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THE LOW SERUM FERRITIN AS AN INDICATOR OF INADEQUATE NUTRITION IN INTERNATIONAL-LEVEL FEMALE SWIMMERS

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ABSTRACT

Introduction: Iron deficiency is a common feature in athletes, and optimizing iron levels may become a contributing factor to improved athletic performance.

Purpose: This study aimed to evaluate body iron stores and their relationship with sports performance. It also sought correlations between the swimmers' hematological, hormonal, anthropometric, and functional status and their sports achievements.

Methodology: The research involved 19 athletes (11 women and 8 men) from the Bulgarian national swimming team. They were tested for maximal aerobic capacity on a cycle ergometer and had blood samples taken to determine iron status and hematological and hormonal markers. Their swimming achievements (Swimming points) were evaluated as a percentage of the world records in the respective discipline.

Results: There were statistically significant differences between the female and male swimmers for Unbound Iron Binding Capacity (UIBC) and ferritin. A higher UIBC in women indicated lower iron levels in them. Among female swimmers, five had ferritin levels below 40 ng/mL. In women, a highly reliable correlation between the Swimming points and ferritin concentration ($r = .68$) was observed. All male swimmers had ferritin values above 40 ng/mL, and there was no reliable correlation between ferritin concentration and Swimming points, probably because ferritin was in the optimal range and is no longer a significant performance factor.

Conclusions: In swimmers, the optimal serum ferritin concentration is probably in the range of 40–90 ng/mL. Many female swimmers have a relative iron deficiency with sub-optimal ferritin values. In competitive female swimmers, low ferritin level is an indicator of both iron deficiency and inadequate diet. It can be expected that an adequate nutritional regime in athletes with low ferritin values will lead both to the replenishment of iron stores and to an increase in muscle mass and, ultimately, to an improvement in sports performance.

Keywords: swimmers, iron status, hematological status, hormones, sports achievements

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INTRODUCTION

Iron deficiency is common in athletes, especially those practicing endurance sports. Athletes are more susceptible to iron loss than sedentary individuals due to many factors associated with sports activity, such as more frequent hemolysis, hematuria, sweating, gastrointestinal bleeding, altered dietary

patterns, and related effects of pro-inflammatory cytokines, leading to hepcidin-mediated changes in iron transport and metabolism (Pedlar et al., 2018; Babic et al., 2001; DeRuisseau et al., 2002; Roecker et al., 2005). Several studies have shown that iron supplementation has a markedly positive effect on the performance of iron-deficient

athletes but not in athletes with optimal iron levels and stores. The most used biomarkers of iron status are ferritin, hemoglobin, sTfR, TSAT, hematocrit, hepcidin, and IL-6 (Solberg, Reikvam, 2023).

Often, athletes can be diagnosed with iron deficiency, even with hemoglobin and hematocrit values that fall within the clinical reference norms (Peeling et al., 2007). Scientific and clinical studies have shown that the normative values for blood parameters, especially serum ferritin, in elite athletes may differ substantially from the norms for the general human population (Chatard et al., 1999). The need for higher iron stores in athletes is determined by the increased need for iron in physiological adaptation to exercise and avoidance of impaired exercise response. Determining suboptimal iron status in athletes and its effects on athletic performance is poorly studied. Optimizing athletes' iron levels may contribute to improved athletic performance. It was suggested that serum ferritin levels are a reliable indicator of iron deficiency (Nabhan et al., 2020). The World Health Organization currently defines 20 ng/ml ferritin as a threshold lower limit in the general human population. The study by Custer et al. (Custer et al., 1995) is probably the most detailed study to date to determine the physiological range of serum ferritin in the general human population. It is the basis for interpreting clinical values. The authors defined four ferritin threshold values, with levels <35 ng/mL corresponding to first-stage iron depletion. This value is also accepted as the threshold of iron deficiency requiring therapy in athletes (Govus et al., 2015; Nielsen et al., 1998). Based on the study of Custer et al. (1995), Nabhan et al. (2020) showed that the distribution of serum ferritin levels in male and female elite athletes was different from that in the general

population of both men and women aged 20 to 28 years. In 3% of male athletes, serum ferritin levels were found to be lower than 20 ng/ml, and in 15% - <35 ng/ml. In female athletes, serum ferritin levels < 20 ng/ml were found in ~23% and in 52% - <35 ng/ml (Nabhan et al., 2020).

