

CARDIOVASCULAR, BIOCHEMICAL, AND FUNCTIONAL CHARACTERISTICS OF MALE AND FEMALE NATIONAL BASKETBALL ATHLETES - INTERPRETING THE SPORTS MEDICAL EXAM BASED ON AGE GROUP

Djordje Batinić¹, Milos Maletic¹, Andrija Djuranovic¹, Milena Antić¹, Gordana Korolija Mrdjanov¹, Jelisaveta Trajkovic¹,
Emilija Filipovic¹, Božidar Pindović^{2,3}, Vladimir Jakovljević^{1,3,4,5}
¹Serbian Institute of Sport and Sports Medicine, Medical Department, Belgrade, Serbia
²University of Kragujevac, Faculty of Medical Sciences, Department of Pharmacy, Kragujevac, Serbia
³University of Kragujevac, Center of Excellence for the Study of Redox Balance in Cardiovascular and Metabolic Disorders, Kragujevac, Serbia
⁴University of Kragujevac, Faculty of Medical Sciences, Department of Physiology, Kragujevac, Serbia
⁵First Moscow State Medical University, IM Sechenov, Department of Human Pathology, Moscow, Russia

KARDIOVASKULARNE, BIOHEMIJSKE I FUNKCIONALNE KARAKTERISTIKE KOŠARKAŠA I KOŠARKAŠICA NACIONALNE SELEKCIJE – TUMAČENJE SPORTSKOMEDICINSKOG PREGLEDA U ODNOSU NA STAROSNU GRUPU

Dorđe Batinić¹, Miloš Maletić¹, Andrija Đuranović¹, Milena Antić¹, Gordana Korolija Mrđanov¹, Jelisaveta Trajković¹,
Emilija Filipović¹, Božidar Pindović^{2,3}, Vladimir Jakovljević^{1,3,4,5}
¹Zavod za sport i medicinu sporta Republike Srbije, Medicinsko odeljenje, Beograd, Srbija
²Univerzitet u Kragujevcu, Fakultet medicinskih nauka, Katedra za farmaciju, Kragujevac, Srbija
³Univerzitet u Kragujevcu, Centar izvrsnosti za izučavanje redoks ravnoteže u kardiovaskularnim i metaboličkim poremećajima, Kragujevac, Srbija
⁴Univerzitet u Kragujevcu, Fakultet medicinskih nauka, Katedra za fiziologiju, Kragujevac, Srbija
⁵Prvi moskovski državni medicinski Univerzitet „I. M. Sečenov“, Katedra za patologiju čoveka, Moskva, Rusija

ABSTRACT

Objective. The aim of this study is to examine differences in cardiovascular, biochemical, and functional parameters obtained during preparticipation screening among elite male and female basketball players across various age categories competing for the national team.

Methods. A total of 204 basketball players (122 male and 82 female) completed a sports medical exam that included blood pressure measurement, electrocardiogram, body composition analysis, biochemical analyses, echocardiogram, and a cardiopulmonary stress test. Age categories included under-16 (U16), U18, U20, senior (both genders), and U19 (male players only).

Results. None of the athletes had any significant findings that would require suspension from play. Significant gender differences are observed across most parameters. The most notable findings concern maximal oxygen uptake (VO_{2max}) and cardiac adaptation across age categories, when the parameters are indexed to body size and muscle mass. VO_{2max} levels develop early in young players, and the values are not greater in older player groups. Physiological cardiac adaptations are shown in all age groups, starting at U16, and are consistent with physiological adaptation to basketball, ranging from normal geometry to eccentric left ventricular hypertrophy. Left chamber volumes are the largest in the senior player group.

Conclusion. The results aim to provide additional insight into interpreting the findings of sports medical examination of

SAŽETAK

Cilj. Cilj ovog rada je ispitivanje razlika u kardiovaskularnim, biohemijskim i funkcionalnim parametrima dobijenim tokom sportskomedicinskog pregleda kod vrhunskih košarkaša i košarkašica različitih starosnih grupa koji nastupaju za nacionalnu selekciju.

Metode. Sportskomedicinski pregled su obavila ukupno 204 igrača (122 muškog pola, 82 ženskog pola). Pregled uključuje merenje krvnog pritiska, elektrokardiogram, analizu telesne kompozicije, biohemijske analize, ultrazvučni pregled srca i ergospirometrijski test opterećenja. Uzasne kategorije su ispod – U16, U18, U20, senior (oba pola) i U19 (samo košarkaši).

Rezultati. Nijedan sportista nije imao patološki nalaz koji bi zahtevao prekid trenaznog procesa. Razlike između polova postoje u većini parametara. Najznačajniji rezultati tiču se maksimalne potrošnje kiseonika (VO_{2max}) i adaptacije srca na sport kroz uzrasne kategorije kada se parametri indeksiraju prema konstituciji i mišićnoj masi. VO_{2max} se razvija rano kod mladih igrača, a više vrednosti se ne registruju u starijim grupama. Fiziološka adaptacija srca na sport registruje se u svim grupama, počevši od U16 kohorte i konzistentna je sa fiziološkom adaptacijom u košarci, sa najčešće normalnom geometrijom do ekscentrične hipertrofije. Zapremine levih šupljina se povećavaju, grupa seniora ispoljava najveće zapremine.

Zaključak. Ovi rezultati služe boljoj interpretaciji sportskomedicinskog pregleda košarkaša i košarkašica. Naši

basketball players. According to our results, cardiac adaptation to basketball and aerobic capacity develop early in young players. Further longitudinal follow-up studies with larger participant numbers are needed to support these findings.

Key words: basketball; cardiomegaly, exercise-induced; endurance training; echocardiography

INTRODUCTION

Basketball has been part of the Olympic Games since 1936 for men and 1976 for women. Apart from the Olympic Games, international athletes compete in international tournaments, such as the FIBA World Cup and regional competitions (1). Basketball is classified as an intermittent court sport that requires brief, high-intensity movements, such as short sprints, quick direction change, and jumping, all while maintaining specific skills, such as dribbling, passing, and shooting (2). Adequate training for the intense demands of basketball develops both anaerobic and aerobic metabolic pathways. During games, variations depend on the player's position and the activities performed, such as jogging, sprinting, shuffling at low to high intensities, and jumping, utilizing mixed energy systems (3). Long training hours and numerous matches accumulate their effects over the years, resulting in specific cardiovascular adaptations. Basketball is classified as a contact sport with high dynamic and moderate static components (4). According to the 2020 European Society of Cardiology (ESC) Guidelines on sports cardiology and exercise in patients with cardiovascular disease, basketball is classified as a high-intensity "mixed" sport, since skill, endurance, strength, and power components are all present (5).

A study from the US in the National Collegiate Athletic Association (NCAA), analyzing ten years of data on NCAA athletes, showed that basketball players are at the highest risk of sudden cardiac death (SCD), with male athletes facing a greater risk. Autopsy-negative SCD was the most common finding, but cardiomyopathies, primarily hypertrophic cardiomyopathy, were also prevalent (6). Subsequent NCAA analysis by Petek et al. continued to show that basketball, along with football players, had the highest SCD risk, with no clear explanation for this finding (7). To ensure safe sports participation, it is crucial to perform regular preparticipation cardiovascular screening. There are differences across countries and systems in the screening strategies and diagnostic methods used (8). Understanding the specific cardiac adaptations in elite basketball athletes is important for accurately interpreting screening results, particularly echocardiogram (ECHO) findings (9).

