

A follow-up study on the physique, body composition, physical fitness, and isokinetic strength of female collegiate Taekwondo athletes

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The purpose of the study was to analyze changes in physique, body composition, physical fitness, and isokinetic strength in female collegiate taekwondo athletes. The study included 14 subjects, of whom 8 were followed up throughout the study. Anthropometric characteristics included body weight, height, sitting height, circumferences, and bone width. Physical fitness parameters included flexibility, agility, muscle strength, muscular endurance, power, speed, and cardiorespiratory endurance. Peak torque, mean power, and H/Q ratio were analyzed by using Cybex 770. All data were analyzed by using the SAS statistical program. Paired t test was performed, with 0.05 as the significance level.

The results indicated significant changes in body weight, and upper arm and flexed upper arm circumferences during the experimental period. Test scores for plate tapping, and sit and reach significantly increased, but that for power decreased. In addition, the peak power of right flexion at 180°/sec was significantly increased, as well as the mean power of right and left flexion, and the H/Q ratio at 180°/sec.

Keywords: Physical fitness, Body composition, Isokinetic strength, Taekwondo

INTRODUCTION

Since Taekwondo was selected to be among the official events in the 2000 Sydney Olympics, its value as a new Olympic event has been recognized and it has evolved as a martial art sport, undergoing various changes (Kazemi and Pieter, 2004). Since the 2012 London Olympic Games, Taekwondo has shifted from the single-point scoring system to the differential point scoring system, increasing the possibility of quick turnaround of scores. The size of the Taekwondo arena was reduced to 10 (wide)×10 m (long) from 12×12 m. Passive progression of the game was improved to active progression through the application of the 10-sec rule. In addition, the sudden-death system implemented during overtimes was introduced in 2005. Henceforth, the importance of physical fitness started to emerge. In the 2016 Rio de Janeiro Olympics in Brazil, a video replay system will be introduced, and electronic protective gears and headgears will be worn to achieve accurate first judg-

ments. Other trends are expected.

Therefore, the changes in the rules of the game require new skills and trainings, accompanied by adaptations and efforts by coaches and athletes. In reality, leaders are evaluated based on records and prizes achieved through athletic performances. However, many schools and teams do not consider the conditions of individual athletes, thereby causing problems (Brooks et al., 2008; Halson and Jeukendrup, 2004). Most coaches and athletes depend on their skills that pertain to the nature of Taekwondo, based on their experiences, improvement in physical fitness, training for reinforcement of mental power, and amount of training.

In general, annual training of collegiate Taekwondo athletes in South Korea is designed differently depending on the season (in-season and off-season). During the in-season, condition training and skill training are performed for 3-5 h a day, besides attending classes within the semester. During vacation, which is the off-season, athletes perform high-intensity sport training, mostly

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in camps, focusing on sport-related skills and physical fitness, in preparation for the in-season (Jeong et al., 2011). Athletes of the Taiwan national team are known for their high-intensity training, conducted 6 times a week, 5-6 h daily, before competitions (Tsai et al., 2011).

High-intensity training, excessive training, overreaching training, and overtraining without appropriate rest periods reduce athletic performance via the accumulation of fatigue and cause sport-related injuries. Therefore, positive effects are likely unexpected from such trainings (Halson and Jeukendrup, 2004). On the contrary, individual physical fitness, intensity level, and efficiency should be considered in the training. However, although these factors have been recognized by sports leaders and coaches, they have been overlooked because of issues of practicality.

Considering that Taekwondo is a weight division game, the physical characteristics of athletes are a critical factor of winning or losing (Claessens et al., 1994). Moreover, the differential point system is beneficial to relatively tall athletes for scoring by attacking the opponent's face. In addition, low body fat percentage and high fat-free mass, which are body composition factors (Lanay et al., 2007) that can serve as sensitive indicators of athletic performance in weight division events, are common characteristics found in excellent Taekwondo players (Fong et al., 2011; Kim et al., 2011; Markobic et al., 2005). These characteristics are also closely related to the physical fitness of athletes. The important physical fitness factors in the sport of Taekwondo reportedly include power, muscular strength, muscular endurance, agility, and flexibility (Bouhler et al., 2006; Markobic et al., 2008). In particular, muscular functions such as muscular strength and endurance of the lower extremities are important factors for executing a strong and accurate kick. They are considered as training targets of individual athletes because they measure the muscular functions of the lower extremities (Cools et al., 2007; Markobic et al., 2008).

