

Profesyonel Badminton Oyuncularında Dayanıklılık Testlerinin Kan Parametreleri Üzerine Etkisi

ÖZ

Egzersiz sırasında oluşan hemoreolojik ve mikrodolaşım parametrelerindeki değişiklikler ve bunların olası sonuçları son zamanlarda çok ilgi çekmektedir. Bu çalışmanın amacı, profesyonel erkek badminton oyuncularında Yo-Yo aralıklı toparlanma testi (YIRT1) öncesi, sonrası ve 24 saat sonrasında kan parametreleri üzerindeki değişiklikleri araştırmaktır. Bu çalışmaya 16 profesyonel erkek badminton oyuncusu gönüllü olarak katıldı. Toplam kan sayımları, eritrosit deformabilitesi ve agregasyonu, testten önce ve sonra ve testten 24 saat sonra alınan örneklerde değerlendirildi. Test sırasında toplam mesafe kaydedildi. Eritrosit deformabilitesi, 0.53, 0.95, 1.69, 3.00 ve 5.33 Pascal (Pa) altında değerlendirildi ve test sonunda anlamlı bir artış gösterdi ($p<0.05$). Testten sonra agregasyon indeksi artarken eritrosit birikimi anlamlı şekilde azaldı ($p<0.05$). Hematokrit seviyeleri, hemoglobin konsantrasyonları ve eritrosit sayıları testten hemen sonra anlamlı artışlar gösterdi ($p<0.05$), ancak bu değerler testten 24 saat sonra, ön test seviyelerine göre anlamlı şekilde daha düşüktü ($p<0.05$). Lökosit parametreleri test öncesi değerlere göre belirgin bir artış gösterdi ($p<0.05$). Trombosit sayıları test öncesi, test sonrası ve testten 24 saat sonra yapılan ölçümler arasında anlamlı farklılıklar gösterdi ($p<0.05$). Hemoreolojik değişiklikler egzersiz şiddetine paralel olarak artmakta ve egzersiz sonrasında da devam etmektedir. Oyuncuların fiziksel kapasiteleri hakkında bilgi veren YIRT1'in hemoreolojik parametreleri etkilediği bulunmuştur. Yapılacak diğer araştırmalarda farklı egzersiz protokollerinin olası etkileri için, hemoreolojik değişikliklerde hücresel faktörlerin (enzim, hormon, oksidan stres) rolleri dikkate alınarak incelenebilir.

Anahtar Kelimeler: Badminton, Eritrosit deformabilitesi, Eritrosit agregasyonu, Tam kan sayımı

The Effects of Endurance Tests on Blood Parameters in Professional Badminton Players

ABSTRACT

Changes in hemorheological and microcirculatory parameters that occur during exercise and their possible consequences have attracted much attention recently. The aim of this study was to investigate the changes in blood parameters before, after and 24 hours after the Yo-Yo intermittent recovery test (YIRT1) in level 1 professional male badminton players. Sixteen professional male badminton players voluntarily participated in this study. Total blood counts, erythrocyte deformability and aggregation were evaluated in samples taken prior to and following the test and 24h after the completion of the test. During the test, the total distance was recorded. Erythrocyte deformability, evaluated under shear stresses of 0.53, 0.95, 1.69, 3.00, and 5.33 Pascal (Pa), showed a significant increase at the end of the test ($p<0.05$). Following the test, the aggregation index rose while erythrocyte accumulation decreased significantly ($p<0.05$). Hematocrit levels, hemoglobin concentrations, and erythrocyte counts also demonstrated significant increases immediately after the test ($p<0.05$), but these values were significantly lower 24 hours post-test compared to pre-test levels ($p<0.05$). Leukocyte parameters exhibited a marked increase relative to pre-test values ($p<0.05$). Additionally, thrombocyte counts displayed significant differences between pre-test, post-test, and 24-hour post-test measurements ($p<0.05$). Hemorheological changes increase parallel with exercise intensity and it continues after the exercise. YIRT1, which provides information about the physical capacities of the players, was found to affect the hemorheological parameters. In further studies, the possible effects of different exercise protocols can be examined by taking into account the roles of cellular factors (enzymes, hormones, oxidant stress) in hemorheological changes.