Limited data exists on how basketball players differ across demographics in cardiovascular, biochemical, and functional parameters. Therefore, this study aims to examine differences in these parameters during

rezultati pokazuju da se adaptacija srca na sport i razvijanje aerobnog kapaciteta dešava rano, kod mladih sportista. Da bi se podržali ovi nalazi neophodne su dodatne longitudinalne studije sa više ispitanika.

Cljučne reči: košarka; kardiomegalija izazvana vežbanjem; trening izdržljivosti; ehokardiografija.

preparticipation screening among elite male and female basketball players in various age groups competing for the national team.

SUBJECTS AND METHODS

In this observational, cross-sectional study, data from 204 male and female Caucasian basketball players were analyzed. All players have been selected for the Serbian national team. Age categories included under-16 (U16), U18, U20, and senior (age range 21-36) for both genders, with male athletes also having a U19 category. All athletes underwent a comprehensive sports medical screening exam at the Serbian Institute of Sport and Sports Medicine in 2024 and 2025, while senior athletes' data range from 2021 to 2025. All athletes were tested at the same point in the season (May and June).

This study was conducted in accordance with the Declaration of Helsinki and the principles of Good Clinical Practice, and it was approved by the Institutional Ethics Committee of the Serbian Institute of Sports and Sports Medicine (no. 3731 on 31.12.2025). Informed consent was obtained from all subjects involved in the study as part of the standard procedure. Written informed consent was obtained from the participants to publish this paper (and one parent's consent for participants younger than 18 years).

The athletes underwent a comprehensive sports medical screening exam that included a physical exam, resting 12-lead electrocardiogram (ECG) (Cardiovit AT-102 G2, Schiller, Baar, Switzerland), body composition assessment using the bioelectrical impedance analysis (BIA) method (InBody 370, Republic of Korea), routine laboratory analyses, ECHO (Affiniti CVx and CX50, Philips, Amsterdam, The Netherlands and Acuson Juniper, Siemens, Munich, Germany), and a maximal cardiopulmonary exercise test (CPET) (Quark CPET metabolic cart and h/p/cosmos pulsar treadmill, Cosmed, Rome, Italy).

A sample for the basic laboratory analyses was collected in the morning (8 to 10 a.m.) after an overnight fast. The laboratory analyses conducted on the Mythic 18 analyzer (Orphee, Plan-les-Ouates, Switzerland) included a complete blood count of leukocytes, erythrocytes, and platelets, as well as a measurement of hemoglobin concentration. Routine biochemical parameters in serum, including glucose, urea, serum creatinine, total proteins, albumin, total cholesterol, triglycerides, ferritin, as well as

enzyme activities of aspartate transaminase (AST) and alanine aminotransferase ALT were determined using commercial reagents on the Aries analyzer (Instrumentation Laboratory, Milan, Italy).

Body height (HT) was measured on a stadiometer, and BIA was used to obtain body weight (BW), body fat percentage (BF), skeletal muscle mass (MM), and free fat mass (FFM). Body mass index (BMI) and body surface area (BSA) were calculated. Measurements were made after an overnight fast.

Two-dimensional transthoracic ECHO measurements were performed as recommended by the American Society of Echocardiography and the European Association of Cardiovascular Imaging (10). Aortic root z-score calculations were performed as described (11). All ECHO examinations were performed by the same two experienced cardiologists.

Maximum oxygen consumption (VO_2max) was measured during CPET, and expressed in absolute (ml) and relative (ml/kg/min) values, as well as indexed to skeletal muscle mass (SMM) and fat-free mass (FFM).

For this study, an a priori sample size calculation was not performed, as this study was based on an available national cohort of elite athletes (12) and included a broad range of physiological systems, primarily ECHO and VO_2max , rather than a single primary endpoint. However, a post hoc power analysis was conducted using G*Power software (version 3.1; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) to evaluate whether our sample size was sufficient to detect meaningful group differences. We used the following assumptions: one-way analysis of variance (ANOVA) for comparisons between selection categories within sex, a medium effect size (Cohen's $f=0.25$), $\alpha=0.05$, total sample size per sex ranging from 82 to 122, and the number of groups ranging from 4 to 5. After the calculation, the statistical power exceeded 80% for detecting medium between-group effects. Larger effects would be detectable with substantially higher power. These assumptions also align with effect sizes reported in prior physiological and echocardiographic studies of elite athletes.

For the statistical analysis, we tested continuous variables for normality using the Shapiro–Wilk test and visual inspection of histograms. Between-sex comparisons were performed using Independent-samples t-tests for normally distributed variables and Mann–Whitney U tests for non-normally distributed variables. Comparisons between selection categories within the same sex (effect for age on a given parameter) were performed using One-way ANOVA with appropriate post-hoc tests (Tukey or Bonferroni) for normally distributed data, and Kruskal–Wallis tests with post-hoc pairwise comparisons for non-parametric data. Categorical variables were compared using the χ^2 test. Statistical significance was set

to be at $p<0.05$, and strong statistical significance at $p<0.001$. Analyses were performed using SPSS Statistics 24 software (IBM Corporation, Armonk, NY, USA).

RESULTS

Gender differences in athlete characteristics

Gender differences are presented in Table 1. Male athletes reported more weekly training hours and had higher body composition parameters ($p<0.001$ for all). They also had higher SBP ($p<0.001$) and DBP ($p<0.001$). ECG shows a lower resting HR in males ($p=0.021$), a larger QRS complex ($p<0.001$), and higher voltages for the R wave ($p<0.001$), S wave ($p=0.011$), and T wave ($p<0.001$). Laboratory parameters reveal significantly lower values in females for Hb ($p<0.001$), Er ($p<0.001$), and ferritin concentration ($p<0.001$). Conversely, male athletes show higher levels of glucose, aspartate transaminase (AST), alanine aminotransferase (ALT), urea, and creatinine ($p<0.001$ for all). VO_2max values, measured in both absolute (ml) and relative (ml/kg/min) terms, are higher in males ($p<0.001$ for all). However, when indexed to FFM or SMM, no difference is observed. Echocardiographic comparison is shown in Table 2. Significant difference is observed for all parameters except aortic root z-score and ejection fraction.

Male basketball players characteristics

Male basketball players are divided into five age categories, and the parameters are presented in Tables 3 and 4. SPB shows the highest values in U20, and the lowest in U16 ($p=0.046$), while DBP shows no difference between categories. Senior players show the highest and U16 the lowest values for HT ($p=0.018$), BW, BM, BMI, SMM, and FFM ($p<0.001$), whereas no difference is observed in BF between groups. Senior athletes had the lowest mean HR, while the U19 cohort had the highest ($p=0.023$). The ECG intervals showing differences between groups are PQ (the highest mean in senior athletes, and the lowest in U18 athletes, $p<0.001$) and QTc (the highest mean in U19 athletes, and the lowest in the senior cohort, $p=0.012$). Senior athletes had the highest mean Hb (148.80g/L), while the U20 cohort had the lowest (139.94g/L; $p=0.016$). Ferritin levels below 35ng/mL are registered in 3 players (1 U18, 2 U19), and were the lowest in the U19 cohort. Also, the senior athlete cohort showed statistically higher values for total cholesterol, triglycerides, creatinine ($p<0.001$ for all), and urea ($p=0.004$).

