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Is testosterone responsible for athletic success in female athletes?

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ABSTRACT

BACKGROUND: The aim of this study was to determine the interrelationship between the resting serum testosterone (T) levels of female athletes from different types of sporting events and their athletic success.

METHODS: The study involved 599 Russian international-level female athletes (95 highly elite, 190 elite, and 314 sub-elite; age: 16-35 years) and 298 age-matched female controls. The athlete cohort was stratified into four groups according to event duration, distance, and type of activity: 1) endurance athletes; 2) athletes with mixed activity; 3) speed/strength athletes; 4) sprinters. Athletic success was measured by determining the level of achievement of each athlete.

RESULTS: The mean T levels of athletes and controls were 1.65 ± 0.87 and 1.76 ± 0.6 nmol/L ($P=0.057$ for difference between groups) with ranges of 0.08-5.82 and 0.38-2.83 nmol/L in athletes and controls, respectively. T levels were positively associated with athletic success in sprinters ($P=0.0002$ adjusted for age) only. Moreover, none of the sub-elite sprinters had $T > 1.9$ nmol/L, while 50% of elite and highly elite sprinters had $T > 1.9$ nmol/L (OR=47.0; $P < 0.0001$).

CONCLUSIONS: Our data suggest that the measurement of the serum T levels significantly correlates with athletic success in sprinters but not other types of athletes and in the future may be useful in the prediction of sprinting ability.

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Key words: Athletic performance; Women; Hyperandrogenism; Testosterone.

Testosterone (T), which is normally present in the circulation of both men and women, has an anabolic effect and stimulates the growth of muscle by increasing muscle protein synthesis and inhibition of protein breakdown via a ubiquitin-mediated pathway.¹ There is agreement that T supplementation increases muscle mass and maximal voluntary strength and reduces body fat.²⁻⁴ High T concentrations or precursor androgens were found to be associated with greater lean body mass and higher bone mineral density in women.⁵⁻⁷ T also acts on specific substrates in the

brain to increase aggression and motivation for competition.^{8, 9} Thus, high endogenous T concentrations may confer both psychological and physiological advantage in sports.⁴

Exercise (especially resistance exercise training) is globally able to induce an increase in resting T and other hormones.¹⁰ Therefore, it was suggested that the measurements of T and T to cortisol ratio may be useful biological markers of training responses.^{11, 12} Due to the dynamic regulation of endogenous T production, including the acute effects of competition and exercise, T concentrations may vary considerably within and among individuals,⁴ which can be determined, in part, by genetic polymorphisms. Studies in at least male twins indicate that there is a strong heritability of serum T, with genetic factors accounting for 65% of the variation in serum T.¹³ Several polymorphisms of the sex hormone-binding globulin (*SHBG*; transports androgens and estrogens in the blood), α -actinin-3 (*ACTN3*; interacts with calcineurin which negatively regulates the production of T), aromatase (*CYP19A1*; converts androgens to estrogens) and other genes were identified to be associated with serum T concentration in different populations including athletes of both sexes.¹⁴⁻¹⁶ Given an important physiological role of T in the growth and metabolism, one might suggest that natural T levels could predict athletic potential of an individual and thus the measurement of serum or salivary T may be used in sports selection. On the other hand, other factors may influence T concentrations in female athletes, including circadian variation, oral contraceptive use, nutrition, load demands of training etc.¹⁷ There is much debate over whether or not women whose testosterone (T) levels cross into the male range (*i.e.* ≥ 10 nmol/L) should not compete with other women unless it was shown that they are resistant to the effects of T (androgen insensitivity). Recent study has shown that female athletes (N.=300) with high T levels have a significant competitive advantage over those with low T in 400-800 m running, hammer throw and pole vault.¹⁸ The aim of the study was to determine the interrelation between the resting serum T levels of female athletes from different sporting disciplines and their athletic success.

