Sports cardiology screening, follow-up and physical fitness evaluation of special athlete populations

Ph.D. thesis

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1. Introduction

Regular physical activity unequivocally reduces disease risk and all-cause mortality, establishing itself as a cornerstone of preventive medicine. Yet, high-intensity exercise is contraindicated in certain cardiovascular conditions, necessitating rigorous screening, also for underexamined special athlete populations like referees and post-SARS-CoV-2 athletes who often lack comprehensive preparticipation evaluations.

Athletes' heart reflects physiological adaptations at multiple levels (structural, functional, and electrical remodeling). Sport classification evolved in recent years to the ESC guideline skill/power/mixed/endurance model, stratified by intensity for individualization.

Referees require substantial physical capacity to officiate fairly amid high cognitive demands and mental stress; also inadequate fitness impairs decision-making during peak loads. Hungarian handball referees undergo annual shuttle/12-minute run tests per HHF standards, yet the literature focuses mainly on football referees, leaving scarce data on handball elite referees despite their role in high-intensity indoor matches.

Post-SARS-CoV-2 athletes faced evolving protocols: strict 2020 return-to-play (ECG/echo/troponin after 3-week training pause) relaxed by 2022 for asymptomatic cases. Long-term fitness sequelae remain understudied, despite potential cardiopulmonary effects impacting performance beyond the acute recovery.

2. Objectives

2.1 Evaluation of cardiovascular risk factors of elite handball referees

In our cross-sectional study, we aimed to evaluate the prevalence of cardiovascular diseases and risks among top Hungarian handball referees.

2.2 Examination the physical fitness of elite handball referees

In our research, we aimed to examine the top 100 Hungarian handball referees to assess their physical fitness.

2.3 Examination of the long-term effects of a SARS-CoV-2 infection on sport performance and physical fitness of elite athletes

We aimed to examine elite athletes three months after a SARS-CoV-2 infection and to compare these results with their measurements before the pandemic in a cross-sectional and self-controlled study.

3. Methods

3.1 Participants

3.1.1 Handball referee examinations

In our research, 100 asymptomatic adult elite referees of the Hungarian Handball Federation were examined. Any symptoms or suspension of regular physical activity counted as exclusion criteria. All the examined referees were Caucasian.

3.1.2 Athletes post-SARS-CoV-2 infection

In one year from 2020 autumn, cardiology control examinations and CPET examinations were carried out following returning to high-intensity training after suffering a SARS-CoV-2 infection in 183 athletes. Athletes with previously known cardiovascular diseases (excluding hypertension) or musculoskeletal symptoms were excluded from the study.

Detailed CPET analysis was carried out on 165 asymptomatic elite athletes. Moreover, the results of the cardiovascular evaluation of 18 athletes, either symptomatic or with previous pathological findings, were also examined, however they were evaluated separately and individually from the asymptomatic elite athletes.

3.2 Procedures

3.2.1 Resting examinations in both studies

All measurements were performed at least 12 hours after the last training, competition or refereeing. Personal and family history

was taken by a detailed questionnaire and a personal interview. Following a physical examination and resting blood pressure measurement, a standard 12-lead ECG was recorded in a resting, lying position. The fasting laboratory examination contained complete blood cell count, ions, detailed lipid analysis, liver and kidney panel, iron profile, creatine kinase (CK), lactate dehydrogenase, glucose, haemoglobin A1C, and thyroid panel. Lipid cut-off values were determined per the ESC/EAS guidelines in force at the time of the execution of the study. Body-composition analyses were carried out by bioelectrical impedance measurements. Routine echocardiography was performed according to the guidelines in force at the time of the examinations. When indicated, Holter ECG, ambulatory blood pressure monitorization, cardiac MRI, cardiac CT, dobutamine stress echocardiography or cardiac percutaneous coronary intervention were also performed. For the evaluation of fatal cardiovascular risk among the handball referee, the ESC SCORE score was calculated in every cases with the European High Risk table.