To date, although many studies have been conducted on the positive effects of short- to medium-term training for 1-3 months (Kim et al., 2011; Melhim, 2001; Storen et al., 2008; Sunde et al., 2010), no long-term follow-up study and proper evaluation of training efficiency and relevance have been conducted (Jeong et al., 2011).

Therefore, the goal of the present study was to provide useful information for designing and developing long-term training programs, and basic data for longitudinal studies by identifying changes in physique, physical fitness, body composition, and isokinetic strength of female collegiate Taekwondo athletes with 1 yr of long-term highly intensive training.

MATERIALS AND METHODS

Subjects

As subjects, 12 female athletes with a mean age of 18.9 yr who were attending K University in Y City were randomly selected. This study was conducted from December 2004 to December 2005. All examinations were completed in 1 week. The subjects trained daily for 3 h. Four female athletes refused to participate in the examination for personal reasons. Finally, 8 female athletes participated in the study and were informed of the test procedures before providing written consent. All of the subjects had no physical and weight loss problems, and were not taking any medication

Variables

Physique

Measurements were performed with the participants barefoot and in minimal clothing. Body weight was measured to the nearest 0.1 kg by using a digital weighing scale (Seca 841, GmbH & Co., Germany); and body height, to the nearest centimeter by using an extensometer (STDK Model1 HD, Japan). The circumferences of 7 sites (upper arm, flexed upper arm, chest, waist, hip, thigh, and calf) and bone widths (humerus and femur) were measured to the nearest centimeter by using a tape measure and spreading caliper, respectively. The skinfold thickness of 5 sites (triceps, subscapular, suprailiac, thigh, and medial calf) was measured twice on the left side of the body by using a Harpenden caliper (Holtain, Crymych, UK).

Body composition

Body composition variables were measured by performing a bioelectrical impedance analysis (Inbody 3.0, Biospace, Korea). Measurements were performed with the participants barefoot and in minimal clothing without any metallic materials. Percent body fat, fat mass, fat-free mass, and total body water were measured.

Physical fitness

For the physical fitness tests, the European test was used, and 9 variables from 7 factors were tested. Each test was performed according to the following sequence: balance (flamingo balance), speed (plate tapping), flexibility (sit and reach), power (standing long jump), static muscle strength (grip strength), muscular endurance (sit-ups and bent-arm hang), agility (50-m shuttle run), and cardiorespiratory endurance ($V_{O_{2max}}$). $V_{O_{2max}}$ was determined for each subject during an "all-out" progressive exercise test on Vmax 229 (Sensor Medics, USA), according to the Bruce proto-

col. The $V_{O_{2max}}$ was considered to have been reached if at least 3 of the following criteria were met: (1) when the heart rate does not increase even if the test strength is increased; (2) when the respiratory rate is greater than 1.10%; (3) when the rating of perceived exertion according to Borg's scale is greater than 17; (4) when heart rate is higher than 90% of the predicted heart rate; and (5) when oxygen consumption is stagnant despite the increase in intensity.

Isokinetic strength

Isokinetic dynamometry (Cybex 770, NORM, USA) was performed to evaluate flexion and extension of the right and left knees. Each test included 3 maximal contractions at 60°/sec for muscle strength and 25 maximal contractions at 180°/sec for muscle endurance.

Statistical analyses

Statistical analyses were performed by using the SAS version 12.0 software for Windows. All data were presented as mean and standard deviation values. Paired t test was used to analyze changes over time in each parameter. $P < 0.05$ was considered as statistically significant.

RESULTS

Changes in physique

The changes in physique during the follow-up study from 2004 to 2005 are shown in Table 1. Body weight and upper arm circumference statistically significantly increased ($P < 0.05$), as well

Table 1. Changes in physique

	2004	2005	t value	P
	Mean±SD	Mean±SD		
Body weight (kg)	58.4±7.22	61.4±7.76	-2.862	0.024*
Standing height (cm)	165.5±5.48	165.2±5.57	1.503	0.177
Upper arm circumference (cm)	26.0±1.85	27.4±1.38	-2.818	0.026*
Flexed upper arm circumference (cm)	26.9±1.70	28.0±1.53	-3.636	0.008**
Chest circumference (cm)	82.2±3.80	85.9±3.32	-4.764	0.002***
Waist circumference (cm)	68.6±4.09	70.1±4.73	-1.638	0.145
Hip circumference (cm)	92.3±4.56	97.1±5.23	-4.084	0.005**
Thigh circumference (cm)	58.4±4.06	56.5±2.58	1.625	0.148
Calf circumference (cm)	37.7±2.25	36.8±2.11	1.849	0.107
Humerus diameter (cm)	5.9±0.29	5.9±0.33	0.000	1.000
Femur diameter (cm)	8.8±0.96	9.5±0.68	-1.662	0.140

* $P < 0.05$. ** $P < 0.01$. *** $P < 0.005$.

as the flexed upper arm and hip circumferences ($P < 0.01$), and chest circumference ($P < 0.005$).

