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COMPREHENSIVE MEDICAL CARE OF ELITE SWIMMERS: SCREENING, PERFORMANCE AND COMPETITIONS DURING THE COVID ERA

PhD thesis

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List of Abbreviations

AQUA	World Aquatics
B	Base time
BPM	Beats per minute
CI	Confidence Interval
CK	Creatin Kinase
COVID-19	Coronavirus disease 2019
CPET	Cardiopulmonary Exercise Testing
CT	Computed Tomography
ECG	Electrocardiogram
F	Female
FINA	Fédération Internationale de Natation
HR	Heart Rate
IQR	Interquartile range
LV	Left Ventricle
MRI	Magnetic Resonance Imaging
O_2	Oxygen
OR	Odds Ratio
P	Points
PCR	Polymerase Chain Reaction
RER	Respiratory Exchange Ratio
RR	Respiratory Rate
RV	Right Ventricle
T	Time
VCO_2	Carbon-dioxide elimination
VE	Minute ventilation
VE_{max}	Maximal Ventilation

VO_2	Oxygen uptake
VO_{2max}	Maximal aerobic capacity
VT	Tidal volume
VT1	Ventilatory Threshold1
VT2	Ventilatory Threshold 2
WHO	World Health Organization

1. Introduction

The pandemic of the Coronavirus disease 2019 (COVID-19) has influenced various aspects of society, including high-level athletes. It has changed the world of sports, including medical care of athletes. Besides the respiratory consequences of the infection, COVID-19 enhanced the risk of myocarditis and thromboembolism, increasing the likelihood of sudden cardiac death. Therefore, comprehensive post-COVID cardiovascular screening of athletes was crucial during the initial phase of the pandemic (1, 2). The fact that athletes were at a higher cardiovascular risk following the COVID-19 infection brought new challenges to the sports cardiology screenings. It raised several questions about the safe return-to-play. Recommendations for return-to-play have been continuously updated along with the latest evidence of the disease (3). Early identification of the virus and its consequences, along with vaccination, helped reduce disease progression and prevent unexpected events, allowing athletes to train and compete with minimized health risks (4-6). During the pandemic, healthcare services were mainly focused on COVID-19-related issues, and in parallel, the focus of competition was distracted as the events were postponed. Aquatic athletes were particularly affected by the closure of swimming pools, which forced them to maintain their sports adaptation through land-based training (7, 8). Performance assessment tests were also de-emphasized, especially cardiopulmonary exercise testing (CPET), due to the higher risk of airborne transmission (9-11). However, routine performance diagnostics are crucial for optimizing training programs and monitoring sport adaptation, especially since COVID-19 also impacted athletes' preparation (12-16).

The subsequent introduction provides a comprehensive overview of physiological adaptation to exercise and the importance of comprehensive sports cardiology screening in swimmers. It additionally reviews the organization and implementation of medical services during international aquatic events and describes the clinical characteristics and impacts of COVID-19 infection among aquatic athletes.

1.1. Sport Adaptation in Swimmers

The mode, the frequency, and the intensity of exercise mainly influence cardiac remodeling related to sports activity. Competitive swimming is categorized as an endurance sport (5). The mechanisms of cardiopulmonary remodeling in swimming may differ from those in other endurance sports. Exercising in the water results in different gravitational effects on the body compared to land-based training. Additionally, supine position during swimming affects the circulation and the cardiovascular adaptation (17), as right ventricle (RV) preload increases in this position due to the enhanced venous return (18). Periodic respiratory patterns with prolonged breath-holding episodes may lead to hypoxia, which can trigger alveolar hyperplasia. Ventilation is also limited during the underwater breath-holding episodes, meaning that the respiratory muscles must work against an increased load (17).

Furthermore, remodeling also affects pulmonary circulation, as exercise increases the diameter of the pulmonary arteries and vascular resistance, decreasing flow velocity (19, 20). The underlying mechanism of chronic pulmonary and RV remodeling is the recurrent increase in pulmonary artery pressure with exercise (21). Compared with athletes in different disciplines, swimmers typically exhibit improved lung volumes and pulmonary efficiency, characterized by elevated vital capacity, forced vital capacity, and forced expiratory volume (22, 23). In swimming, studies show that ventricular end-diastolic volume is pronounced due to the response to volume load. In contrast, the increase in ventricular thickness (which is a result of pressure load in strength-related sports) is less typical. In many studies, no difference was found in left ventricular (LV) wall thickness between swimmers and controls (24-26). Swimming-related RV remodeling appears to be less pronounced than other endurance sports. This observation may be explained by the specific hemodynamic influence that swimming has on pulmonary circulation and the right cardiac chambers (19, 27). Regarding the musculoskeletal system, upper-body muscle work is dominant in swimming (19, 28, 29). All adaptation mechanisms seem more pronounced in males (18, 19).

1.2. Sports Cardiology Screening of Elite Swimmers

When interpreting sports cardiology screening results, it is essential to consider the physiological cardiac adaptations that occur with exercise. Differentiation between physiological adaptation and pathological changes is one of the main goals of screening (30). Baseline examinations, such as personal and family history, electrocardiogram (ECG), and echocardiography, are appropriate for excluding most cardiovascular diseases. However, in elite athletes, a comprehensive approach is required, which includes not only baseline medical exams but also CPET, as it provides the most precise assessment of sport performance and adaptation by identifying exercise-related symptoms and arrhythmias (31, 32). Regular monitoring and re-evaluation are recommended, particularly for elite athletes in intensive training programs conducted by a specially trained and experienced sports physician (33-35). Effective screening programs involve a multidisciplinary approach, engaging healthcare professionals and coaches (31, 36). Sports federations should establish their protocols for screening programs tailored to the specific characteristics and risks associated with sport in each discipline.

1.2.1. Baseline Examinations

The baseline sports cardiology examination involves taking a thorough personal and family medical history, focusing on the cardiovascular, respiratory, musculoskeletal, and neurological systems (32). Special attention is given to any exercise-related symptoms, such as chest pain, palpitations, shortness of breath, or syncope during exercise, as these may indicate underlying cardiac issues. Identifying a family background of heart diseases, especially sudden cardiac death, is also crucial to detect hereditary conditions that could present a risk (5, 30, 31). For athletes, a structured physical examination covering all organ systems is recommended. In the case of a positive finding, further evaluation with targeted, specific testing methods is indicated (5, 32). The use of ECG in athletes' screening remains debated internationally. However, the European Society of Cardiology recommends it as an essential part of the screening (5), but the American College of Cardiology's recommendation does not include it (37). Following recent guidelines, studies have examined the contribution of ECG to pre-participation screening protocols and assessments. They have found that ECG screening results in a low false-positive rate and is superior to medical history and physical examination (38-46). Furthermore, routine echocardiography screening may reveal clinically relevant cardiac diseases in athletes. (5, 43, 47).

