in individuals with obesity (1,8). Prior studies have similarly shown that CrCl may be inflated in patients with sarcopenic obesity or fluid imbalances, such as edema (17,48).

Moderate positive associations were also observed between CrCl and both muscle and bone mass, supporting the notion that CrCl reflects overall body size, including both lean and fat compartments (23,46). This aligns with prior research suggesting that CrCl correlates with total body composition rather than lean mass alone (14). CrCl was weakly correlated with right-hand grip strength but not with left-hand grip or lower-limb performance. This limited association is consistent with previous literature indicating that while CrCl is a useful renal marker, it does not reliably reflect physical fitness or muscle function (3,41,49). Overall, these findings suggest that CrCl may provide a general estimate of renal function and body size but lacks specificity for assessing functional capacity. In clinical practice, especially among patients with obesity or sarcopenia, CrCl should be interpreted with caution (2).

Estimated Glomerular Filtration Rate (eGFR) and Its Relationship with Physical Fitness and Body Composition

eGFR derived from serum Cr using standardized equations is a mainstay in CKD evaluation (19). However, in this study, eGFR was inversely associated with muscle mass and bone mass. It is likely that these findings reflect the influence of serum Cr levels on eGFR estimations. Individuals with greater muscle mass produce more creatinine, which may result in lower eGFR values even when renal function is preserved (26,27). Similar discrepancies have been noted in athletes, older adults with sarcopenia, and individuals with cachexia, where eGFR may over- or underestimate kidney function depending on muscle mass (10,11). Notably, eGFR was not significantly associated with fat mass, BMI, or physical performance measures. Higher eGFR values were paradoxically observed in the participants with lower muscle and bone mass, which is likely a result of reduced creatinine production that inflates eGFR estimates (28).

These findings carry important clinical implications. Overestimation of renal function in individuals with low muscle mass, such as older adults, women, or patients with sarcopenia may delay CKD diagnosis and intervention. Conversely, the underestimation in muscular individuals could lead to unnecessary referrals or treatments. Hence, clinicians should interpret eGFR in the context of body composition and functional status (7,8). The use of muscle-independent biomarkers, such as cystatin C has been recommended as a more accurate alternative for assessing renal function in such cases (30).

Limitations in this Study

This study has several limitations. First, its cross-sectional design precludes causal inference between renal function biomarkers and physical fitness or body composition. Second, the sample size, while adequate for moderate correlations, may be underpowered for detecting small effects. The study's single-center setting may also limit generalizability to other populations. Third, body composition was assessed via BIA, which is practical but less accurate than DEXA or MRI. Similarly, while handgrip strength and the 60-second sit-to-stand test are validated measures of physical function, they may not fully capture the complexity of fitness. Lastly, potential confounding variables, such as physical activity, dietary intake, inflammation, and medication use were not fully controlled. Despite these limitations, the study provides important insights into the physiological interplay between kidney function, body composition, and physical performance in the early-stage CKD.

CONCLUSIONS

This study highlights the nuanced relationships between renal biomarkers, body composition, and physical fitness in individuals with stage 2 to 3 CKD. Serum creatinine was positively associated with muscle mass, bone mass, and upper-limb strength, suggesting its utility as a marker of musculoskeletal health. In contrast, creatinine clearance was more closely associated with adiposity and may overestimate renal function in obese individuals. Although commonly used in clinical practice, eGFR was inversely associated with muscle and bone mass, which raised concerns about its accuracy in muscular or sarcopenic patients. These findings underscore the importance of interpreting renal function biomarkers in conjunction with direct assessments of physical fitness and body composition. Incorporating such measures into routine care may enhance risk stratification, individualized treatment, and early intervention. Future studies should employ longitudinal designs and consider muscle-independent filtration markers to better understand the complex dynamics of renal and musculoskeletal health in CKD.

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Address for correspondence: Tadsawiya Padkao, PhD, PT, MS, Faculty of Allied Health Sciences, Burapha University, Chonburi Province, Thailand, 20131, Email: tadsawiya@go.buu.ac.th.

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Acute Metabolic Benefits of High-Intensity Interval Exercise Combining Green Tea Supplementation in Severely Obese Individuals.

Sasiwimon Saeli[1], Atinya Deechuen[1], Kornkanok Namkang[1], Apanchanit Siripatt[2], Tunyakarn Worasettawat[3]

[1]School of Human Kinetics and Health, HRH Princess Chulabhorn College Medical Science, Chulabhorn Royal Academy, Bangkok, Thailand, [2]Faculty of Sport Science, Burapha University, Chonburi, Thailand, [3]Faculty of Sport Science, Chulalongkorn University, Bangkok, Thailand

ABSTRACT

Saeli S, Deechuen A, Namkang K, Siripatt A, Worasettawat T. Acute Metabolic Benefits of High-Intensity Interval Exercise Combining Green Tea Supplementation in Severely Obese Individuals. High-intensity interval exercise (HIIE) and green tea (GT) are known to improve metabolic health, yet their combined acute effects remain unclear in severe obesity. This study examined the metabolic responses to a single bout of HIIE versus HIIE with GT (HIIE+GT). Twelve adults with severe obesity (BMI = 41.5 ± 3.1 kg/m^2; age 20–45 years) completed a randomized cross-over trial with two conditions separated by ≥72 hours. The HIIE protocol involved six 1-min bouts at 80–85% heart rate reserve (HRR) interspersed with 4-min bouts at 40–45% HRR. In HIIE+GT, the participants ingested 800 mg GT extract (400 mg EGCG, 200 mg catechins) 1 hour before exercise. Metabolic responses, including substrate oxidation and resting metabolic rate (RMR), were measured via indirect calorimetry at baseline and at 5 minutes, 30 minutes, and 60 minutes post-exercise. Fat oxidation significantly increased at all post-exercise time points ($P < 0.05$), peaking at 30 minutes (HIIE: 189.8 ± 19.7 vs. HIIE+GT: 205.8 ± 19.7 g/day), with no between-group differences. Carbohydrate oxidation decreased at 30 minutes and 60 minutes ($P < 0.05$), while protein oxidation rose at 5 minutes and 30 minutes ($P < 0.05$) in both conditions. RMR increased at 5 minutes in HIIE and at 5 minutes and 30 minutes in HIIE+GT, but declined below baseline at 60 minutes in HIIE; whereas, it remained stable in HIIE+GT. In conclusion, HIIE with GT is feasible and may better sustain post-exercise metabolic responses than HIIE alone. Further studies should evaluate its chronic effects in severe obesity.