Changes in body composition

The changes in body composition during the follow-up study from 2004 to 2005 are shown in Table 2. The mean body fat percentage showed a statistically significant increase ($P < 0.005$) from 21.1±2.61% in 2004 to 25.7±4.20% in 2005, as well as the mean body fat mass ($P < 0.01$), from 12.4±2.57 kg to 15.9±4.33 kg.

Changes in physical fitness

The changes in physical fitness during the follow-up study from 2004 to 2005 are shown in Table 3. Balance (flamingo balance), grip strength, abdominal muscular endurance (sit-ups), muscular endurance (bent arm hang), and agility (50-m shuttle run) showed no significant changes. However, hand agility (plate

Table 2. Changes in body composition

	2004	2005	t value	P
	Mean±SD	Mean±SD		
% Body fat	21.1±2.61	25.7±4.20	-5.062	0.001***
Fat mass (kg)	12.4±2.57	15.9±4.33	-3.868	0.006**
Fat free mass (kg)	46.0±5.31	45.3±4.48	1.138	0.293
Total body water (ℓ)	32.3±3.92	31.4±3.14	1.698	0.133

** $P < 0.01$. *** $P < 0.005$.

Table 3. Changes in physical fitness

	2004	2005	t value	P
	Mean±SD	Mean±SD		
Flamingo balance (n)	5.3±1.91	4.9±2.30	0.341	0.743
Plate tapping (sec)	9.3±0.74	8.7±0.71	3.192	0.015*
Sit and reach (cm)	18.8±7.87	22.0±6.87	-3.377	0.012*
Grip strength (kg)	25.9±6.63	29.5±5.03	-1.150	0.294
Sit-ups (n)	29.4±5.01	30.6±3.02	-1.234	0.257
Long-distance jump (cm)	204.0±8.65	191.0±15.20	3.073	0.018*
Bent arm hang (sec)	5.7±3.69	9.1±7.29	-1.919	0.103
50-m Shuttle run (sec)	19.3±0.69	19.5±0.62	-1.104	0.350
HR _{max} (beats/min)	192.7±3.51	193.7±4.04	-0.480	0.678
VO ₂ (L/min)	2.7±0.31	3.0±0.43	-2.291	0.084
VO _{2max} /kg (mL/kg/min)	45.2±3.69	48.6±6.11	-1.385	0.238
VCO ₂ (L/min)	3.1±0.56	3.4±0.47	-3.724	0.020*
RQ	1.2±0.08	1.1±0.13	0.246	0.818
VE (L/min)	91.9±21.02	97.2±17.53	-1.887	0.132

* $P < 0.05$.

HR_{max}, maximal heart rate; VO₂, oxygen consumption; VO_{2max}, maximal oxygen consumption; VCO₂, carbon dioxide production; RQ, respiratory quotient; VE, min ventilation.

tapping) showed a significantly improved record ($P < 0.05$), from 9.3 ± 0.74 in 2004 to 8.7 ± 0.71 in 2005. Flexibility (sit and reach) also significantly increased ($P < 0.05$) from 18.8 ± 7.87 in 2004 to 22.0 ± 6.87 in 2005. However, power (long-distance jump) significantly decreased ($P < 0.05$) from 204.0 ± 8.65 in 2004 to 191.0 ± 15.20 in 2005. As for cardiovascular endurance, maximal heart rate, oxygen intake, oxygen intake per body weight, min ventilation volume, and respiratory rate showed no significant differences, but carbon dioxide emission significantly increased ($P < 0.05$).

Isokinetic strength

Maximum muscular strength (peak torque)

Maximum muscular strength was defined as the maximum value during extensor muscle exercise performed 3 times in $60^\circ/\text{sec}$ of angular speed and during flexor muscle exercise performed 25 times in $180^\circ/\text{sec}$ (distance \times force). The changes in the muscular strength of the research participants are shown in Table 4. The maximum muscular strength of the right flexor muscle at $180^\circ/\text{sec}$ of angular speed significantly increased ($P < 0.005$) from 61.8 ± 11.11 Nm in 2004 to 73.5 ± 10.64 Nm in 2005.