1.2.2. Performance Assessment

CPET assesses cardiovascular, pulmonary, and metabolic responses to exercise, providing insight into potential limitations in cardiac function, respiratory capacity, or metabolic efficiency. Beyond its clinical roles (48) — investigating exercise-related complaints, diagnosing arrhythmias, guiding prognoses, risk-stratification in known diseases, and evaluating medications — it serves as the gold standard for measuring athletic performance. It is a reliable and reproducible tool for optimizing training, enhancing performance, and promoting athletes' health (49). During the test, gas exchange parameters (VO_2, VCO_2, ventilation (VE)) are measured using computerized breath-by-breath technology (48). This system provides comprehensive analyses that can be easily retrieved, stored, and combined with standard exercise test measurements, including heart rate (HR), blood pressure, continuous ECG monitoring, oxygen saturation, and work rate (48). CPET is also an essential tool for evaluating performance in swimmers. Even for swimmers, the treadmill ergometer is preferred over the cycle ergometer, as the maximal aerobic capacity (VO_{2max}) is 10-20% higher on the treadmill. (48, 50). Choosing the appropriate exercise test protocol is crucial when evaluating athletic performance. Personalized, sports-specific ramp protocols are recommended, with a gradual increase in work rate (typically over 10 to 60 seconds per interval) until an exercise duration of 8-12 minutes is reached, thereby limiting fatigue (48). Finally, the treadmill test should be performed with minimal or no handrail support, as using the handrails decreases the work rate and influences VO_2 levels (48, 50). The detailed assessment of CPET parameters provides valuable insight into swimmers' adaptation responses to exercise. The consumption rate (O_2 uptake, VO_2 – L/min) measures the oxygen uptake from the environment to peripheral tissue (48). It is a crucial parameter for diagnosing cardiovascular disease and evaluating sports performance (50). Maximal aerobic capacity is the highest oxygen consumption rate during exercise (48). A higher VO_{2max} represents more effective oxygen transport and aerobic capacity (48), crucial for endurance sports such as swimming (51). Oxygen pulse (VO_2/HR - ml/beat) means the amount of oxygen consumed per heartbeat. It represents the stroke volume and cardiovascular efficiency (48, 50). Heart rate recovery (HR_{max}–1-minute recovery HR) is measured one minute after exercise and indicates autonomic recovery (48). The faster and more pronounced HR drop means better endurance (50).

Respiratory rate (1/min) is the number of breaths taken in one minute (48). Swimmers have lower values due to trained breath control and higher respiratory capacity (52). Minute ventilation (VE (L/min)=tidal volume (VT) * respiratory rate (RR)) reflects the amount of air inhaled and exhaled in one minute, while maximal ventilation (VE_{max}) represents the highest achievable value (48, 53). Swimmers have higher values due to sports-specific pulmonary adaptations (52). Tidal volume (L) is the amount of inhaled and exhaled volume of air during one breath (48). Higher values in swimmers mean better pulmonary capacity (52). The respiratory equivalent for CO_2 (VE/VCO_2) indicates the efficiency of CO_2 elimination; a lower value demonstrates that decreased ventilation is needed to remove CO_2 (48). The level of CO_2 elimination (VCO_2, L/min) is the amount of CO_2 produced in one minute. Respiratory exchange ratio ($RER=VCO_2/VO_2$) represents the metabolic change from aerobic to anaerobic (48). Ventilatory thresholds (VT1 and VT2) are the points at which the linear increase in ventilation stops and becomes exponential due to acidosis, indicating a metabolic change from aerobic to anaerobic (48).

1.3. COVID-19 Infection in Athletes

The COVID-19 pandemic and its effects have impacted society, including high-level athletes. The infection itself, along with quarantine and lockdowns, negatively affected athletes' quality of life, leading to decreased physical activity and fitness, disrupted daily routines, reduced sleep quality, increased anxiety, and unhealthy eating habits (12-16). Research has indicated that athletes experienced increased incidences of COVID-19 infection throughout the pandemic (54). This is partly because athletes underwent a higher testing frequency and were more susceptible to COVID-19 due to the decline in immune function caused by intense exercise (55). Furthermore, closer contact related to training sessions and competitions (such as shared changing rooms and travelling together) also contributes to the higher infection rates, particularly affecting team sports (56-58).

1.3.1. Symptoms of COVID-19 Infection and post-COVID Cardiology Exam

Although the infection rate was high, most athletes had a mild to moderate disease course. Severe clinical patterns and hospitalization were rare (59). The primary determinant of the clinical manifestation of COVID-19 was the dominant variant type in the given period. According to a systematic review containing 16 studies, the most commonly reported acute symptoms among athletes included headache, anosmia, ageusia, fatigue, and fever (59). In contrast, severe respiratory manifestations such as shortness of breath and gastrointestinal complaints were generally uncommon. The COVID-19 infection has raised the risk of unpredictable health problems and the issue of safe return to sports, particularly for professional athletes engaged in intense physical activity. The primary health concern was myocarditis, as COVID-19 is a cardiotropic virus (1, 2). Both clinical and subclinical myocarditis could have occurred in athletes, which could contribute to an increased risk of sudden cardiac death. To identify possible subclinical myocardial injury, a post-COVID cardiology assessment was necessary after COVID-19 infection in athletes (60-62). According to the return-to-play recommendations, physical examination, resting ECG, blood test containing troponin, and echocardiography were performed. The exercise test was not part of the baseline protocol and could only be performed after all negative baseline exams. CPET could assess post-COVID performance and exercise-related complaints (63, 64). The cardiac consequences of COVID-19 have become a highly researched area in athletes, with several cardiac magnetic resonance imaging (MRI) studies conducted. These results were initially very ambivalent, with several showing a high myocardial injury incidence rate in athletes (65-67). Following this, experts emphasized the need for stronger evidence by including control groups (62, 68). Further studies did not confirm a higher incidence rate of myocardial injury compared to the control population (69). Since several return-to-play studies have shown that the course of athletes' illnesses was mainly mild and that changing COVID-19 variants over time only caused flu-like symptoms, current recommendations no longer require post-COVID return-to-play cardiology examinations in case of mild symptoms (70, 71).

