JOURNAL OF PHYSIOLOGY AND PHARMACOLOGY 2008, 59, Suppl 7, 89–103
www.jpp.krakow.pl

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THE EFFECT OF ENDURANCE TRAINING ON MUSCLE STRENGTH IN YOUNG, HEALTHY MEN IN RELATION TO HORMONAL STATUS

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The objective of this study was to establish the effect of moderate intensity endurance training on muscle strength in relation to hormonal changes in the body. Fifteen young, healthy men took part in 5 week endurance training performed on a cycloergometer. Before and after training program, exercise testing sessions were performed involving all participants. Training program significantly increased $\dot{V}_{O_2\,max}$ ($P<0.05$) and time to fatigue at 50% of maximal voluntary isometric contraction (TTF 50% MVC), $P<0.03$, but it did not affect maximal voluntary isometric contraction (MVC). This was accompanied by an increase ($P<0.001$) in total plasma testosterone (T) and free testosterone (fT) concentrations, whereas a decrease in sex hormone-binding globulin (SHBG) ($P<0.02$), growth hormone ($P<0.05$), free triiodothyronine ($P<0.001$) and free thyroxine ($P<0.02$) concentrations was observed. No changes were found in plasma cortisol (C) and insulin-like growth factor-I (IGF-I) concentrations. Additionally, MVC was positively correlated to T/C, fT/C and IGF-I/C ratios after the training, whereas time to fatigue at 50% of MVC was closely positively correlated to the SHBG concentration, both before and after endurance training. We have concluded that moderate intensity endurance training resulting in a significant increase in $\dot{V}_{O_2\,max}$, did not affect the MVC, but it significantly increased time to fatigue at 50% of MVC. This index of local muscular endurance was greater in subjects with higher concentration of SHBG, both before and after the training.

Key words: *endurance training, muscle strength, sex hormones, insulin-like growth factor, thyroid hormones*

INTRODUCTION

Skeletal muscle strength is one of the main features that determine motor performance in humans (1). Maximal muscle strength plays a pivotal role in a variety of sport disciplines (2, 3) and higher level of strength decreases occurrence of motor disabilities in aged people (1).

Resistance training increases skeletal muscle strength by a different physiological mechanisms, which are related to neural factors (4), skeletal muscle hypertrophy (5) and hormonal changes (6). The muscle strength alterations are related to testosterone (T) concentration changes as well as to testosterone to cortisol ratio (T/C) (see *e.g.* 7-9), free testosterone to cortisol ratio (fT/C) and insulin-like growth factor-I to cortisol ratio changes (see 10, 11). Increase in these indices may evidence an enhanced anabolic processes in the muscle, which can promote skeletal muscle hypertrophy and strength improvement. Besides the hypothalamic-pituitary-gonadal axis (HPG), skeletal muscle strength may be influenced by the activity of the somatotropic axis (GH-IGF-I) (12) and hypothalamic-pituitary-thyroid axis (HPT) (13).

It has also been shown that endurance exercise training has a marked impact on the acute hormonal response to single bout of exercise (14, 15) as well as on the chronic changes in basal hormone concentrations (16). Although, the acute hormonal changes are quite well described, the data concerning the influence of endurance training on basal hormone levels are inconsistent and it also pertains to the hormonal axes involved in strength development. Moreover, conflicting evidence exists regarding the impact of endurance training on muscle strength. While there is substantial amount of data indicating that endurance training has no effect on maximal muscle strength (17-20), occasionally increase in muscle strength (21, 22) or even muscle mass (23) was observed.

It could be postulated that the pattern of hormonal changes induced by endurance training may affect the skeletal muscle strength after this type of training program. This study was designed to establish the effect of moderate intensity and low volume endurance training on muscle strength in relation to hormonal status in young, healthy men.