Table 4. Maximum muscular strength (Nm)

		2004	2005	t value	P
		Mean \pm SD	Mean \pm SD		
Peak torque $60^\circ/\text{sec}$	Extension	147.5 \pm 14.67	142.3 \pm 20.03	1.107	0.305
		135.0 \pm 21.74	139.9 \pm 18.11	-0.935	0.381
	Flexion	90.6 \pm 7.41	88.9 \pm 20.50	0.268	0.797
		83.5 \pm 11.29	92.6 \pm 14.80	-2.002	0.085
Peak torque $180^\circ/\text{sec}$	Extension	96.5 \pm 12.48	89.5 \pm 11.55	1.513	0.174
		88.4 \pm 13.70	88.3 \pm 11.35	0.043	0.967
	Flexion	63.4 \pm 8.53	71.6 \pm 13.15	-1.675	0.138
		61.8 \pm 11.11	73.5 \pm 10.64	-4.652	0.002***

*** $P < 0.005$.

Table 6. Ratios of ipsilateral muscular strength (%)

		2004	2005	t value	P
		Mean \pm SD	Mean \pm SD		
H/Q ratio $60^\circ/\text{sec}$	Left	61.7 \pm 3.65	63.1 \pm 13.89	-2.269	0.796
	Right	62.2 \pm 3.03	66.5 \pm 9.46	-1.649	0.143
H/Q ratio $180^\circ/\text{sec}$	Left	64.1 \pm 5.21	78.3 \pm 13.06	-2.514	0.040*
	Right	69.9 \pm 6.45	81.2 \pm 11.86	-2.533	0.039*

* $P < 0.05$.

Muscular strength according to body weight (peak torque % body weight)

Muscular strength according to body weight was presented as the percentage of exerted maximum muscular strength to the total body weight during extensor muscle exercise performed 3 times in $60^\circ/\text{sec}$ of angular speed and during flexor muscle exercise performed 25 times in $180^\circ/\text{sec}$ of angular speed (peak torque/body weight $\times 100$). Changes in the percentage of muscular strength to the total body weight of the research participants are shown in Table 5. The percentages of muscular strength of the extensor and flexor muscles of the left and right sides in $60^\circ/\text{sec}$ and $180^\circ/\text{sec}$ of angular speeds significantly increased ($P < 0.05$, $P < 0.005$, $P < 0.001$).

Ipsilateral muscular strength ratio (hamstring-to-quadriceps ratio)

Ipsilateral muscular strength ratio was defined as the ratio of the flexor muscle to the extensor muscle (flexion peak torque/extension peak torque $\times 100$). Changes in ipsilateral muscular strength ratio in the research participants are shown in Table 6. The ipsilateral muscular strength ratio in the left side in $180^\circ/\text{sec}$ of angular speed significantly increased ($P < 0.05$) from $64.1\% \pm 5.21\%$ in 2004 to $78.3\% \pm 13.06\%$ in 2005, as well as the right side ($P < 0.05$), from $69.9\% \pm 6.45\%$ in 2004 to $81.2\% \pm 11.86\%$ in 2005.

Table 5. Percentage of muscular strength to the total body weight (%)

		2004	2005	t value	P
		Mean \pm SD	Mean \pm SD		
Peak torque % BW $60^\circ/\text{sec}$	Extension	189.4 \pm 21.84	234.5 \pm 31.26	-7.314	0.000****
		160.0 \pm 42.45	231.1 \pm 29.80	-4.854	0.002***
Flexion		113.0 \pm 21.79	146.0 \pm 30.12	-2.436	0.045*
		107.0 \pm 9.39	152.3 \pm 20.63	-6.098	0.000****
Peak torque % BW $180^\circ/\text{sec}$	Extension	126.4 \pm 13.67	147.9 \pm 20.70	-4.489	0.003***
		112.9 \pm 12.48	145.5 \pm 16.46	-5.838	0.001***
Flexion		81.1 \pm 11.61	117.5 \pm 15.01	-5.098	0.001***
		78.8 \pm 9.41	120.8 \pm 11.86	-10.542	0.000****

* $P < 0.05$. *** $P < 0.005$. **** $P < 0.001$.