3.2.2 Additional resting examinations in athletes post-SARS-CoV-2 infection

The SARS-CoV-2 infection was confirmed by polymerase chain reaction or by rapid antigen test; these tests were carried out individually prior to the study and were necessary for the enrolment. Athletes underwent cardiology screening in accordance with the return-to-sport recommendations 2-3 weeks after the infection. In case the first screenings were negative, athletes were advised to build up their regular training step-by-step. Athletes were invited for the second examination between 2 and 4 months after the SARS-CoV-2 infection, after returning to their current maximal intensity training.

3.2.3 Exercise examinations

For the referee examination the CPET was implemented on a treadmill ergometer using an incremental protocol starting with

a 1-minute flat walk of 6 km/h, followed by continuous 10 km/h uphill running with an increasing slope of 1.0% every minute until exhaustion.
In case of the post COVID-19 athletes the maximal CPET examinations were carried out on the same treadmill with sport-specific incremental protocols (starting with a 1-min sitting resting phase, followed by 1–2 min flat walk of 6 km/h as a warm-up, then by continuous 8–10 km/h uphill running with an increasing slope of 1.0–1,5% every minute until exhaustion). For athletes with prior CPET data available in our Clinic, the same protocols were applied to both examinations, and comparisons were made between pre- and post-SARS-CoV-2 CPET measurements. For inclusion into the study, it was mandatory to achieve maximal intensity at the CPET examination after the infection and, in the case of CPET comparisons, in the CPET examination before the infection as well.The maximal intensity was considered to be achieved if the athlete reported maximal subjective fatigue and either the respiratory exchange ratio (RER) was over 1.1 or flattening could be seen in the oxygen uptake and the heart rate curves. Breath-by-breath gas analysis was carried out using an automated cardiopulmonary exercise system. During the CPET examinations, continuous ECG monitorization was carried out, and the estimated maximal heart rate (HR) was calculated as 220-age. Blood lactate levels were measured from fingertip capillary blood drops at rest, during the exercise every second minute, at maximal load, and in the fifth minute of the cool-down. The anaerobic threshold was determined based on the lactate levels and the kinetics of the recorded Wasserman graphs. All CPET data were reported as an average of 10 seconds. All examinations and data collection were supervised by a cardiology and sports medicine specialist.

3.3 Statistical analysis

Statistical analyses were performed using dedicated software (Microsoft Excel, Microsoft Corporation, USA; Real Statistics Resource Pack software (Release 7.6), Copyright (2013–2021) Charles Zaiontz). Descriptive statistical values are shown as number (percentage), mean ± SD for normally distributed parameters, and median (interquartile range: 1st quartile –3rd quartile) for non-normally distributed parameters. Ethical approvals: 13687-1/2011-EKU and IV/9697-1/2020/EKU

4. Results

4.1 Elite handball referee studies

4.1.1 Referee population

The studied 100 elite handball referees (age: 29.6 ± 7.9 years, age range: 18–46 years, male: 64.0%) trained an average of 4.3 ± 2.0 hours/week (range: 1–11.5 hours/week) (*Table 1*). In all, 51.0% participated as referees in the first division, and 49% in the second division of the Hungarian National Handball League.

4.1.2 Personal and family history

None of the examined referees had any cardiovascular symptoms or diseases except for treated arterial hypertension in 4.0% and ablated AV re-entry tachycardia in 1.0%. Regarding the cardiovascular risk factors or diseases, 24% had a positive personal or family history. At the time of the study, 21.0% of the referees were smoking (male: 15.0%).

4.1.3 Physical examination

Without increased BMI, 5.0% of the referees proved to have an isolated increase in body fat percentage. Due to fat-free mass increase, 31.0% had higher BMI values. Considering both higher body fat and increased BMI, 10.0% were overweight (male: 9.0%), whereas 3.0% obese, all males. Resting mean systolic blood pressure was 133.5 ± 16.2 mmHg, while resting mean diastolic blood pressure was 82.4 ± 10.5 mmHg. Isolated elevation of the systolic blood pressure was found in 17.0%,

while isolated diastolic blood pressure in 9.0%. Both systolic and diastolic resting blood pressures were higher in 12.0%.

Table 1. Basic parameters of Hungarian elite handball referees according to the division of refereeing.