MATERIAL AND METHODS

Subjects

Fifteen healthy, non-smoking and physically active men participated in this study. The mean (± SD) age, body height, body mass and BMI were 22.73 (± 1.83) yr, 180.3 (± 5.83) cm, 76.39 (± 8.95) kg, and 23.46 (± 2.20) kg · m^{-2}. Maximal oxygen uptake ($\dot{V}_{O_2\ max}$) measured before the training program was 46.0 (± 3.7) ml · kg^{-1} · min^{-1}. The volunteers were informed about the purpose and procedures of the research project and all gave their written, informed consent to the experimental procedures. The study was approved by the Local Ethical Committee and done in accordance with the Declaration of Helsinki.

Experimental protocol

Before and after of five weeks of endurance training all participants completed testing sessions including incremental exercise test to exhaustion, isometric maximal voluntary contraction (MVC) force of the knee extensors and time to fatigue at 50% of maximal voluntary contraction (TTF 50% MVC) measurements.

Incremental exercise test

Incremental exercise test until exhaustion was performed on a cycloergometer Ergoline 800 S in order to determine maximal oxygen uptake ($\dot{V}_{O_2\,max}$), power output at $\dot{V}_{O_2\,max}$ (PO_{max}) and lactate threshold (LT) as described by Zoladz *et al*. (24). Briefly, baseline cardiorespiratory variables were measured during 6 minutes rest in sitting position on the ergometer, which was followed by a 3 minutes exercise bout at the power output of 30 W. The load was increased every 3 minutes by 30 W until the subjects could not continue cycling at the required pedaling rate (60 rev · min^{-1}) and power output. During the test, gas exchange variables were measured continuously breath-by-breath using the Oxycon Champion Jaeger (Netherlands). Heart rate was determined continuously from the ECG curve registered by the Hellige SMS 181 Unit (Germany). Moreover, blood samples for plasma lactate were taken prior to the exercise and at the end of each exercise stage (the last 15 second before an increase in power output). Lactate threshold (LT) was defined as the highest power output above which plasma lactate concentration ($[La^-]_{pl}$) elicited sustained increase of at least 0.5 mmol · l^{-1} or more at each subsequent step of the incremental test (see 24).

Isometric maximal voluntary contraction (MVC)

Isometric maximal voluntary contraction (MVC) of the knee extensor muscle was performed on the prototype device equipped with strain gauge, according to Edwards *et al*. (25). The subjects sat on the chair with their hips and knees fixed at 90° of flexion. The pelvis and the thigh were firmly stabilized by restraining straps to minimize unwanted movement. Other inextensible strap was placed around the ankle above the medial malleolus and was attached to the strain gauge located at the back of the chair. The signal from the strain gauge was amplified and sent to the computer. Purpose made software allowed continuous monitoring and storing of the signal. The testing session began with 10 minutes warm-up, consisting of low intensity bicycling at 60 watts and self-chosen lower extremity stretching exercises. After the subjects were seated and positioned in the testing chair, they performed additionally several submaximal isometric contractions with each leg. Maximal isometric voluntary contraction (MVC) of the knee extensors (subjects were asked to push as forcefully as possible for about 3 s against the strap) was performed both for right and left leg with 2 minute brake in between. This procedure was repeated three times and the MVC was assessed as the average force for all consecutive measurement. Moreover, torque was calculated by multiplying the MVC by the lever arm (26). The length of the lever arm during MVC and TTF 50% MVC measurement was constant before as well as after the training program.

Time to fatigue at 50% of isometric maximal voluntary contraction (TTF 50% MVC)

The TTF 50% MVC measurement was performed also for each leg and took place 6 minutes after completed last MVC trial. The measurements for right and left leg was also spaced by 6 minutes of rest. During this test the subjects were asked to reach and hold a force level at 50% of MVC, which was displayed on the computer monitor. Time to fatigue was measured in seconds from onset of the test to the point when appropriate level of force (50% of MVC) could no longer

be held. Time to fatigue at 50% of MVC was expressed as a mean value of two measurements (right and left leg). This time is regarded as an index of local muscular endurance (see 27).