Key Words: Badminton, Erythrocyte deformability, Erythrocyte aggregation, Total blood count

INTRODUCTION

Blood tissue has a different characteristic as it is fluid and this fluidal feature depends on firstly erythrocyte mass and characteristics of plasma¹. The ability to alter shapes of erythrocytes', which has a special structural feature to carry respiration gasses, takes its origin from ideal biconcave discoid geometrics². Erythrocyte deformability has an effect on mass condition of blood flow. Also, it contributes to micro circulation to continue most suitable for tissues' needs^{3,4,5}. Erythrocyte aggregation affects blood flow in especially lower rate of velocity. As a result, erythrocytes' rheologic features have a high importance to perform the function of circulation^{6,7}. Blood viscosity is closely related with plasma viscosity-hematocrit and erythrocytes' rheologic features^{8,9,10}. It can be said that during exercise, there is no change in the structure of erythrocytes, but plasma viscosity and hematocrit values increase^{5,11}. After intense exercise, there is an increase in blood and plasma viscosity, erythrocyte deformability is impaired^{5,12} and aggregation increased^{9,13}. Leukocyte activation increases during exercise. Its effect on erythrocytes can be described as oxidative stress, leukocyte mobility, and increased intracellular lactic acid^{6,14}. Badminton is an aerobic sport, which is consists of speed attacks, changes of direction and various offenses, and frequently used high intensity repeated rallies; however, includes low rest rate. Badminton requires high motor skills and is an aerobic branch where the aerobic energy system is at the forefront^{15,16}. It is known that hemorheological changes increase parallel with exercise intensity and it continues after the exercise⁹. Players must have a good level of anaerobic endurance to perform movements effectively^{17,18} and to be able to repeat these movements without fatigue^{19,20}. According to the intermittent structure of sports, Yo-Yo Intermittent Recovery Tests (YIRT) are frequently used to determine the aerobic endurance of players. While these tests (YIRT1/YIRT2) measure the repetition abilities of players in violent movements, they also provide information about their resting capacity between these movements^{21,22}.

In this high-performance sport, which is an aerobic-based anaerobic branch, existing variables (morphological, physiological, psychological, biomechanical, cognitive, etc.) need to be constantly improved. In addition to the intense daily training schedule, players have to play national/international matches. These competitive needs may reflect changes in various physiological systems (musculoskeletal, nervous, hormonal and metabolic), biochemical and hematological parameters. These changes may be affected by factors such as the type of exercise, gender of the subjects, their age, training status, and time of study^{23,24}. Controls on blood parameters are important indicators that provide information about the athlete's health status, prevention of coronary or peripheral adverse events, and cardiovascular risk factors, as well as metabolic changes that occur during exercise. In particular, hemorheological changes and how training should be shaped by various systems provide many answers to coaches and sports scientists in preparing training programs suitable for the energy needs of athletes^{25,26}. Changes in hemodynamic factors during exercise also cause changes in blood fluidity, and compensatory mechanisms reduce the size of these changes and keep them at a certain level. Lack of blood flow can be observed when hemodynamic factors returned to normal levels after exercise, hemorheological factors don't turn the normal levels, especially reduced autoregulatory reserve tissues^{27,28}. Evaluation of blood parameters plays an important role in determining the stress that exercise intensity creates on the athlete, in organizing the training content and in monitoring the athlete's health status. A good knowledge of the mechanisms of due to exercise hemorheological changes in the cardiovascular system problems, regulations

and exercise protocols in the creation of their daily activity can provide important clues. As a result, the superiority of hemorheological changes caused by exercise is expected to increase in parallel with the increase in the intensity of the exercise. In this study, the effects of YIRT1 test on blood parameters in male badminton players were investigated.

MATERIAL AND METHODS

Subject

Sixteen professional male badminton players participated in this study voluntarily. Antrenman etkisinin test sonuçlarını etkilememesi amacı ile aynı takımın oyuncularını ile sınırlı tutulmuştur. The training effect was limited to players from the same team so as not to affect the test results. All players had been training for at 7 years of training experience. Athletes who did not smoke, did not have a known history of cardiovascular disease and chronic disability, did not use any medication, and had no disease/infection status were included in the study. The study started with twenty athletes and four athletes were excluded from the study due to injuries. This study was approved by the Research Ethics Committee of Süleyman Demirel University Faculty of Medicine (date: 21.11.2024 decision no 85/5) and was consistent with the institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki. The athletes who formed the research group were given detailed information about the study in advance and a consent form was obtained from those who wanted to participate in the study voluntarily.

Procedures

On the first day, players underwent anthropometric measurements followed by the Yo-Yo Intermittent Recovery Test Level 1 (YIRT1). Total blood counts, as well as erythrocyte deformability and aggregation, were assessed using blood samples collected both before and immediately after the test. On the second day, 24 hours post-test, these parameters were re-evaluated for each player.