The issue of establishing optimal ferritin levels in athletes relevant to optimal performance has been debated but not fully clarified (Eichner et al., 2012; McClung et al., 2012; Yu et al., 2013; Fallon, 2004). Okazaki et al. recommend serum ferritin values of 40–90 ng/mL before altitude training, assuming a cutoff for iron deficiency of 20 and 30 ng/mL for women and men, respectively (Okazaki et al., 2019). According to them, these ferritin levels provide an increase in hemoglobin and VO_2 max during exercise in hypoxic conditions and, therefore, an increase in endurance. Similar 20 ng/mL values have been suggested as borderline in rowers (DellaValle et al., 2014). Woods et al. suggest normal ferritin values between 30–100 ng/mL in distance runners (Woods et al., 2014). Mielgo-Ayuso et al. (2018) defined higher ferritin levels above 100 ng/mL as recommended and values 30–99 ng/mL as an indicator of functional deficiency and below 30 ng/mL as an absolute iron deficiency in elite female volleyball players (Mielgo-Ayuso et al., 2018). Studies are needed on functional iron deficiency associated with low ferritin levels in athletes, including evaluating its possible effects on sports performance.

Purpose and objectives of the study

This study aimed to evaluate body iron stores and their relationship with sports performance and the hormonal and hematological status of swimmers from the Bulgarian National Swimming Team.

METHODS

Participants

Nineteen athletes (11 women and 8 men) from the Bulgarian National Swimming Team competing in the distances 50, 100, 200, and 400 m with two training sessions per day (10 training sessions per week) were studied. The average age of the female swimmers was 16.9 ± 3.27 years (max. 26 years, min. 14 years), and they had a sports experience of 8.09 ± 3.7 years (max. 18 years; min. 5 years), and for male swimmers, 16.9 ± 1.13 years (max. 19 years; min. 16 years) and sports experience 7.88 ± 1.46 years (max. 10 years; min. 6 years). The athletes were informed about the aims and methodology of

the study and signed an informed consent to participate in it. All tests were performed following the ethical standards of the Helsinki Declaration.

Swimming Points

The point evaluations of swimming performance (Swimming points) were calculated according to the International World Aquatics Federation. Point evaluations served to compare the results achieved in different disciplines by competitors of different ages and genders. The calculation formula is based on the world record in each discipline:

$$\text{Swimming Points} = 1000 * (\text{Word Record}/\text{Time})^3$$

where: Word record (s); Time (s) – the best time of swimmer in the same discipline

Anthropometry

The height was measured with a stadiometer with an accuracy of 0.5 cm. The body composition analyzer InBody 230 (InBody Co., Ltd., South Korea) was used to assess Body Mass [kg], Percentage Body Fat (BF%) [%], Lean Body Mass (LBM) [kg], and Percentage Muscle Mass (MM%) [%].