1.3.2. Effect of COVID-19 on Athletic Performance

In athletes, the impact of COVID-19 may have differed from that observed in the overall population due to their elevated levels of physical activity. Even a brief break in preparation may substantially affect sports performance, potentially leading to withdrawal from training and competition (72). Several factors, including limited training opportunities, postponement of competitions, acute COVID-19 infection, long COVID syndrome, vaccination, and psychological factors, contributed to the decrease in training time during the pandemic.

Although there is limited data concerning the average duration of missed training due to acute COVID-19 infection, it was tendentiously greater than that associated with non-COVID infections. After an acute illness, symptoms may have persisted for an extended period or new symptoms have developed, even in mild cases, which could have impaired sports performance (73). Long-COVID syndrome refers to the ongoing presence of symptoms that last between 4 and 12 weeks after the initial infection, or symptoms that begin 12 weeks after the start of acute illness, persisting for at least 2 months and not explained by another disease. (73, 74). In general, the long-term effects of COVID were more common in females (75). Post-COVID syndrome has meant multiorgan impairment, and most commonly has affected the pulmonary, cardiovascular, and nervous systems, and has psychological consequences. The multiorgan impairment resulted in numerous clinical manifestations, including chronic fatigue, dyspnea, exercise intolerance, palpitation, chest pain, endocrine pathologies, anxiety, and depression (Figure 1) (74). These long-term effects could have delayed and hindered athletes' return-to-play period or permanently impacted their high-level performance.

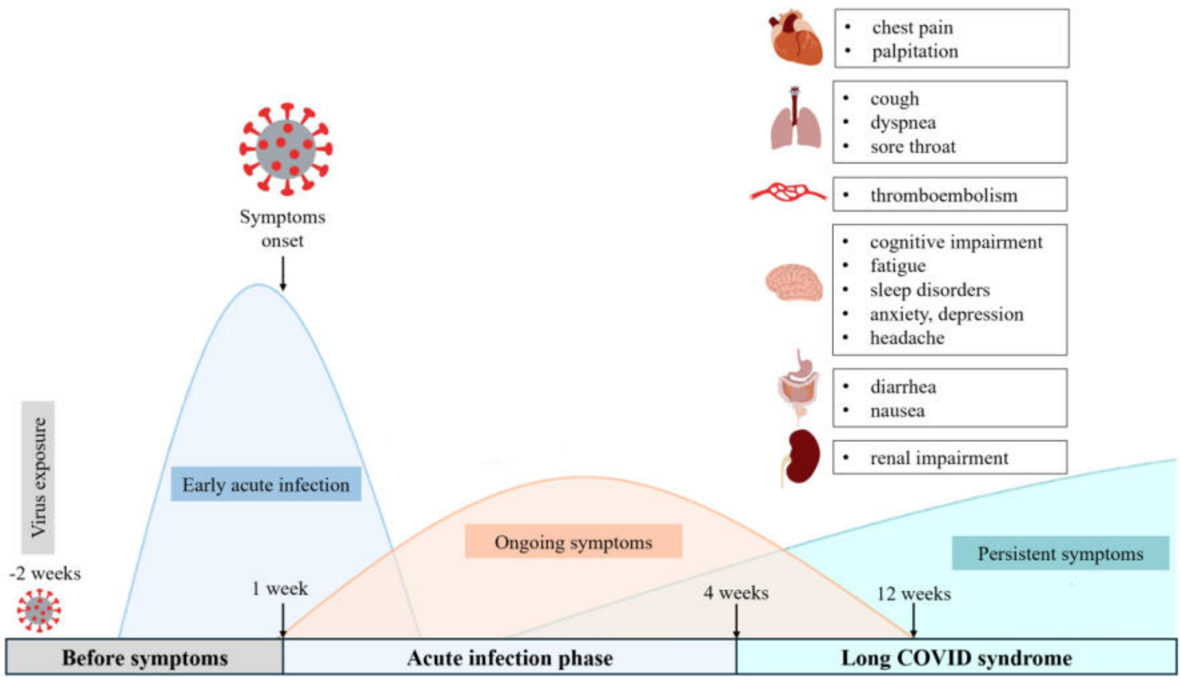

Figure 1. Timeline of COVID-19 infection and the multiorgan involvement in long COVID syndrome.
Legend: The figure illustrates the temporal course of COVID-19 infection, including early acute infection, ongoing symptoms, and long COVID syndrome, along with the associated multiorgan manifestations (adapted from (73) reference)

Post-COVID syndrome has been observed across all variants, although recent data indicate that newer variants like Omicron may cause fewer clinical symptoms (76, 77). The spread of vaccination reduced the number of severe cases and prevented post-COVID syndrome (73, 78). Fortunately, vaccination rates among athletes were high. However, some concerns have been raised among athletes and coaches, particularly about vaccine-related side effects and their impact on training and sports performance (72). Vaccination resulted in significantly less disruption, and its timing for the off-season further minimized any impact on the preparation. Therefore, it is recommended that athletes should prioritize vaccination as a preventive strategy whenever possible, since the benefits outweigh the risks (72, 73). The pandemic had several effects on athletes' mental health by disrupting their daily routines, training schedules, and competitions. The quarantine, uncertainty about the future, social isolation, and limited access to training facilities have caused increased stress, anxiety, loss of motivation, and depression in many athletes (79). The pressure to maintain peak physical condition without regular competitions also increased mental strain. Meanwhile, the fear of acquiring the virus and dealing with its effects has worsened psychological stress. These mental health issues may impair both sports performance and overall well-being, highlighting the importance of mental health support in sports (79, 80).