Anthropometric Measurements

The stature of male badminton players was measured using a stadiometer with a precision of 1 cm (SECA, Germany), while body mass and body fat percentage were assessed using electronic scales (Tanita BC 418, Japan) with an accuracy of 0.1 kg.

Yo-Yo Intermittent Recovery Test

The test is an endurance assessment involving shuttle runs over a 2 × 20 m course at progressively increasing speeds, guided by auditory signals from a timing device. Following each 40-meter run, participants rest for 10 seconds within a designated 2 × 5 m recovery zone (Figure 1). The test concludes when the athlete either reaches voluntary exhaustion or fails to meet two consecutive signals²⁹. Prior to the commencement of the Yo-Yo Intermittent Recovery Test Level 1 (YIRT1), participants were briefed with detailed instructions about the procedure.

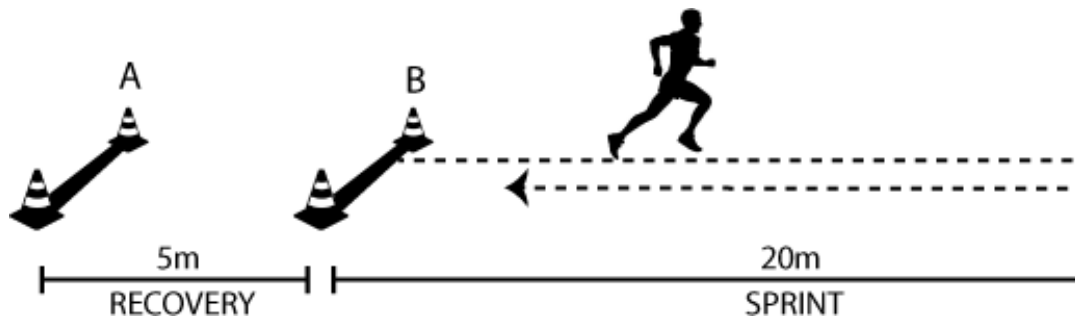


Figure 1. YIRT1

Heart Rate Monitoring

Heart rate was recorded prior to the YIRT1, immediately after and 3 min following the test via telemetry (Polar Team Sport System, Polar Electro Oy, Finland).

Blood Sampling

6 ml blood samples were obtained from antecubital vein of each subject in pre-test, immediately after and 24h following the test. Total blood counts were measured with electronic hematology analyzer (Coulter LH 750 Analyzer Beckman Coulter, Germany) in biochemistry laboratory. Blood samples were collected by healthcare personnel. They were stored in appropriate containers using EDTA tubes and their hematological levels were determined at the central laboratory. All measurements were made at Süleyman Demirel University Research and Practice Hospital.

Lactate Measurement

To monitor the subjects' recovery, lactate measurements were only taken 3 minutes after the end of the test using a blood sample taken from the earlobe using a Lactate Plus brand lactate analyzer.

Erythrocyte Deformability Measurements

Erythrocyte deformability was assessed at 37°C under fluid shear stresses ranging from 0.5 to 15 Pascal (Pa) using laser diffraction analysis performed with an ektacytometer (LORCA - Laser- Assisted Optical Rotational Cell Analyzer, The Netherlands). This method calculates the erythrocyte elongation index (EI), where higher EI values reflect enhanced cellular deformability³⁰.

Erythrocyte Aggregation Measurements

Erythrocyte aggregation was measured by increasing light transmission through the erythrocyte suspension using a photometric aggregometer³¹. Erythrocyte aggregation was made for cells in autologous plasma and for cells resuspended in isotonic PBS (290 mosM/kg, pH=7.4) containing 1% Dextran 500 (molecular weight 500,000, Sigma Chemical, St. Louis, MO). These measurements provide information about the accumulation of erythrocytes³². The hematocrit of the samples used was adjusted to 0.4 l/l at room temperature (20±2°C).

Statistical Analyses

All variables were expressed as mean ± SD. Statistical comparisons between groups were done by repeated measures ANOVA followed by Bonferroni post hoc test, with $p < 0.05$ values accepted as statistically significant.

RESULTS

Male badminton players' physical parameters and test performances are reported in Table 1.