Training program

5 week endurance training program was performed on the cycle ergometer (Monark 874 E, Sweden) as described by Majerczak *et al*. (28). Briefly, training involved four sessions per week and two different kinds of exercise protocols of equal duration (40 minutes) were used. The first kind of training consisted of continuous cycling (continuous endurance cycling) at the power output corresponding to 90% of the $\dot{V}_{O_2}$ found at the previously determined lactate threshold (90% $\dot{V}_{O_2\ LT}$). The second kind (intermittent endurance cycling) consisted of 6 minutes of unloaded cycling followed by a 3 minutes exercise bout performed at the power output corresponding to 50% Δ, repeated 4 times. This training was finished with 4 minutes of unloaded cycling. The power output corresponding to 50% Δ was calculated as the difference between the power output reached at $\dot{V}_{O_2\ max}$ and the power output obtained at the LT [50% $\Delta = PO_{LT} + 0.5\ (PO_{max} - PO_{LT})$] (see *e.g*. 29). The continuous endurance cycling was performed on Tuesdays and Fridays, and the intermittent endurance cycling on Mondays and Thursdays.

Blood collection

Blood samples (20 ml) were taken from the antecubital vein using an Abbot Int-Catheter, Ireland (18G/1.2 x 45 mm). Samples were taken at rest in the morning hours between 7:30-8:00 a.m., in fasting state before and after the training program. Moreover, blood samples were taken prior to the incremental exercise test and at the end of each exercise stage (the last 15 second before an increase in power output), both before and after 5 weeks of training. Fasting blood samples were used for the measurements of testosterone (T), sex hormone-binding globulin (SHBG), thyroid stimulating hormone (TSH), free triiodothyronine (fT3), free thyroxine (fT4) and albumin (Alb) plasma or serum concentrations. Resting blood samples (15 ml) were taken 10 min before the incremental exercise test and were used for measurements of cortisol (C), growth hormone (GH), insulin-like growth factor-I (IGF-I) and IGF-binding protein 3 (IGFBP-3). The blood samples taken at the end of each exercise stage were used to determine lactate concentration.

Blood biochemistry and plasma hormones measurements

Blood for hormone assays were collected in tubes containing EDTA. Then samples were centrifuged at 3000 rev · min^{-1} for 10 min at 4°C and the plasma was stored at minus 40°C before concentrations of hormones were measured. The plasma level of testosterone (T) and sex hormone-binding globulin (SHBG) were measured by electrochemiluminescence immunoassay using the Elecsys 2010 analyzer (Roche Diagnostics, Switzerland). To evaluate free testosterone concentration, serum albumin concentration was determined using the agarose gel electrophoresis (Paragon System, Beckman, USA). Free testosterone (fT) was calculated from total testosterone, sex hormone-binding globulin and albumin levels using the standard method of Vermeulen *et al*. (30), as follows: $fT = ([T] - (N \times [fT])) / (K_t\{SHBG - [T] + N[fT]\})$, where [fT], [T] and [SHBG] are free testosterone, total testosterone and sex hormone-binding globulin concentrations, respectively, $N = K_aC_a + 1$, where K_a is the association constant of albumin for T and C_a is the albumin concentration, whereas K_t is the association constant of SHBG for T at 37°C. Plasma C (Spectria Cortisol RIA, Orion Diagnostica, Finland), GH (HGH-RIACT, CIS Bio International, France) and IGF-I (SM-C-RIA-CT, BioSource, Belgium) concentrations were measured by radioimmunoassay and IGFBP-3 level was assessed by immunoradiometric assay (IGFBP-3 IRMA, DSL, USA).