	First division referees	Second division referees	p-value
Participant (%)	51 (51.0)	49 (49.0)	-
Male (%)	39 (76.5)	25 (51.0)	*0.008*
Age (year)	33.0 ± 8.1	24.8 ± 5.2	*<0.001*
Training (h/w)	3.8 ± 2.0	4.8 ± 2.0	*0.006*
BMI (kg/m^2)	25.1 ± 2.3	23.8 ± 3.0	*0.016*
Body fat (%)	16.4 ± 5.4	21.0 ± 6.9	*<0.001*
FFMI (kg/m^2)	21.0 ± 2.1	18.8 ± 2.7	*<0.001*
Former elite player (%)	23 (45.1)	16 (32.7)	0.202

4.1.4 Resting ECG

By the results of the resting 12-lead ECG recordings, isolated QRS voltage criteria for left ventricular hypertrophy were found in 2.0%, incomplete right bundle branch block in 47.0%, sinus bradycardia in 10.0%, sinus arrhythmia in 6.0%, first degree AV-block in 2.0%. Out of the 55 referees who had at least one sport-related physiological ECG changes, 37 were male. Right axis deviation appeared at 2.0% and left axis deviation at 14.0%. These grey zone ECG changes were isolated in all of the cases. Pathological resting inferior ST-depression was found in 1.0%, and pathological T-wave inversion or biphasic T-waves in 6.0%. Sinus tachycardia was detected in 2.0%, out of one case combined with monomorphic ventricular bigeminy. In total, 10 referees had one or two pathological ECG changes, and 4 of them were male.

4.1.5 Laboratory examinations

Due to physical activity, the mean level of CK was slightly elevated (230.2 ± 399.1 U/l). Individually, slightly elevated CK

values were measured in 26.0%, and markedly elevated values in 4.0%. Dyslipidaemia requiring lifestyle changes was found in 38 patients; 33 out of them were male, while lipid-lowering medication was indicated in 3 cases. Decreased free iron levels were found in 20.0%, while total iron-binding capacity increased in 16.0%, transferrin increased in 5.0%, transferrin saturation decreased in 16.0%, and ferritin level decreased in 6.0%. Lower red blood cell count was found in 9 female referees, while a lower haemoglobin level in 9 females as well. All these cases were attributed to iron deficiency. No other significant laboratory test deviations were found.

4.1.6 Systematic coronary risk estimation

Four referees had a SCORE point between ≥1 and <5, all of them were male with personal history of smoking.

4.1.7 Echocardiography

The average left ventricular ejection fraction was 59.9 ± 3.3%, while the average posterior and interventricular septal end-diastolic wall thicknesses were 8.6 ± 1.4 mm and 9.5 ± 1.5 mm respectively. Grey zone posterior wall thickness was found in 2.0%, and grey zone interventricular septal wall thickness in 3.0%. Pathological echocardiographic changes affected 6 male and 6 female patients (first-grade mitral valve insufficiency: 6.0%; mitral prolapse syndrome: 3.0%; interatrial septal aneurysm without shunt flow: 1.0%; increased trabecularization: 1.0%; dilated aortic root: 2.0%; bicuspid aortic valve: 1.0%; increased right ventricular dimensions: 1.0%).

4.1.8 Cardiopulmonary exercise testing

On our running protocol, the average running time was 9.3 ± 2.9 min for all referees (range: 4.3 – 15.7 min), further data are shown in *Table 2*. There was no significant difference in the exercise time between males and females (respectively, 9.6 ± 2.8 vs. 8.8 ± 2.8 min; $p = 0.17$), while $\dot{V}O_{2max}$ proved to be higher in male referees (respectively, 47.0 ± 5.7 vs. 40.4 ± 4.3 ml/kg/min; $p < 0.001$). In all the parameters mentioned above,

significant individual differences could be observed among the referees, as presented in *Figure 1* and *Figure 2*.

The most common pathological changes were hypertensive pressure values in 10.0%, multiple PVCs during exercise or recovery in 8.0%, and pathological ST-T changes in 8.0%. Heart rate-dependent left bundle branch block was detected in one patient, and decreased maximal aerobic capacity was found in another patient.