Table 1. Male badminton players' physical characteristics and test performances

Age (years)	24.2 ± 1.5
Body Height (cm)	176.2 ± 3.6
Body Mass (kg)	71.1 ± 5.6
PBF (%)	14.01 ± 3.36
Rest HR (b.min ⁻¹)	75.00 ± 10.20
At the end of test HR (b.min ⁻¹)	178.68 ± 15.19
3 min after test HR (b.min ⁻¹)	121.39 ± 9.32
Lactate (mmol/L)	6.48 ± 2.35
Distance covered (m)	1662.36 ± 264.59

Values are given as mean ± SD; PBF: Percentage of body fat; HR: Heart rate; * p< 0.05

Erythrocyte deformability of subjects of the pre-posttest and 24 hours after the test elongation index values obtained are presented in Table 2. As a result of blood analysis performed at different shear stress (Pa) obtained from the elongation indexes, post-exercise values for all subjects were higher than pre-exercise values. Subjects were 0.53, 0.95, 1.69, 3.00, 5.33 Pa levels EI values at p<0.05 as statistically significant differences were found (Table 2).

Table 2. Erythrocyte Deformability of Subjects of the Pre-Posttest and 24 Hours After the Test Elongation Index Values

Shear stress (Pa)	Pre-test EI	Post-test EI	24 h after test EI	p
0.30	0.040 ± 0.015	0.043 ± 0.018	0.039 ± 0.017	0.081
0.53	0.060 ± 0.018	0.080 ± 0.011	0.059 ± 0.015	0.013*(A)
0.95	0.146 ± 0.017	0.168 ± 0.024	0.144 ± 0.030	0.014*(A)
1.69	0.236 ± 0.019	0.256 ± 0.021	0.232 ± 0.026	0.011*(B)
3.00	0.357 ± 0.016	0.373 ± 0.032	0.352 ± 0.030	0.032*(A)
5.33	0.448 ± 0.012	0.463 ± 0.037	0.444 ± 0.026	0.031*(A)
9.49	0.516 ± 0.013	0.516 ± 0.043	0.521 ± 0.022	0.092
16.87	0.59 ± 0.015	0.583 ± 0.036	0.591 ± 0.014	0.363
30.00	0.620 ± 0.006	0.610 ± 0.032	0.617 ± 0.011	0.631

EI: Elongation Index; (A): between pretest and posttest; (B): between posttest and 24 hours after test; Pa: Pascal* p< 0.05

As a result of the analysis, these differences were statistically significant, the shape of the cells under the influence of certain forces to change the properties of a reversible, which is accepted as the control value when compared with the results of measurement applied to the pre-exercise increased after acute exercise. Erythrocyte deformability decreased 24 hours after exercise.

While there was a significant difference in erythrocyte elongation indexes measured

at 0.53, 0.95, 3.00, 5.33 Pascal shear stress values between pre and posttest; the difference in values 1.69 Pascal shear stress was found between posttest and 24 h after the test ($p < 0.05$) (Table 2). Compared to the pre-test and post-test an increase in Hct (Hematocrit), Hgb (hemoglobin), and RBC (red blood cells) parameters, was observed (Table 3). While there was a difference in subjects, WBC (white blood cells), NE (total neutrophil), MO (monocyte) and PLT (platelet counts) before and after the test and post-test and after 24 hours; the difference in values between, NE%, LY (lymphocyte), LY% and EO (eosinophil) was observed between before and after test ($p < 0.05$). EO % values of the subjects statistically significant differences were found between posttest and 24 h after the test ($p < 0.05$) (Table 3).

