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Comparison of maximum muscle strength and isokinetic knee and core muscle functions according to pedaling power difference of racing cyclist candidates

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The purpose of this study was to investigate differences of maximum muscle strength and isokinetic knee and core muscle functions according to pedaling power of racing cyclist candidate. Subjects for this study were 200 racing cyclist candidates and divided into four groups: top 10% peak power group (TPP, n=20), low 10% peak power group (LPP, n=20), top 10% average power group (TAP, n=20), and low 10% average power group (LAP, n=20). The maximum muscle strength was consisted of grip strength, bench press and squat measured by Ariel device, and isokinetic knee and core muscle functions were analyzed by Humac Norm device. Significant differences between groups were determined with one-way repeated analysis of variance. As the result of this study, TPP and TAP groups showed significantly decreased body-fat mass and increased free fat mass when compared to LPP and LAP groups. The maximum strength of grip and squat was significantly higher in TPP and TAP than in other groups. Isokinetic knee extension and flexion strength was higher in TPP and TAP groups as well as isokinetic trunk extension and flexion functions were highest in TPP group. Thus, our findings suggest new evidence that muscle mass, maximal muscle strength, and isokinetic muscle functions might be important predictors of racing cyclist performance.

Keywords: Maximum strength, Isokinetic muscle function, Pedaling power, Wingate test, Racing cyclist

INTRODUCTION

Cycling race is a sprint competition in which seven players in the Velodrome run seven laps of 333.33-m raceway along the inductor and determine the ranking by the last two laps. The pedaling power that explodes in a short time is an important factor in determining the win or loss of the competition (Atkinson et al., 2007).

Pedaling power is the force applied repeatedly to the pedals by the extensor and flexor muscles of the hip, knee, and ankle (McDaniel et al., 2014). Among the muscle fibers in the lower limbs, pedaling power affected by the muscle type and volume of muscle fibers involved in the pedaling, and it is closely related to the coordination of the hip, knee, ankle and external oblique abdominal muscle (Elmer et al., 2011). In the previous studies, Baum and Li (2003) reported that maximum and average power in cyclists are highly correlated with maximum muscle strength around the knee and hip joint, and quadriceps strength, anaerobic power and maximum oxygen uptake are crucial physical fitness to win the competition (Sakamoto et al., 2018).

In order to improve the pedaling power of cyclist, it is necessary to apply a systematic training program for effective interaction of core strength and upper and lower muscular strength that can maintain the body posture during cycling (Hartmann et al., 2015; Rønnestad and Hansen, 2018). The core stability exercise is a method of exercise that enhances the maximum strength of the back, thigh and hip muscles, suggesting that this increased maximum strength can improve the flexibility and balance as well as

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shorten cycling records to cyclists (Willson et al., 2005). According to various studies that reported a relationship between performance and core strength in elite athletes, core exercise increased maximum strength of hip flexor muscles and range of motion of hip joint (Hodges, 2003). Also in the study related to cycling performance, the increase of isokinetic lumbar muscle strength in men and women cyclists was associated with the game record (Drust et al., 2005).

In addition to core strength, basic physical fitness of upper and lower body is another factor in deciding whether to win the cycle competition (Mujika et al., 2016; Rønnestad et al., 2016). One-repetition maximum (1RM) of bench press, squat, hand-grip and back strength have been used for measuring basic physical fitness of cyclists. Particularly, hand-grip and back strength are important fitness factors to hold steady handles and transmit power to cycle, and it has been known that two factors have a high correlation with the game record (Faria et al., 2005; Hansen et al., 2007).

With these results mentioned by previous studies, maximum muscle strength of core and upper and lower body is essential for increasing performance of amateur cyclist. However, a study on the variety of fitness factors related to the performance that affects the pedaling power of the top level racing cyclists is rare.

Therefore, the purpose of this study was to investigate differences of maximum muscle strength and isokinetic knee and core muscle functions according to pedaling power of racing cyclist candidate.

MATERIALS AND METHODS

Participants

The participants in this study were 200 athletes selected as racing cyclist candidates. As shown in Table 1, all participants were randomly divided into four groups after anaerobic Wingate test: top 10% peak power group (TPP, n=20), low 10% peak power group (LPP, n=20), top 10% average power group (TAP, n=20), and low 10% average power group (LAP, n=20). Before beginning the study, all participants had a detailed explanation of this study and submitted their written informed consent to researchers. This research was conducted ethically according to international guidelines.