4.1.9 Comparison of the first and second division referees

Compared to the first-division referees, second-division referees reached higher exercise time, maximal HR, and maximal ventilation values, with similar peak lactate and $\dot{V}O_{2max}$ values. The second-division referees also reached their anaerobic threshold later. Data are shown in *Table 2*. 2.0% of the first and 4.1% of the second-division referees did not reach the calculated values of the general population in oxygen uptake. However, all results were within the physiological range.

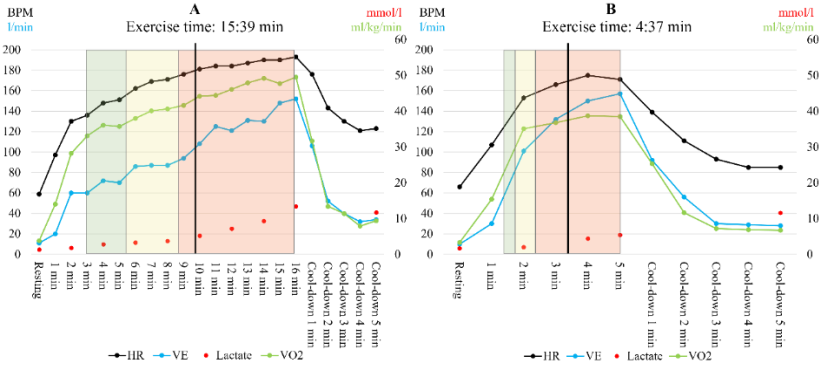

Figure 1. Representative cardiopulmonary exercise testing curves of two male referees with the longest and shortest exercise running times.

Table 2. Cardiopulmonary exercise testing results of Hungarian elite handball referees according to the division of refereeing.

	First division referees	Second division referees	p-value
HR_{rest} (BPM)	78.7 ± 11.1	79.3 ± 14.1	0.745
Exercise testing time (min)	7.7 ± 2.2	11.0 ± 2.4	*<0.001*
HR_{max} (BPM)	183.3 ± 15.9	190.0 ± 10.2	*0.012*
Lac_{peak} (mmol/l)	9.0 ± 3.6	9.5 ± 2.6	0.421
$\dot{V}O_{2max}$ (ml/kg/min)	45.1 ± 5.6	44.0 ± 6.7	0.291
VE_{max} (l/min)	134.0 ± 28.1	121.8 ± 30.3	*0.016*
AT time (min)	4.4 ± 1.7	5.8 ± 2.0	*<0.001*
AT time/total time (%)	58.7 ± 16.2	53.4 ± 15.2	0.103
HR_{AT} (BPM)	168.4 ± 14.9	173.8 ± 13.4	*0.013*
HR_{AT}/HR_{max} (%)	92.8 ± 11.2	91.4 ± 5.1	0.245
$\dot{V}O_{2AT}$ (ml/kg/min)	39.4 ± 5.3	37.1 ± 5.5	*0.036*
$\dot{V}O_{2AT}/\dot{V}O_{2max}$ (%)	88.1 ± 7.7	84.8 ± 8.4	*0.049*

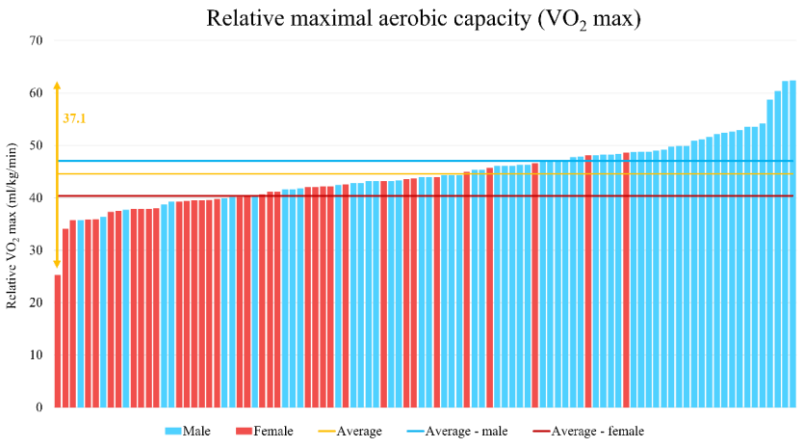

Figure 2. The relative maximal oxygen uptakes of elite Hungarian handball referees on a sport-specific protocol.