Key Words: High-Intensity Interval Exercise, Green Tea Supplementation, Severe Obesity, Substrate Metabolism, Resting Metabolic Rate

INTRODUCTION

Severe obesity, typically defined as a body mass index (BMI) of 40 kg/m^2 or higher, has become increasingly prevalent worldwide due to sedentary lifestyles and unhealthy dietary patterns (1). In Southeast Asia, including Thailand, the prevalence of severe obesity has continued to rise over the past decade, particularly among adults aged 30 to 60, contributing to a growing burden on healthcare systems (2). Severe obesity is strongly associated with a wide range of non-communicable diseases (NCDs), such as type 2 diabetes, cardiovascular disease, certain cancers, and chronic kidney disease (3). Moreover, individuals with severe obesity are at substantially higher risk of premature mortality, with life expectancy reduced by up to 10 years compared to individuals with normal weight (4).

One effective strategy to combat severe obesity and its associated comorbidities is to implement interventions that improve metabolic function and facilitate fat loss. Enhancing metabolic function refers to increasing energy expenditure, improving insulin sensitivity, and promoting lipid oxidation, all of which can reduce the risk of developing metabolic syndrome, type 2 diabetes, and cardiovascular disease (5). Recent evidence supports this notion, demonstrating that even a single bout of exercise can induce widespread alterations in the circulating metabolome, with over 85% of measured metabolites significantly changed. These alterations include reductions in metabolites related to insulin resistance and increases in those associated with lipolysis, nitric oxide bioavailability, and adipose tissue browning (6).

Among exercise interventions, high-intensity interval training (HIIT) has been shown to enhance skeletal muscle oxidative capacity by increasing mitochondrial content and function, as well as upregulating substrate transporter proteins. These physiological adaptations are largely driven by mitochondrial biogenesis pathways with PGC-1α and its upstream signaling mechanisms playing a central role (7). Additionally, interval training has been reported to increase whole-body fat oxidation (FOx) in approximately half of the studies reviewed, with HIIT more consistently eliciting these improvements than sprint interval training (SIT). The greater enhancements in FOx observed in HIIT protocols are likely due to significant upregulation of key oxidative enzymes and proteins, including β-HAD, citrate synthase, fatty acid binding protein, and FAT/CD36 (8). These molecular adaptations not only reflect improvements at the cellular level but also translate into meaningful physiological outcomes. Indeed, participating in HIIT has been shown to enhance whole-body fat oxidation, with more pronounced effects observed following longer training durations and among individuals with overweight or obesity. Although the magnitude of some improvements may appear modest, they may nonetheless contribute significantly as part of an integrated approach to improving metabolic health and managing obesity (9).

In addition to exercise, nutritional strategies such as calorie restriction, high-protein diets, and the intake of bioactive compounds like green tea catechins have also demonstrated benefits in weight loss, improved body composition, and regulation of metabolic processes (10-12). Several studies have reported that green tea and its bioactive compounds can stimulate thermogenesis and promote fat oxidation. The key active components in green tea are catechins and caffeine. Catechins are believed to increase energy expenditure by inhibiting an enzyme called catechol O-methyltransferase (COMT), which normally breaks down norepinephrine. When COMT is inhibited, norepinephrine remains active for a longer time, leading to increased energy use. However, COMT activity can vary among individuals, which may result in different responses to green tea intake (13-15). In addition, short-term green tea consumption may enhance metabolic responses by increasing fat oxidation and energy expenditure, while reducing carbohydrate reliance during moderate-intensity exercise in inactive or recreationally active individuals. When combined with moderate aerobic or resistance training over a period of 8 to 10 weeks, green tea intake can further boost fat oxidation, improve body composition, lower triglyceride levels, and increase HDL cholesterol, particularly in sedentary individuals who are overweight or obese (16).

While both HIIT and green tea consumption have shown metabolic benefits individually, the acute combined effect of high-intensity interval exercise and green tea intake in severely obese individuals has not yet been clearly established. Investigating these acute responses is important for understanding early-phase physiological adaptations and designing effective, scalable interventions. Therefore, this crossover study aimed to examine and compare the acute effects of HIIT alone and HIIT combined with green tea consumption (HIIT+GT) on substrate utilization and resting metabolic rate (RMR) in individuals with severe obesity, with each participant completing both conditions.

METHODS

Subjects

Participants were recruited from staff and students of Chulabhorn Royal Academy, Thailand. Twelve adults with severe obesity (BMI: 41.49 ± 3.14 kg/m²; age range: 20–45 years) were enrolled in the study. Eligible participants had not been regularly engaged in structured exercise during the preceding three months. Exclusion criteria were uncontrolled hypertension, cardiovascular disease, diabetes mellitus, chronic pulmonary disease, musculoskeletal disorders limiting physical activity, and smoking. All participants provided written informed consent prior to enrollment, and the study protocol was approved by the Institutional Review Board of Chulabhorn Royal Academy, Thailand (Approval No.EC075/2565, dated February 3, 2023). Baseline characteristics of the participants are presented in Table 1.

Procedures

Study Design and Intervention Protocol

This study was conducted as a randomized crossover trial. The participants were randomly assigned, using a computer-generated sequence, to begin with either high-intensity interval exercise (HIIE) alone or HIIE combined with green tea supplementation (HIIE+GT). Each intervention period lasted 7 days, followed by a 7-day washout to minimize carry-over effects, after which the participants crossed over to the alternate condition. Thus, all the participants completed both interventions in randomized order. All exercise sessions were supervised by qualified exercise specialists to ensure adherence and safety.

Each session consisted of a 10-minute warm-up, a 30-minute HIIE protocol, and a 10-minute cool-down. The HIIE protocol comprised six sets of 4-minute bouts at 80–85% of heart rate reserve (HRR), interspersed with 4-minute active recovery periods at 40–45% HRR. High-intensity bouts involved whole-body movements (e.g., step jack, punch with high knee, two-step with high knee, butt kick with arm raises, step back jack, and crossover knee to elbow), while recovery periods consisted of low-intensity marching. The protocol was reviewed by three experts in exercise science using the Index of Item-Objective Congruence (IOC), yielding a score of 1.00, indicating excellent content validity.

The green tea supplement contained 400 mg epigallocatechin gallate (EGCG) and 200 mg catechins per capsule. The participants ingested two capsules (total: 800 mg extract, including 400 mg EGCG and 200 mg catechins) 1 hour before the HIIE session, following the protocol of Roberts et al. (17).

Measurements

Body Composition Assessment

Body composition variables that included body weight, height, body mass index (BMI), percent body fat (%BF), fat mass (FM), fat-free mass (FFM), muscle mass (MM), visceral fat, and waist-to-hip circumference ratio were assessed using a Medical Body Composition Analyzer (SECA mBCA 514, Germany).