Table 3. Total Blood Counts Pre-Post and 24 Hours After Test

Parameter	Pre-test	Post-test	24 h after test	p
WBC	9.31 $\pm$ 2.71	14.5 $\pm$ 4.11	8.50 $\pm$ 1.72	0.001*
NE %	67.3 $\pm$ 7.9	69.4 $\pm$ 8.83	62.27 $\pm$ 8.1	0.004*
LY %	23.5 $\pm$ 7.8	31.38 $\pm$ 8.82	26.52 $\pm$ 7.0	0.006*
MO %	6.2 $\pm$ 1.9	6.42 $\pm$ 1.94	7.43 $\pm$ 2.5	0.062
EO %	1.77 $\pm$ 2.06	1.86 $\pm$ 1.3	2.16 $\pm$ 1.94	0.022*
BA %	0.65 $\pm$ 0.48	0.62 $\pm$ 0.31	0.62 $\pm$ 0.26	0.861
NE	5.79 $\pm$ 2.75	8.28 $\pm$ 3.94	4.76 $\pm$ 1.65	0.000*
LY	1.88 $\pm$ 0.36	4.12 $\pm$ 0.76	1.98 $\pm$ 0.41	0.001*
MO	0.49 $\pm$ 1.16	0.84 $\pm$ 0.26	0.54 $\pm$ 0.13	0.001*
EO	0.15 $\pm$ 0.16	0.23 $\pm$ 0.22	0.15 $\pm$ 0.14	0.017*
BA	0.02 $\pm$ 0.03	0.06 $\pm$ 0.04	0.03 $\pm$ 0.04	0.072
RBC	5.18 $\pm$ 0.26	5.34 $\pm$ 0.31	5.12 $\pm$ 0.25	0.006*
HGB	15.72 $\pm$ 0.79	16.25 $\pm$ 0.89	15.52 $\pm$ 0.66	0.008*
HCT	47.1 $\pm$ 2.32	49.10 $\pm$ 2.53	46.47 $\pm$ 1.89	0.004*
MCV	89.15 $\pm$ 3.0	89.96 $\pm$ 2.93	89.42 $\pm$ 3.04	0.001*
MCH	30.6 $\pm$ 1.0	30.53 $\pm$ 1.01	30.12 $\pm$ 0.88	0.382
MCHC	34.6 $\pm$ 0.2	35.93 $\pm$ 0.31	33.13 $\pm$ 0.54	0.025*
RDW	13.21 $\pm$ 0.5	13.23 $\pm$ 0.3	13.25 $\pm$ 0.48	0.655
PLT	256 $\pm$ 43	308 $\pm$ 31	257 $\pm$ 42	0.001*
MPV	8.56 $\pm$ 0.92	9.23 $\pm$ 0.91	8.61 $\pm$ 1.03	0.062

WBC: white blood cells; NE: total neutrophil; LY: lymphocyte; MO: monocyte; EO: eosinophil; BA: basophil; RBC: red blood cells; HGB: hemoglobin; HCT: hematocrit; MCV: mean corpuscular volume; MCH: mean corpuscular hemoglobin; MCHC: mean corpuscular hemoglobin concentration; RDW: red cell distribution; PLT: platelet counts; MPV: mean platelet volume; * $p < 0.05$

Within the parameters of the subjects examined in erythrocyte aggregation as a result

of blood analysis Amp, AI (aggregation index) values increased in posttest; $t \frac{1}{2}$ (aggregation time) and γ at the disc min (aggregation tendency) values decreased in posttest (Table 4). $t \frac{1}{2}$ values of the subjects statistically significant differences were found between posttest and 24 h after the test ($p < 0.05$) (Table 4). At the end of the test, as the aggregation index increased, there was a decrease in erythrocyte aggregation times.

Table 4. Erythrocyte aggregation of subjects of the pre-post and 24 hours after the test values

Parameter	Pre-test	Post-test	24 h after test	p
Amp (au)	21.4 $\pm$ 5.1	21.9 $\pm$ 3.3	23.4 $\pm$ 2.4	0.241
AI (%)	63.40 $\pm$ 5.4	65.6 $\pm$ 5.1	63.1 $\pm$ 5.2	0.093
$t \frac{1}{2}$ (s)	2.35 $\pm$ 0.56	2.09 $\pm$ 0.52	2.43 $\pm$ 0.64	0.012*(B)
γ at disc min (s)	172.6 $\pm$ 231.1	156.5 $\pm$ 237.2	81.34 $\pm$ 22.26	0.052

AI: Aggregation index; $t \frac{1}{2}$: Aggregation time; γ at disc min: Aggregation tendency; (B): between posttest and 24 hours after test; * $p < 0.05$

DISCUSSION AND CONCLUSION

The aim of this study was to investigate the possible mechanisms of the changes in hemorheological parameters of professional male badminton players via pre-post and 24h later following the YIRT1. In this study, it was found that the YIRT1 test, performed in pre-post and 24h later used to measure players' physical attributes, affected hemorheological values. As a result, the superiority of hemorheological changes caused by exercise increased in parallel with the increase in exercise intensity. Many studies in the literature have examined the effects of exercise on blood parameters, and it has been stated that the difference, duration and intensity of exercise cause changes in hemorheological parameters^{21,33,34,35}. Although what the hemorheological changes are was given in detail in the literature^{36,37,38}, it's required to make new research for source of changes and for the periods these changes happened and that the progress in changes are not explained.