Blood analyses

Blood samples were taken by a medical person and in an authorized clinical laboratory the following parameters were determined: white blood cells (WBC) [G/L], neutrophils percent (NEU%) [%], neutrophils number (NEU) [G/L], eosinophils percent EOS% [%], eosinophils number EOS [G/L], lymphocytes percent (LYM%) [%], lymphocytes number (LYM) [G/L], monocytes percent (MONO%) [%], monocytes number (MONO) [G/L], basophils percent (BASO%) [%], basophils number (BASO) [G/L], red blood cells (RBC) [T/L], hemoglobin (HGB) [g/L], hematocrit (HCT) [L/L], mean corpuscular volume

(MCV) [fL], mean corpuscular hemoglobin (MCH) [pg], mean corpuscular hemoglobin concentration (MCHC) [g/L], red cell distribution width (RDW) [%], platelets (PLT) [G/L], mean platelet volume (MPV) [fL], platelet distribution width (PDW) [fL], and plateletcrit (PCT) [L/L]. In serum were measured: Ferritin [ng/mL], serum iron [$\mu\text{mol/L}$], total iron binding capacity (TIBC) [$\mu\text{mol/L}$], unsaturated iron binding capacity (UIBC) [$\mu\text{mol/L}$], Testosterone (T) [ng/mL], Cortisol [$\mu\text{g/dL}$], thyroid stimulating hormone (TSH) [$\mu\text{IU/mL}$], free Triiodothyronine (fT3) [pg/mL], free Thyroxine (fT4) [ng/dL], and Urea [mmol/L].

Maximal Aerobic Capacity measurement

All swimmers performed the Maximal Aerobic Capacity Test on cycle-ergometer Ergoselect 100 (Ergoline GmbH, Mitz, Germany) with respiratory gas exchange analysis using a metabolic cart (Quark CPET, CosMed Srl, Rome, Italy). The load started at 60W and increased by 30W every 1.5 min until failure.

The following parameters were determined: VO₂max [mL/min], VO₂max/kg [mL/min/kg], Wmax [W], Wmax/kg [W/kg], and HRmax [bpm].

Statistical analysis

The data were analyzed using the statistical package SPSS26 - descriptive statistics. The variables' distribution parameters were determined - such as those with a normal and those with a non-normal distribution. An analysis was made of the differences in the

average values or medians between men and women in the separate groups using adequate methods (Student's t-test for independent samples and the non-parametric Mann-Whitney test). Full correlation matrices were made of all variables studied.

RESULTS

Table 1 presents the anthropometric and functional parameters of the studied swimmers.

Table 1. Anthropometric and functional parameters of tested swimmers

	Females (n = 11)			Males (n = 8)			Distr.	Sig.	Mean Diff.
	Min	Max	Mean ± SD	Min	Max	Mean ± SD			
Hight	161.50	178.00	167.95±5.89	175.00	194.00	183.75±5.36	Normal	.000	15.800
Body mass	49.00	66.00	57.36±5.05	70.00	78.00	72.88±2.79	Normal	.000	15.515
LBM	44.80	63.80	51.31±5.60	61.50	70.20	66.21±3.12	Norma	.000	14.903
BF%	3.40	13.80	10.62±3.44	6.00	12.70	9.15±2.05	Normal	.303	-1.470
MM%	41.20	51.30	45.29±2.68	47.30	53.60	50.41±2.37	Normal	.001	5.122
Wmax/kg	3.45	4.55	4.03±0.32	3.69	4.93	4.52±0.52		.033	0.490
VO ₂ max/kg	43.10	63.03	52.38±5.28	47.44	65.07	56.66±5.9	Normal	.124	4.287
HRmax	171.00	202.00	187.4±9.34	183.00	200.00	190.88±6.13	Normal	.379	3.480
Swimming points	601.00	831.00	707.82±53.04	626.00	799.00	728.63±53.59		.070	20.810

All anthropometric parameters were normally distributed, and except for BF%, they were significantly greater in male swimmers. The lack of a reliable difference in BF% between men and women was because all of them were elite swimmers, and a BF% around 10% is optimal for swimmers in this sport. Both men and women had a high percentage of muscle mass within the fit limits for athletes; MM% for men was 50.41±2.37% and for women - 45.29±2.68%. Maximal oxygen consumption was at values typical of short- and medium-distance swimmers, where an-

aerobic energy supply also plays an essential role. The maximum reached heart rate (HRmax) is not gender-related and, in this study, was within the limits predicted for the swimmers' age (about 200 bpm). The mean values of Swimming points 707.82±53.04 and 728.63±53.59 for women and men, respectively, were not significantly different. The absence of significant differences in age, sports experience, and sports performance assessment indicated the high homogeneity of the sample in terms of non-sex-related traits.

