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**METABOLIC ACIDOSIS AS A CONSEQUENCE OF MAXIMAL EFFORT
IN FEMALE FIELD HOCKEY PLAYERS IN AN ANNUAL TRAINING CYCLE**

Key words: field hockey, macrocycle, acid-base balance, female, physiology.

ABSTRACT

The goal of the study was to determine the influence of maximal physical effort on the acid-base balance in female field hockey players in a yearly training cycle. Twelve members of the National Polish Field Hockey Team were tested once in the preparatory and twice in the competitive period of one training macrocycle. Using a portable ergospirometry system, the athletes were examined on a motorized treadmill to determine their maximal oxygen uptake ($VO_2\text{max}$) and ventilatory threshold (VT). Lactate (LA) concentration in capillary blood was assessed to calculate the intensity of physical effort and metabolic response. The biochemical parameters of acid-base balance were determined using a blood gas analyzer. Mean $VO_2\text{max}$ VT values indicated a medium level of the tested competitors' aerobic fitness. The highest $VO_2\text{max}$ and VT values were observed at the beginning of the competitive period. After each test, the lactate concentration was elevated, while pH, concentration of bicarbonate ions, and base excess rapidly decreased. All calculated differences in biochemical parameters measured at rest and post-exercise were highly significant. The lowest differences in pH and lactate concentration were observed in the mid-competitive period. Those biochemical changes showed that metabolic acidosis was present in all three examinations. The lowest acid-base balance disturbances were observed in the mid-competitive period.

INTRODUCTION

Field hockey, classified as one of the most dynamic sports [13], is characterized by aerobic and anaerobic efforts taking up 60% and 40% of the game time, respectively [15]. However, the exact proportion of that ratio depends on players' tactical positions and tasks on the pitch as well as their individual preferences [3].

Anaerobic effort is known to generate some acidic metabolites, especially lactic acid, and leads

to metabolic acidosis followed by acid-base balance disturbances. Metabolic acidosis, independent of respiratory mechanisms and accompanied by a loss of bicarbonate ions and a decrease in pH, causes muscle fatigue and decreases psychomotor efficiency. Living organisms possess highly effective compensatory mechanisms, especially blood buffers assisted by the respiratory system and renal excretion, which counteract the formation of metabolic acidosis and prevent acid-base balance disturbances [16].

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The most important aim of sports training is increasing one's fitness level considering standard principles of training. The body needs effective metabolic pathways to react promptly upon disturbances of the acid-base balance and to diminish that effect's dependency on the training type and physical efficiency. Additionally, the periodization of training, including preparatory, competitive and out of season periods, leads to focusing on different elements and detailed training aims during such a training macrocycle. In the preparatory period, primarily aerobic fitness, and then on its basis, speed efficiency, are developed. Next, during the competitive period, mainly anaerobic abilities are improved [9, 22].

There have been only five research papers published to date that concern the acid-base balance in field hockey players. The absence of data about exercise-induced metabolic acidosis in female field hockey players in an annual training cycle provided the basis for our determination to pursue the goal of this study.

METHODS

Twelve out of twenty Polish National Team female field hockey players, excluding goalkeepers, took part in this study. Detailed information about the subjects is presented in Table 1. All of them gave their written informed consent to participate in the study, which was approved by the Ethics Committee of the University of Medical Sciences in Poznań, Poland.

Each athlete was examined three times during a yearly training cycle: in the preparatory period (T1), at the beginning of the competitive period (T2), and just before the main competition in the competitive period (T3). Aerobic fitness of all competitors was estimated during graded effort on a mechanical treadmill (Woodway, USA) and defined as ventilatory threshold (VT) and maximal oxygen uptake ($VO_2\text{max}$), using a portable spirometric-telemetric device (Oxycon Mobile, Jaeger, Germany). For each player, running speed until reaching the maximal individual load as well as time to exhaustion (tEx – min) were recorded. The initial speed of the treadmill of $8 \text{ km}\cdot\text{h}^{-1}$ was increased by $2 \text{ km}\cdot\text{h}^{-1}$ every three minutes, after a steady state was achieved. During this exercise, the heart rate was constantly monitored using a sport tester (Polar S610i, Finland).

Before and three minutes after the test was carried out, two $100 \mu\text{l}$ samples of capillary blood were taken from the fingertip. In one sample, pH, base excess (BE), bicarbonate (HCO_3^-), carbon dioxide partial pressure (pCO_2), and oxide partial pressure (pO_2) were determined using an acid-base balance parameter analyzer – Cobas b121 (Roche, Germany). In the second sample, the lactate (LA) concentration was analyzed to describe the intensity of physical effort. The LA level was estimated before and three minutes after the exercise, using an enzymatic method based on Warburg's optical test [12] and the measurement was performed on a multi-mode microplate reader – Synergy 2 SIAFRT (BioTek, USA). Each round of tests took place in standard environment (temperature range $20\text{-}22^\circ\text{C}$, humidity $50\text{-}60\%$) in the morning (9-12 am) at least two hours after light breakfast.