In badminton, factors determining aerobic capacity such as heart rate and VO_{2max} are more decisive than fatigue metabolites (lactate, inorganic phosphate, etc.)^{39,40}. Heart rate is an important parameter for a badminton player^{39,41,42}. The rest heart rate (HR) values of subjects paralleled in the literature. Ghosh et al. (1990)⁴⁰ found that 8 national badminton players after test HR= 197.0 $\pm$ 6.65 b/min, Faude et al. (2007)⁴³ 12 badminton players rest HR= 89 $\pm$ 4.6 b/min, after test HR= 169 $\pm$ 9 b/min. While Scot and Dormandy, (1996)⁴⁴ stated rest HR=70 $\pm$ 10.02 b/min, after test HR=169.13 $\pm$ 18.56 b/min and recovery HR=115.02 $\pm$ 15.03 b/min. in tennis players, Achten and Jeukendrup, (2003)⁴⁵ found rest HR=75 $\pm$ 11.32 b/min, after test HR= 168.10 $\pm$ 15.75 b/min and recovery HR= 109.42 $\pm$ 10.11 b/min. An athlete, who is genetically capable or who has the capacity to carry high oxygen as a result of training, is characterized by a large stroke volume, low heart rate and early

recovery. Low resting heart rate can be an indicator of high aerobic power in failing heart disease. Studies have shown that badminton players play at a high VO₂max percentage, maximum heart rate, but obtain moderate energy from the anaerobic glycolysis system. It can be said that 60-70% of the energy during the game is provided by the aerobic system and 30% from the anaerobic system⁴⁶. Hemorheological determinant of the maximal oxygen consumption (VO₂max) is highly correlated to indices of aerobic exercise capacity. Increases in total blood volume and hemoglobin are important for oxygen transport and are indicative of high VO₂max capacity. Exercise-induced metabolic and hormonal changes affect hemorheology.

In our study Hct, Hgb, RBC parameters and WBC, NE, LY, MO, EO and PLT counts were increase after exercise. Perez et al. (2001)⁴⁷ found an increase in white blood cell counts in children after laboratory and field tests. White blood cell and neutrophil counts increased from resting values after a soccer practice. Following YIRT1 testing, changes in erythrocyte and leukocyte parameters were observed. This results in increased blood flow and shear forces³² and accumulation of leukocytes in the marginal pool⁴⁸. Changes in plasma volume⁹ and increased erythrocyte damage in the circulation⁴⁹ may cause these changes. As indicated in Table 2, structural deterioration of erythrocytes is also associated with increased elongation indices. At the end of the test, structural deterioration of erythrocytes began. The main task of the erythrocyte in the circulation is to meet the oxygen needs of the tissues, by being highly deformable in order to pass through narrow capillaries [54]. The decrease in plasma volume and structural changes in erythrocytes reduce aggregation. The fibrinogen concentration that changes with the increasing plasma volume at the end of exercise may also have affected this change⁵⁰. A decrease in aggregation is observed due to structural disorders in erythrocytes. Some cells form low levels of aggregation⁵⁰. Increased erythrocyte aggregation may cause changes in lactic acid levels and circulation in muscles⁵¹. When measurements showing metabolite accumulation in muscles are made, exercise protocols that include appropriate loading/rest periods should be applied. Yo-Yo protocols such as this one allows us to look at physiological and performance responses simultaneously during the test⁵². The change in blood cell deformability after aerobic exercise applied in this study is similar to other literature findings^{12,32,37,38}. However, studies on changes in aggregation have yielded different results^{9,32,36,37}. The reason for this may be the exercise protocols applied in the studies, the difference in the subject groups, and the different measurement methods used for blood measurement.

In summary in our study, erythrocyte deformability, evaluated under different shear stresses showed a significant increase at the end of the test. Following the test, the aggregation index rose while erythrocyte accumulation decreased significantly. Hematocrit levels, hemoglobin concentrations, and erythrocyte counts also demonstrated significant increases immediately after the test, but these values were significantly lower 24 hours post-test compared to pre-test levels. Leukocyte parameters exhibited a marked increase relative to pre-test values. Additionally, thrombocyte counts displayed significant differences between pre-test, post-test, and 24-hour post-test measurements. Hemorheological changes increase parallel with exercise intensity and it continues after the exercise. YIRT1, which provides information about the physical capacities of the players, was found to affect the

hemorheological parameters. The fact that the source of hemorheological changes caused by exercise, the periods in which they occur after exercise, and the course of these changes have not been revealed indicates that new research can be conducted on this subject. The effects of different exercise protocols on blood values can be examined in future studies. The roles of cellular factors (enzymes, hormones, oxidant stress, blood-lactate levels, etc.) in exercise-induced hemorheological changes can be investigated.

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