Plasma lactate measurements

The blood samples for lactate concentration measurement (0.5 ml each) were placed in 1.8 ml Eppendorf tubes containing 1 mg ammonium oxalate and 5 mg sodium fluoride and mixed for about 20 seconds and then centrifuged at 4000 rev · min^{-1} for 4 min. The obtained samples of blood plasma (200 µl) were stored at minus 32°C for further analysis of lactate concentration ($[La]_{pl}$) using an automatic analyser Vitros 250 Dry Chemistry System, Kodak (USA).

Statistical analysis

The data are presented as mean ± SD. Normality of distribution was tested with Shapiro-Wilk's test. Differences between means were assessed with Student's t test for paired samples or Wilcoxon paired-sample test in case of non-normal data distribution. Pearson's or Spearman's correlation coefficient was used to evaluate the relation between muscle strength characteristics and hormonal status. Statistical significance was chosen as $P < 0.05$. Presented analyses were performed using statistical packet STATISTICA 7.1.

RESULTS

Body mass (BM) and BMI did not change substantially during five weeks of endurance training, whereas $\dot{V}_{O_2\,max}$ was significantly increased (expressed in absolute values as well as expressed per kg body mass). Power output reached at $\dot{V}_{O_2\,max}$ (PO_{max}) was also significantly higher after the endurance training, but the power output reached at lactate threshold (PO_{LT}) remained unchanged. BM,

Table 1. Characteristics of the 15 subjects before and after the training program ($\bar{x} \pm SD$). *** $P < 0.001$, * $P < 0.05$, significantly higher level after 5 weeks of endurance training.

	Before training	**After training**
BM [kg]	76.39 ± 8.95	75.78 ± 8.51
BMI [kg · m^{-2}]	23.46 ± 2.20	23.28 ± 2.04
$\dot{V}_{O_2\,max}$ [ml · min^{-1}]	3498 ± 333	3601 ± 333*
$\dot{V}_{O_2\,max}$ [ml · kg^{-1} · min^{-1}]	46.04 ± 3.73	47.76 ± 4.08*
PO_{max} [W]	256 ± 24	277 ± 23***
PO_{LT} [W]	114 ± 34	122 ± 31

BM, body mass; BMI, body mass index; $\dot{V}_{O_2\,max}$, maximal oxygen uptake; PO_{max}, power output reached at $\dot{V}_{O_2\,max}$; PO_{LT}, power output reached at lactate threshold.

BMI, $\dot{V}_{O_2\ max}$, PO_{max} and PO_{LT} changes in response to endurance training are presented in *Table 1*.

Muscle strength characteristics

It was observed that 5 weeks of endurance training did not affect neither MVC (707 ± 91 N and 708 ± 101 N before and after the training, respectively) nor torque level (233 ± 33 Nm and 234 ± 36 Nm before and after the training, respectively). In contrast, we found significant increase in TTF 50% MVC from 69.91 ± 16.12 s before training to 75.98 ± 15.22 s after training, $P < 0.03$.

Hormonal profile

Changes in hormone concentration in response to training are presented in *Table 2*. Five weeks of endurance training induced significant increase in the concentrations of total T as well as in fT. We also observed significant decrease

Table 2. Changes in hormonal concentrations after moderate endurance training. *** $P < 0.001$, ** $P < 0.02$, * $P < 0.05$, significantly different concentration after 5 weeks of endurance training. Data in the table are presented as mean ± SD.

	Before training	**After training**
T [nmol · l^{-1}]	18.84 ± 5.73	22.03 ± 6.61 ***
SHBG [nmol · l^{-1}]	34.45 ± 11.26	31.95 ± 10.40 **
fT [pmol · l^{-1}]	374 ± 116	470 ± 153 ***
C [nmol · l^{-1}]	334 ± 138	367 ± 135
fT3 [pmol · l^{-1}]	5.37 ± 0.59	4.66 ± 0.59 ***
fT4 [pmol · l^{-1}]	16.38 ± 2.40	15.30 ± 2.27 **
TSH [µIU · ml^{-1}]	2.28 ± 1.09	2.52 ± 1.42
GH [ng · ml^{-1}]	1.23 ± 1.74	0.48 ± 0.76 *
IGF-I [ng · ml^{-1}]	205 ± 61	195 ± 57
IGFBP-3 [µg · ml^{-1}]	4.55 ± 0.73	4.31 ± 0.60

T, testosterone; SHBG, sex hormone-binding globulin; fT, free testosterone; C, cortisol; fT3, free triiodothyronine; fT4, free thyroxine; TSH, thyroid stimulating hormone; GH, growth hormone; IGF-I, insulin-like growth factor-I; IGFBP-3, IGF-binding protein 3.