VO_2max analyses show the highest absolute values in U20 ($p=0.004$), while the U16 cohort has the highest relative values (ml/kg/min) and when indexed to FFM and SMM ($p<0.001$ for all). ECHO measurements show the

Table 1. Gender differences.

Parameter	Male players (n=122)	Female players (n=82)	Statistical significance
General characteristics			
Age (years)	20.07±5.43	20.45±5.80	NS
Training history (years)	11.44±4.83	11.12±5.55	NS
Average weekly training (Hours)	19.57±4.72	15.15±4.88	p<0.001
SBP (mmHg)	108.40±8.29	102.13±7.50	p<0.001
DBP (mmHg)	66.31±7.30	62.68±5.45	p<0.001
Body composition			
Body height (cm)	200.55±7.99	180.05±7.56	p<0.001
Body mass (kg)	94.63±11.91	71.27±9.58	p<0.001
BMI (kg/m ²)	23.47±1.97	21.95±2.21	p<0.001
BSA (m ²)	2.32±0.18	1.90±0.15	p<0.001
Body fat (%)	8.20±3.78	18.73±4.50	p<0.001
Skeletal muscle mass (kg)	49.83±5.62	32.34±3.74	p<0.001
Fat-free mass (kg)	86.66±9.59	57.71±6.40	p<0.001
ECG			
Heart rate (bpm)	57.52±9.23	60.77±10.43	p=0.021
PQ interval (ms)	160.16±25.09	154.76±23.37	NS
QRS duration (ms)	101.46±9.30	90.73±9.40	p<0.001
QTc interval (ms)	409.10±21.67	414.27±19.50	NS
Maximal R+S wave (mm)	33.69±8.91	25.31±6.93	p<0.001
Maximal T wave (mm)	9.36±2.51	5.46±2.34	p<0.001
Laboratory analyses			
Leukocytes (n)	5.70±1.13	5.90±1.56	NS
Erythrocytes (n)	4.99±0.34	4.43±0.30	p<0.001
Hemoglobin (g/L)	145.87±8.86	127.42±8.85	p<0.001
Platelets (n)	240.36±47.89	269.07±61.30	p<0.001
Glucose (mmol/L)	5.14±0.46	4.92±0.47	p<0.001
Total cholesterol (mmol/L)	4.10±0.77	4.27±0.78	NS
Triglycerides (mmol/L)	0.72±0.42	0.65±0.38	NS
Urea (mmol/L)	6.37±1.42	5.21±1.28	p<0.001
Serum creatinine (μmol/L)	93.26±14.60	77.51±11.45	p<0.001
AST (U/L)	30.52±8.40	25.10 ± 8.82	p<0.001
ALT (U/L)	24.27±9.61	18.65±10.54	p<0.001
Total proteins (g/L)	70.10±3.70	69.30±3.82	NS
Ferritin (ng/mL)	89.03±39.74	54.59±23.95	p<0.001
CPET			
VO ₂ max (ml)	5056.78±457.71	3350.39±462.06	p<0.001
VO ₂ max (ml/kg/min)	53.92±5.47	47.15±4.50	p<0.001
VO ₂ max/FFM	58.73±5.44	57.97±5.09	NS
VO ₂ max/SMM	102.18±9.73	103.45±9.02	NS

The results are presented as mean±SDNS, not significant; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; BSA, body surface area; ECG, electrocardiogram; QTc, corrected QT interval; AST, aspartate transaminase; ALT, alanine aminotransferase. CPET, cardiopulmonary exercise test; VO₂max, maximal oxygen

highest absolute values of ascending aorta, cardiac chamber dimensions, and LV wall thickness in senior athletes. Indexed measurements for BSA display differences in aortic root, z-score, and LA biplane/BSA, with the highest in the senior group, while ESV/BSA is highest in the U18 group. Other indexed parameters do not show statistically significant differences.

Female basketball players characteristics

Characteristics of female basketball players, divided into four age categories, are presented in Tables 5 and 6. Body composition measurements reveal statistically significant differences for BMI, MM, and FFM, with the highest values in the senior cohort (p<0.001 for all). BF percentage is the highest in the U18 cohort (p=0.001).

Table 2. Gender differences in echocardiographic parameters.

Parameter	Male players (n=122)	Female players (n=82)	Statistical significance
Aortic root (mm)	33.66±3.44	28.75±2.56	p<0.001
Aortic root/BSA (mm/m ²)	14.55±1.33	15.17±1.33	p=0.001
Aortic root z-score	-0.15±1.11	-0.29±0.83	NS
Aortic annulus (mm)	25.02±2.25	22.10±1.87	p<0.001
Ascending Aorta (mm)	28.04±2.60	25.46±2.64	p<0.001
Aortic arch (mm)	23.99±2.13	21.53±2.06	p<0.001
LA (mm)	44.48±1.97	40.99±2.35	p<0.001
LA Biplane volume/BSA (ml/m ²)	32.11±3.58	29.75±3.45	p<0.001
LV EDD (mm)	57.35±2.72	50.73±3.01	p<0.001
EDD/BSA (mm/m ²)	24.85±1.70	26.78±1.64	p<0.001
LV ESD (mm)	37.47±2.09	33.00±2.29	p<0.001
LV ESD/BSA (mm/m ²)	16.24±1.21	17.43±1.36	p<0.001
LV EDV (ml)	169.82±17.39	124.92±17.26	p<0.001
LV EDV/BSA (ml/m ²)	73.41±6.56	65.65±6.92	p<0.001
ESV (ml)	61.91±7.57	44.96±6.98	p<0.001
ESV/BSA (ml/m ²)	26.74±2.81	23.65±3.13	p<0.001
RA (mm)	50.61±3.19	45.15±2.86	p<0.001
RV (mm)	38.84±2.65	33.81±2.20	p<0.001
EF (%)	63.54±2.51	63.98±2.86	NS
SV (ml)	107.91±12.08	79.96±11.88	p<0.001
IVS (mm)	10.94±0.65	9.39±0.70	p<0.001
PW (mm)	10.93±0.59	9.37±0.68	p<0.001
LVMI (g/m ²)	113.43±12.77	92.35±13.98	p<0.001
RWT	0.38±0.02	0.37±0.02	p<0.001

the results are presented as mean±SD; NS, not significant; BSA, body surface area; LA, left atrium; LV, left ventricle; EDD, end-diastolic diameter; ESD, end-systolic diameter; EDV, end-diastolic volume; ESV, end-systolic volume; RA, right atrium; RV, right ventricle; EF, ejection fraction; SV, stroke volume; IVS, interventricular septum; PW, posterior wall; LVMI, left ventricular mass index; RWT, relative wall thickness.