All data was presented as means (M) and standard deviations (SD). Verification of data distribution to determine whether the kind of test was parametric or non-parametric was conducted using the Shapiro-Wilks test. Differences between the resting and post-exercise values of biochemical parameters (anthropometric, physiological and deltas of biochemical parameters) were assessed using the Wilcoxon signed rank test. Statistical calculations were made with the use of STATISTICA 8.0 (StatSoft, Inc., 2007) package for MS Windows.

RESULTS

The players understudy were 19.8 ± 2.66 years old and started their field hockey training at 9.8 ± 2.78 years of age. The anthropometric characteristics of the analyzed group in the successive periods of observation are presented in Table 1. There were no significant differences in BMI, body mass and body height between the three terms of measurement.

Table 2 summarizes physiological parameters of the examined field hockey players. The increased levels of $VO_2\text{max}$ and VT speed indicate a high level of aerobic fitness. Also, time to exhaustion (tEx) shows the right physical fitness tolerance in those athletes. The highest values of all physiological parameters, apart from HR max, were found in the competitive period (T2). Statistical differences were observed in the case of HR max, tEx, VT speed and tVt between T1 and T2, and T1 and T3. The changes in $VO_2\text{max}$ were not significant.

Table 1. Anthropometric characteristics of female field hockey players [M ± SD]

	T1	T2	T3	Wilcoxon test
Body mass (kg)	62.83 ± 6.87	63.36 ± 7.19	63.28 ± 5.77	NS
Body height (cm)	169.79 ± 7.56	169.79 ± 7.56	169.79 ± 7.56	NS
BMI (kg/m ²)	21.75 ± 1.19	21.92 ± 1.28	21.95 ± 1.01	NS

T1 – preparatory period; T2 – beginning of the competitive period; T3 – mid-competitive period; BMI – body mass index; NS – non-significant

Table 2. Physiological characteristics of the tested female field hockey players [M ± SD]

	T1	T2	T3	Wilcoxon test
VO ₂ max (ml/kg/min)	44.48 ± 4.69	45.38 ± 5.03	44.72 ± 3.90	NS
HR max (beat/min)	198.08 ± 8.30	195.58 ± 9.63	195.92 ± 7.86	T1-T2*, T1-T3*
tEx (min)	10.88 ± 1.33	11.69 ± 1.54	11.64 ± 1.37	T1-T2*, T1-T3*
VT speed (km/h)	9.83 ± 1.34	10.50 ± 0.90	10.37 ± 1.34	T1-T2*, T1-T3*
tVT (min)	4.58 ± 1.53	5.65 ± 1.6	5.20 ± 1.78	T1-T2*, T1-T3*

T1 – preparatory period; T2 – beginning of the competitive period; T3 – mid-competitive period; VO₂maximal – maximal oxygen uptake; HR max – maximal heart rate; tEx – time to exhaustion; VT speed – speed on ventilatory threshold; tVT – time to reach ventilatory threshold

* – p < 0.05; NS – non-significant

Table 3. Lactate concentration and acid-base balance parameters [M ± SD] in a group of female field hockey players. The presented data shows deltas (Δ) between post-exercise and resting values of blood parameters

	T1	T2	T3	Wilcoxon test
LA (mmol/l)	10.04 ± 1.46	9.84 ± 1.10	6.90 ± 1.92	T1-T3**, T2-T3**
pH	0.153 ± 0.048	0.144 ± 0.040	0.110 ± 0.046	T1-T3*
HCO ₃ ⁻ (mmol/l)	8.61 ± 1.92	8.68 ± 1.65	7.85 ± 2.06	NS
BE (mmol/l)	11.27 ± 2.55	11.26 ± 2.16	10.23 ± 2.71	NS
pCO ₂ (mm/Hg)	6.05 ± 2.37	6.51 ± 1.62	6.94 ± 3.54	NS
pO ₂ (mm/Hg)	24.13 ± 7.74	20.02 ± 5.60	25.37 ± 10.50	NS

T1 – preparatory period; T2 – beginning of the competitive period; T3 – mid-competitive period; LA – lactate concentration; HCO₃⁻ – bicarbonate concentration; BE – base excess; pCO₂ – carbon dioxide partial pressure; pO₂ – oxide partial pressure

* p < 0.05; ** p < 0.001; NS – non-significant

All biochemical parameters of acid-base balance in Table 3 are presented as resting and post-exercise differences (Δ = deltas). Changes in the lactate concentration and acid-base balance parameters (Table 3) point to a clear, significant, declining trend in LA, pH, HCO₃⁻ and BE, which is indicative of the occurrence of metabolic acidosis throughout the analyzed periods.