Table 1. Physical characteristics of the subjects

Variable	TPP (n=20)	LPP (n=20)	TAP (n=20)	LAP (n=20)
Age (yr)	24.5±1.9	25.5±1.7	24.9±1.8	26.1±1.3
Height (cm)	169.6±33.7	174.4±4.4	171.1±34.1	172.5±6.3
Weight (kg)	85.6±8.2	82.1±7.1	85.9±8.1	84.7±10.3

Values are presented as mean±standard deviation.
TPP, top 10% peak power; LPP, lower 10% peak power; TAP, top 10% average power; LAP, lower 10% average power.

Anaerobic Wingate test

Anaerobic Wingate test is a method to confirm the maximum pedaling power capability using a Monark bicycle (Ergomedic 823E, Monark Exercise AB, Vansbro, Sweden). After 3 min of light pedaling, participants maintained maximum pedaling for 30 sec with the 'start' signal from when the maximum speed is reached at the set load. The peak power (PP) is the anaerobic power, the average power (AP) is the speed-endurance, and the fatigue index (FI) is the fatigue resistance ability.

Body composition analysis

The subjects visited the laboratory by 9:00 a.m. with 8 hr of fasting. Body height and weight was measured in light clothing and without wearing shoes using Jenix (DS-103M, Dong Sahn Jenix, Seoul, Korea) and Body composition was measured by Inbody 770 (Inbody 770, Inbody, Seoul, Korea) to confirm the body fat, % body fat and lean body mass.

Basic physical fitness level test

The basic physical strength was composed of squat, bench press, and grip strength. The grip strength (Tachometer, TKK 5401, Takei, Japan) was measured twice at left and right sides and was recorded at the highest value. The absolute value measured by Ariel (16120 Smith Press, Cybex, MA, USA) was used as a relative value for the squat and bench press. All subjects took a rest for 3 min after 5 times of preliminary exercise and then measured maximal muscle strength.

Isokinetic knee and trunk muscle strength test

Isokinetic knee and trunk extension and flexion muscle strength was measured using HUMAC NORM (Humac Norm 776, CSMi, Stoughton, MA, USA). The maximum isokinetic flexion and extension exercises of the knee repeated three times at an angular velocity of 60°/sec, and the lumbar spine exercises measured three times at 30°/sec. The range of motion of knee and trunk during the test was set from 0° to 90° and -10° to 70°, respectively.

Statistical analysis

SPSS ver. 18.0 (IBM Co., Armonk, NY, USA) program was used to confirm differences of maximum muscle strength and isokinetic

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knee and core muscle functions between groups. Statistical analysis was performed using one-way repeated analysis of variance followed Tukey *post hoc* test, and All values are expressed as mean ± standard deviation. $P < 0.05$ was considered significant.

RESULTS

Change in anaerobic pedaling power

To examine difference in anaerobic pedaling power of racing cyclists, we performed Wingate test for 30 sec. As shown in Table 2, absolute and relative values of PP and AP in TPP and TAP ($F = 47.30$, $P = 0.001$) showed significantly differences compared to LPP and LAP groups. There is not significant difference of FI between all groups.

Change in body composition

We measured the body fat percentage (%Fat), free fat mass (FFM), and body mass index (BMI) to identify characteristics of racing cyclists. As shown in Table 3, %Fat ($F = 4.79$, $P = 0.004$) and FFM ($F = 3.08$, $P = 0.032$) was significantly higher and lower in low 10% groups (LPP and LAP) than those in top 10% groups (TPP and TAP), respectively. BMI ($F = 2.40$, $P = 0.074$) showed no significant differences between groups.

Change in basic physical fitness

Changes in maximum muscle strength of squat, bench press and hand-grip are shown in Table 4. Absolute value of maximum squat strength ($F = 6.06$, $P = 0.001$) showed significant differences in TPP and TAP groups compared to LPP and LAP groups, but

Table 2. The different of pedaling power/Wingate test

Variable	TPP[1]	LPP[2]	TAP[3]	LAP[4]	*F*-value	*Post hoc*
PP (W)	1,033.9 ± 100.7	745.3 ± 74.4	1,028.6 ± 102.8	790.6 ± 115.9	47.30***	2, 4 < 3, 1
PP (W/kg)	12.1 ± 0.4	9.1 ± 0.3	12.0 ± 0.5	9.3 ± 0.6	248.41***	2, 4 < 3, 1
AP (W)	798.9 ± 87.8	607.5 ± 57.5	809.0 ± 81.5	618.2 ± 80.0	40.58***	2, 4 < 3, 1
AP (W/kg)	9.3 ± 0.4	7.4 ± 0.3	9.4 ± 0.2	7.2 ± 0.2	327.48***	2, 4 < 3, 1
FI (%)	49.0 ± 8.4	48.3 ± 4.3	47.6 ± 7.8	51.3 ± 6.2	1.10	-

Values are presented as mean ± standard deviation.
TPP, top 10% peak power; LPP, lower 10% peak power; TAP, top 10% average power; LAP, lower 10% average power; PP, peak power; AP, average power; FI, fatigue index.
***$P < 0.001$, one-way analysis of variance.