Energy Expenditure Assessment

Resting metabolic rate (RMR) was measured using a breath-by-breath cardiopulmonary gas exchange system with indirect calorimetry (METAMAX® 3B, Cortex Biophysik GmbH, Germany) under spontaneous-breathing conditions. The system calculated oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER = VCO_2/VO_2). The participants were instructed to refrain from food intake for at least 8 hours and from caffeine consumption for at least 12 hours prior to testing. Each measurement lasted approximately 30 minutes in a resting, seated position.

Fat and carbohydrate oxidation rates were determined from the VO_2 and VCO_2 values using the stoichiometric equations of Frayn (18):

$$\text{Fat oxidation (g/min)} = 1.67 \times VO_2 - 1.67 \times VCO_2$$

$$\text{Carbohydrate oxidation (g/min)} = 4.55 \times VCO_2 - 3.21 \times VO_2$$

Protein oxidation was assumed negligible under resting conditions. Therefore, gas analysis provided estimates of RMR, fat oxidation, and carbohydrate oxidation.

Statistical Analyses

All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, version 26; IBM Corp., Armonk, NY, USA). Descriptive statistics were computed and are reported as means and standard deviations (SD). The assumption of normality for each variable was evaluated using the Shapiro–Wilk Test, with statistical significance set at $P < 0.05$. A non-significant result from this test was considered to indicate that the data were normally distributed.

To examine both within-group changes over time and between-group differences, a two-way repeated-measures analysis of variance (ANOVA; 2 × 4) was conducted. When a significant interaction effect (group × time) was observed, pairwise comparisons were subsequently performed using the least significant difference (LSD) *post hoc* test to determine the specific sources of variation. Statistical significance for all analyses was established at $P < 0.05$.

RESULTS

Table 1 presents the physiological characteristics of the participants with severe obesity (n = 12). The mean age was 27 ± 5.54 years, with a sex distribution of 5 males and 7 females. The participants had a mean body mass index (BMI) of 41.49 ± 3.14 kg/m², reflecting the severe obesity classification. Mean body weight and height were 117.87 ± 14.58 kg and 168.33 ± 3.85 cm, respectively.

Body composition analysis indicated a mean percent body fat of 44.20 ± 6.21% and a fat mass of 52.57 ± 11.63 kg, alongside a fat-free mass of 65.30 ± 12.79 kg and skeletal muscle mass of 59.96 ± 9.64 kg. The visceral fat score averaged 25.50 ± 2.64.

Resting metabolic and hemodynamic measures showed a basal metabolic rate (BMR) of 2135.67 ± 142.34 kcal/day, with mean resting heart rate of 79.67 ± 17.44 bpm. Resting systolic blood pressure averaged 140.67 ± 18.10 mmHg, while diastolic blood pressure was 87.17 ± 16.09 mmHg. Waist-to-hip ratio and waist-to-height ratio were 1.26 ± 0.73 and 0.95 ± 0.11, respectively.

These baseline characteristics confirm the obese phenotype with elevated adiposity, impaired hemodynamic indices, and reduced metabolic efficiency typical of this population.

Table 1. Mean ($\bar{x}$) and Standard Deviation (SD) of Physiological Characteristics in Severely Obese Individuals.

Variables	Severely Obese Individuals (n = 12)
Age (yrs)	27 ± 5.54
Sex	Male = 5, Female = 7
Body Weight (kg)	117.87 ± 14.58
Height (cm)	168.33 ± 3.85
Body Mass Index (kg/m²)	41.49 ± 3.14
Percent Body Fat (%)	44.20 ± 6.21
Fat Mass (kg)	52.57 ± 11.63

Fat-Free Mass (kg)	65.30 ± 12.79
Skeletal Muscle Mass (kg)	59.96 ± 9.64
Visceral Fat Level (score)	25.50 ± 2.64
Basal Metabolic Rate (kcal/day)	2135.67 ± 142.34
Waist-to-Hip Ratio	1.26 ± 0.73
Waist-to-Height Ratio	0.95 ± 0.11
HR at Rest (bpm)	79.67 ± 17.44
SBP at Rest (mmHg)	140.67 ± 18.10
DBP at Rest (mmHg)	87.17 ± 16.09

Values are means ± SD. **SBP** = Systolic Blood Pressure, **DBP** = Diastolic Blood Pressure, **HR** = Heart Rate.