DISCUSSION

The present study has been the second publication in literature to date that concerns the acid-base balance in female field hockey players. It is the first complex study on acid-base balance in female field hockey players covering an entire training macrocycle. The earlier paper by Bishop et al. [2] focused on the determination of acid-base

balance changes during repeated-sprint and VO_2max tests during a single exercise.

The studied female field hockey players had a mesomorphic type of body build, and their body height did not differ from the values found by other investigators [5, 7, 23]. The body mass of the Polish players was comparable to the body mass of British female field hockey players [5] and American female students playing field hockey [6, 18, 24]. A comparison of anthropometric results of the tested female field hockey players with the data of Australian, British and Welsh athletes in the 1980s showed that present-day Polish females were characterized by a higher body stature but lower BMI [7, 15]. Moreover, the Polish female field hockey players demonstrated lower body height and body mass than representatives of other team sports such as soccer and softball. The observed trends provide evidence that the body shape of present-day female field hockey players reveals more ectomorphic components of body build [6]. That type of body build reflects a high percentage of muscle tissue in the athlete's total body mass and it is, especially, a consequence of more strength exercises in the modern training structure. The increased level of total muscle mass accompanies the adaptation of fibers to intensified training, which affects cell metabolism, and eventually, results in modification of blood biochemical parameters associated with acid-base balance [8]. An important training adaptation is rationalization of the distribution of anaerobic metabolic products (lactate, hydrogen ions) within the muscles and also their transfer to the circulatory system through specific membrane monocarboxylate transporters (MCT1, MCT4). This leads to liver utilization of metabolic products during very intensive exercises [8].

The VO_2max values found in the present study (44.48 – 45.38 ml/kg/min) indicated an average level of aerobic fitness in the tested field hockey players [25]. The maximal values of oxygen uptake obtained by the Polish Female Field Hockey National Team were slightly higher than those found in American college football players (42.9 ml/kg/min) [10]. In comparison with the examined Polish female athletes, 10 to 30 percent higher VO_2max values were found in representatives of the U.S. National Team (51.7 ml/kg/min), Australian (50.1 ml/kg/min), Welsh (54.5 ml/kg/min), Canadian (59.3 ml/kg/min) and English (52.2 ml/kg/min) [15].

The obtained values of ventilatory threshold expressed as running speed (9.83 – 10.5 km/h) proved that the general efficiency determined in the female field hockey players was at an average level. Higher threshold load values were found in Australian female field hockey players (11.5 km/h) [17] and in young Czech female triathletes (12.7 km/h) [4].

In the monitored training macrocycle, no statistically significant differences between VO_2max values were noted. Similar observations were reported by Astorino et al. [1]. An increase in VO_2max values was observed after several weeks' training in Australian female field hockey players [2, 19, 20]. Stagno et al. [21] reported relative changes in a male field hockey team. No differences in VO_2max in our study can be explained by the low susceptibility of this parameter to the training loads in athletes with well-shaped aerobic capacity index level [14].

Statistically significant increases in the parameters characterizing the ventilation threshold (VT) were found in the studied group of female athletes. An elevation of VT values was observed between the beginning of the preparatory period (T1) and the competitive period (T2, T3). Similar changes were found by Stagno et al. [21] in a study of male field hockey players. The observed direction of changes confirms the use of correct training loads in endurance training.

The studied female field hockey players were subjected to progressive physical effort to exhaustion, which in all cases caused a statistically significant decrease in the values of the acid-base balance parameters and an increase in blood lactate concentration. Those disturbances are typical for that type of load and indicative of effects of metabolic acidosis [16]. During each study period (T1 to T3), a gradual reduction of disorder parameters of the acid-base balance and blood lactate concentration were observed. In the second study period (T2), despite application of a much larger effort for testing purposes as compared with the first measurement (T1), fluctuations of the acid-base balance and lactate concentration corresponded to the values from the first period. In the third period (T3), when the tested women performed a greater effort than in the first period (T1), and similar to the second period (T2), the lowest resting and post-exercise increases in lactate concentration and decreases in blood pH were found in the field hockey players. The observed changes confirm

beneficial training adaptation to carry out longitudinal effort by the athletes, which was manifested by an increase in the blood buffering capacity and lower disturbances of the acid-base balance [11].

The authors believe that in the monitored period of field hockey training, two types of adaptation to exertion were observed. The first occurred after the preparatory period and included the physiological parameters of aerobic fitness (VT). A desirable increase in the parameters characterizing the ventilation threshold was observed after the pre-season training, and high values of VT were maintained throughout the whole competitive period (T2, T3). The second type of adaptation to physical effort included metabolic processes occurring in the players' bodies. It was expressed by an increase in the blood buffering capacity and lower post-exercise fluctuations of the acid-base balance. That was only clearly noticeable during the third period (T3), when the post-exercise differences in pH values and lactate concentrations were significantly the lowest.

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