Table 3. The different of body composition

Variable	TPP[1]	LPP[2]	TAP[3]	LAP[4]	*F*-value	*Post hoc*
%Fat (%)	17.0 ± 5.2	19.3 ± 2.4	16.0 ± 4.9	20.1 ± 2.3	4.79**	3 < 4, 2
FFM (kg)	71.1 ± 7.9	66.3 ± 5.3	72.2 ± 7.4	67.7 ± 7.7	3.08*	2 < 4, 1 < 3
BMI (kg/m^2)	26.5 ± 2.0	27.0 ± 1.9	26.1 ± 2.0	27.7 ± 2.0	2.40	-

Values are presented as mean ± standard deviation.
TPP, top 10% peak power; LPP, lower 10% peak power; TAP, top 10% average power; LAP, lower 10% average power; %Fat, body fat percentage; FFM, fat-free mass; BMI, body mass index.
*$P < 0.05$, **$P < 0.01$, one-way analysis of variance.

Table 4. The different of fitness level

Variable	TPP[1]	LPP[2]	TAP[3]	LAP[4]	*F*-value	*Post hoc*
Squat (kg)	227.4 ± 19.5	204.2 ± 23.5	228.4 ± 18.4	200.4 ± 40.6	6.06***	4, 2 < 1, 3
Squat (kg/kg)	2.7 ± 0.3	2.5 ± 0.4	2.7 ± 0.3	2.4 ± 0.5	2.54	-
Bench press (kg)	123.8 ± 25.4	111.8 ± 17.7	118.8 ± 27.4	111.0 ± 15.5	1.52	-
Bench press (kg/kg)	1.5 ± 0.2	1.4 ± 0.2	1.4 ± 0.3	1.3 ± 0.2	1.06	-
Left grip strength (kg)	70.6 ± 14.4	58.0 ± 8.6	68.9 ± 15.5	58.9 ± 9.4	5.64**	2 < 4, 3 < 1
Right grip strength (kg)	69.6 ± 11.5	55.2 ± 9.3	69.1 ± 12.1	58.4 ± 9.5	9.51***	2, 4 < 3, 1

Values are presented as mean ± standard deviation.
TPP, top 10% peak power; LPP, lower 10% peak power; TAP, top 10% average power; LAP, lower 10% average power.
**$P < 0.01$, ***$P < 0.001$, one-way analysis of variance.

there is no significant difference between relative value. In the *post hoc* results, the maximum strength of squat was higher in TPP and TAP than in the LPP and LAP groups. Absolute (F = 1.50, P = 0.215) and relative maximum value (F = 1.06, P = 0.369) of bench press did not showed any significant difference between all groups. Maximum grip strength showed significant difference in top 10% group, and in the *post hoc* results, there was higher in TPP and TAP than in the LPP and LAP groups.

Change in isokinetic knee functions

We performed isokinetic knee extension and flexion test at 60°/sec for identifying maximum strength and balance of the quadriceps and hamstring muscles. As shown in Table 5, absolute and relative peak values of isokinetic left knee flexion muscle (F = 9.85, P = 0.001) showed significant differences in TPP and TAP compared to LPP and LAP groups. However, isokinetic right knee flexion strength is significantly higher only in absolute peak value (F = 7.49, P = 0.001) in top 10% group. Also absolute peak values of isokinetic left knee extension muscle (F = 5.52, P = 0.002) showed significant differences in TPP and TAP compared to LPP and LAP groups. Isokinetic bilateral balance ratio and hamstring:quadriceps ratio of the knee showed no significant differences between groups.

Change in isokinetic trunk functions

We performed isokinetic trunk extension and flexion test for identifying maximum strength and balance of core muscles. As shown in Table 6, absolute and relative peak values of isokinetic trunk extension (F = 3.61, P = 0.017) and flexion muscles (F = 5.19, P = 0.003) showed significant differences in TPP and TAP compared to LPP and LAP groups. In the *post hoc* results, all factors on maximum isokinetic trunk strength were the highest in TPP group. Flexion:extension ratio of Isokinetic trunk peak torque showed no significant differences between groups.