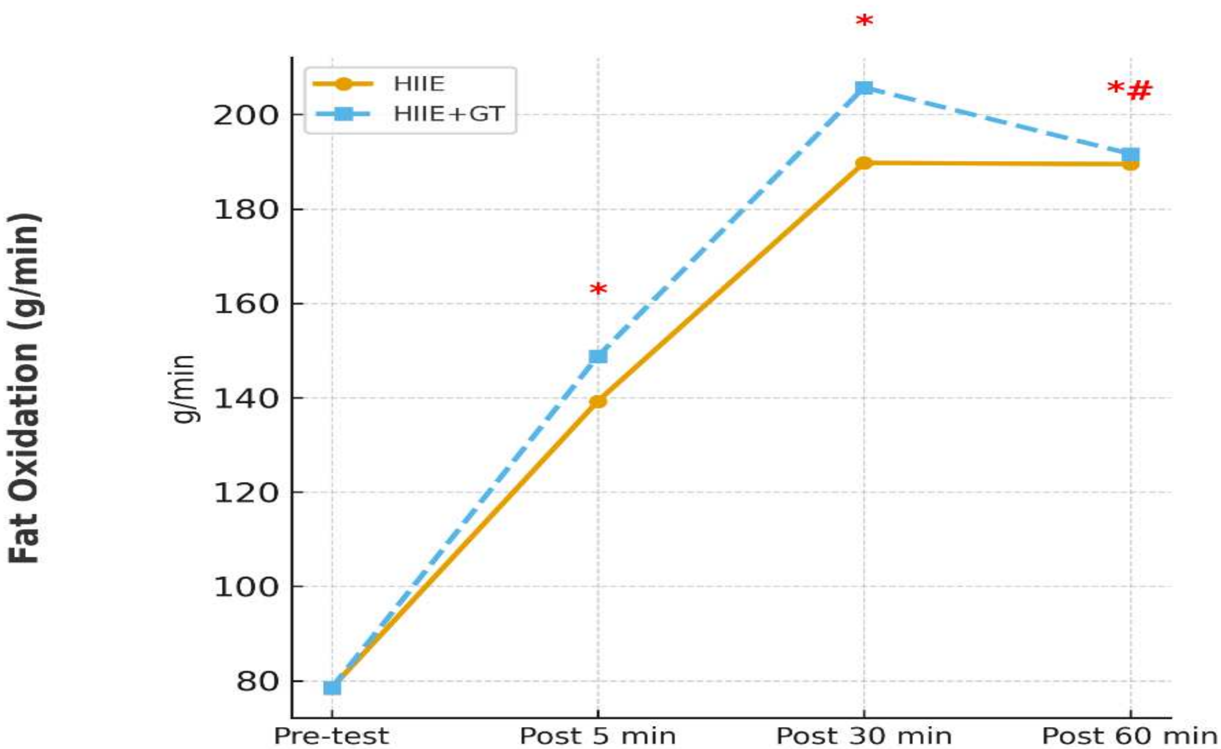

Figure 1. Changes in Fat Oxidation (g/min) at Baseline and 5, 30, and 60 Minutes after High-Intensity Interval Exercise (HIIE) Alone and HIIE Combined with Green Tea Supplementation (HIIE+GT) in Severely Obese Individuals. Values are presented as mean ± SD. *P < 0.05 vs. pre-test within group; #P < 0.05 vs. post 5 min within group.

At baseline (pre-test), fat oxidation values were similar between HIIE (78.42 ± 16.40) and HIIE+GT (78.42 ± 16.40). In both groups, fat oxidation significantly increased at 5 minutes post-exercise (HIIE: 139.25 ± 17.95; HIIE+GT:148.75 ± 17.95; P < 0.05 vs. pre-test). A further increase was observed at 30 minutes post-exercise, reaching the highest values in the HIIE+GT (205.75 ± 19.73) and moderately elevated levels in HIIE group (189.75 ± 19.73). At 60 minutes, fat oxidation remained significantly higher than pre-test in both conditions (HIIE: 189.50 ± 17.12; HIIE+GT: 191.67 ± 17.12; P < 0.05), with a decline compared to the 30-minute peak.

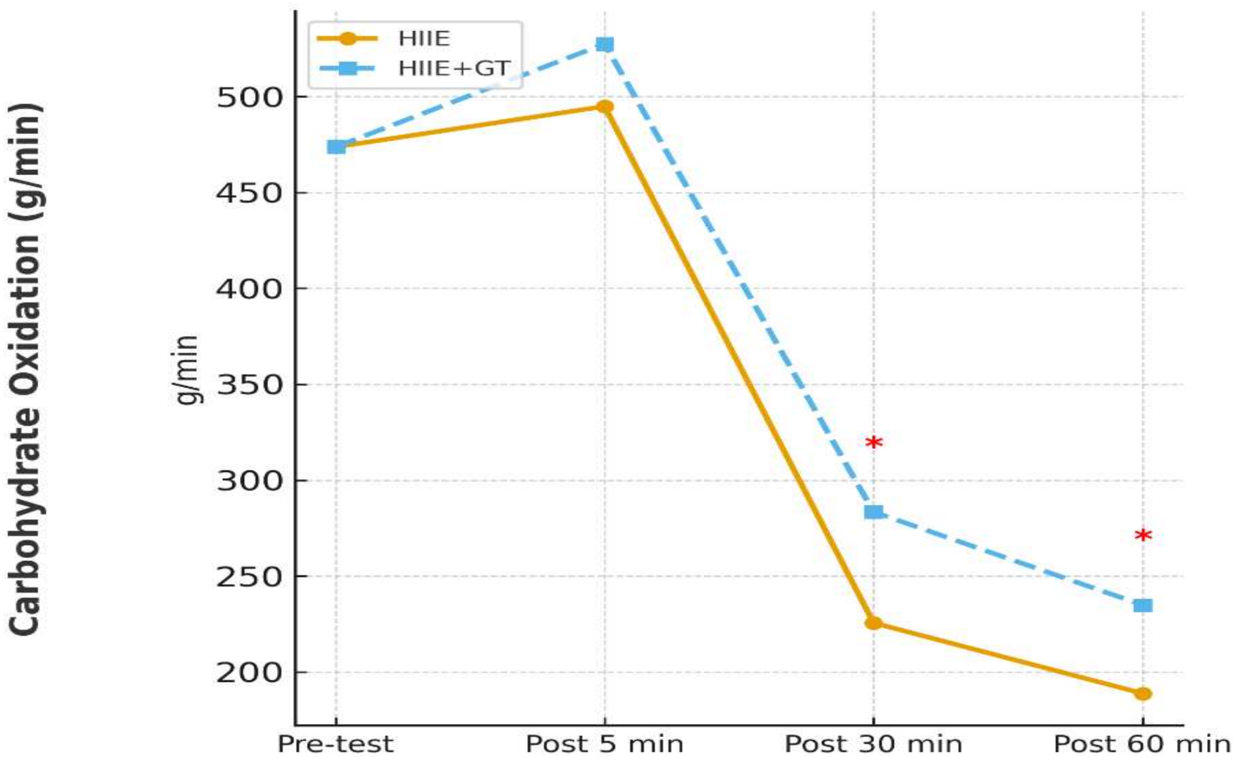

Figure 2. Changes in Carbohydrate Oxidation (g/min) at Baseline and 5, 30, and 60 Minutes after HIIE Alone and HIIE+GT in Severely Obese Individuals. Values are presented as mean ± SD. *P < 0.05 vs. pre-test within group.

Carbohydrate oxidation was comparable at baseline (HIIE: 473.67 ± 55.59; HIIE+GT: 473.67 ± 55.59). At 5 minutes post-exercise, CHO remained elevated relative to baseline (HIIE: 494.83 ± 60.62; HIIE+GT: 527.42 ± 60.62). However, a marked reduction was observed at 30 minutes (HIIE: 225.58 ± 58.11; HIIE+GT: 283.42 ± 58.11; P < 0.05 vs. pre-test), which persisted at 60 minutes post-exercise (HIIE: 188.83 ± 49.07; HIIE+GT: 234.92 ± 49.07; P < 0.05 vs. pre-test).