Table 7. Maximum muscular strength ratios in both sides (%)

		2004	2005	t value	P
		Mean \pm SD	Mean \pm SD		
Deficit $60^\circ/\text{sec}$	Extension	-7.0 \pm 11.10	-3.8 \pm 13.95	-0.485	0.648
	Flexion	-2.3 \pm 12.75	-9.3 \pm 6.47	1.518	0.189
Deficit $180^\circ/\text{sec}$	Extension	-2.2 \pm 14.09	-3.0 \pm 7.48	0.117	0.911
	Flexion	4.7 \pm 12.13	-6.8 \pm 7.63	1.883	0.118

Maximum muscular strength ratios in both sides (deficit ratio)

The maximum muscular strength ratio in both sides was defined as the percentage of the maximum muscular strength of the opposite side to that of the mainly used side (dominant side peak torque/non-dominant side peak torque \times 100). Changes in the maximum muscular strength ratios in both sides are shown in Table 7, and no significant differences in both extension and flexor muscles were observed in 60°/sec and 180°/sec of angular speeds.

DISCUSSION

Although it is impossible to directly compare between the results of the present study, which targeted female collegiate Taekwondo athletes, and those of previous studies because of the lack of similarities between the results, we will discuss our results in comparison with similar results from preceding studies. Among the physique factors in the female collegiate Taekwondo athletes, body weight showed a significant change from 58.4 ± 7.22 in the first year to 61.4 ± 7.76 in the second year. Tsai et al. (2011) reported that the mean body weight of female Taekwondo athletes in the Taiwan National Sports University was 56.7 ± 6.0 kg, which was approximately 4.7 kg lighter than that in the second year in the present study. Meanwhile, the mean body weight of the female athletes in the Iran national team, which consisted of 13 individuals, was 57 kg.

Although identifying the causes of the body weight increase despite the high-intensity training during the in-seasons and off-seasons is difficult, significant increases in body fat percentage and body fat mass were identified as possible causes based on the present study results. In addition, we speculated that the other possible causes were the effects of inappropriate applications of time, frequency, and intensity of training on program management for each individual. Moreover, the results are also considered to be caused by the training being more focused on skills rather than body weight.

For circumference measurements of physique, the circumferences of the upper arms, folded upper arms, chests, and hips, except those of the calves, thighs, and waists, significantly increased. By contrast, the circumferences of the calves and thighs unexpectedly showed no significant changes.

For body composition, the women generally had 12.5% and 5 kg higher body fat percentage and fat mass, respectively, than the men. Body fat percentage and fat mass are used as basic data to directly and indirectly evaluate athletic performance of athletes (Lanay et al., 2007; Li et al., 2009). In the present study, body fat percentage (25.7%) and body fat mass (15.9 kg) statistically sig-

nificantly increased in the second year. Ghorbanzadeh et al. (2011) reported that the body fat percentage in 16 female Taekwondo athletes who attended the Turkey national team camp was approximately $11.19\pm 1.58\%$. In a preceding study, the value in 13 female Taekwondo athletes of the Iran national team whose ages ranged from 18 to 25 yr was $17.3\pm 4.4\%$ (Rahmani-Nia et al., 2007). In addition, the body fat percentage of female athletes in the Kazakhstan national team was also 15.4%, showing that the athletes at national team levels maintained lower body fat percentages than the athletes in the present study (Fong et al., 2011). Athletes need to maintain appropriate levels of body fat in order to exert the best athletic performance (Linda, 1996), but the present collegiate athletes showed contradicting results. Therefore, coaches and trainers should manage their athletic performance more efficiently by continually paying more attention to and regularly assessing body composition.

Fat-free mass showed no significant changes in the results of the present study. Ratamess et al. (2012) reported that the amount of fat-free tissues of wrestling athletes also tended to decrease during the off-season, but a higher proportion of weight training is considered to improve muscular and muscular endurance.

Among the physical fitness factors in the present study, hand agility and flexibility significantly increased, whereas power decreased. These results were similar to the results of a study by Kim et al. (2011) in that change in flexibility tended to increase as regular training continued. High flexibility is considered effective in injury prevention, beneficial for scoring by attacking the opponent's face in the differential point system, and an important factor in confronting changes during the game. However, considering that no positive changes occurred in the physical fitness factors such as cardiorespiratory endurance and agility even after 1 yr of training and that power reduction could cause a decline in athletic performance in the sudden-death system, readjustment of the year-long training program is necessary to improve these problems.