1.4. Medical Service at Aquatic Events

1.4.1. Main Regulations

Providing medical support at aquatic sport events is a comprehensive and essential role, as its primary responsibility is to protect the health of all participants. World Aquatics (AQUA), formerly known as FINA (Fédération Internationale de Natation), is the international governing organization for aquatic sports. AQUA is responsible for establishing the rules of medical guidelines and protocols for international competitions (81), which are adopted from the current Olympic Movement Medical Code (33, 34). This means that on-site athletic medical services should be available during all official training and competition sessions. Experienced sports medicine specialists or primary care physicians, lifeguards, and paramedics are essential medical team members. Nurses, first aid responders, massage therapists, and physiotherapists may also be included in the service. All medical services had to align with the latest recommendations of the Advanced Trauma Life Support and Advanced Cardiac Life Support guidelines, as well as the International Olympic Committee Manual of Emergency Sports Medicine (33, 82). Furthermore, they must be aware of banned drugs and methods in sports medicine. Water rescue teams specializing in the aquatic environment are crucial for responding rapidly to drowning or water-related issues or injuries. They work closely with medical personnel to ensure prompt rescue and treatment. The number of healthcare professionals and medical stations depends on the size of the event, especially on the number of athletes. An emergency action and transport plan had to be prepared for every event. A fully equipped, on-site medical station at each competition venue and field of play is essential. Off-site medical services should also be available after hours (33, 82). Pre-competition medical screenings help identify potential risks, such as heart conditions or respiratory issues, which could lead to emergencies during the event (33, 82). This comprehensive approach to medical support ensures that aquatic events are conducted with safety as the primary priority, reducing the risk of life-threatening incidents and providing immediate care when necessary.

1.4.2. COVID-19 Specific Regulations on Sports Events

Among the many postponed competitions, the biggest disappointment for the sporting world was the rescheduling of the 2020 Tokyo Olympics during the pandemic (83). However, as COVID-19 vaccines have been developed and distributed globally, and variants have been mitigated, the health risks associated with major events have decreased. Consequently, many organizations have chosen to hold competitions under strict rules, often without spectators (84). Therefore, the Tokyo Olympics took place in 2021 with strict restrictions (85). During the pandemic, AQUA established a new committee, the "COVID-19 Task Force," and introduced guidelines designed to ensure the safety of athletes and other participants during the events (86). The comprehensive recommendation aligned with World Health Organization (WHO) instructions and covered the COVID-19 testing protocol, hygiene, and social distancing (87). According to this, initially, the "Bubble system" was applied during events, which meant that participants could only stay within the designated bubble (venue, official transport, and hotel) and could not meet anyone outside of it (84, 88). The main hygiene rules included wearing masks, washing hands, maintaining distance, avoiding physical contact (such as handshaking and hugging), and staying home if experiencing symptoms. Wearing masks was obligatory except during exercising or eating. Social distancing meant maintaining a 1.5-meter distance or using physical barriers, which were also applied in hotels, restaurants, and call rooms. Furthermore, only a limited number of swimmers could use the pool at a time during the training sessions. A pre-participation polymerase chain reaction (PCR) test was required for participants to enter the bubble, followed by an arrival PCR test and an antigen test. After the arrival testing, antigen tests were needed on days 5 and 10. In case of positive test results, the participant was isolated in the hotel, and medical services were provided. Close contacts were also tested and quarantined. The host country determined spectator attendance. Following this strict, fully isolated bubble system during the initial phases of the pandemic, AQUA started to reduce restrictions in the second half of 2021. The widespread availability of vaccines, the emergence of milder COVID-19 variants, and the generally mild clinical presentation among healthy athletes mainly enabled this (70). By the end of 2021, entry testing and frequent on-site testing, along with vaccination status requirements, were applied instead of the bubble structure.

Isolation was used only for confirmed positive cases, and spectators were allowed to return to events (89).

2. *Objectives*

- Our primary aim was to assess how the COVID-19 pandemic affected elite swimmers' physiological adaptation and sports performance, preparing for the Tokyo Olympics. To evaluate the impact of COVID-19 infection on their Olympic preparation and to compare the performance parameters of those who had been infected with those who had not, we compared the two annual detailed sports cardiology screenings of the Hungarian National Swim Team.
- Our secondary aim was to more precisely investigate the effects of COVID-19 in a multinational cohort of aquatic athletes during the 19th AQUA World Championship.
- Our third aim was to examine, in detail, the COVID-19 and non-COVID-19-related medical services during the 19th AQUA World Championship.
- Lastly, we aimed to survey, through a questionnaire-based study, the COVID-19 experience of the multinational cohort of elite aquatic athletes competing in the first global sports event without an isolation "bubble." We assessed the infection rate, disease course, symptoms, vaccination experiences, and psychological well-being of the athletes participating in the 19th AQUA World Championship.

3. Methods

3.1. Sports Cardiology Screening Protocol

In our observational study of the Hungarian National Swim Team, detailed sports cardiology screening was performed in 2019 and 2021, both when the athletes were in the same training phase. In swimming, a periodized training program is used during Olympic preparation. This is structured into macrocycles, which are seasonal or annual training plans, and mesocycles, representing shorter training segments lasting between six and eight weeks. This comprehensive training plan is designed to help athletes reach peak performance at major events, aiming for their most significant achievement at the Olympics (90).

The sports cardiology screening comprised the following examinations for all athletes: a sport-specific questionnaire, resting ECG, blood analysis, echocardiography, evaluation of body composition, and performance testing using a CPET. Participants were required to refrain from physical activity for 24 hours prior to the examination and to maintain their regular morning routine, which comprised breakfast and adequate fluid consumption. The swimmers' individual and family medical history and symptoms were assessed using a sport-specific questionnaire. A standard 12-lead resting ECG was recorded with CardioSoft PC (General Electric Healthcare, Helsinki, Finland). The evaluation of athletes' ECGs was conducted in accordance with the European Society of Cardiology guidelines. (91). Standard laboratory investigations—covering counts of red and white blood cells, renal and hepatic function, C-reactive protein, electrolytes, and creatine kinase (CK)—were complemented with an iron profile (ferritin, total iron-binding capacity, transferrin, and transferrin saturation), vitamin D levels, and a COVID-19 spike-protein antibody test in 2021. Iron deficiency was determined by ferritin concentrations under 100 μg/L, in the absence of laboratory or clinical indicators of infection. Vitamin D insufficiency was classified when levels fell under 50 ng/mL. Athletes' weight and height were measured using an automatic body mass index measuring stadiometer, the InBody BSM370 (InBody Co. Ltd., Seoul, Republic of Korea). Body composition assessment, including body mass, fat, and muscle percentages, was conducted with the InBody 770 device, which applies bioelectrical impedance analysis (InBody 770, InBody Co. Ltd., Seoul, Republic of Korea).