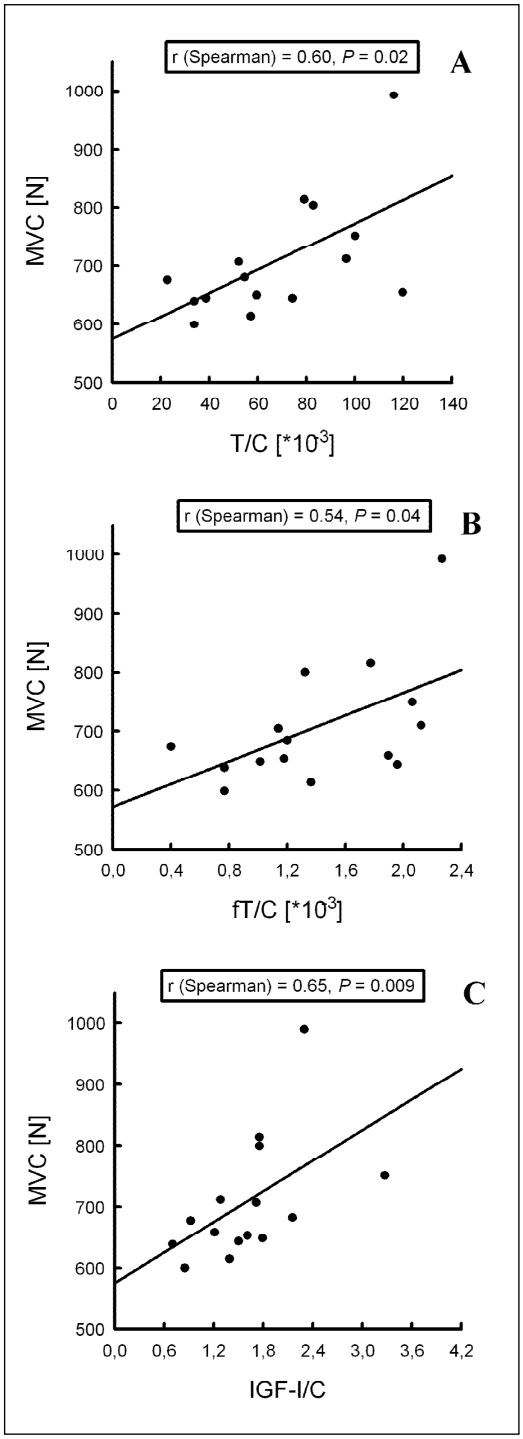

Fig. 1. Positive correlation between maximal voluntary contraction force (MVC) and testosterone to cortisol ratio (T/C) - panel A, free testosterone to cortisol ratio (fT/C) - panel B, and insulin-like growth factor-I to cortisol (IGF-I/C) ratio - panel C, found at the end of endurance training.