A high level of maximum oxygen intake is required to continuously manage 3 rounds of a 2-min high-intensity game, which is used as an endurance training index and is determined by muscle mass and physical fitness (Basset and Boulay 2000; Kang et al., 2006). The maximum oxygen intake in the present study was 45.2 ± 3.69 mL/kg/min in the first year and 48.6 ± 6.11 mL/kg/min in the second year, showing a trend of increase but no significant change. When compared with Italian female athletes (42.9 mL/kg/min) of karate, a one-on-one physical match similar to Taekwondo, the maximum oxygen intake was superior, with the amount of intake slightly higher in the female athletes (49.8 ± 1.7 mL/kg/min)

of the Croatia national team than in those in the present study (Markovic et al., 2008). Meanwhile, the absence of change after 1 yr training suggests that the aerobic capacity of athletes reached the maximum. A follow-up study is proposed to measure the best conditions before the game to accurately determine the maximum oxygen intake. In addition, the results could be caused by the fact that oxygen intake during training in the present study did not increase in proportion to the muscle mass used in the training. This is because maximum oxygen intake changes depending on cardiac function, air exchange capacity of the lungs, and ability of the muscle in training to utilize oxygen (Frielingsdorf et al., 1995).

Determining isokinetic strength is a method of measuring tension that is exerted on muscular tissue while moving regularly in a selected angular speed (Coburn et al., 2006). It is used to measure the effect of rehabilitation treatment (Lee et al., 1997; Pringle et al., 1998) and is widely used as an objective assessment method to digitize muscular strength in sports due to its superior reproducibility (Cools et al., 2007; Kannus, 1994).

Because scoring spots need to be hit accurately in addition to performing a kicking combination to score points during a Taekwondo game, assessment of flexor and extensor muscles play an important role in a proportion of athletes (Kim et al., 2011). According to the results of the present follow-up study, when angular speed was 60°/sec, the maximum muscular strengths (peak torque) of the left and right sides in the second year were respectively 142.3 and 139.9 Nm for the extensor muscle, and 88.9 and 92.6 Nm for the flexor muscle, showing no significant differences. Although a direct comparison was not possible, the study by Machado et al. (2010) reported in male Taekwondo athletes that when the angular speed was 60°/sec, the maximum muscular strengths (peak torque) of the left and right sides were respectively 155.53 ± 17.78 and 157.23 ± 25.34 Nm for the extensor muscle, and 88.31 ± 12.97 and 89.21 ± 13.03 Nm for the flexor muscle. This shows that the maximum muscular strength of the flexor muscle of the female Taekwondo athletes in the present study was superior. In addition, Fong and Ng (2011) reported that in both non-athletic men ($n=48$) and women ($n=20$) who practiced Taekwondo 2 times a week, at 1-1.5 h per session, the maximum muscular strength (peak torque) was 147.82 ± 37.54 for extensor muscle and 80.31 ± 21.83 for flexor muscle. The maximum muscular strength of the flexor muscle was shown to be higher than that of the extensor muscle, as demonstrated in the female Taekwondo athletes in the present study.

The maximum muscular strength of the right flexor muscle in 180°/sec of angular speed significantly increased from 61.8 ± 11.11

Nm in the first year to 73.5 ± 10.64 Nm in the second year. This value was higher than the 59.03 ± 19.06 Nm of the flexor muscle in the study of Fong and Ng (2011). Therefore, training of the flexor muscle for the past 1 yr was considered effective. However, developing a method to improve the extensor muscle needs more attention. Toumi et al. (2004) reported that plyometric training affected elongation step. Luebbers et al. (2003) evaluated jumping training by using a box that improved muscular strength. Therefore, the combination of the aforementioned trainings is necessary.

In addition, the percentages of muscular strength to body weight (peak torque % body weight) in all the extensor and flexor muscles of the left and right sides, in 60°/sec and 180°/sec of angular speeds, significantly increased. We speculate that the increase was due to the fact that muscular strength of the extensor muscle is required to instantaneously perform a strong kicking motion and a positive effect of proper training that was obtained during the function process of the flexor muscle used for the preparation of the next motion, in which the leg is folded instantly at the last ending motion before initiating a strong impact. The ipsilateral muscular strength ratio (hamstring-to-quadriceps ratio) significantly increased from $64.1\% \pm 5.21\%$ in 180°/sec of angular speed in the first year to $78.3\% \pm 13.06\%$ in the second year for the left side, and from $69.9\% \pm 6.45\%$ to $81.2\% \pm 11.86\%$ in 2005 for the right side. The ipsilateral muscular strength ratio in Taekwondo provides important information about the knee joint related to the muscles used for kicking. This is because this information enables the prevention of injuries by providing understanding the ratio between flexor and extensor muscular strengths of the knee joint in athletes. When the ipsilateral muscular strength ratio was low, a high incidence of injury was reportedly caused by external shocks or stresses (Söderman et al., 2001). The proper ratio of the flexor muscle to the extensor muscle was between 50% and 80% (Appen and Duncan, 1986). This is considered to be caused by the complex training related to Taekwondo because rapid muscle fibers are mainly involved in muscular contraction in most high-speed loads.