4.1.10 Additional examinations

Holter ECG recordings were carried out in seven cases; a significant number of PVCs was found in 2, and 1 out of these patients also had significant ventricular bigeminy episodes and ventricular triplets. In total, 10 ambulatory blood pressure monitoring examinations were indicated. Normal blood pressure values were measured in 3 cases, new onset hypertension was diagnosed in 2 cases, undertreated hypertension in 1 case, and slightly elevated blood pressure values in 2 cases; all of these patients were male. Two patients did not undergo the examinations for their personal decisions.

All together 27 referees have undergone CMR due to offered screening in 12 cases and for diagnostic indications in 15 cases. Hypertrabecularization was seen in 2 cases, borderline left and right ventricular functions in 3 cases - 1 out of them also had a wall motion abnormality. One case of aortic dilatation and bicuspid aortic valve, previously found with echocardiography, was confirmed by CMR. In the case of 1 referee, circular pericardial contrast enhancement referring to previous pericardial inflammation was detected. A CCT was carried out in 4 cases due to wall motion abnormality in 1 case and stress ECG ST-T abnormalities and PVCs in 3 cases. Non-significant coronary artery atherosclerosis was diagnosed in 1 case, and LAD bridge was found in another. Two more patients with CCT indications have not undergone the examinations because of their personal decisions.

4.1.11 Interventions

Lifestyle changes were advised to 58.0%, including quitting smoking, losing weight, and introducing dietary changes. Antihypertensive drug therapy was induced in 2.0%, modified in 1.0%, aslo regular blood pressure monitorization adviesed in 12.0%. Lipid-lowering therapy was started in 3.0%. Beta-blocker therapy was initialized in 1.0% (frequent PVCs). Oral iron supplementary therapies were suggested in 22.0% (male:

9.0%). Regular cardiology control were recommended for 29.0%. Recommendation of lifestyle changes was more often in male referees, and iron supplementation was suggested in more female referees. No difference was found between former elite and former non-elite referees regarding the number of interventions indicated.

4.2 Long-term effects of a SARS-CoV-2 infection on sport performance and physical fitness of elite athletes

4.2.1 Results of asymptomatic elite athletes

The analysis was performed on 165 asymptomatic elite athletes (male: 122 (73.9%), age: 20 years (IQR: 17–24 years), training: 16 hours/week (IQR: 12–20 h/week)) from various types of sport. The examinations were performed 93.5 days (IQR: 66.8–130.0 days) following the first signs of a verified SARS-CoV-2 infection, including 21 days (IQR: 14–28 days) of training cessation and after achieving maximal training intensity. During the acute phase, 17.0% had an asymptomatic infection, 82.4% had mild symptoms, while 0.6% had moderate symptoms.

Slightly elevated high-sensitive Troponin T levels were measured in one elite asymptomatic athlete. After skipping training for 2 weeks, hs Troponin T level normalized; therefore, the increase was considered sports-related in this case.

Control echocardiographic examinations proved reversible slightly increased pulmonary pressure in 1.2%; no other supposedly COVID-19-related changes were measured. Further echocardiographic findings independent from the infection were preserved left and right ventricular ejection fraction (0.6%), slight diastolic dysfunction (0.6%), Barlow type mitral valve with mitral annular disjunction (0.6%) and left ventricular hypertrabecularization (1.2%).Most asymptomatic elite athletes had satisfactory fitness levels, as indicated by CPET results. (*Table 3.*)

Table 3. Cardiopulmonary exercise testing follow-up results of elite asymptomatic athletes after a SARS-CoV-2 infection.