The General Electric Vingmed Ultrasound E95 system (4Vc-D probe, Horten, Norway) was utilized to conduct echocardiography assessments. We used standardized imaging protocols, which encompassed 2D loops from parasternal, apical, and subxiphoid perspectives (92). Regarding the parameters evaluated, we measured the thickness of the left ventricular septal and posterior walls, the end-diastolic diameter, the ejection fraction, and the right ventricular basal end-diastolic diameter.

To assess cardiorespiratory fitness, participants completed a maximal treadmill test with incremental workload increases (General Electric T-2100, Healthcare, Helsinki, Finland). The implemented sport-specific protocol starts with an initial preparation phase that includes one minute of standing followed by two minutes of warm-up walking at 6 km/h, then progresses to running at 8 km/h. The workload gradually increases by 1.5% every 120 seconds until reaching maximum effort. The protocol ends with a one-minute active recovery and a four-minute passive recovery phase. Lactate was determined from fingertip samples every 2 minutes throughout the running period, and after 5 minutes of recovery (Lactate Scout, EKF Diagnostics Holdings plc, Penarth, United Kingdom). Participants were requested to avoid holding the handrail. Heart rate recovery was determined by subtracting the 1-minute recovery heart rate from the peak heart rate (93). Gas exchange parameters were assessed with a breath-by-breath automated cardiopulmonary system (Respiratory Ergostik, Geratherm, Bad Kissingen, Germany). Participants were motivated to exert maximum effort, verified by the RER, reaching the age-predicted maximum heart rate, and observing a plateau in maximal oxygen uptake. The assessed parameters are the following: treadmill time (minutes), VO_2 max (L/min and mL/kg/min), RER, VE (L/min), VE/VCO_2, and O_2 pulse (L/min).

Individual swimming performance was assessed using the time-ranking points given by AQUA. The AQUA point is calculated by assigning point values to time-ranking scores, which helps determine swimming performance. These points enable the comparison of time results across different events. Higher scores indicate faster performance, while lower scores reflect slower performance. Time-ranking points are derived from a cubic curve. Using the swim time (T) and the baseline time (B), both expressed in seconds, the points (P) are computed according to the formula: $P = 1000 \times (B/T)^3$. The resulting point values are subsequently truncated to integers (94). The AQUA points are recalculated annually, and the table is designated by the year in which the baseline times were determined. Our research used the “FINA Point Scoring 2019” and “FINA Point Scoring 2021” tables. These tables present the latest long-course world records for each discipline, for both female and male categories, validated by AQUA and remaining in effect until the end of that calendar year.

Additional examinations were performed as part of the comprehensive screening to identify other performance-limiting factors, including pulmonary, gynecological, dermatological, and ear-nose-throat assessments as needed.

Ethical approval was obtained from the Central Ethics Committee of Hungary (athletic screening -ETT TUKEB IV/10282-1/2020/EKU and post-COVID screening -ETT TUKEB IV/9697-1/2020/EKU). All participants provided their informed consent.

3.1.1. Post-COVID Examinations

Members of the National Swim Team have been instructed to report any signs of infection during the pandemic. If a COVID-related symptom was reported, we performed a PCR and an antigen test immediately at our clinic. The detection and results usually took less than 24 hours. In the occurrence of a COVID-19 infection, a post-COVID cardiology examination was required after the 10–14-day quarantine period before return to training. The baseline examination contained the following: patient history, sport-specific and COVID-19-specific questionnaire, physical examination, blood test, resting ECG, body composition, and echocardiography. The clinical characteristics of the infection were assessed using a COVID-specific questionnaire. Comprehensive patient history and information on training routines were additionally collected with the sport-specific questionnaire (the same as used during the sports cardiology screening). During the sports cardiology screening, the laboratory test was supplemented with a highly sensitive troponin T and D-dimer test. In case of a finding at the baseline tests or prolonged complaints, a 24-hour Holter ECG, chest computed tomography (CT), or cardiac MRI was performed.

3.2. Sport Event Medical Services During the COVID era

Semmelweis University provided medical services at several AQUA events. The 19th AQUA World Championship was held in Budapest between June 13 and July 13, 2022. This was the second World Championship, organized in cooperation between Semmelweis University and AQUA. We recruited staff with prior experience from the 2017 World Championships for medical services. Pre-event procedures were performed according to the AQUA guidelines. Medical services were available at all competition venues, including medical rooms and poolside care points. Medical care was provided for all accredited participants. The COVID-19 Regulations Guideline was established to reduce the risk of infection for athletes. According to this, a semi-bubble structure was created. Vaccination was highly recommended, and all vaccine types were accepted, regardless of the expiration date. Participants had to show a negative PCR or antigen test result in English taken within the previous 48 hours, along with a statement confirming their COVID-19 infection and vaccination status. Furthermore, an entry PCR and an antigen test were required before obtaining accreditation. The participants had to wait on-site for their test results and were required to wear FFP2 masks until then. In case of negative results, masks were no longer mandatory. Apart from the entry test, no additional exams were necessary for vaccinated participants. An additional antigen test was performed on the 5^{th} day for unvaccinated participants. Symptomatic participants and their close contacts were tested immediately using PCR and antigen tests. Participants with mild symptoms were isolated and treated at the hotel. The isolation period lasted 6 days for vaccinated individuals and 10 days for non-vaccinated individuals. Participants with a negative antigen test result were eligible to return to competition; however, an FFP2 mask was required for an additional 5 days. Medical encounters were recorded in an application developed by our team. Treatments were categorized based on whether they were COVID- or non-COVID-related issues. The non-COVID problems were divided by primary medical specialties into nine categories: (1) acute trauma or injury, (2) chronic orthopedic conditions, (3) upper respiratory tract infection; ear, nose, and ophthalmology issues, (4) dental problems, (5) headaches, (6) neurology or psychiatric issues, (7) dermatology, (8) gastroenterology, and (9) urology problems.

3.3. COVID-specific Questionnaire Research

As a result of collaboration between the AQUA Sports Medicine Committee, the AQUA COVID-19 Task Force, and Semmelweis University, an anonymized COVID-19 questionnaire was created. It covers basic demographics, sports activity, infection and vaccination status, and psychological factors during the pandemic. Accredited athletes voluntarily completed the questionnaire during the 19th AQUA World Championship or within 10 days after the event. This was a cross-sectional questionnaire-based study, collecting retrospective self-reported data on infection history, vaccination, and psychological factors. The questionnaire link and QR code were emailed to team leaders and distributed to participants by volunteers during the event. These enabled athletes to fill in the survey using their own devices, reducing the risk of infection.