Table 2. Complete Blood Count and biochemical parameters of tested swimmers

	Females (n = 11)			Males (n = 8)			Distr.	Sig.	Mean Diff.
	Min	Max	Mean ±SD	Min	Max	Mean ±SD			
WBC	4.40	10.20	7.11±2.04	4.10	10.90	7.26±2.76	Normal	.892	0.152
NEU%	29.10	78.70	47.16±12.34	37.30	67.60	52.6±13.2		.658	5.444
NEU#	1.69	7.09	3.46±1.64	1.82	7.19	4.09±2.39		1.000	0.627
EOS%	0.99	11.50	4.16±3.02	1.17	8.33	4.32±2.6		1.000	0.162
LYM%	14.20	52.00	38.93±9.68	17.40	48.30	33.55±11.77		.650	-5.383
LYM#	1.28	4.12	2.66±0.85	1.53	3.21	2.23±0.6	Normal	.237	-0.433
MONO%	3.98	13.00	8.54±2.55	6.28	11.30	8.67±1.73	Normal	.898	0.136
BASO%	0.46	2.93	1.24±0.69	0.46	1.65	0.75±0.39	Normal	.092	-0.486
RBC	4.39	5.25	4.73±0.22	5.06	5.70	5.33±0.22	Normal	.000	0.601
HGB	131	152	142.56±6.18	150	163	156.38±4.34	Normal	.000	13.820
HCT	0.39	0.47	0.43±0.02	0.44	0.50	0.47±0.02	Normal	.002	0.035
MCV	84.60	94.30	90.88±2.60	82.10	91.00	87.06±3.19	Normal	.011	-3.815
MCH	28.10	31.70	30.14±1.18	28.50	30.80	29.36±1.02		1.000	-0.781
MCHC	321.0	341.0	331.56±5.39	326.0	351.0	337.25±7.59	Normal	.072	5.690
RDW	12.50	14.90	13.29±0.72	12.80	13.70	13.34±0.32	Normal	.861	0.049
PLT	175.0	373.0	273.78±51.11	182.0	282.0	251.88±33.52	Normal	.307	-21.90
MPV	9.30	10.70	10.04±0.38	9.50	11.40	10.28±0.70	Normal	.420	0.231
PDW	11.70	13.40	12.56±0.51	11.60	13.80	12.95±0.75	Normal	.188	0.394
Iron	9.10	25.40	17.47±5.40	8.20	40.40	24.41±10.08	Normal	.068	6.946
UIBC	31.00	60.00	42.56±9.00	16.00	49.00	32.88±9.51	Normal	.037	-9.681
TIBC	45.10	76.40	60.02±8.20	49.70	67.00	57.29±5.79	Normal	.431	-2.734
Ferritin	8.97	314.5	66.6±84.03	46.56	126.32	74.73±25.27		.033	8.122

No significant differences between female and male swimmers were found in white blood cell counts (Table 2). This result was expected since there is no data on pronounced gender differences in the indicators of the white blood cell. Red blood cell counts (RBC, HGB, HCT, and MCV) were statistically higher in men than in women because men's higher testosterone levels positively influenced them. The only exceptions were MCH, MCHC, and PDW.