Mean resting HR is the lowest in the senior cohort (p=0.012). Laboratory analyses show the lowest mean Hb values in U20 and the highest in U16 (p=0.032), with no difference in serum ferritin between cohorts. Ferritin levels below 35ng/mL are observed in 10 players (1 U16, 2 U18, 8 seniors). Biochemical parameters vary in mean values for glucose (the lowest in the senior group, p=0.03), total cholesterol (the highest in the senior cohort, p<0.001), creatinine (the lowest in the U16 cohort, p=0.01), AST (p=0.04), and ALT (p=0.018), both the lowest in the U18 cohort. VO₂max values, both absolute and indexed, reveal no statistically significant difference between groups. Aortic measurements indicate the highest absolute values in the senior group, while indexed aortic measurements show no difference. The dimensions of the absolute cardiac chambers and both absolute and indexed LV volume dimensions are highest in the senior group. No difference is shown in the LV dimensions when indexed to BSA. LV wall thickness and LVMI are the highest in the senior cohort.

Additional findings

All athletes were asymptomatic, with negative family history for SCD, and were cleared to play after completing

the sports medical exam. No athlete had any findings that would necessitate suspension from sports. One senior male player had an aortic root z-score of +3.41 (44mm). He is asymptomatic, has no SCD or aortopathy family history, has a tricuspid aortic valve, normal blood pressure, and no signs of connective tissue disorder. No significant increase over the years were shown on ECHO, and no other significant findings were registered. Therefore, this player was cleared to play with yearly follow-ups. Some athletes had minor findings. The most common registered ECG changes were IRBBB (9 players), AV I-degree block (7 players, maximal 250ms), sinus bradycardia with the lowest HR of 35 beats per minute (bpm), and two players showed a benign premature ventricular complex (PVC) form at rest (none during CPET). T wave inversion (TWI) in leads other than D3, aVR, and V1 was observed in isolation in only one lead in 8 players, and 3 young players demonstrated "juvenile" TWI pattern. All these players had normal findings on ECHO and CPET. The most frequent ECHO findings were MVP (3 athletes with mild regurgitation, no characteristics of arrhythmogenic MVP and a normal CPET) and a small, hemodynamically insignificant patent foramen ovale (8

Table 3. Male subgroup comparison.

Parameter	U16 (n=35)	U18 (n=22)	U19 (n=15)	U20 (n=19)	SENIOR (n=31)	Statistical significance*
General characteristics						
Age (years)	15.83±0.66	17.45±0.74	17.93±0.46	19.32±0.58	28.19±4.59	p<0.001 (between each group)
Training history (years)	8.49±1.71	8.98±2.47	10.07±1.28	10.66±2.19	17.68±5.16	p<0.001 (U16 vs U19, U16 vs U20, U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR, U20 vs SENIOR)
Average Weekly Training (Hours)	18.89±5.89	21.14±4.61	20.80±3.10	19.53±2.50	18.65±4.85	NS
SBP (mmHg)	105.14±7.81	107.05±8.26	110.33±8.34	111.32±8.47	110.32±7.74	p=0.046
DBP (mmHg)	64.14±6.24	66.82±6.64	67.00±6.76	66.58±9.29	67.90±7.61	NS
Body composition						
Body Height (cm)	197.59±6.59	201.01±8.66	198.50±7.47	201.74±8.86	203.85±7.62	p=0.018 (SENIOR vs U16)
Body Mass (kg)	88.01±12.01	92.15±10.69	93.20±9.05	97.32±8.08	102.91±10.92	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR)
BMI (kg/m ²)	22.47±1.95	22.77±1.77	23.63±1.62	23.93±1.51	24.73±1.82	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR)
BSA (m ²)	2.22±0.17	2.29±0.17	2.29±0.15	2.36±0.15	2.43±0.16	p<0.001 (U16 vs U20, U16 vs SENIOR)
Body Fat (%)	8.25±3.48	8.21±3.69	7.26±2.76	7.44±2.86	9.07±4.93	NS
Skeletal Muscle Mass (kg)	46.03±4.83	48.55±5.45	49.91±5.22	51.91±4.77	53.71±4.16	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR)
Fat-Free Mass (kg)	80.44±8.43	84.48±9.29	86.44±8.88	90.11±8.23	93.22±7.23	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR)
ECG						
Heart Rate (bpm)	59.23±9.86	55.23±9.53	62.53±6.93	58.42±7.76	54.26±8.94	p=0.023 (SENIOR vs U19)
PQ interval (ms)	151.14±17.11	149.09±19.25	161.33±19.95	161.05±28.07	177.10±28.42	p<0.001 (SENIOR vs U16, SENIOR vs U18)
QRS duration (ms)	99.40±8.66	103.64±11.77	98.00±8.62	103.11±9.94	102.90±7.39	NS
QTc interval (ms)	410.00±21.69	406.82±21.69	424.67±15.98	411.05±19.41	400.97±22.11	p=0.012 (SENIOR vs U19)
Maximal R+S wave (mm)	34.74±8.77	35.64±8.83	31.71±5.69	36.44±9.17	30.42±9.49	NS
Maximal T wave (mm)	9.51±3.01	9.62±2.33	8.64±2.06	9.50±2.33	9.26±2.38	NS
Laboratory analyses						
Leukocytes (n)	5.58±1.04	5.65±0.89	5.91±0.86	5.91±1.38	5.65±1.37	NS
Erythrocytes (n)	4.99±0.33	5.05±0.30	4.90±0.40	4.88±0.37	5.04±0.32	NS
Hemoglobin (g/L)	147.14±8.54	145.43±9.48	144.00±7.75	139.94±8.99	148.80±7.97	p=0.016 (SENIOR vs U20, U16 vs U20)
Platelets (n)	235.86±43.21	243.10±50.02	237.13±58.12	253.88±57.45	238.10±42.18	NS
Glucose (mmol/L)	4.96±0.42	5.28±0.37	5.17±0.26	5.24±0.48	5.20±0.58	NS

Total Cholesterol (mmol/L)	3.67±0.70	4.01±0.74	3.98±0.77	3.99±0.56	4.76±0.54	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U19, SENIOR vs U20)
Triglycerides (mmol/L)	0.52±0.20	0.69±0.35	0.72±0.26	0.72±0.47	0.98±0.54	p<0.001 (U16 vs SENIOR)
Urea (mmol/L)	5.80±1.08	6.03±1.33	6.33±1.23	6.92±1.77	6.98±1.47	p=0.004 (U16 vs SENIOR)
Serum creatinine (μmol/L)	84.11±12.90	93.57±14.40	92.40±13.08	99.38±14.21	100.90±12.03	p<0.001 (U16 vs U20, U16 vs SENIOR)
AST (U/L)	29.63±6.63	31.10±12.50	34.47±7.18	30.75±8.59	29.07±6.98	NS
ALT (U/L)	21.80±7.60	26.76±15.79	22.80±4.97	23.31±7.02	26.67±8.55	NS
Total Proteins (g/L)	69.80±3.21	71.33±4.20	71.60±4.03	69.94±3.89	68.93±3.34	NS
Ferritin (ng/mL)	71.80±23.56	80.55±24.01	60.99±18.88	91.90±35.20	133.17±43.61	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR, U20 vs SENIOR)
CPET						
VO ₂ max (ml)	4932.60±386.82	5011.31±470.07	4894.73±410.25	5350.06±438.12	5138.82±484.31	p=0.012 (U16 vs U20, U19 vs U20)
VO ₂ max (ml/kg/min)	56.63±5.61	54.64±4.02	52.71±4.13	55.43±4.03	50.28±5.56	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20)
VO ₂ max/FFM	61.61±5.33	59.57±4.40	56.89±4.79	60.05±4.95	55.24±4.80	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U20 vs SENIOR)
VO ₂ max/SMM	107.69±9.52	103.69±7.94	98.55±8.39	104.21±8.68	95.88±8.39	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20, U16 vs U19)