CPET results after SARS-CoV-2 (N=165)	Parameters	CPET follow-up results (N=62)		
		Before SARS-CoV-2	After SARS-CoV-2	p
70 (64–79)	HR_{rest} (BPM)	72 ± 14	69 ± 14	0.174
187 (181–195)	HR_{max} (BPM)	190 (183–200)	187 (181–196)	*0.024*
94.7 ± 4.3	HR_{max} (% of calc. max.)	95.6 ± 5.0	94.3 ± 4.4	0.077
173 (166–184)	HR_{AT} (BPM)	170 (163–179)	171 (166–179)	0.277
93.2 (90.7–95.3)	HR_{AT} (% of HR_{max})	90.6 (86.3–93.5)	91.4 (90.2–93.4)	*0.004*
27 (22–34)	$HR_{recovery}$ (BPM)	29 (22–35)	27 (21–34)	0.290
50.9 ± 6.0	$\dot{V}O_{2max}$ (ml/kg/min)	49.9 ± 5.6	52.2 ± 5.6	*0.004*
44.2 ± 5.5	$\dot{V}O_{2AT}$ (ml/kg/min)	41.8 ± 4.5	44.2 ± 5.0	*<0.001*
87.0 ± 6.4	$\dot{V}O_{2AT}$(% of $\dot{V}O_{2max}$)	84.0 ± 7.4	85.1 ± 7.3	0.289
143.7 ± 30.4	VE (l/min)	146.9 ± 27.8	155.3 ± 29.2	*0.008*
8.1 (6.6–10.0)	Lac_{max} (mmol/l)	8.5 (7.0–11.1)	8.7 (6.8–10.6)	0.465
13.1 (11.0–15.0)	Exercise time (min)	13.0 (11.0–15.0)	14.0 (12.0–15.8)	*0.003*
100.8 ± 16.8	FEV1 (% of exp.)	105.3 ± 14.7	107.1 ± 17.6	0.198
26.3 ± 3.0	VE/VCO_2 slope	26.2 (24.3–28.3)	25.7 (24.7–27.7)	0.713

4.2.2 Comparison of CPET results before and after a SARS-CoV-2 infection in elite athletes

In 62 athletes, previous CPET results from before the SARS-CoV-2 infection were also available (Follow-up: 0.7 years (IQR: 0.6–1.8 years, *Table 3.*). The CPET exercise time proved to be longer after the infection. Regarding $\dot{V}O2_{max}$ and maximal ventilation, even higher values were observed after the infection as compared to the previous examinations. Resting or exercise-induced atrial or ventricular arrhythmias or significant ST-T changes were revealed in 4.8%. Behind these no structural cardiac abnormalities were found. The exercise-induced sustained ventricular tachycardia proved to be a Belhassen-type arrhythmia. Regarding the ST-depression cases, 1 athlete had non-significant ischemic heart disease, while another one had a coronary artery bridge. New initiation of antihypertensive therapy was necessary in 7 cases. In 13.3% of the asymptomatic elite athletes, only the echocardiography (4.2%) or CPET examinations (9.1%) revealed cardiovascular pathologies requiring treatment or follow-up. In cases of cardiac pathologies, further examinations, restrictions in sports activity, and follow-up were recommended.

4.2.3 Results of athletes with pathological findings or ongoing symptoms during the visit

The results of those elite and non-elite athletes who still had symptoms or had positive clinical findings during the visit (n = 18, elite athlete: n = 9) were evaluated separately. At the time of the control measurements, 11 athletes were still symptomatic (elite athletes: n = 5), although previously all of them only had mild symptoms in the acute phase of the infection. One athlete, who had mild acute symptoms previously, suffered from a long-standing mild, stabbing chest pain. Due to these late symptoms, a CMR examination was carried out and revealed preserved left and right ventricular ejection fractions, and potential signs of previous myocarditis. A follow-up CMR

carried out 8 months later detected the regression of these pathological signs. Due to the timing of the infection, the long-standing symptoms and in the absence of other infections, this case was considered as a previous COVID-19 myocarditis.

In an elite athlete with symptoms of effort dyspnea, decreased exercise capacity was revealed. This athlete suffered from asthma bronchiale, diagnosed before the SARS-CoV-2 infection and treated with optimal medical therapy. However, the symptoms of asthma bronchiale worsened in the long-term following the infection.