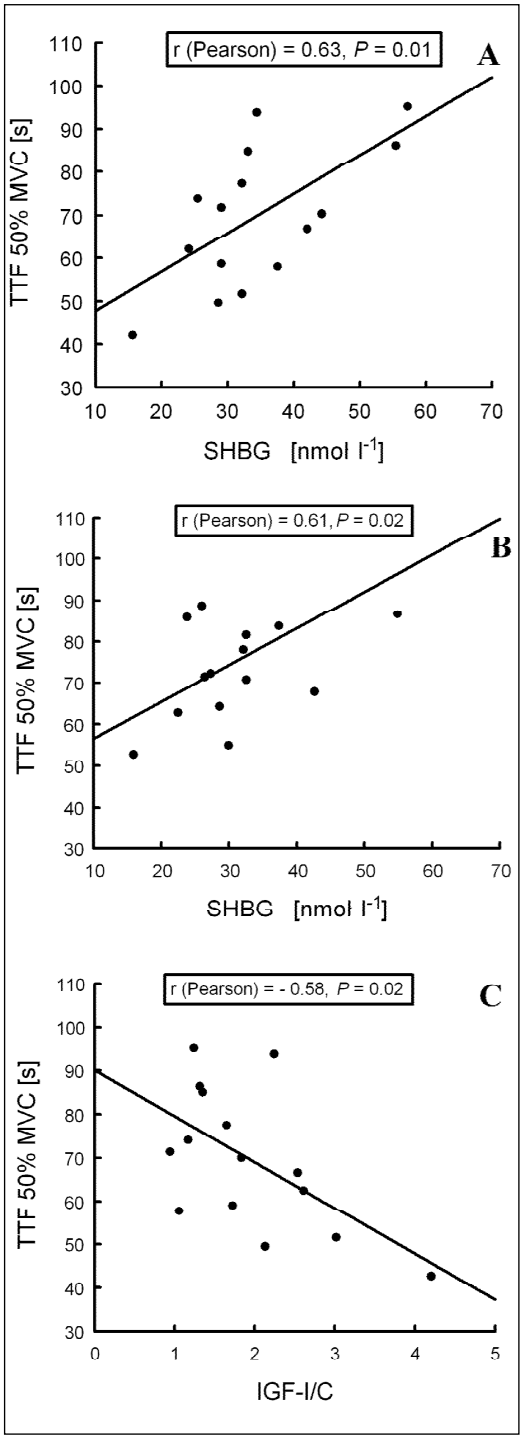

Fig. 2. Time to fatigue at 50% of MVC was positively correlated with SHBG concentration both before - panel A, and after endurance training - panel B, and inversely correlated with insulin-like growth factor-I to cortisol (IGF-I/C) ratio before training - panel C.

of fT3, fT4, GH and SHBG concentrations, whereas no changes were found for C, TSH, IGF-I and IGFBP-3 levels.

Correlations

We found positive correlations between maximal voluntary contraction force and T/C, fT/C and IGF-I/C ratios (see *Fig. 1*) at the end of endurance training, but not before training.

Moreover, time to fatigue at 50% of MVC was inversely correlated to IGF-I level before the training and closely positively correlated to the SHBG level, both before and after the training (see *Fig. 2*). We also found that post-training 50% of MVC level was also correlated with SHBG concentration (r Spearman = 0.62, $P = 0.01$), and a trend to correlation between these two variables was showed before the training (r Spearman = 0.37, $P = 0.17$).

DISCUSSION

Five weeks of moderate intensity and volume endurance training resulted in a significant increase in $\dot{V}_{O_2\ max}$ and PO_{max}. The improvement of physical performance occurred concomitantly with an increase in TTF 50% MVC, but without any changes in maximal isometric strength. The increase in the TTF 50% MVC, regarded as the measurement of the local muscle endurance, indicate that endurance exercise training performed at moderate intensity as applied in the present study, is also able to improve muscle strength performance.

In one of the first study using TTF 50% MVC to determine differences in pre and post-training skeletal muscle characteristic (26), it was observed that TTF 50% MVC augmented by 19%. It is substantially higher increase that the one we have reported (9%), however, Thorstensson *et al*. (26) employed in their study 8 week long training with much higher intensities (sprint training).