The questionnaire included 60 questions in English, consisting of single-choice, multiple-choice, scale-type (1–10 points), and open-ended formats. First, sociodemographic factors such as age, sex, nationality, aquatic discipline (swimming, water polo, artistic swimming, diving, open water swimming), training hours, and years of training experience were analyzed. Questions about the clinical characteristics of COVID-19 infection, including the course of the disease, severity, and timing, followed. Athletes were asked to identify the timing of their infection(s) within a six-month period. Additionally, we gathered information on vaccination status and psychological data related to individual perceptions of the pandemic. Answer sheets that were significantly incomplete or contained controversial information were eliminated.

Athletes were classified based on their symptoms. The categories of symptom severity were defined as follows: asymptomatic (1), mild (2), moderate (3), and severe (4). Symptoms such as smell or taste disturbances, cough, fever, headache, fatigue, significant weakness, palpitations, eye pain, muscle or joint pain, and rhinorrhea were considered mild. Moderate symptoms were shortness of breath, chest pain, and loss of consciousness without hospitalization. If hospitalization was required, regardless of symptoms, it was considered a severe disease course. Based on the responses, an ordinal variable with seven categories was developed to measure symptom duration: no symptoms (1), up to 24 hours (2), 1–3 days (3), 4–6 days (4), 1–2 weeks (5), 3–4 weeks (6), and longer than 4 weeks (7). Missed training intervals were categorized into six groups: no days missed (1), 1–3 days (2), 4–6 days (3), 1–2 weeks (4), 3–4 weeks (5), or over 4 weeks of missed training

(6). Symptoms persisting for over 4 weeks following the onset of infection were classified as long COVID symptoms. Regarding the psychological section of the questionnaire, athletes were asked to rate their overall well-being during the pandemic on a scale of 1 to 10. A higher score indicated a worse experience. Further psychologically focused questions assessed mood changes, subjective performance decline, and need for psychological support.

All methods complied with relevant guidelines and regulations, adhering to the ethical standards outlined in the 1964 Declaration of Helsinki and its subsequent amendments. Informed consent was obtained from all participants and/or their legal guardian(s). Participants included in the calculations consented to the anonymous use of their data as part of the questionnaire. All experimental protocols and ethical approval were approved by the National Public Health Center (5200-6/2020/EÜIG) or by the Semmelweis University Regional and Institutional Committee of Science and Research Ethics (Effect of the COVID pandemic on sport event medical services SE RKEB: 32/2021).

3.4. Statistical Analysis

Statistical analysis was conducted using the GraphPad Prism 8.0.1 software package. For the COVID-19 Questionnaire, descriptive statistics were performed using MedCalc v.20.112. The Shapiro-Wilk test assessed the normality of variables. Normally distributed data are expressed as mean ± standard deviation; non-normally distributed data, as median with interquartile range. Categorical variables are expressed as percentages and frequencies. Group differences in continuous variables were assessed with unpaired t-tests, whereas non-normally distributed continuous variables were analyzed using the Mann–Whitney test. A p-value less than 0.05 was considered statistically significant. Chi-squared and Fisher's exact test (and its extensions for larger tables) were used to assess non-random associations between categorical variables. The relationship between non-normally distributed variables was examined using the Spearman rank correlation. Logistic regression was used to predict dichotomous outcomes.

4. Results

4.1. Participants – Swimmers of the Hungarian National Team

Forty-six Hungarian National Team swimmers underwent detailed sports cardiology screening in 2019 and 2021. In both years, the training schedule was similar, since the Hungarian National Championship was held in March. The competitive summer season concluded with the 2019 World Championship and the 2021 Olympic Games. The primary target in both years at the Hungarian Championships was to qualify for participation in the annual world-class competition. To achieve this, all swimmers had to be in a similar preparation phase for both screening periods. The average training time was more than 20 hours/week for at least 13 years. Between March 2020 and April 2021, 14 athletes experienced COVID-19 infections. Among them, ten cases were confirmed by PCR testing, while four were identified through antibody assay. No significant differences were observed between COVID and non-COVID athletes regarding age, sport experience, and training hours before and after COVID-19 infection. Hospitalization was not required in any case. The quarantine period lasted 10–14 days, but the average time missed from training was 18.6 ± 4.3 days.

4.2. Findings of the Sports Cardiology Screening

Most of the findings from the sports cardiology screening were identified in 2019. The athletes exhibited no familial predisposition or risk factors associated with cardiovascular diseases. During the initial screening, three athletes underwent 24-hour ambulatory blood pressure monitoring. One was diagnosed with hypertension, which led to the start of anti-hypertensive medication. By 2021, all three athletes had normal blood pressure. No abnormalities were observed on the resting ECG. During the initial screening, a pulmonology exam was required for 10 swimmers. Previous asthma treatments were adjusted in seven cases, and two athletes were newly diagnosed with asthma (95). Following the initial screening, which revealed that many swimmers had asthma, we arranged pulmonary screenings for all athletes in 2021. Out of the 11 athletes with asthma, 10 required additional therapy adjustments, and five new cases were identified, receiving treatment accordingly. A gynecology exam was performed in six cases to regulate the menstrual cycle in 2019. Before the 2021 Olympics, we scheduled gynecology appointments for all female athletes to help regulate their cycles, ensuring their menstrual cycles were at an optimal stage during the Olympics. Additionally, five cases required ear, nose, and throat exams, and seven needed dermatological assessments during the initial exams.

Laboratory, echocardiography, and body composition measurements were evaluated in relation to the athletes' COVID-19 status. Basic laboratory parameters revealed no major changes or significant differences between athletes with COVID and those without. Similarly, CK levels showed no statistical differences between the groups (females: non-COVID vs. COVID 190 ± 126 U/L vs. 134 ± 76 U/L, $p = 0.14$; males: non-COVID vs. COVID: 230 ± 155 U/L vs. 230 ± 205 U/L, $p = 1.0$). The prevalence of iron deficiency was 50% among COVID athletes and 53% among non-COVID athletes ($p = 0.2$). Ferritin levels among non-COVID athletes declined in both females (from 68 ± 45.6 µg/L to 58 ± 39.5 µg/L, $p = 0.6$) and males (from 124.4 ± 62.2 µg/L to 116.5 ± 38.8 µg/L, $p = 0.7$) between 2019 and 2021. However, no statistically significant difference was detected across the two years. Among the COVID athlete group, low vitamin D levels were more common (64% vs. 50%), and their vitamin D levels were significantly lower than those of the non-COVID athlete group (37.8 ± 11.0 ng/mL vs. 47.7 ± 11.0 ng/mL, $p < 0.05$). Echocardiography findings are presented in Table 1. Across all groups, the thickness of the left ventricular posterior wall and the ejection fraction showed improvement, with no statistically significant difference observed between the COVID and non-COVID participants. Additionally, left ventricular end-diastolic diameters decreased, whereas right ventricular diameters increased among all examined groups.