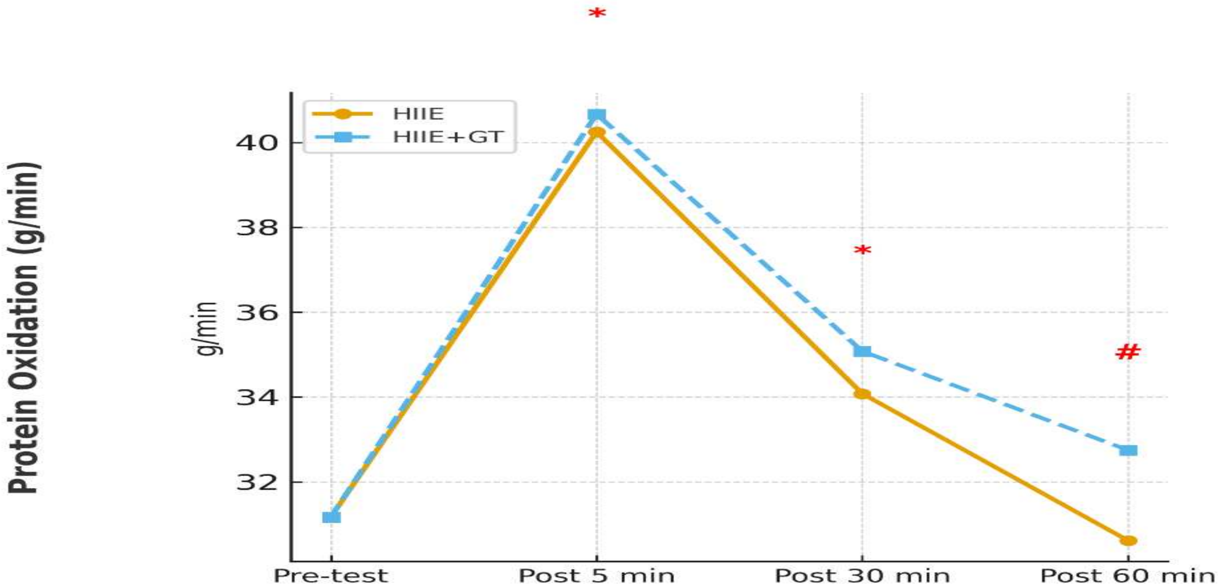

Figure 3. Changes in Protein Oxidation (g/min) at Baseline and 5, 30, and 60 Minutes after HIIE Alone and HIIE+GT in Severely Obese Individuals. Values are presented as mean ± SD. *P < 0.05 vs. pre-test within group; #P < 0.05 vs. post 5 minutes within group.

Protein oxidation (PRO) did not differ between groups at baseline (31.17 ± 1.80). At 5 minutes post-exercise, a significant increase was observed in both groups (HIIE: 40.25 ± 2.83; HIIE+GT: 40.67 ± 2.83; P < 0.05 vs. pre-test). At 30 minutes, PRO remained significantly elevated compared to pre-test (HIIE: 34.08 ± 2.36; HIIE+GT: 35.08 ± 2.36). By 60 minutes post-exercise, values returned close to baseline (HIIE: 30.62 ± 2.22; HIIE+GT: 32.75 ± 2.22; post 60 vs. post 5 minutes), suggesting a transient rise in PRO during the early recovery phase.

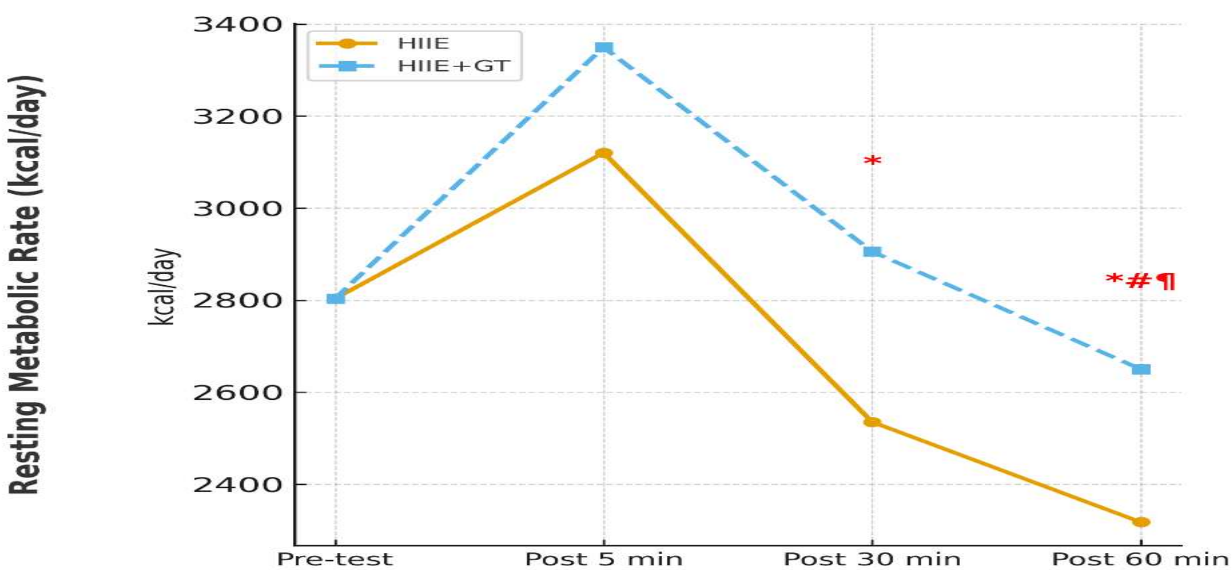

Figure 4. Changes in Resting Metabolic Rate (RMR, kcal/day) at Baseline and 5, 30, and 60 Minutes after HIIE Alone and HIIE+GT in Severely Obese Individuals. Values are presented as mean ± SD. *P < 0.05 vs. pre-test within group; #P < 0.05 vs. post 5 minutes within group; ¶P < 0.05 vs. post 30 minutes within group.

RMR values were identical between groups at baseline (2,803.25 ± 163.08). At 5 minutes post-exercise, both groups demonstrated an increase (HIIE: 3,120.17 ± 368.83; HIIE+GT: 3,349.42 ± 368.83). At 30 minutes, RMR remained significantly higher than baseline (HIIE: 2,535.42 ± 279.05; HIIE+GT: 2,905.58 ± 279.05; $P < 0.05$ vs. pre-test). At 60 minutes, RMR further declined but remained above baseline in HIIE+GT groups (HIIE: 2,317.83 ± 280.42; HIIE+GT: 2,650.17 ± 280.42; $P < 0.05$).

DISCUSSION

In this crossover study, both conditions (HIIE and HIIE+GT) elicited notable changes in substrate utilization and resting metabolic rate (RMR) during the recovery period after high-intensity interval exercise. The findings suggest that the addition of green tea extract provides further metabolic benefits beyond those induced by HIIE alone.

Consistent with previous research, green tea catechins, particularly epigallocatechin gallate (EGCG), appear to enhance fat oxidation through mechanisms related to sympathetic stimulation. This process may increase thermogenesis and lipolysis, resulting in greater mobilization of fatty acids for energy production. One proposed mechanism is the inhibition of catechol-O-methyltransferase (COMT), the enzyme responsible for norepinephrine degradation, which prolongs adrenergic receptor activation and facilitates lipolytic activity. This explanation is supported by studies reporting that EGCG supplementation augments fat oxidation both at rest and during exercise (17, 19).