The results are presented as mean±SD. *significant pair-wise differences between age groups in post-hoc analysis are shown in brackets. NS, not significant; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; BSA, body surface area; ECG, electrocardiogram; QTc, corrected QT interval; AST, aspartate transaminase; ALT, alanine aminotransferase. CPET, cardiopulmonary exercise test; VO₂max, maximal oxygen consumption; FFM, fat-free mass; SMM, skeletal muscle mass.

athletes). Two players had borderline aortic root dimensions (39mm and 40mm, with z-scores<+3). In one U16 male player, BAV was diagnosed, without stenosis or regurgitation, and with normal dimensions in all aortic segments.

DISCUSSION

This study provides an overview of cardiovascular, biochemical, and functional parameters in male and female elite basketball players measured during preparticipation screening. All players represent the Serbian national team, and most age groups can be classified as elite, according to the 2020 ESC guidelines (5), based on their weekly training volume. Players in the senior, U20, and some younger categories compete in multiple league and cup competitions for their respective clubs, as well as in national team competitions. Some players compete in elite leagues such as the National Basketball Association (NBA), the Euroleague, and the

NCAA. None of the athletes had any major findings during screening according to the most recent sports cardiology guidelines (5, 13).

Resting SBP and DBP differ, with higher values in males and higher SBP in the male senior cohort than in the younger male players. None of the players showed increased BP values or hypertension, and the findings were consistent with body composition and cardiac adaptation (as discussed later). Nevertheless, while no evidence exists linking long-term sport participation to an increased risk of developing hypertension, regular BP monitoring is an integral part of a basic sports-medical exam, and should be continued after the end of a player's career, given the cardiovascular risk factors that can develop over the years (14). Resting HR is lowest among senior players of both genders, consistent with the cardiac adaptation that occurs with the years of training (5). There were no findings of profound sinus bradycardia, defined as <30bpm in Seattle/International criteria (15). Resting HR

Table 4. Male subgroup echocardiographic parameters.

Parameter	U16 (n=35)	U18 (n=22)	U19 (n=15)	U20 (n=19)	SENIOR (n=31)	Statistical significance*
Aortic root (mm)	31.54±2.34	33.14±3.45	32.87±3.04	33.79±2.27	36.71±3.20	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U19, SENIOR vs U20)
Aortic root/BSA (mm/m ²)	14.23±1.06	14.49±1.69	14.44±1.63	14.36±0.97	15.13±1.25	NS
Aortic root z-score	-0.65±0.79	-0.22±1.30	-0.32±1.20	-0.14±0.80	0.54±1.12	p<0.001 (SENIOR vs U16)
Aortic annulus (mm)	23.83±1.90	24.91±1.69	23.87±2.20	25.58±1.98	26.65±2.09	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR)
Ascending Aorta (mm)	26.77±1.86	27.14±1.81	27.60±3.66	28.63±1.89	29.97±2.47	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR)
LA (mm)	43.80±2.06	44.05±1.46	43.87±1.64	44.58±1.50	45.77±2.03	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR, U20 vs SENIOR)
LA Biplane Volume/BSA (ml/m ²)	30.65±3.05	31.38±2.75	31.80±2.60	32.21±3.58	34.36±4.10	p<0.001 (SENIOR vs U16, SENIOR vs U18)
LV EDD (mm)	56.06±2.50	57.32±2.17	56.93±2.89	58.11±2.21	58.58±2.95	p<0.001 (U16 vs U20, U16 vs SENIOR)
EDD/BSA (mm/m ²)	25.32±1.62	25.08±1.63	24.95±0.99	24.74±1.75	24.20±1.95	NS
LV ESD (mm)	36.60±1.67	37.64±2.01	37.27±2.31	37.74±2.28	38.26±2.11	p=0.009 (U16 vs SENIOR)
LV ESD/BSA (mm/m ²)	16.53±1.02	16.46±1.13	16.33±0.85	16.06±1.35	15.82±1.44	NS
LV EDV (ml)	158.63±16.0 9	168.36±14.9 0	167.73±15.9 4	174.53±17.8 2	181.61±12.4 1	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U19, U16 vs U20)
LV EDV/BSA (ml/m ²)	71.49±6.37	73.54±6.27	73.36±4.51	74.19±7.71	75.02±6.92	NS
ESV (ml)	56.77±6.69	63.73±7.59	60.00±6.78	64.05±5.99	66.03±6.46	p<0.001 (SENIOR vs U16, SENIOR vs U19, U16 vs U18, U16 vs U20)
ESV/BSA (ml/m ²)	25.56±2.47	27.78±2.73	26.22±2.04	27.29±3.20	27.25±2.93	p=0.028 (SENIOR vs U16, SENIOR vs U19, U16 vs U18, U16 vs U20)
RA (mm)	49.09±3.02	48.68±3.03	51.13±2.85	50.84±2.19	53.29±2.16	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR, U20 vs SENIOR)
RV (mm)	37.26±2.39	38.32±1.67	39.53±2.88	38.63±2.50	40.77±2.26	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20, U16 vs U19)
EF (%)	64.21±2.19	62.20±2.33	64.24±1.82	63.17±2.79	63.62±2.78	p=0.031 (U16 vs U18)
SV (ml)	101.86±10.9 1	104.64±9.07	107.73±10.3 4	110.47±14.7 1	115.58±10.0 5	p<0.001 (U16 vs SENIOR, U18 vs SENIOR)
IVS (mm)	10.49±0.52	10.93±0.56	10.77±0.37	11.18±0.71	11.39±0.54	p<0.001

						(U16 vs U20, U16 vs SENIOR, U19 vs SENIOR)
PW (mm)	10.53±0.51	10.86±0.52	10.83±0.36	11.25±0.68	11.29±0.46	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs SENIOR, U19 vs SENIOR)
LVMI (g/m ²)	108.17±11.4 4	113.32±8.80	110.73±8.80	117.95±15.9 9	117.97±13.9 9	p=0.010 (SENIOR vs U16, U16 vs U20)
RWT	0.38±0.01	0.38±0.02	0.38±0.02	0.39±0.02	0.39±0.02	NS

The results are presented as mean±SD *significant pair-wise differences between age groups in post-hoc analysis are shown in brackets. NS, not significant; BSA, body surface area; LA, left atrium; LV, left ventricle; EDD, end-diastolic diameter; ESD, end-systolic diameter; EDV, end-diastolic volume; ESV, end-systolic volume; RA, right atrium; RV, right ventricle; EF, ejection fraction; SV, stroke volume; IVS, interventricular septum; PW, posterior wall; LVMI, left ventricular mass index; RWT, relative wall thickness.