Changes in maximum muscular strength ratios in both sides (deficit ratio) showed no significant differences between the extension and flexor muscles in 60°/sec and 180°/sec of angular speeds. Kannus (1994) published that the maximum muscular strength ratios of both sides were closely related to sports injury. A difference in muscular strength between the left and right sides that is within the $\pm 10\%$ range corresponds to the normal range, and that between $\pm 10\%$ and $\pm 20\%$ corresponds to an increase in the incidence of sports injury. In the present study, the maximum muscular strength ratios of both sides were within $\pm 10\%$. These results

show that the training had a balanced combination because the overall ratio of muscular strength did not correspond to sports injury. Balanced muscular strength and endurance between the left and right feet were shown to be maintained during Taekwondo kicking. These findings suggest that training was also effectively performed to the other foot without being shifted to the dominant foot. Thus, it is considered as beneficial for scoring with both the right and left feet, and positively affects steps that move the body rapidly.

In the present study, we performed a follow-up investigation of changes in physique, physical fitness, and isokinetic strength in female collegiate Taekwondo athletes, and obtained the following results. With regard to physical fitness, no significant changes were found in balance, grip strength, abdominal muscular endurance, muscular endurance, and agility, whereas hand agility and flexibility significantly increased and power significantly decreased. In addition, maximum heart rate, maximum oxygen intake, oxygen intake, oxygen intake per body weight, min ventilation volume, and respiratory rate showed no significant differences, but carbon dioxide emission significantly increased.

With regard to isokinetic strength, the maximum muscular strength of the flexor muscle of the right side significantly increased in 180°/sec of angular speed. The percentage of maximum muscular strength to the total body weight significantly increased in all the extensor and flexor muscles of the left and right sides in 60°/sec and 180°/sec of angular speeds. The ipsilateral muscular strength ratio significantly increased in the left and right sides in 180°/sec of angular speed, and the maximum muscular strength ratio in both sides showed no significant differences between the extensor and flexor muscles in 60°/sec and 180°/sec of angular speeds.

As suggested earlier, continuous observation of individual changes in physique, physical fitness, and isokinetic strength is necessary to improve the athletic performance of female Taekwondo athletes. Furthermore, long-term longitudinal studies are required to develop measures of preventing injury among such athletes

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

Appen L, Duncan PW. Strength relationship of the knee musculature: effects of gravity and sport. *J Orthop Sports Phys Ther* 1986;8:232-235.

- Basset FA, Boulay MR. Specificity of treadmill and cycle ergometer tests in triathletes, runners and cyclists. *Eur J Appl Physiol* 2000;81:214-221.
- Bouhleb E, Jouini A, Gmada N, Nefzib A, Ben AK, Tabka Z. Heart rate and blood lactate responses during taekwondo training and competition. *Sci Sports* 2006;21:285-290.
- Brooks JHM, Fuller CW, Kemp SPT, Reddin DB. An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training, injuries. *J Sports Sci* 2008;26:863-873.
- Claessens AL, Hlaaty S, Lafevre J, Holdhaus H. The role of anthropometric characteristic in modern pentathlon performance in female athletes. *J Sports Sci* 1994;12:391-410.
- Coburn JW, Housh TJ, Malek MH, Weir JP, Cramer JT, Beck TW, Johnson GO. Neuromuscular responses to three days of velocity specific isokinetic training. *J Strength and Cond Res* 2006; 20:891-898.
- Cools AM, Greerrooms E, Van den Berghe DF, Cambier DC, Witvrouw EE. Isokinetic scapular muscle performance in young elite gymnasts. *J Athl Train* 2007;42:458-463.
- Fong SS, Ng GY. Does Taekwondo training improve physical fitness? *Phys Ther Sport* 2011;12:100-106.
- Frielingsdorf J, Dür P, Gerber AE, Vuilliomont A, Bertel O. Physical work capacity with rate responsive ventricular pacing(VVIR) versus dual chamber pacing (DDD) in patients with normal and diminished left ventricular function. *Int J Cardiol* 1995;49:239-248.
- Ghorbanzadeh B, Müniroğlu S, Akalan C, Khodadadi MR, Kırzaci S, Şahin M. Determination of taekwondo national team selection criteria by measuring physical and physiological parameters. *Ann Biol* 2011;2:184-197.
- Halson SL, Jeukendrup AE. Does overtraining exist? An analysis of overreaching and overtraining research. *Sports Med* 2004;34:967-981.
- Jeong TS, Reilly T, Moron J, Bae SW, Drust B. Quantification of the physiological loading of one week of "pre-season" and one week of "in-season" training in professional soccer players. *J Sports Sci* 2011;29:1161-1166.
- Kang J, Hoffman JR, Chaloupka EC, Ratamess NA, Weiser PC. Gender differences in the progression of metabolic responses during incremental exercise. *J Sports Med Phys Fitness* 2006;46:71-78.
- Kannus P. Isokinetic evaluation of muscular performance. *Int J Sports Med* 1994;15:11-18.
- Kazemi M, Pieter W. Injuries at the Canadian National Tae Kwon Do Championships: a prospective study. *BMC Musculoskeletal Disord* 2004;5:1-8.
- Kim HB, Stebbins CL, Chai JH, Song JK. Taekwondo training and fitness in female adolescents. *J Sports Sci* 2011;29:133-138.
- Lanay M, Willa F, James MP. Bone mineral density in collegiate female