Table 5. Isokinetic knee strength at 60°/sec

Variable	TPP[1]	LPP[2]	TAP[3]	LAP[4]	*F*-value	*Post hoc*
Right flexor (BW)	189.5 ± 20.7	175.3 ± 17.6	189.4 ± 17.5	176.0 ± 17.1	3.80*	-
Right flexor (N·m)	161.4 ± 17.0	143.5 ± 14.4	161.9 ± 13.7	148.3 ± 15.6	7.49***	2, 4 < 1, 3
Right extensor (BW)	325.6 ± 52.1	304.6 ± 39.5	318.3 ± 52.0	299.7 ± 39.1	1.35	-
Right extensor (N·m)	278.3 ± 46.2	248.3 ± 23.0	273.7 ± 49.1	252.7 ± 37.9	2.74*	-
Left flexor (BW)	185.9 ± 16.5	167.2 ± 13.7	184.1 ± 15.1	168.5 ± 10.7	9.85***	2, 4 < 3, 1
Left flexor (N·m)	158.7 ± 14.8	137.5 ± 17.7	157.7 ± 13.4	143.1 ± 20.8	7.89***	2, 4 < 3, 1
Left extensor (BW)	326.4 ± 41.8	293.5 ± 35.6	320.9 ± 43.1	295.8 ± 40.0	3.52*	-
Left extensor (N·m)	278.4 ± 35.8	239.6 ± 22.7	275.2 ± 38.6	250.1 ± 44.0	5.52**	2, 4 < 3, 1
Bilateral balance ratio for extensors (%)	5.8 ± 4.8	7.7 ± 5.3	6.1 ± 5.6	7.0 ± 4.9	0.55	-
Bilateral balance ratio for flexor (%)	4.8 ± 3.5	5.1 ± 3.3	4.3 ± 3.2	4.0 ± 2.9	0.44	-
H:Q ratio for right (%)	58.7 ± 9.0	58.3 ± 8.8	60.1 ± 9.0	59.5 ± 8.7	0.17	-
H:Q ratio for left (%)	57.4 ± 6.0	58.0 ± 9.2	58.1 ± 8.0	58.3 ± 9.0	0.04	-

Values are presented as mean ± standard deviation.
TPP, top 10% peak power; LPP, lower 10% peak power; TAP, top 10% average power; LAP, lower 10% average power; H:Q ratio, hamstring:quadriceps ratio.
*P < 0.05, **P < 0.01, ***P < 0.001, one-way analysis of variance.

Table 6. Isokinetic trunk strength at 30°/sec

Variable	TPP[1]	LPP[2]	TAP[3]	LAP[4]	*F*-value	*Post hoc*
Flexor (BW)	373.4 ± 34.6	332.9 ± 50.4	362.7 ± 34.9	333.3 ± 52.1	4.45**	2 < 1
Flexor (N·m)	320.6 ± 48.2	274.2 ± 51.9	311.8 ± 40.5	279.7 ± 39.2	5.19**	2 < 4, 3 < 1
Extensor (BW)	481.1 ± 53.3	434.2 ± 68.7	475.2 ± 57.3	438.9 ± 69.4	2.99*	-
Extensor (N · m)	412.8 ± 66.7	357.5 ± 68.6	409.1 ± 64.8	369.0 ± 63.0	3.61*	2 < 1
F:E ratio (%)	78.4 ± 9.6	77.5 ± 9.1	77.2 ± 11.4	76.8 ± 10.6	0.08	-

Values are presented as mean ± standard deviation.
TPP, top 10% peak power; LPP, lower 10% peak power; TAP, top 10% average power; LAP, lower 10% average power; BW, body weight; F:E ratio, flexor:extensor ratio.
*P < 0.05, **P < 0.01, one-way analysis of variance.

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DISCUSSION

Wingate test has been known to be an appropriate devise for evaluating anaerobic capabilities of cyclists and this result is important information that predicts the pedaling power of cyclists (Craig and Norton, 2001). In Wingate test, PP (W or W/kg) means power for about 5 sec after peak pedaling, and it is closely related to fast speed up in the competition. AP and FI also is the ability to maintain the cadence for 30 sec after the start of the peak pedaling, predicting the performance at the end of the competition (Rønnestad et al., 2015). Thus, we think that the training program for improving the performance of racing cyclists should be composed of training to increase the pedaling power through up-regulating the contribution of anaerobic energy system.