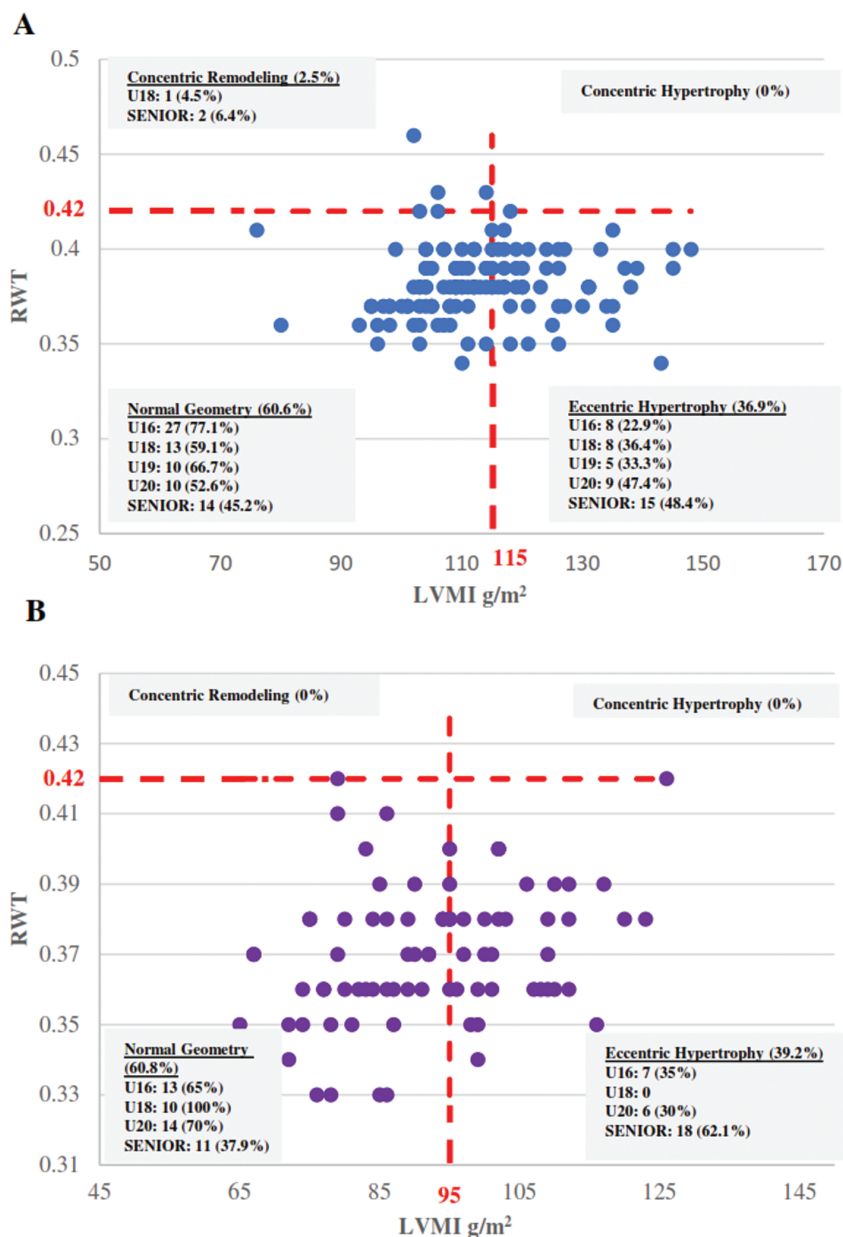


Table 5. Female subgroup comparison

Parameter	U16 (n=21)	U18 (n=12)	U20 (n=20)	SENIOR (n=29)	Statistical significance*
General characteristics					
Age (years)	15.24±0.70	16.58±0.67	18.80±0.83	26.97±4.84	p<0.001 (between each group)
Training history (years)	6.90±2.12	7.42±1.68	9.45±1.86	16.86±5.22	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs U20, U18 vs SENIOR, U20 vs SENIOR)
Average Weekly Training (Hours)	10.71±3.07	12.67±2.93	17.40±4.79	17.83±3.86	p<0.001 (U16 vs U20, U16 vs SENIOR, U18 vs U20, U18 vs SENIOR)
SBP (mmHg)	101.67±7.96	106.25±8.29	102.00±8.80	100.86±5.36	NS
DBP (mmHg)	61.67±6.39	65.00±5.64	62.75±5.73	62.41±4.35	NS
Body composition					
Body Height (cm)	181.90±9.82	178.57±5.05	176.85±6.36	181.53±6.76	NS
Body Mass (kg)	70.36±13.84	69.74±9.54	69.49±6.27	73.80±7.45	NS
BMI (kg/m ²)	21.19±3.19	21.85±2.54	22.19±1.31	22.37±1.60	p=0.013 (U16 vs U20, U16 vs SENIOR)
BSA (m ²)	1.90±0.20	1.87±0.13	1.86±0.11	1.94±0.12	NS
Body Fat (%)	16.93±5.11	21.18±5.06	20.82±3.17	17.57±3.68	p=0.001 (U16 vs U20, U20 vs SENIOR)
Skeletal Muscle Mass (kg)	32.43±4.39	30.56±3.59	30.72±2.82	34.13±3.12	p=0.003 (U18 vs SENIOR, U20 vs SENIOR)
Fat-Free Mass (kg)	57.87±7.46	54.72±6.09	54.98±4.90	60.71±5.42	p=0.004 (U18 vs SENIOR, U20 vs SENIOR)
ECG					
Heart Rate (bpm)	63.10±10.01	61.33±12.41	65.00±9.46	55.93±8.99	p=0.012 (SENIOR vs U20)
PQ interval (ms)	149.52±17.4 6	150.00±17.5 8	155.50±24.1 7	160.00±28.0 3	NS
QRS duration (ms)	90.48±9.73	89.17±6.69	90.00±9.18	92.07±10.48	NS
QTc interval (ms)	417.14±19.5 3	410.00±29.5 4	416.50±15.3 1	412.41±17.4 6	NS
Maximal R+S wave (mm)	26.62±7.05	23.83±6.91	26.68±6.77	24.04±6.96	NS
Maximal T wave (mm)	5.71±2.33	6.08±2.27	4.79±2.23	5.46±2.47	NS
Laboratory analyses					
Leukocytes (n)	5.70±1.58	5.85±0.67	6.59±1.58	5.61±1.69	NS
Erythrocytes (n)	4.43±0.28	4.59±0.41	4.49±0.20	4.34±0.31	NS
Hemoglobin (g/L)	131.10±8.77	126.00±5.83	123.11±9.85	128.14±8.21	p=0.032 (U16 vs U20)
Platelets (n)	279.43±66.0 9	294.18±57.7 1	272.37±56.8 2	249.90±59.1 6	NS
Glucose (mmol/L)	5.01±0.46	5.06±0.64	5.02±0.31	4.73±0.46	p=0.03
Total Cholesterol (mmol/L)	3.84±0.61	4.35±0.79	4.05±0.49	4.69±0.84	p<0.001 (U18 vs SENIOR)
Triglycerides (mmol/L)	0.68±0.25	0.69±0.24	0.61±0.21	0.65±0.56	NS
Urea (mmol/L)	4.66±1.26	5.64±0.97	5.31±1.37	5.38±1.28	NS
Serum creatinine (μmol/L)	71.48±12.20	74.64±9.94	82.11±10.16	79.97±10.53	p=0.01 (SENIOR vs U16, U16 vs U20)
AST (U/L)	27.33±7.09	21.82±5.06	24.11±5.35	24.55 ± 11.23	NS
ALT (U/L)	21.33±7.64	14.73±2.94	17.11±7.38	19.21±14.84	p=0.018 (U16 vs U18)
Total Proteins (g/L)	68.71±4.11	70.55±4.78	70.58±4.00	68.41±2.81	NS
Ferritin (ng/mL)	56.25±11.91	49.49±15.43	60.33±30.27	50.74±28.08	NS
CPET					
VO ₂ max (ml)	3400.77±605	3158.80±443	3207.72±338	3491.52±379	NS