Table 1. Echocardiography results by COVID-status.

		non-COVID swimmers (n = 32)			COVID swimmers (n = 14)			2019 non-COVID vs. 2019 COVID	2021 non-COVID vs. 2021 COVID
		2019	2021	p	2019	2021	p	p	p
Ejection fraction (%)	M	55.8 ± 2.1	58.8 ± 4.1	0.02*	59.7 ± 8.0	59.3 ± 4.8	0.93	0.1	0.81
	F	59.1 ± 2.6	60.0 ± 3.3	0.48	56.9 ± 3.3	60.0 ± 4.7	0.17	0.097	1.0
Septal wall thickness (mm)	M	11.0 ± 1.2	10.8 ± 1.1	0.62	11.3 ± 2.5	11.4 ± 1.3	0.94	0.72	0.25
	F	9.2 ± 0.8	9.2 ± 1.3	0.97	9.9 ± 0.9	10.1 ± 0.7	0.52	0.11	0.15
Posterior wall thickness (mm)	M	9.6 ± 0.99	10.7 ± 1.1	0.009*	9 ± 0	10 (10 – 11)	0.002**	0.32	0.36
	F	8.4 ± 0.85	9.9 ± 1.3	0.003*	8.4 ± 1	11 ± 1.4	0.002**	1.0	0.12
LV end-diastolic diameter (mm)	M	55.7 ± 4.1	51.4 ± 2.9	0.003*	54.7 ± 4.7	50.1 ± 3.5	0.14	0.71	0.02*
	F	48.4 ± 2.3	44.4 ± 2.8	0.001*	49 ± 2.5	46.4 ± 2	0.046*	0.48	0.12
RV diameter (mm)	M	35.5 ± 3.3	37.9 ± 3.2	0.06	35.3 ± 4.2	39 (38 – 41)	0.24	0.93	0.20
	F	31.8 ± 4.0	34.6 ± 4.4	0.11	32.9 ± 3	37.6 ± 2.3	0.006*	0.54	0.12

Legend: Data are presented as mean ± SD or median (IQR), stratified by sex. P-values in the central columns refer to within-group comparisons between 2019 and 2021, while the rightmost columns indicate between-group comparisons (COVID vs. non-COVID) for 2019 and 2021, respectively. Significance level: * $p < 0.05$, ** $p < 0.005$. Abbreviations: M—male, F—female, LV—left ventricular, RV—right ventricular.

We did not observe significant differences between female and male athletes, regardless of their COVID-19 status, in terms of muscle mass and percentage of fat mass. From 2019 to 2021, both COVID-19-positive and COVID-19-negative athletes consistently maintained their muscle mass. Additionally, COVID athletes showed a trend toward increasing muscle mass and decreasing body fat percentage (Table 2).

Table 2. Body composition results in swimmers by COVID-status.

		Non-COVID swimmers (n = 32)			COVID swimmers (n = 14)			2019 non-COVID vs. 2019 COVID	2021 non-COVID vs. 2021 COVID
		2019	2021	p	2019	2021	p	p	p
Muscle mass (%)	M	50.6±1.9	50.6±1.5	1.0	49.1±1.5	50.2±1.6	0.33	0.18	0.58
	F	44.7±3.8	44.7±2.0	0.98	44.6±2.6	46.0±1.2	0.21	0.93	0.14
Fat mass (%)	M	11.2±3.3	11.6±2.6	0.72	13.2±2.9	12.6±2.5	0.71	0.29	0.41
	F	18.0±4.8	19.3±3.1	0.48	19.0±4.0	18.6±4.3	0.87	0.66	0.71

Legend: Data are presented as mean ± SD, stratified by sex. P-values in the central columns refer to within-group comparisons between 2019 and 2021, while the rightmost columns indicate between-group comparisons (COVID vs. non-COVID) for 2019 and 2021, respectively. Significance level: * $p < 0.05$. Abbreviations: M—male, F—female.

4.2.1. Performance Assessment Findings

During CPET, no clinically significant pathological changes were diagnosed. All athletes reached a respiratory exchange ratio of 1.1, indicating a strong effort. The CPET results showed values typical of elite swimmers. An improving trend in maximal aerobic capacity was observed in female non-COVID and male COVID athletes. Otherwise, as Table 3 shows, there was no clinically relevant difference between COVID and non-COVID athletes from 2019 to 2021.

Table 3. Cardiopulmonary exercise testing results in swimmers by COVID-status.