In the case of a master athlete who had palpitations and fatigue after a moderate symptomatic SARS-CoV-2 infection, multiple PVCs, ventricular couplets, a short non-sustained ventricular tachycardia (5 beats), and multiple supraventricular premature beats were recorded on the CPET. Multiple polymorphic ventricular couplets and a 19-beat-long paroxysmal atrial fibrillation episode were recorded on the 24-hour Holter ECG. A borderline stenosis was revealed on the proximal part of the right coronary artery on the CCT examination. Dobutamine stress echocardiography did not revealed ischaemic signs.

An asymptomatic non-elite master athlete with horizontal ST-depression in V4-V6 precordial leads proved to have anomalous right coronary artery origin and a significant pre-occlusive coronary artery disease as per the CT. The right coronary artery originated from the left aortic sinus of Valsalva and turned immediately rightwards at a very acute angle and traversed between the pulmonary trunk and the aorta before returning to its ordinary course. At the coronarography a 70-89% stenosis was revealed on the right coronary artery and a drug eluting stent was implanted.

In an asymptomatic case, elevated hs Troponin T levels were measured repeatedly starting from a previous visit 4 weeks following the SARS-CoV-2 infection, and similar values were measured during a more than 6-month follow-up (all hs

Troponin T levels were between 40-50 ng/L). During this time, no symptoms appeared, and all examinations - including CMR - were negative. In this case, hs Troponin changes were considered an individual characteristic without cardiac diseases. In cases of symptoms or cardiac pathologies, further examinations, restrictions in sports activity, and follow-up were recommended according to the current European guidelines.

5. Conclusions

Our investigations fundamentally reshape our understanding of cardiovascular health in special athletic populations by demonstrating that comprehensive screening can identify substantial hidden pathologies either with immediate clinical implications or long-term negative cardiovascular effects. The finding that nearly half of cardiovascular conditions in handball referees would remain undetected through conventional mandatory screening, combined with the identification of serious cardiac pathologies in some post-COVID athletes, establishes compelling evidence for expanded cardiovascular assessment protocols in sports medicine. The high prevalence of risk factors in handball referees demonstrates that athletic participation whether as competitors or officials, does not confer immunity from cardiovascular disease, and may create unique risk profiles requiring specialized evaluation approaches. Our examinations of athletes after SARS-CoV-2 infection as a part of worldwide athletic screening never seen before also highlight the importance of widely implemented extended cardiology. Although long-term pathological effects of COVID-19 proved to be rare due to our results, other severe pathologies not connected to the infection were also revealed. These results are in line with research showing that even Olympic athletes can have significant cardiovascular risk factors. Studies of professional athletes across various sports have consistently identified substantial prevalence of hypertension, dyslipidaemia, and other modifiable risk factors

Regarding physical fitness, our data underline the great individual differences among elite Hungarian handball referees, as well as the remarkable differences in the amount of training regularly done by them. Therefore, although refereeing experience highly affects the quality of refereeing, individual training plans should be prescribed for referees to reduce the differences observed in their physical fitness levels.

The success of comprehensive screening in handball referees and post-COVID athletes suggests similar approaches may benefit other athletic populations. International evidence supports expanding screening programs, with research from multiple countries demonstrating that systematic cardiovascular evaluation can identify significant pathology in apparently healthy athletic populations. However, significant variability exists in screening protocols, with only a minority of organizations including echocardiography and stress testing as standard practice. We recommend that these extended examinations be performed regularly, or at minimum following infections (e.g. SARS-CoV-2 infection) in all elite athletes to reduce the risk of sudden cardiac death. Supplementing these tests with CPET measurements whenever possible provide additional information on cardiovascular health.

The clinical significance of our findings extends beyond individual patient care to encompass broader questions of sports safety, preparticipation screening adequacy, and resource allocation in preventive cardiology. When compared to international studies, these results consistently support the value of comprehensive screening while highlighting the unique cardiovascular challenges faced by different athletic populations. The integration of advanced diagnostic techniques with functional assessment provides a model for contemporary sports cardiology that balances diagnostic thoroughness with practical implementation considerations, ultimately serving to enhance both safety and performance in athletic populations.