Materials and methods

Subjects

The study involved 599 Russian female athletes (age: 16-35 years) from the National teams who were tested negative for doping substances. The athletes were stratified into four groups according to event duration, distance and type of activity. The first group ('endurance group'; N.=133) included long (N.=77) and middle (N.=56) distance athletes (31 rowers, five 800 m runners, one 10,000 m runner, 18 biathletes, five middle-distance kayakers, eight 1.5-3 km speed skaters, 38 cross-country skiers, one marathon runner, ten 200-10000 m swimmers, 13 triathletes, three middle-distance short-trackers). The second group ('mixed group'; N.=321) comprised athletes whose sports utilized mixed anaerobic and aerobic energy production (six badminton players, 28 basketball players, 15 water polo players, 29 volleyball players, 26 handball players, seven curling players, two equestrian athletes, four freestyle skiers, 13 sailors, seven divers, seven lugers, 27 artistic (synchronized) swimmers, three skeleton athletes, 16 snowboarders, 10 modern pentathletes, eight archers, 14 shooters, 23 fencers, 21 figure skaters, 19 field hockey players, 36 ice hockey players). The third group ('speed-strength group'; N.=100) included strength athletes and explosive power athletes with predominantly anaerobic energy production (55 wrestlers, seven alpine skiers, two throwers, four jumpers (track and field), three heptathletes, 22 artistic gymnasts, seven weightlifters). The fourth group ('sprint group'; N.=45) included sprinters (two 100-400 m runners, ten sprint cyclists, two 200 m kayakers, six 500-1000 m speed skaters, 19 50-100 m swimmers, six 500-1000 m short-trackers).

Athletic success was measured by determination of the level of achievement of each athlete. There were 95 athletes classified as 'highly elite' ('merited masters of sport' according to the unified sports classification system of Russia (USCSR; awards only for results on the official competitions); equates to international champion who has made valuable contributions to the sport (prize winners of Olympic Games and World/Europe championships). There were 190

athletes classified as 'elite' ('masters of sport of international class' according to the USCSR; equates to international champions). The other athletes (N.=314) were classified as 'sub-elite' athletes ('masters of sport' (equates to national champions) and 'candidates for master of sport' (equates to nationally ranked athletes) according to the USCSR). Controls (N.=298) were age-matched (16-35 years old) Russian women without any sports experience.

The procedures followed in the study were conducted ethically according to the principles of the World Medical Association, the Declaration of Helsinki and ethical standards in sport and exercise science research. The overall study was approved by the Ethics Committee of the Physiological Section of the Russian National Committee for Biological Ethics and written informed consent was obtained from each participant.

Biochemical study

Resting T (*i.e.* T which was measured on a day when the athlete did not train) was examined in serum of athletes. For these purposes, 10 mL of venous blood was collected the morning after an overnight fast and sleep into EDTA vacutainer tubes and placed at 4 °C until processing. For each sporting discipline blood was collected on the same day at least 15 h after the last training. T was analyzed on a Benchmark Plus Microplate Spectrophotometer (Bio-Rad, Hercules, CA, USA) using enzyme immunoassay and commercial test systems (Alkor-Bio, Russia). The athletes were from the same team and trained under supervision of the same coach (*i.e.* were under the same conditions to minimize external factors which may influence T levels).

Statistical analysis

Statistical analyses were conducted using GraphPad InStat. Differences in testosterone levels between athletes and controls, as well as between groups of athletes (*e.g.* endurance athletes *versus* sprinters, etc.) were analyzed using unpaired *t*-tests. All data are presented as mean and standard deviation. Spearman's correlation was used to assess the relationship (*r*) between the T level and age. Multiple regression was used for testing association between T levels and athletic success adjusted for age (athletic success was coded as 1, 2 and 3 for sub-elite, elite and highly elite, respectively). Odds ratio was calculated for the categorical data; the difference between the expected and observed frequencies was calculated using Chi-square test. P values <0.05 were considered statistically significant.