Regarding the indices of iron metabolism (Iron, UIBC, TIBC, and Ferritin), statistically significant differences between the female and male swimmers were found for UIBC and ferritin (Table 2). A higher UIBC in women indicates lower iron levels in them. Regarding serum ferritin, we adopted the optimal

concentrations from the literature study: 40–90 ng/mL (Okazaki et al., 2019). In the tested female swimmers, the large standard deviation (66.6±84.03 ng/mL) was due to a very high ferritin value in only one of the athletes (314.5 ng/mL). The remaining female swimmers' mean value was 41.8±18.32 ng/mL, with 5 women below the 40 ng/mL limit. All male swimmers had ferritin values above 40 ng/mL, the mean value being 74.73±25.27 ng/mL and the maximum 126.32 ng/mL. There was no reliable correlation between ferritin concentration and swimming performance in male swimmers, probably because ferritin in the optimal range (40–90 ng/mL) is no longer such a significant performance factor.

Table 3. Urea, Cortisol, Testosterone, and thyroid-related hormones of tested swimmers

	Min	Max	Mean ±SD	Min	Max	Mean ±SD	Distr.	Sig.	Mean Diff.
Urea	3.50	6.60	5.02±0.94	4.20	8.10	6.06±1.42	Normal	.071	1.041
Cortisol	12.50	21.90	16.58±3.04	14.30	23.70	17.65±3.45	Normal	.485	1.068
T	0.21	0.45	0.33±0.07	2.92	7.52	4.82±1.58	Normal	.000	4.481
TSH	1.17	3.29	2.26±0.58	1.03	3.41	2.05±0.76	Normal	.498	-0.211
ft3	1.86	3.57	2.83±0.48	3.06	3.62	3.34±0.22	Normal	.013	0.511
ft4	0.71	1.05	0.89±0.08	0.87	1.11	1±0.08	Normal	.014	0.105

Table 3 presents the research results on the tested swimmers' Urea, Cortisol, Testosterone, and thyroid-related hormone levels. Differences were found not only in testosterone levels but also in ft3 and ft4, which were significantly lower in women compared to men.

Table 4 presents the correlation matrix of the gender-independent parameters of the studied swimmers (the rows in the table show only the reliable correlations). Swimming points had significant positive correlations with WBC, NEU%, and NEU# and a significant negative correlation with LYM%. VO₂max had a significant negative correlation with BF%.

Tables 5 and 6 present the correlation matrices of the investigated parameters in female and male swimmers, respectively, and the reliable correlations are marked in bold.

In female swimmers, reliable correlations were established (Table 5) between the red blood cells and iron status parameters. There were high correlations between anthropo-

metric parameters, body mass, BF% and MM%, and the indicators of iron status. Positive correlations were found between Wmax and VO₂max with MM% and negative with BF%. Swimming points had strong positive correlations with HGB, HTC MCV, ferritin, body mass, LBM, and MM% and strong negative correlations with UIBC and TIBC. In women, we observed a very high reliable correlation between swimming performance, assessed as Swimming points (percentage of world record) and serum ferritin concentration ($r = .843$).

In male swimmers, the expected significant negative and positive correlations were observed between red blood indices RBC, RDW, HGB, HCT, MCV, and MCH and between RBC indices and iron status indices: TIBC, UIBC, iron, and ferritin (Table 6). Testosterone had high positive correlations with MCV, MCH, and ferritin and very high negative correlations with RDW. VO₂max correlated strongly positively with MM% and positively with Vmax/kg.

Table 4. Correlation matrix of sex-independent parameters of female and male swimmers (n=19)

	WBC	NEU%	NEU#	LYM%	LYM#	Iron	TIBC	BF%
Iron	-.286	.072	-.117	-.163	-.456*	1		
TIBC	-.174	-.185	-.197	.095	-.100	.135	1	
TSH	-.371	-.424	-.444	.524*	.113	-.495*	-.073	
BF%	-.380	-.091	-.261	.166	-.279	-.011	.329	1
VO ₂ max/kg	.100	.244	.187	-.339	-.235	.331	-.199	-.637**
Swimming points	.480*	.522*	.536*	-.551*	-.032	-.047	-.590**	-.441

Correlation is significant at the * - .05 level; ** - .01; Reliable correlations are marked in bold.