6. Bibliography of the candidate's publications

6.1 Bibliography related to the present thesis

O Kiss*, **M Babity***, A Kovacs, et al. (2021) Significance of extended sports cardiology screening of elite handball referees. PLoS One, 10.1371/journal.pone.0249923 IF: 3,752

M Babity, M Zámodics, BK Lakatos, et al. (2022) Cardiorespiratory fitness status of elite handball referees in Hungary. PLoS One, doi: 10.1371/journal.pone.0270999 IF: 3,7

M Babity*, M Zamodics*, A Konig, et al. (2022) Cardiopulmonary examinations of athletes returning to high-intensity sport activity following SARS-CoV-2 infection. Sci Rep, 10.1038/s41598-022-24486-x IF: 4,6

6.2 ***Bibliography not related to the present thesis***

D Balla, L Szabo; F Graziano, et al. (2025) The role of sex, training load, and sports type in athletic cardiac remodelling: Insights from T1 and T2 mapping via cardiac magnetic resonance. Int J Cardiol, 10.1016/j.ijcard.2025.133080 IF: 3,2

T Leel-Őssy; M Babity; M Zámodics, et al. (2025) A testösszetétel meghatározásának módszerei a klinikai gyakorlatban. Orvosi Hetilap, 10.1556/650.2025.33154 IF: 0,8

M Zamodics; M Babity; A Mihok; et al. (2025) Evaluation of treadmill cardiopulmonary exercise testing and field measurement results in women's youth and adult national team water polo players. Heliyon, 10.1016/j.heliyon.2024.e41131 IF: 3,4

M Zamodics; M Babity; G Schay; et al. (2025) Correlations Between Body Composition and Aerobic Fitness in Elite Female Youth Water Polo Players. Sports, 10.3390/sports13020051 IF: 2,2

M Zamodics, M Babity, G Schay, et al (2025). Investigation of Body Composition and Cardiac Sports Adaptation in Elite Water Polo Players. Sports, 10.3390/sports13060180 IF: 2,2

V Juhász; A Ország; D Balla et al. (2024) Blood Test-Based age Acceleration Is Inversely Associated with High-Volume

Sports Activity. Med Sci Sports Exerc, 10.1249/MSS.0000000000003380 IF: 4,1

A Ujvári; A Fábián; BK Lakatos et al. (2024) Right ventricular structure and function in adolescent athletes: a 3D echocardiographic study. Int J Sports Med, 10.1055/a-2259-2203 IF: 2

V Juhász; L Szabó; A Pavlik et al. (2023) Short and mid-term characteristics of COVID-19 disease course in athletes: A high-volume, single-center study. Scand J Med Sci Sports, 10.1111/sms.14265 IF: 3,5

A Fábián; A Ujvári; M Tokodi et al. (2022) Biventricular mechanical pattern of the athlete's heart: comprehensive characterization using three-dimensional echocardiography. Eur J Prev Cardiol, 10.1093/eurjpc/zwac026 IF: 8,3

BK Lakatos; M Tokodi; A Fábián et al. (2022) Frequent Constriction-Like Echocardiographic Findings in Elite Athletes Following Mild COVID-19: A Propensity Score-Matched Analysis. Front Cardiovasc Med, 10.3389/fcvm.2021.760651 IF: 3,6

A Fábián; BK Lakatos; M Tokodi, et al. (2021) Geometrical remodeling of the mitral and tricuspid annuli in response to exercise training: a 3-D echocardiographic study in elite athletes. Am J Physiol Heart Circ Physiol, 10.1152/ajpheart.00877.2020 IF: 5,125

BK Lakatos; A Molnár; O Kiss et al. (2020) Relationship between Cardiac Remodeling and Exercise Capacity in Elite Athletes: Incremental Value of Left Atrial Morphology and Function Assessed by Three-Dimensional Echocardiography. J Am Soc Echocardiogr, 10.1016/j.echo.2019.07.017 IF: 5,251

BK Lakatos; O Kiss; M Tokodi, et al. (2018) Exercise-induced shift in right ventricular contraction pattern: novel marker of athlete's heart? Am J Physiol Heart Circ Physiol, 10.1152/ajpheart.00304.2018 IF: 4,048

∑IF: 71.476