In this study, PP of racing cyclist candidates after Wingate test were 1,033.9 W (12.1 W/kg) for TPP, 1,028.6 W (12.0 W/kg) for TAP, 745.3 W (9.1 W/kg) for LPP and 790.6 W (9.3 W/kg) for LAP, respectively. All PP values were higher in top 10% groups than in the lower 10% groups and there are significant differences between all groups. Korea Institute of Sport Science (KISS) analyzed the results of Wingate test on elite cyclists in 2008. They suggested that the A grade of PP was over 1,091.09 W, the B grade was over 959.63 and less than 1,091.09 W, the C grade was over 828.17 and less than 959.63 W and the D grade was over 696.71 and less than 828.17 W. PP in PPT and APT groups belongs to B grade, PP in PPL and APL groups was D grade, and there are differences between the upper 10% group and the lower 10% groups. AP of racing cyclist candidates were 789.9 W (9.3 W/kg) for TPP, 809.0 W (9.4 W/kg) for TAP, 607.5 W (7.4 W/kg) for LPP and 618.2 W (7.2 W/kg) for LAP, respectively. All AP values were higher in top 10% groups than in the lower 10% groups. In addition, AP measurement standard proposed by KISS is the A grade of over 800.58 W, B grade of over 734.04 and less than 800.58 W, C grade of over 661.5 and less than 731.04 W and D grade of over 591.96 and less than 661.50 W. The TAP group had a grade A, the TPP was a grade B, and LPP and LAP belong to D grade. FI showed no significant difference between groups. Previous studies reported Wingate test results for cyclists suggested that PP and AP improvements were necessary for a positive change in cycle performance (Rønnestad et al., 2015; Vikmoen et al., 2016). These findings were in agreement with the results of this study that maximum pedaling power training w applied to win the game.

Cyclists try to maintain their body fat percentage at 5%–9% through dietary restrictions and to increase muscle strength by anaerobic high intensity training (Lericollais et al., 2011). In the present study, %Fat in racing cyclists were 17% for TPP, 16% for TAP, 19.3% for LPP and 20.1% for LAP. The top 10% groups had lower percentage body fat as well as FFM was 71.1 kg for TPP, 72.2 kg for TAP, 66.3 for LPP and 67.7 kg for LAP. The top 10% groups were about 5 kg higher than low 10% groups. Haakonssen et al. (2016) represented that amateur cyclists have higher %Fat and BMI than elite cyclists and must be controlled to improve performance (Lee et al., 2002; Martin et al., 2001). In general, a cyclist with a low body weight, %Fat, and BMI can minimize the wind resistance that worsens the propulsive force, which can lead to a positive result in the competition (Craig and Norton, 2001).

In the present study, the results of 1RM squat and grip strength test and in racing cyclist candidates showed significant difference in absolute value of top 10% groups, but 1RM bench press did not show any significant between groups. These findings suggest that leg and grip strength are more relevant to the improvement of performance of cyclists than that of pectoralis major muscle. The present results are consistent with several previous studies that cyclists with excellent performance had higher maximum strength of quadriceps, hamstring and latissimus dorsi muscle (Hansen et al., 2007; Hodges, 2003).

Cycle pedaling produces in the movement of knee joint by strength of gluteus and hamstring muscles. Muscular activity in the gluteus and quadriceps muscle is high at the pedaling angle of 0°–180° and hamstring muscle activation increases at 181°–360° (Elmer et al., 2011; McDaniel et al., 2014). Willson et al. (2006) stated that isokinetic equipment is an important tool for measuring the maximum muscle functions of elite cyclists, and isokinetic evaluation index is necessary for predicting performance. In this study, isokinetic right knee flexor ($P<0.013$) and extensor ($P<0.001$) strength, and left knee extensor ($P<0.002$) strength was significantly higher in the top 10% groups compared to the low 10% groups. Also isokinetic trunk flexor ($P<0.003$) and extensor ($P<0.017$) strength in the top 10% groups showed significantly higher values than those in the low 10% groups. The previous study reported the correlation between isokinetic knee and trunk functions and pedaling power (Howe et al., 2013), and van Soest and Casius (2000) increased the reliability of our results.

In conclusion, we think that the maximum strength and pedaling power training program should be applied to improve the performance of the racing cyclist candidates and extend the life of the athletes. Therefore, our findings provide important evidence that maximal strength of upper and lower limbs and isokinetic knee and core muscle functions are predictors of the pedaling power in racing cyclist candidates.

CONFLICT OF INTEREST

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

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