	.03	.73	.10	.25	
VO ₂ max (ml/kg/min)	48.66±4.20	45.52±5.42	45.73±3.96	47.68±4.38	NS
VO ₂ max/FFM	58.69±5.08	57.91±7.10	57.62±4.97	57.71±4.38	NS
VO ₂ max/SMM	104.75±8.68	103.81±13.19	103.04±8.88	102.59±7.53	NS

The results are presented as mean±SD. *significant pair-wise differences between age groups in post-hoc analysis are shown in brackets. NS, not significant; SBP, systolic blood pressure; DBP, diastolic blood pressure; BMI, body mass index; BSA, body surface area; ECG, electrocardiogram; QTc, corrected QT interval; AST, aspartate transaminase; ALT, alanine aminotransferase. CPET, cardiopulmonary exercise test; VO₂max, maximal oxygen consumption; FFM, fat-free mass; SMM, skeletal muscle mass.

should be routinely monitored as a parameter to adjust training-load, and personalize HR monitoring (16), keeping in mind that significant bradycardia may indicate relative energy deficiency (17).

ECG findings in a study investigating NBA athletes (18), with more participants and a large proportion of the African American individuals, show more borderline and pathological findings (15) than in our study. This could be due to larger sample size and racial differences in ECG changes and cardiac adaptation. Isolated voltage criteria (S wave in V1 and R wave in V5 or V6, a Sokolow-Lyon index) are observed in some male (33.69±8.91mm), but not in female athletes (25.31±6.93mm). It is also worth noting that the largest voltage is observed in the male U20 group (36.44±9.17mm; not statistically significant between groups), while the largest wall thickness and LVMI were observed in the senior group (117.97±13.99g/m²). None of the athletes had significant repolarization changes or other ECG markers that would suggest pathological findings. This is consistent with the guidelines (15), which state that the Sokolow-Lyon index in itself is not a significant ECG finding. Also, the longest QTc interval is not observed in the senior cohort of either gender, and none of the athletes experienced QTc prolongation. This contradicts the finding that high training volumes can increase the QTc interval (19).

Male and older players tend to be larger. BF percentage shows a similar trend, albeit with lower values than those reported in the Sansone et al. meta-analysis (20), but aligns with the findings that international players had the lowest BF percentage in the respective group. Female U18 (21.18±5.06) and U20 (20.82±3.17) players exhibited the highest BF percentages, while U16 players (16.93±5.11) had the lowest in the female cohort. These values still represent a healthy range, but large variations in this parameter highlights the need for proper nutrition education and screening for eating disorders in young athletes (21).

Screening for depleted iron stores and iron-deficiency anemia in sports is recommended, iron's vital role in hemoglobin synthesis, oxygen transport, and immune function. A high prevalence of iron deficiency is shown among basketball players of both genders (22). In our study, we found significant differences between male and female players in hemoglobin (145.87±8.86 vs 127.42±8.85 g/L) and ferritin levels (89.03±39.74 vs

54.59±23.95 ng/mL). Ferritin levels, below <35ng/mL are used as a threshold for iron supplementation (23). Only a small number of players (10 female, 3 male) meets this criterion, with no players having hemoglobin levels below 115g/L.

Other biochemical parameters align with studies in athletes that show greater variation in basal values of AST, ALT, urea, and creatinine compared to the reference range for the general population (24), with higher creatinine levels in older (and larger) male players and higher SMM.

Absolute VO₂max (ml) and relative (ml/kg/min) differ between male and female athletes. However, after indexing to FFM and SMM, no gender differences are observed. U16 male players show the highest relative values, indexed to BW, SMM, and FFM, whereas senior male players show the lowest. In females, neither the absolute nor the indexed value shows a significant difference between age groups. Mean VO₂max values for males and females (53.92±5.47 vs 47.15±4.50ml/kg/min) are consistent with the reported data (25). However, differences may stem from the varying protocols and equipment (treadmill vs bicycle) used. Some variation in measured VO₂max has been observed across the season (26). All players in our study were tested at the same point in the season. A study by Gocentas et al. (27) compared 42 players divided by perimeter and post playing positions and it did not find a consistent correlation between body height and composition in the two groups. As a key marker of aerobic capacity and cardiorespiratory fitness, our results suggest that, with proper training, VO₂max develops early in young players, with more marked differences noticeable in male players. A large Dutch study (28) that compared subjects aged 6 to 65 found the highest relative VO₂max (ml/kg/min) values in males aged 15-19, and females aged 10-14. Athletes were excluded from this study. Given the same sport type, relative VO₂max differences in our population are consistent with the age differences observed in the Dutch study. SMM can also explain the VO₂max differences, given the differences in indexed values, as well as the similar results in gender groups. Our findings are consistent with those of Dimitros et al. (12), as VO₂max develops early and the values are not greater in older players with more training years behind them.

Data from the ECHO exam show that cardiac chamber dimensions and LA and LV volumes adapt to exercise