Results

The mean T levels of all athletes and controls were 1.65 ± 0.87 and 1.76 ± 0.6 nmol/L ($P=0.057$ for difference between groups), respectively with range 0.08-5.82 nmol/L in athletes and 0.38-2.83 nmol/L in controls (Table I). There were 11.6% female athletes and 7.4% female controls with a T level >2.7 nmol/L, the upper limit of the normal reference range. T levels were positively correlated with the age in sprinters ($r=0.39$; $P=0.0085$), but negatively correlated with the age in controls ($r=-0.17$; $P=0.0042$) (Table II). No significant differences in T levels were found between the different groups (*e.g.* endurance athletes *versus* sprinters) of athletes (all $P>0.05$). T levels were positively associated with athletic success in sprinters ($P=0.0002$ adjusted for age) only. None of sub-elite sprinters had T >1.9 nmol/L, while 50% of elite and highly elite sprinters had T >1.9 nmol/L (OR=47.0; $P<0.0001$). No correlations were found in other groups of athletes (Table I).

Discussion

Our main finding was that T levels were positively correlated with athletic success in Russian female sprinters adjusted for age. Importantly, 11.6% of female athletes from our study had T levels >2.7 (up to 5.8) nmol/L (above the normal reference range) which is similar (13.7%) with previously published data on 239 female athletes from the UK.¹⁹ The novelty of the study was

that the association of the T levels with athletic success was found not only in sprinters specialized in running, but also in swimming, cycling, kayaking, speed skating, and short-track.

Although the role of androgens in female physiology has not been well established, several studies have indicated that T may induce skeletal muscle hypertrophy and increase muscle strength through genomic (long-term, transcriptional) mechanisms.^{20,21} In the recent study, testosterone (10 mg) administration increased running time to exhaustion and lean mass in physically active young women.²² Additionally, T was shown to act quickly through non-genomic mechanisms (short-term, non-transcriptional).²³ Based on the current understanding of non-genomic T action, Dent *et al.*²⁴ suggested that T may be able to produce an increase in intracellular calcium levels and calcium mobility within the human skeletal muscle cell. This may increase the sensitivity of the contractile elements to calcium, which could increase the speed of myosin head binding and/or the force at which the myosin head pulls, such that more force is produced per contraction. Combined, these effects would likely result in greater whole muscle power production and thus, sprinting ability. Consistent with this hypothesis and our data, Cardinale, Stone²⁰ identified a significant positive relationship between T levels and vertical jump performance both in male ($r=0.62$) and female ($r=0.48$) elite athletes involved in sprinting, volleyball, soccer and handball. Furthermore, Bosco *et al.*^{25,26} reported a positive correlation between T levels and vertical jump height and power output in professional male soccer players. The same authors found that T levels were higher in explosive male athletes, such as sprinters, and lowest in endurance athletes such as cross-country skiers.²⁷ Recently, Bermon *et al.*²⁸ confirmed that T levels of female sprinters were higher in comparison with long distance athletes. It is possible that T might improve athletic performance in sprint events by decreasing reaction time, as T has been shown to regulate neuromuscular transmission.²⁹ It was, therefore, suggested that T plays an important role in explosive performance by influencing skeletal muscle excitation-contraction coupling, phenotypization of fast-twitch muscle fibers, protein synthesis and aggressive behaviour.²⁰ Interestingly, in the mixed cohort of 18 female athletes (track and field, netball, cycling, swimming and bob skeleton), Cook *et al.*³⁰ revealed that salivary free T concentrations were significantly higher in elite athletes in comparison with non-elites, suggesting that T could influence the expression of behavior (*i.e.* dominance) and thereby help to regulate sporting potential.

The second main outcome of the study was that T levels did not confer competitive advantage in other types of sport events such as endurance disciplines, events with mixed sport activities and speed-strength sports.