- athlete: comparisons among sports. *J Athl Train* 2007;42: 403-408.
- Lee AJ, Mayers JL, Garraway WM. Influence of physique in rugby football injuries. *Br J Sports Med* 1997;31:135-138.
- Li C, Ford ES, Balluz LS, Giles WH. Estimates of body composition with dual-energy X-ray absorptiometry in adults. *Am J Clin Nutr* 2009;90: 1457-1465.
- Linda BH. Assessment of body composition in youth and relationship to sports. *Int J Sport Nutr* 1996;6:146-164.
- Luebbbers PE, Potteiger JA, Hulver MW, Thefault JP, Carper MJ, Lockwood RH. Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res* 2003; 17:704-709.
- Machado SM, Osório RAL, Silva NS, Magini M. Biomechanical analysis of the muscular power of martial arts athletes. *Med Biol Eng Comput* 2010;48:573-577.
- Markovic G, Misigoj DM, Trninc S. Fitness profile of elite Croatian female taekwondo athletes. *Coll Antropol* 2005;29:93-99.
- Markovic G, Vucetic V, Cardinale M. Heart rate and lactate responses to taekwondo fight in elite women performers. *Biol Sport* 2008;25:135-146.
- Melhim AF. Aerobic and anaerobic power responses to the practice of taekwon-do. *B J Sports Med* 2001;35:231-234.
- Mitchell JH. Neural control of the circulation during exercise. *Med Sci Sports Exerc* 1990;22:141-154.
- Pringle RG, McNair P, Stanley S. Incidence of sporting injury in New Zealand youth aged 5-15 yr. *Br J Sports Med* 1998;2:49-52.
- Rahmani-Nia F, Rahnema N, Masoumi S. The effects of physical exercise on soluble transferrin receptor and other indicators of iron status in female taekwondoist. *Int J Sports Sci Eng* 2007;1:189-194.
- Ratamess NA, Hoffman JR, Kraemer WJ, Ross RE, Tranchina CP, Rashti SL, Kelly NA, Vingren JL, Kang J, Faigenbaum AD. Effects of a competitive wrestling season on body composition, endocrine markers, and anaerobic exercise performance in NCAA collegiate wrestlers. *Eur J Appl Physiol* 2012;113:1157-1168.
- Söderman K, Alfredson H, Pietilä T, Werner S. Risk factors for leg injuries in female soccer players: a prospective investigation during one outdoor season. *Knee Surg Sports Traumatol Arthrosc* 2001;9:313-321.
- Støren O, Helgerude J, Stoa EM, Hoff J. Maximal strength training improves running economy in distance runners. *Med Sci Sports Exerc* 2008;40:1087-1092.
- Sunde A, Støren O, Bjerkaas M, Larsen M. H, Hoff J, Helgerud J. Maximal strength training improves cycling economy in competitive cyclists. *J Strength Cond Res* 2010;24:2157-2165.
- Toumi H, Best TM, Martin A, Guyer S, Poumarat G. Effects of eccentric phase velocity of plyometric training on the vertical jump. *Int J Sports Med* 2004;25:391-398.
- Tsai ML, Ko MH, Chang CK, Chou1 KM, Fang SH. Impact of intense training and rapid weight changes on salivary parameters in elite female Taekwondo athletes. *Scand J Med Sci Sports* 2011;21:758-764.