In addition to promoting fat oxidation, green tea supplementation has been shown to elevate energy expenditure through thermogenic effects. Previous work demonstrated that acute ingestion of EGCG-containing extracts modestly increases 24-hour energy expenditure, reflecting an enhancement of resting metabolic rate. In the present study, RMR increased significantly at 5 minutes post-exercise in both conditions and remained elevated above baseline at 30 minutes and 60 minutes, with higher values consistently observed in the HIIE+GT condition. This finding suggests that green tea supplementation may prolong the post-exercise elevation of metabolic rate, thereby contributing to greater overall energy expenditure (20, 21).

Carbohydrate oxidation showed a marked decline at 30 minutes and 60 minutes post-exercise in both conditions, coinciding with the increase in fat oxidation. This substrate shift from carbohydrate toward fat utilization is consistent with the metabolic response to high-intensity exercise recovery and may be amplified by green tea supplementation (22). Protein oxidation demonstrated only a transient increase at 5 and 30 minutes post-exercise before returning toward baseline at 60 minutes, suggesting that amino acid catabolism was not a primary contributor to post-exercise energy metabolism (23). Overall, these results align with systematic reviews and meta-analyses reporting that green tea catechins can increase fat oxidation during exercise, although findings on long-term supplementation are mixed (24, 25). The present study adds evidence that acute green tea supplementation, when combined with HIIE, augments fat oxidation and sustains RMR during early recovery with practical implications for exercise and nutritional strategies aimed at improving metabolic health and weight management.

Limitations in this Study

However, some limitations should be acknowledged. The small sample size and inclusion of only severely obese individuals restrict the generalizability of the findings, and the assessment of protein oxidation did not incorporate nitrogen excretion, which may reduce accuracy although protein contribution is expected to be minimal. Moreover, the study examined only acute responses. Thus, the long-term effects of repeated HIIE+GT interventions remain uncertain. Despite these limitations, the findings suggest that combining HIIE with acute green tea supplementation may provide a synergistic effect by enhancing fat oxidation and sustaining energy expenditure during recovery, which could be particularly beneficial for overweight and obese individuals requiring efficient interventions to improve metabolic flexibility and energy balance. Importantly, the modest and transient increase in protein oxidation indicates that green tea supplementation does not exacerbate muscle protein breakdown in the post-exercise period, potentially supporting lean mass preservation. Future studies with larger cohorts, diverse populations, and chronic intervention designs are warranted to confirm whether these acute effects translate into sustained metabolic benefits and to explore the impact of individual variability in response to green tea catechins.

CONCLUSIONS

The present study demonstrated that high-intensity interval exercise (HIIE) significantly increased fat oxidation and resting metabolic rate (RMR) during post-exercise recovery, and that the addition of green tea supplementation further enhanced these effects. Specifically, the HIIE+GT condition showed greater elevations in fat oxidation at 30 minutes post-exercise and sustained increases in RMR up to 60 minutes, compared with HIIE alone. These findings support the hypothesis that green tea catechins, particularly EGCG, augment the metabolic benefits of high-intensity exercise by promoting lipid utilization and prolonging post-exercise thermogenesis.

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Address for correspondence: Tunyakarn Worasettawat, PhD, Faculty of Sports Science, Chulalongkorn University, Rama 1 Rd, Patumwan, Bangkok 10330, Thailand. Tel: +66 98 772 9796. Email: Wahn_2231@hotmail.com

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Hip Muscle Strength, Muscle Thickness and Dynamic Balance Control in Female Iliotibial Band Syndrome Runners: No Significant Associations Found

Orawan Jaiharn[1], Komsak Sinsurin[2], Surasa Khongprasert [1,3]

[1]Faculty of Sports Science, Chulalongkorn University, Bangkok, Thailand. [2]Faculty of Physical Therapy, Mahidol University, Nakhon Pathom, Thailand, [1]Faculty of Sports Science, Chulalongkorn University, [3]Center of Excellence in Exercise Physiology in Special Population, Bangkok, Thailand

ABSTRACT

Jaiharn O, Sinsurin K, Khongprasert S. Hip Muscle Strength, Muscle Thickness and Dynamic Balance Control in Female Iliotibial Band Syndrome Runners: No Significant Associations Found. The purpose of this study was to investigate the Gluteus medius (GMed) muscle thickness and hip muscle strength in female runners with iliotibial band syndrome (ITBS), and to examine their associations with dynamic balance performance. Thirty female runners with ITBS (mean age 35.7 ± 6.8 years) participated in this study. GMed muscle thickness was assessed using ultrasound imaging, hip muscle strength was measured with isokinetic dynamometry, and dynamic balance was evaluated using the Y-Balance Test (YBT). Results showed a significant difference only in the hip flexor strength between the injured and non-injured legs. No significant associations were found between GMed muscle thickness, hip muscle strength, and the YBT composite scores. These findings suggest that hip muscle strength and GMed thickness may not directly influence dynamic balance performance in female runners with ITBS.

Key Words: Dynamic Balance Control, Female Runner, Iliotibial Band Syndrome, Muscle Thickness

INTRODUCTION

Running is basically a series of single-leg movement cycle. A runner with poor single-leg balance may have an unstable gait that can lead to inefficient movement patterns and an increase in the risk of knee injuries. Since the Iliotibial Band Syndrome (ITBS) is one of the most common chronic running-related injuries, it is essential to identify the causes and factors of the injury (2). Interestingly, different studies have highlighted the increase in the risk factors of the ITBS, including the anatomical imbalances and a lack of proper running patterns (1,3,10,12,16).

Skeletal muscle strength is influenced by various factors. For example, muscle mass, the size of a muscle's cross-sectional area, muscle fiber type composition, and muscle architecture have an influence on muscle strength (17) as well as the neural factors, such as motor unit recruitment, synchronization, and muscle fiber firing pattern. Although there are several ways to measure muscle strength, studies have shown that muscle thickness as measured by ultrasound is reliable and has been correlated with muscle functions (7). Moreover, a study of a group of healthy subjects indicates that muscle size is important in generating muscle force (15).

It is well documented that the strengthening of hip muscles is crucial for proper mechanics of the lower extremity and reduces stress on the knee joint. The hip abductors, such as the Gluteus medius (GMed) help to stabilize the pelvis and femur during activities like walking and running. Also, it is important to point out that the strength of the hip muscles and their function are considered a strong predictor of controlling balance (5,8,13). Furthermore, the biomechanical evidence indicates that GMed weakness results in a deviation of body's center of mass from the supported leg (14), which may cause a deficiency of balance control and increased tensile strain on the knee joint compartment (18).