Table 5. Correlation matrix of studied parameters of female swimmers ($n=11$)

	HGB	HCT	MCV	MCH	UIBC	TIBC	Ferritin	Body Mass	LBM	BF%	MM%
UIBC	-.379	-.193	-.860**	-.805**	1						
TIBC	-.034	.035	-.630*	-.556	.807**	1					
Ferritin	.470	.471	.335	.229	-.536	-.686*	1				
Body Mass	.492	.260	.688*	.709*	-.781**	-.672*	.653*	1			
LBM	.601	.440	.630	.596	-.708*	-.670*	.807**	.934**	1		
BF%	-.525	-.610	-.184	-.033	.180	.304	-.692*	-.287	-.610	1	
MM%	.592	.535	.354	.298	-.391	-.392	.727*	.501	.748*	-.888**	1
W _{max} /kg	.396	.396	.332	.225	-.448	-.394	.560	.316	.564	-.830**	.838**
VO ₂ max/kg	.521	.489	.369	.296	-.160	-.104	.176	.239	.433	-.647*	.694*
Swimming points	.670*	.644*	.655*	.481	-.766**	-.724*	.843**	.747*	.834**	-.579	.642

Correlation is significant at the * - .05 level; ** - .01; Reliable correlations are marked in bold.

Table 6. Correlation matrix of studied parameters of male swimmers ($n=8$)

	RBC	HGB	HCT	MCV	MCH	RDW	UIBC	T	Body mass	BF%	MM%	W _{max} /kg
HCT	.630	.809*	1									
MCH	-.740	.133	-.080	.823*	1							
MCHC	-.477	-.445	-.874**	-.415	.174							
RDW	.243	-.638	-.445	-.865**	-.812*	1						
Iron	.268	.223	-.070	-.345	-.177	-.058	-.827*					
TIBC	.891**	.698	.684	-.233	-.511	-.051	.202					
T	-.332	.442	.285	.734*	.744*	-.901**	-.200	1				
Ferritin	-.470	.323	-.021	.566	.804*	-.793*	-.163	.867**				
LBM	-.115	-.103	-.068	.161	.086	.095	-.023	-.237	.880**			
MM%	-.308	-.185	-.132	.156	.220	.024	-.071	-.090	-.001	-.834*	1	
VO ₂ max/kg	-.049	-.268	-.318	-.390	-.191	.331	-.426	-.190	-.289	-.598	.746*	.860**
Swimming points	-.398	-.437	-.197	.051	.114	.121	.253	-.020	-.602	-.065	.446	.557

Correlation is significant at the * - .05 level; ** - .01; Reliable correlations are marked in bold.

DISCUSSION

The main objective of this study was to evaluate iron status and its relationship with the scores of international-level swimmers. Correlations were also sought between the various measured indicators, including blood, hormonal, anthropometric, and functional, and the sports achievements of the studied male and female swimmers to clarify their informativeness and propose measures to improve sports performance.

The working hypothesis of this work suggested a positive relationship between serum ferritin levels and athletic performance. The

obtained results showed that in women, ferritin, which is assumed to be the most reliable indicator of body iron stores (Garcia-Casal et al., 2021), has strong positive correlations with body mass, percentage of muscle mass, and an exceptionally high correlation with LBM (0.8087, $p < .01$). The high correlations between swimming points and indicators of red blood count and iron status can be explained by their high correlation with LBM%. In our opinion, the observed decreased indicators of iron status in female swimmers are also indicators of irrational nutritional status, which also explains the