One of the main factors that limit ability to maintain defined level of MVC is restricted (already at 30% of MVC) or totally arrested blood flow in exercised muscle (see 31). Totally arrested blood flow may be present at 50% of MVC and it is related to high intramuscular pressure, which rises linearly with increasing contractile force (32). On the other hand, an endurance training-induced increase in skeletal muscle capillarization is well-known phenomenon (33-35), and this increase may amount to 50% only after 4 weeks of high intensity endurance training (34). We postulate that increase in muscle capillary density in response to endurance training might be the reason for the observed in this study improvement in local muscular endurance.

Another finding regarding this issue is the strong positive correlation between SHBG concentration and local muscular endurance expressed as the time to fatigue at 50% of MVC (*Fig. 2*, panel A and B). To our knowledge this is the first study in which muscle strength performance was related to SHBG concentration.

This observation seems to be specially relevant in light of the finding that SHBG influences the androgen concentrations in men (see *e.g*. 36). The finding of a negative correlation between testosterone and SHBG concentration (37) suggest that subjects with better local muscular endurance in our study (longer TTF 50% MVC) and higher level of SHBG, are characterized by lower anabolic state in their bodies. However, this hypothesis should be taken with caution because the inverse relationship between SHBG and bioavailable plasma testosterone concentration is not confirmed by others (38). On the other hand, we also observed a negative correlation between IGF-I/C ratio and TTF 50% MVC before training (*Fig. 2*, panel C), which seems to support the notion that higher local muscular endurance is related to lower anabolic state. The paper by Hoogeveen and Zonderland (39) showed that endurance exercise training can improve performance even when the tendency to disturbed anabolic/catabolic balance in the body exists.

The observed change in TTF 50% MVC after the endurance training was not accompanied by alteration in MVC and torque level. The lack of change in maximal muscle strength in this study is in line with the most other reports (17-20), which showed that endurance training do not increase muscle strength or muscle mass. On the other hand, there are also the opposite findings indicating that in some circumstances, the increase in muscle strength (21, 22) or even muscle mass (23) in response to endurance training may be present.

The reason for this discrepancy may be related to the use of different training modes (running *vs*. bicycling), differences in initial physical fitness level of the studied subjects and intensity of applied training program. In studies where an increase in muscle strength in response to endurance training was observed, cycling exercise was performed (21-23), and lack of change in muscle strength after endurance training was noticed when other modes of exercise program (mostly running) was applied (17-19). It is in agreement with findings presented by Izquierdo *et al*. (2), which showed that endurance trained cyclists demonstrated higher level of strength than runners. It suggests that in contrast to running, cycling exercise has potential to increase maximal muscle strength.

The low fitness level of the studied subjects could be also the reason for the observed increase in muscle strength after endurance training (22). However, in the study by Bell *et al*. (21) increase in muscle strength could not be explained by low initial fitness level of the subjects. The participants were physically active students, with comparable fitness level to our subjects. Nevertheless, training loads used in the study of Bell *at al*. (21) were much higher than those applied in our experiment and corresponded up to 90% $\dot{V}_{O_2\ max}$. This training intensity requires muscles to work against high resistance loads, causing recruitment of fast-twitch glycolytic fibers and motor units with a high threshold (31), and this in turn can improve muscle strength by increase in the number of recruited motor units and/or increase in the motoneuron firing frequency (4). It seems, therefore, that cycling endurance training can increase muscle strength when its intensity is

sufficiently high. The absence of change in the level of MVC in this study is a consequence of relatively moderate intensities used during endurance training (50-70% $\dot{V}_{O_2\,max}$, see methods).

Although we did not observe change in maximal muscle strength, there was a significant increase in fT and T concentrations (see *Table 2*) after endurance training. This pattern of changes may be a characteristic feature of endurance training, because increase in basal level of gonadal hormones after resistance training is usually related to improvement in muscle strength (see 6). However, it is interesting to note that we found significant correlation between MVC level and T/C, fT/C and IGF-I/C ratios after endurance training. It shows that generation of high forces is related to hormonal status of the body. Higher level of muscle strength was obtained in subjects characterized by more anabolic hormonal profile, expressed as higher T/C, fT/C and IGF-I/C ratios. This finding is supported by Izquierdo *et al*. (40), who stated that low T concentration may be a limiting factor in strength development. Moreover, athletes with better strength-related performance are characterized by higher basal level of T (41).