The Y Balance Test (YBT) is a useful clinical tool that requires the subject to balance on one leg and reach the furthest as possible in 3 directions: Anterior (A), Posteromedial (PM), and Posterolateral (PL). The test provides important information about the person's risk of injury, physical readiness, functional strength, and dynamic balance. Even though a correlation study on a group of athletes at 6 months following anterior cruciate ligament reconstruction showed no correlation between the hip muscles strength and the YBT composite score in either the injured or the non-injured legs. A strong positive correlation was found between the eccentric hip abductor and the YBT composite score (5). In addition, the study by Paz and colleagues (13) also found a strong correlation between hip external rotator strength and the YBT composite score in young recreationally resistance-trained women.

Moreover, a significant difference was found between the dominant and non-dominant legs in the anterior reach distance of the YBT. However, the link between the hip muscles' strength and the single-leg balance in runners is scant. Understanding these relationships could enhance the advantage of addressing the effective treatment and functioning exercise in a group of knee pain runners. Therefore, the purpose of this study was to examine the thickness of the GMed muscle and strength of the hip muscles in female ITBS runners and to determine the relationship between GMed thickness, hip muscles' strength, and single-leg balance during the dynamic YBT.

METHODS

Subjects

Thirty female distanced runners (aged between 20 and 45 years) were recruited in this study. The inclusion criteria were as follows: Experiencing pain on the outer aspect of the knee during running for at least 3 months, reporting a minimum pain score (12) of 3 out of 10, and positively confirmed by the Noble Compression Test. Individuals with previous lower extremity abnormalities, surgery, and/or impaired ability to control postural balance were excluded. All the participants reported a single injured leg (ITBS leg). This study was approved by Chulalongkorn University Institutional Review Board for Humans (COA number 002/67). The informed consent was obtained from all the participants.

Procedures

Before the examination protocol, the subjects' weight, height, and limb length were collected. ITBS legs were evaluated by a licensed physiotherapist to determine if the individuals met the criteria. The provocative Noble compression technique was applied to either Gerdy's tubercle or the lateral epicondyle while the knee was flexed to 90° at starting. The subjects reported pain if they had a current symptom of ITBS.

Ultrasonography Assessments

Ultrasound imaging (USI) is a non-invasive method to observe muscle thickness changes. The use of USI has been reported to be reliable and valid in measuring muscle morphology (7). The USI method was conducted by a single examiner to investigate the GMed muscle thickness. The subjects were in a side-lying position with the test leg-up. The hip was in neutral and slightly adduction while the knee was in fully extension. Three static images of the bilaterally GMed muscle were obtained using a C5-1 MHz curvilinear transducer (EPIQ5, Philips, USA). To locate the GMed muscle, the examiner located the greater trochanter and a point 25% of the distance between the anterior superior iliac spine (ASIS) and the posterior superior iliac spine (PSIS). Then, the transducer was perpendicularly placed to examine the GMed muscle thickness. The transducer was removed and repositioned within a 10-sec rest between the trials (18).

Strength Assessments

An isokinetic testing device (Biodex, USA) was used to conduct muscle strength tests in the following positions: hip abduction, hip adduction, hip extension, and hip flexion. The strength of the hip muscles was tested in the standing position. Testing was performed on both legs. To become familiarized with the procedure, a total of 5 repetitions of a warm-up session was allowed with a 2-min rest period before the test. The subjects were instructed to perform 5 repetitions of concentric contractions for each position, across 2 sets, with a 2-min rest between sets at an angular velocity of 60°/s. The average peak muscle torque (Nm/kg) was analyzed.

Balance Assessments

The Y-Balance Test (YBT)

The YBT is a functional balance test that integrates a single-leg stance and a maximum reaching distance of the opposite leg. The YBT consists of anterior, posteromedial, and posterolateral directions employed to examine the dynamic balance control. The tape was attached in a Y shape which is 120 cm long on each axis on the laboratory floor. The subjects wore standard training shoes and were instructed to maintain a single-leg stance while reaching as far as possible with the opposite leg along the designated axis, before returning to the starting position. Each subject was given practice trials before completing 3 successful test trials in each direction. The trials were repeated if compensatory movements occurred, such as deviation from the starting point or loss of balance. Reach distances were normalized to limb length that was measured in the supine position from the anterior superior iliac spine (ASIS) to the center of the medial malleolus. The composite YBT score was calculated using the following formula: The formula (15): % Composite YBT Score = (sum of total 3 reach distance directions / 3 times limb length) x 100.

Statistical Analyses

All statistical analyses were performed using the SPSS version 26.0 for Windows (SPSS Inc., Chicago, IL, USA). Between-leg differences in GMed thickness and hip muscle strength were examined using the paired *t*-test. The data are presented as mean ± standard deviation (SD). Pearson's correlation coefficients were calculated to assess the relationships among the hip muscle strength, GMed thickness, and single-leg balance performance during the dynamic Y-Balance Test (YBT). The strength of correlations was interpreted as strong ($r \geq 0.50$), moderate ($0.30 \leq r < 0.50$), or weak ($r < 0.30$). Statistical significance was set at a $P < 0.05$.

RESULTS

A total of 30 female runners with ITBS were included in the study. All the subjects reported unilateral ITBS, providing 30 affected legs and 30 contralateral non-affected legs as controls. The mean age of the subjects was 35.7 years (SD = 6.78), with a mean body weight of 53.61 kg (SD = 7.00) and a mean height of 1.60 m (SD = 0.06). There was no significant difference in leg length between the ITBS leg (82.70 ± 3.68 cm) and the contralateral leg (82.63 ± 3.53 cm). The subjects' characteristics are summarized in Table 1.

Table 1. Descriptive Data of the Participants.

Variables	N = 30
Age (yrs)	35.7 ± 6.78
Weight (kg)	53.61 ± 7.00
Height (m)	1.60 ± 0.06
Leg Length (cm)	
▪ ITBS-Leg	82.70 ± 3.68
▪ Normal-Leg	82.63 ± 3.53

The data are presented as mean ± SD.

No significant differences were observed in the Gluteus medius (GMed) thickness between the ITBS and the contralateral legs. However, the hip flexor strength was significantly lower in the ITBS leg compared with the non-affected leg ($P = 0.002$; Table 2).

Table 2. The Difference of GMed Thickness and Hip Muscle Strength Between Legs.