Interestingly, we found that T levels negatively correlated with the age in controls, but were positively associated with the age in sprinters. One might suggest that power-specific exercise may protect from the age-related decline of T levels in female athletes.

We could not take into consideration several possible confounding factors which were not determined, such as menstrual cycle, the use of oral contraceptives (OC), menstrual status (*e.g.*, oligo- and amenorrhea, OC intake, as well as follicular and luteal phases (compared to ovulatory phase) lead to lower androgen levels), some disorders and competition effect (elevations in testosterone in winners compared to losers).^{31,32} It is also well established that a mass spectrometry-based measurement instead of immuno-assay method of T detection should be preferred. These are limitations of this study. In addition, there are already other factors that have been reported to show associations with sprinting ability, such as body mass, body mass index and height,^{33,34} muscle fiber composition^{35,36} and several genetic variants.³⁷⁻⁴²

Conclusions

Taken together, our data indicate that baseline T is responsible for athletic success in female sprinters but not in athletes from other types of sport events such as endurance disciplines, events with mixed sport activities and speed-strength sports. The preliminary data suggest that the measurement of serum T (which is an inherited trait) may be used in the prediction of sprinting ability in women.

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Table I.—Interrelationship between resting serum testosterone levels and athletic success in female athletes stratified into four groups

Groups	N.	Testosterone, nmol/L								P value
		All athletes		Sub-elite		Elite		Highly elite		
		Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range	
Endurance athletes	133	1.67±0.85	0.08-4.45	1.68±0.87	0.08-4.45	1.72±0.90	0.57-4.1	1.44±0.58	0.47-2.44	0.859
Athletes with mixed activity	321	1.72±0.91	0.15-5.82	1.74±0.99	0.15-5.82	1.81±0.86	0.54-4.7	1.55±0.75	0.18-3.8	0.455
Speed/strength athletes	100	1.46±0.79	0.08-3.79	1.44±0.78	0.08-3.79	1.47±0.82	0.4-3.54	1.43±0.81	0.48-3.21	0.567
Sprinters	45	1.52±0.73	0.53-3.89	1.09±0.40	0.53-2.01	1.97±0.63	0.99-3.67	2.0±0.93	1.17-3.89	0.0002*
All athletes	599	1.65±0.87	0.08-5.82	1.64±0.92	0.08-5.82	1.72±0.86	0.4-4.7	1.56±0.75	0.18-3.89	0.553
Controls	298	1.76±0.60	0.38-2.83	-	-	-	-	-	-	-

*P<0.05, statistically significant association between T levels and athletic success within one group (adjusted for age).

Table II.—Testosterone levels in different age groups of athletes and controls.

Groups	N.	Testosterone, nmol/L						<i>r</i>	P value
		16-25 years		26-30 years		31-35 years			
		Mean±SD	Range	Mean±SD	Range	Mean±SD	Range		
Endurance athletes	133	1.74±0.92	0.08-4.45	1.56±0.62	0.49-2.9	1.31±0.68	0.47-2.44	-0.03	0.743
Athletes with mixed activity	321	1.72±0.96	0.15-5.82	1.78±0.84	0.35-4.6	1.64±0.68	0.54-3.38	0.01	0.909
Speed/strength athletes	100	1.45±0.82	0.08-3.79	1.58±0.69	0.48-3.2	0.96±0.61	0.6-1.87	0.18	0.073
Sprinters	45	1.48±0.75	0.53-3.89	2.11±0.46	1.59-2.46	1.24±0.09	1.17-1.3	0.39	0.0085*
All athletes	599	1.66±0.91	0.08-5.82	1.7±0.76	0.35-4.6	1.48±0.68	0.47-3.38	0.06	0.139
Controls	298	1.88±0.58	0.38-2.83	1.72±0.63	0.57-2.83	1.62±0.6	0.6-2.83	-0.17	0.0042*

*P<0.05, statistically significant correlation (Spearman) between age and T levels within one group.