Training-induced effect on muscle strength may be related to somatotropic axis hormones (GH-IGF-I) activity, because it was shown that IGF-I has a role in skeletal muscle hypertrophy (12). In this study, five weeks of moderate intensity endurance training did not change the basal level of IGF-I, whereas in other experiments a decrease (16, 42) as well as an increase (43, 44) in basal IGF-I concentration was observed. The reason for this difference can be attributed to the variety of factors that influence IGF-I concentration, namely the nutrition status, body composition characteristics, age and physical fitness level (see *e.g*. 45-47), but nutrition status is probably the most important. For example, Berg and Bang (48) pointed out that even training-induced changes in IGF-I concentration are related to nutrition status of the body. However, this hypothesis should be taken with caution, because although the decrease in IGF-I concentration is indeed observed in a state of negative energy balance (49), the sufficient energy intake during exercise training leads in some cases to increase (43-44), and in others similarly to the results of this study, no changes in IGF-I concentration are observed (50).

An interesting hypothesis related to GH-IGF-I response to training was proposed by Eliakim *et al*. (42), who stated that this response has at least two phases. The first one, the catabolic-type with a decrease in IGF-I and GH binding protein, lasts up to 5 weeks. The second begins a little later and is associated (when adequate nutrition is provided) with chronic anabolic adjustment of the GH-IGF-I axis. It is therefore possible that the training program used in this study was to short to elicit increased activity in the GH-IGF-I axis, although the improvement of physical fitness (increase in $\dot{V}_{O_2\,max}$, PO_{max}, TTF 50% MVC) after endurance training was observed. We postulate that extended period of this training could indeed enhance somatotropic axis activity, especially that the increase in T concentration stimulate IGF-I secretion (51). Increased IGF-I

concentration is associated with higher fitness level (47), but the mentioned correlation between MVC and IGF-I/C ratio shows that IGF-I level could be also related to maximal muscle force production.

Muscle structure and function are also regulated by the thyroid hormones (13, 52, 53). In this study 5 weeks of endurance training decreased fT3 and fT4 levels, but it had no effect on the maximal muscle strength. Moreover, we did not observe any relation between MVC and thyroid hormones concentration. On the other hand, an experimental animal model (54) shows that decrease in plasma triiodothyronine (T3) concentration induces fast-to-slow transition of the myosin heavy chain isoforms (MyHC) and an increase in T3 cause the opposite effect (55). Besides the effect on skeletal muscle shortening velocity, the thyroid hormones may also influence the action potential conduction velocity and/or the effect of acidosis on the conduction velocity (56). These results show the importance of the thyroid hormones in muscle force production, however the interpretation of these data is not so obvious, because in humans the influence of thyroid hormones on muscle structure and function is still not completely understood.

In conclusion, endurance training of moderate intensity and relatively low volume increased $\dot{V}_{O_2\ max}$, PO_{max} and TTF 50% MVC. It was shown that this training resulted in hypothalamic-pituitary-gonadal axis changes that appear to be desirable in the development of muscle strength. However, MVC force did not change (perhaps because of moderate loads applied during the training), but we observed that greater muscle strength after the training was achieved by subjects possessing more anabolic hormonal profile (higher T/C, fT/C and IGF-I/C ratios). Moreover, the muscle's ability to maintain the magnitude of force output corresponding to 50% of MVC was positively correlated with SHBG concentration what suggests that the higher local muscular endurance is observed in the subjects with lower anabolic state in their body.

Acknowledgments: This study was supported by a grant nr 184/IFC/2005 from the University School of Physical Education Krakow, Poland.

Conflicts of interest statement: None declared.

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Received: October 1, 2008
Accepted: December 3, 2008

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