Variables	ITBS-Leg (N = 30)	Normal-Leg (N = 30)	P-value
Gmed Thickness (mm)	20.52 ± 2.95	21.07 ± 3.06	0.297
Muscle Strength (Nm/kg)			
HAB	25.06 ± 10.06	27.67 ± 10.39	0.335
HAD	31.52 ± 14.43	35.63 ± 13.15	0.061
HEXT	44.50 ± 19.12	45.75 ± 19.08	0.562
HFLEX	43.60 ± 14.39	37.85 ± 13.31	0.002*

The data are presented as mean ± SD. **HAB** = Hip Abductors, **HAD** = Hip Adductors, **HEXT** = Hip Extensors, **HFLEX** = Hip Flexors.

Correlation analyses revealed no significant associations between GMed thickness, hip muscle strength, and the Y-Balance Test (YBT) composite scores. Nonetheless, a moderate inverse correlation was observed between the GMed thickness of the contralateral leg and the YBT composite scores when standing on the ITBS leg (r = -0.412, P = 0.024), and when standing on the contralateral leg (r = -0.479, P = 0.007; Table 3).

Table 3. Pearson's Correlations Between GMed Thickness, Hip Muscles Strength and the YBT Composite Score.

Variables The ITBS Leg		YBT Composite Score (the ITBS Leg)	YBT Composite Core (the Normal Leg)
GMed Thickness	r	-0.350	-0.348
	P	0.058	0.060
HAB Strength	r	0.008	-0.033
	P	0.965	0.861
HAD Strength	r	-0.103	-0.030
	P	0.587	0.875

HEXT Strength	r	-0.162	-0.137
	P	0.392	0.470
HFLEX Strength	r	0.086	0.035
	P	0.719	0.855
The Normal Leg			
GMed Thickness	r	-0.412	-0.479
	P	0.024*	0.007*
HAB Strength	r	-0.299	-0.241
	P	0.109	0.199
HAD Strength	r	0.010	-0.005
	P	0.958	0.978
HEXT Strength	r	-0.147	-0.079
	P	0.439	0.678
HFLEX Strength	r	0.073	0.033
	P	0.703	0.988

HAB = Hip Abductors, **HAD** = Hip Adductors, **HEXT** = Hip Extensors, **HFLEX** = Hip Flexors.

DISCUSSION

The primary finding of this study was the presence of a between-leg difference in muscle strength, particularly in the hip flexors among the female runners with ITBS. Although the ITBS leg tended to exhibit smaller Gluteus medius (GMed) muscle thickness compared with the contralateral leg, only hip flexor strength showed a significant difference. Previous research by Strasser and colleagues (15) demonstrated that greater muscle thickness is associated with a higher maximal voluntary contraction (MVC), suggesting that smaller muscle size may reflect reduced strength. Interestingly, however, the present study found that the injured ITBS leg demonstrated significantly greater hip flexor strength, but not hip abductor strength.

The GMed plays a critical role in preventing pelvic drop during single-leg balance. The weakness of this muscle has been identified as a key factor contributing to knee pain in runners, including those with ITBS. Moreover, deficits in hip abductor strength have been linked to impaired postural stability, as reflected by the increased center of pressure displacement during the single-leg stance in females (8).

Running is a repetitive cyclic movement that requires proper postural balance control. The hip flexor muscles are the primary muscles responsible for hip flexion. This movement is a key component of the swing phase in the running gait, which is important for runners. During the single-leg stance, on the other hand, the hip flexor muscles work eccentrically and isometrically to control the movement of the leg and trunk. This mechanism helps to maintain an upright stable posture.

The YBT performance in recreational runners is not influenced by a single biomechanical factor (6). This study indicates that the overall composite YBT score was found to be associated with hip flexor muscle strength, ankle dorsiflexion ROM, and the Q angle. In addition, the PM and PL reach directions were also primarily associated with the strength of the hip flexor muscles. Thus, the performance of anterior YBT reach was most associated with a variety of specific biomechanical factors and the YBT performance and the presence of asymmetries between legs are often linked to a higher risk of injury among athletes.

To our knowledge, only a few studies have reported a balanced assessment in runners with ITBS. Meardon et al. (11) found that only the group of runners with injury of the lower limb (hip, thigh, and/or knee) impaired the dynamic postural control following the landing tasks. Our results show no relationship between the GMed thickness and strength of the hip muscles and YBT composite score when the subjects performed tests on both the injured ITBS and the normal leg. In agreement with this finding is Whiler et al. (19) who reported that there was no correlation between muscle thickness, muscle strength, and function in a group of healthy men and women.

Our results also demonstrated a significant negative correlation between the GMed muscle thickness and the Y-Balance Test (YBT) composite scores, which are derived from reach distances. Although progress has been made in this research area, the evidence remains conflicting. For example, Foch et al. (4) reported no association between isometric hip abductor strength and peak hip adduction angle in healthy runners. On the contrary, Lee and colleagues (9) showed a positive correlation between hip extensor strength and the performance of the YBT in all directions. Therefore, the careful interpretation is advocated.

Clinical Implications and Future Directions

1. Ultrasound imaging (USI) is a useful tool for evaluating muscle thickness in clinical practice and may assist in monitoring muscle adaptations in ITBS runners.

2. Asymmetry between limbs should be carefully assessed, particularly hip flexor strength that showed significant differences between the affected and contralateral legs.

3. Single-leg balance is not determined by an isolated muscle group, but rather it reflects the coordinated interaction of hip, knee, and ankle musculature together with central nervous system control. Future studies should consider multi-joint and neuromuscular mechanisms when examining balance deficits in the ITBS population.

Limitation in this Study

This study has several limitations that should be acknowledged. First, muscle thickness assessment provides only a one-dimensional measure. It may not fully capture the physiological properties underlying muscle structure and function. Second, muscle strength testing was limited to concentric contractions. Future research should also consider eccentric and isometric contractions, which play an important role in functional performance. Finally, the relatively small sample size may have limited the statistical power to detect subtle associations.

CONCLUSIONS

This study demonstrates the significant differences between legs in the hip muscle, particularly the hip flexors in the female ITBS runners. This finding highlights not only the importance of the strength of the GMed as a hip stabilizer muscle but also the hip flexors' key role in active stabilization to control the movement during running. Even though our study did not find the relationships between the hip muscles strength and balance performance. The dynamic control during the YBT reflects the better performance of single-leg balance and daily life activities. Therefore, from the exercise physiology point of view, strengthening the hip flexors as well as the continue training of the hip abductors and extensors, given that they are highly involved in static balance control, can help contribute to an overall hip stability and improve performance in balance-related tasks.

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Address for Correspondence: Surasa Khongprasert, PhD, Faculty of Sports Science
Chulalongkorn University Rama 1 Road, Pathumwan District, Bangkok, Thailand 10330.
Email:surasa.K@chula.ac.th

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