correlation between their swimming score and the active/lean muscle mass. Therefore, we believe that iron deficiency in women with lower ferritin is probably related to dietary (and possibly protein) deficiency since meat is one of the primary dietary sources of iron. In female athletes, inadequate energy (low energy availability) and carbohydrate (low carbohydrate availability) intake have been associated with a lower level of iron reserves (Mountjoy et al., 2023). And that is why there is a high pseudo-correlation between ferritin and sports performance. The correlation matrix of the studied parameters of the male swimmers, who had no suboptimal ferritin values (Table 2), shows no correlation of Ferritin levels with Swimming points (Table 6), which supports the above conclusion. The correlation between sports performance and ferritin levels found in women does not exist in men. Since low ferritin levels are a more accurate indicator of iron deficiency (when other causes are excluded), iron supplementation to replenish these stores is recommended. However, this supplementation will raise ferritin levels but will not improve sports performance. On this basis, it seems more adequate that iron stores in athletes be restored by providing the diet with iron-rich food with high bioavailability and high protein content, such as poultry (Skolmowska et al., 2022). In addition, this approach will lead to a rise in growth factors (IGF-1 and Growth hormone), LBM%, and MM%, and eventually improve sports performance (Giovannucci et al., 2003; Watling et al., 2023).

Unlike females, all male swimmers had ferritin values above 40 ng/mL; the mean value was 74.73 ± 25.27 ng/mL, and the maximum was 126.32 ng/mL. In male swimmers, there was no reliable correlation between ferritin concentration and swimming performance. This is probably because when ferritin is in the optimal range (40–90 ng/mL), it is also an indicator of adequate nutrition and loses its correlation with

sports achievements.

Regarding other studied blood markers, we observed a reliable positive correlation of the sports achievement score (Swimming points) with WBC, NEU#, and NEU% and a reliable negative correlation with LY% (Table 4). The lack of correlation between Swimming points and LY# suggests that, in practice, LY# does not differ between competitors of different ranks but only decreases relative to the total white blood cell count due to the increase in the absolute number of neutrophils. An increase in the total number of granulocytes in connection with exercise and a decrease in the absolute number of lymphocytes after exercise were confirmed (Espersen et al., 1990). A blood neutrophil count increase and lymphocyte count decrease were observed after sports camp (Murakami et al., 2009). We suggest that the observed changes in white blood cells are primarily due to the inflammatory processes associated with training-induced muscle damage. Thus, clinical studies have demonstrated that the antioxidant N-acetylcysteine (NAC), a precursor of GSH, significantly suppresses reactive oxygen species from neutrophils that are increased through exercise. NAC may also reduce the excessive inflammatory response caused by daily intense exercise, inhibit inflammation-mediated immunosuppression, and mitigate muscle damage and hematological changes in athletes (Huupponen et al., 1995; Nielsen et al., 2001; Peake et al., 2004). It could be assumed that the swimmers with higher Swimming points have a greater volume and intensity of training and, accordingly, more pronounced inflammatory processes associated with a more significant increase in neutrophils.

The negative correlation of BF% with $\dot{V}O_{2\max}$ indicates that excess adipose tissue negatively affects maximal oxygen consumption and explains the desire of competitors to maintain BF% within optimal limits around 10% since much lower values reduce swimmers' buoy-

ancy and increase resistance. Maintaining an optimal body fat percentage is more difficult for women, as higher estrogen levels and low testosterone contribute to an increase in BF%. Therefore, female athletes must adhere to more significant dietary restrictions. In turn, the latter may lead to sub-optimal ferritin levels. Thus, the low serum ferritin became a credible indicator of inadequate nutrition.

CONCLUSIONS

Based on the analysis of the obtained results, the following conclusions can be drawn:

In swimmers, the optimal levels of iron stores, estimated by serum ferritin concentration, are higher than the accepted clinical norms; probably, the optimal serum ferritin concentration for athletes is in the range of 40–90 ng/mL.

Most female swimmers have a relative iron deficiency with sub-optimal ferritin values.

From the results obtained, it can be argued that in competitive female swimmers, low ferritin levels are an indicator, in addition to iron deficiency and an inadequate diet.

An adequate nutritional regime can be expected to replenish iron stores in athletes with low ferritin values, increase muscle mass, and, ultimately, improve sports performance.

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