Table 6. Female subgroup echocardiographic parameters

Parameter	U16 (n=21)	U18 (n=12)	U20 (n=20)	SENIOR (n=29)	Statistical significance*
Aortic root (mm)	28.25±1.74	27.50±1.72	27.75±2.07	30.21±2.94	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20)
Aortic root/BSA (mm/m ²)	14.90±1.43	14.87±0.86	14.98±1.24	15.59±1.40	NS
Aortic root z-score	-0.31±0.63	-0.54±0.56	-0.53±0.75	-0.02±1.00	NS
Aortic annulus (mm)	21.95±1.73	21.20±1.69	21.55±1.57	22.90±1.99	p=0.021
Ascending Aorta (mm)	24.45±1.64	24.00±1.41	24.85±1.73	27.07±3.23	p<0.001 (U16 vs SENIOR, U18 vs SENIOR)
LA (mm)	39.95±2.11	39.10±0.99	40.65±1.90	42.59±2.20	p<0.001 (U16 vs SENIOR, U18 vs U20, U18 vs SENIOR, U20 vs SENIOR)
LA Biplane Volume/BSA (ml/m ²)	28.53±2.34	28.35±3.06	28.35±3.05	32.04±3.40	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20)
LV EDD (mm)	50.00±3.08	49.20±1.87	49.65±2.58	52.52±2.79	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U20 vs SENIOR)
EDD/BSA (mm/m ²)	26.34±2.11	26.62±1.12	26.80±1.48	27.12±1.53	NS
LV ESD (mm)	32.70±1.81	31.50±1.96	32.45±2.56	34.10±2.08	p=0.001 (U16 vs SENIOR, U18 vs SENIOR)
LV ESD/BSA (mm/m ²)	17.24±1.54	17.06±1.30	17.51±1.34	17.62±1.29	NS
LV EDV (mm)	120.40±16.82	114.60±15.81	120.25±15.30	134.83±15.12	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20)
LV EDV/BSA (ml/m ²)	63.04±6.14	61.70±5.69	64.70±6.67	69.47±6.40	p<0.001 (SENIOR vs U16, SENIOR vs U18)
ESV (ml)	43.35±6.64	39.90±4.68	43.60±6.71	48.76±6.39	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20)
ESV/BSA (ml/m ²)	22.71±2.67	21.54±2.02	23.47±3.24	25.14±3.08	p=0.003 (SENIOR vs U16, SENIOR vs U18)
RA (ml)	43.85±2.94	43.70±2.00	44.60±2.82	46.93±2.20	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U20 vs SENIOR)
RV (mm)	32.90±2.00	32.90±1.52	33.15±2.16	35.21±1.90	p<0.001 (U16 vs SENIOR, U18 vs SENIOR, U20 vs SENIOR)
EF (%)	63.97±2.43	64.98±2.83	63.76±2.79	63.78±3.25	NS
SV (ml)	77.05±11.28	74.70±12.60	76.65±10.18	86.07±11.10	p=0.006 (U20 vs SENIOR)
IVS (mm)	9.15±0.59	8.75±0.54	9.35±0.63	9.81±0.62	p<0.001 (U16 vs SENIOR, U18 vs SENIOR)
PW (mm)	9.12±0.58	8.70±0.35	9.35±0.59	9.79±0.62	p<0.001 (U16 vs SENIOR, U18 vs U20, U18 vs SENIOR)
LVMI (g/m ²)	87.45±13.24	79.90±7.58	90.05±11.25	101.62±12.47	p<0.001 (SENIOR vs U16, SENIOR vs U18, SENIOR vs U20)
RWT	0.37±0.02	0.35±0.02	0.38±0.02	0.37±0.02	p=0.006 (U18 vs SENIOR)

The results are presented as mean±SD. *significant pair-wise differences between age groups in post-hoc analysis are shown in brackets. NS, not significant; BSA, body surface area; LA, left atrium; LV, left ventricle; EDD, end-diastolic diameter; ESD, end-systolic diameter; EDV, end-diastolic volume; ESV, end-systolic volume; RA, right atrium; RV, right ventricle; EF, ejection fraction; SV, stroke volume; IVS, interventricular septum; PW, posterior wall; LVMI, left ventricular mass index; RWT, relative wall thickness

starting in U16 players, and absolute values tend to be higher in older than younger players, regardless of gender. When indexed to BSA, senior athletes have larger LA volume, although there is no statistical difference in indexed LV end-diastolic and end-systolic dimensions. Older athletes tend to have larger LV volumes, although indexed EDV does not reach statistical significance in males. The values of $75.02 \pm 6.92 \text{ ml/m}^2$ in males and $69.47 \pm 6.40 \text{ ml/m}^2$ in females are the highest observed in senior athlete groups. A similar trend is seen for thoracic aorta diameters, except for the aortic annulus. Indexing to BSA and calculating the z-score eliminates differences between age groups. Wall thickness and LVMI show higher values in older players. Greater HT, BW, and BSA in older cohorts, along with increasing cardiac dimensions, suggest symmetrical and appropriate cardiac adaptation that begins as early as the U16 cohort and is consistent with physiological adaptation to basketball (9). Indexing to BSA is important, especially for athletes with large HT and BSA, such as basketball players. Moccia et al. (29) also show that larger athletes (i.e., those with large BSA) have the largest LV dimensions. Looking at LVMI and RWT values, the adaptation for most players could be considered as normal geometry to eccentric hypertrophy for most players, classified as $\text{LVMI} \geq 115 \text{ g/m}^2$ for males and $\geq 95 \text{ g/m}^2$ for females, with $\text{RWT} \leq 0.42$ for both groups (30), as shown in Figure 1. Three male players show concentric remodeling, and no player exhibits concentric hypertrophy remodeling.

A large study of ECHO characteristics in male NBA players from 2016 (31) investigated 526 senior players (mean age 25.7 years), 406 of whom are African American. The findings of predominant eccentric hypertrophy-type adaptation align with our study. Additionally, mean aortic values plateaued in players with the largest HT and BSA. A cross-sectional study of 140 Women's NBA senior female players (32) also shows eccentric hypertrophy as the predominant adaptation, with chamber sizes correlating with BSA.

In conclusion, these findings offer further insight into the understanding and interpretation of cardiovascular, biochemical, and functional parameters in male and female basketball players across different age groups. To ensure safe participation in sports, regular and comprehensive sports medical exams should be performed. Additionally, interpreting the findings is also important and should be considered for each individual athlete, taking into account the sport type, gender, age, body size, and other relevant information. VO_2max levels develop early in young players, and the values are not greater in older player groups. Physiological cardiac adaptation is observed across all age groups, starting at U16, and is consistent with physiological adaptation to basketball, ranging from normal geometry to eccentric left

ventricular hypertrophy. Left chamber volumes are the largest in the senior player group. Further longitudinal follow-up studies with larger participant numbers are needed to support these findings.

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ABBREVIATIONS:

ALT, alanine aminotransferase
ANOVA, analysis of variance
AST, aspartate transaminase
BF, body fat percentage
BIA, bioelectrical impedance analysis
BMI, body mass index
Bpm, beats per minute
BSA, body surface area
BW, body weight
CPET, cardiopulmonary exercise test
DBP, diastolic blood pressure
ECG, electrocardiogram
ECHO, echocardiogram
EDD, end-diastolic diameter
EDV, end-diastolic volume
EF, ejection fraction
ESC, European Society of Cardiology
ESD, end-systolic diameter
ESV end-systolic volume
FFM, fat-free mass
FIBA, fr. Fédération Internationale de Basketball (International Basketball Federation)
HCT, hematocrit
HR, heart rate
HRmax, maximal heart rate
HT, body height
IRBBB, incomplete right bundle branch block
IVS, interventricular septum
LA, left atrium;
LV, left ventricle
LVMI, left ventricular mass index
MVP, mitral valve prolapse
NBA, National Basketball Association
NCAA, National Collegiate Athletic Association

PVC, premature ventricular complex
 PW, posterior wall
 QTc, corrected QT interval
 RA, right atrium
 RV right ventricle
 RWT, relative wall thickness.
 SBP, systolic blood pressure
 SCD, sudden cardiac death
 SMM, skeletal muscle mass
 SV, stroke volume
 TWI, T wave inversion
 VO₂max, maximal oxygen consumption

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