		Non-COVID swimmers (n = 32)			**COVID swimmers (n = 14)**			**2019 non-COVID vs. 2019 COVID**	**2021 non-COVID vs. 2021 COVID**
		2019	2021	P	2019	2021	p	p	p
Resting HR (bpm)		68.4 ± 13.4	62.0 ± 11	0.06	69.0 ± 15	72.4 ± 17	0.61	0.90	0.024*
Peak HR (bpm)		190.0 ± 10.3	190.5 ± 11.5	0.88	191.2 ± 9.1	188.0 ± 11	0.44	0.74	0.53
HR recovery (1/min)		32.3 ± 10.8	22.0 (20.0 – 32.0)	0.03*	33.1 ± 13.9	23.5 (19.7 – 31.2)	0.32	0.85	0.78
RER		1.15 ± 0.05	1.17 ± 0.08	0.28	1.15 ± 0.07	1.17 ± 0.07	0.38	0.81	0.94
Treadmill time (min)	M	16.0 (13.0 – 16.5)	14.5 ± 2.7	0.12	14.5 ± 1.3	15.0 (13.7 – 15.0)	1.0	0.73	0.40
	F	13.2 ± 2.8	12.9 ± 1.6	0.80	14.4 ± 2.0	13.5 ± 2.0	0.45	0.35	0.55
Max load (Watt)	M	432.6 ± 74.0	402.9 ± 60.8	0.25	464.3 ± 25.8	458.0 ± 31.0	0.75	0.42	0.052
	F	294.0 ± 50.4	270.4 ± 41.3	0.32	311.4 ± 61.7	283.3 ± 41.5	0.37	0.52	0.59
VO_2 max (L/min)	M	4.7 (4.5 – 5)	4.6 ± 0.7	0.89	4.7 ± 0.4	5.2 ± 0.6	0.14	0.89	0.08
	F	2.9 ± 0.3	3.1 ± 0.4	0.48	3.3 ± 0.5	3.2 ± 0.4	0.82	0.10	0.47
VO_2 max (mL/min/kg)	M	56.7 ± 4.7	55.5 ± 4.5	0.49	55 ± 3.8	56.5 ± 4.9	0.53	0.41	0.20
	F	49.6 ± 3.0	50.7 ± 2.6	0.47	53.1 ± 5.5	52.9 ± 4.1	0.97	0.12	0.76
O_2 pulse (mL/bpm)	M	25.0 ± 1.9	24.0 ± 1.8	0.23	25.6 ± 2.1	26.4 ± 2.4	0.58	0.58	0.03*
	F	15.0 (13.7 – 17.9)	16.2 ± 2.1	0.64	17.8 ± 2.8	18.2 ± 2.7	0.82	0.06	0.18
VE (L/min)	M	158.0 ± 33.0	159.0 ± 31.5	0.95	153.0 ± 9.5	178.0 ± 16.6	0.03*	0.74	0.19
	F	114.0 ± 17.0	109.0 ± 25.0	0.64	118.0 ± 10.4	111.0 ± 12.4	0.28	0.60	0.90
VE/VCO_2	M	25.0 ± 2.2	29.4 ± 3.9	0.70	28.5 ± 2.2	28.9 ± 3.5	0.86	0.88	0.78
	F	32.9 ± 2.0	31.0 ± 2.9	0.12	31.5 ± 2.2	30.2 ± 1.6	0.32	0.17	0.58
Peak lactate (mmol/L)	M	7.6 ± 2.5	7.8 ± 3.1	0.88	9.7 ± 4.1	9.5 ± 2.1	0.95	0.22	0.23
	F	8.5 ± 2.5	9.1 ± 2.2	0.58	8.4 ± 1.9	6.6 ± 1.7	0.09	0.99	0.04

Legend: Data are presented as mean ± SD or median (IQR), stratified by sex. P-values in the central columns refer to within-group comparisons between 2019 and 2021, while the rightmost columns indicate between-group comparisons (COVID vs. non-COVID) for 2019 and 2021, respectively. Significance level: * $p < 0.05$. Abbreviation: M—male, F—female, HR—heart rate, BPM—beats per minute, RER—respiratory exchange ratio, VE—ventilation, MIN—minute.

Based on time-ranking points, athletes' overall performance increased by 54.8% from 2019 to 2021, regardless of COVID-19 status. For COVID athletes, AQUA points improved by 55.6%, compared to 54.5% for non-COVID athletes, with no notable difference between the two groups ($p = 0.75$) (Figure 2).

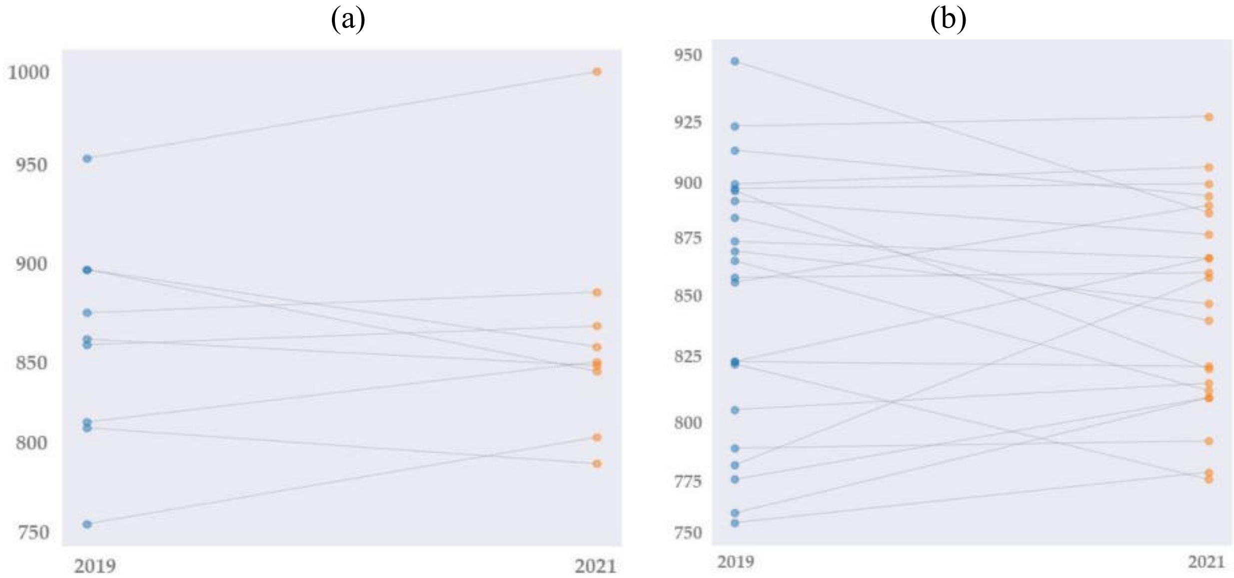

Figure 2. Change in time-ranking points from 2019 to 2021 in athletes with (a) and without COVID-19 infection (b).
Legend: The figure illustrates the comparison of athletes' performance between 2019 and 2021, based on AQUA points calculated from the results of the two national championships. Blue dots represent time-ranking points in 2019, and orange dots represent time-ranking points in 2021. Each line represents the individual change in performance between the two time periods.

4.2.2. Post-COVID Cardiology Exam Findings

Based on the COVID questionnaire results, 86% of athletes reported symptoms during their infection. The frequency of symptoms was as follows: fatigue (64%), fever (50%), muscle aches (43%), shortness of breath (43%), headaches (36%), runny nose and nasal congestion (36%), sleep disorders (36%), cough (21%), loss of taste and smell (21%), sore throat (21%), and palpitations (7%). Laboratory assessments in two athletes demonstrated elevated levels of highly sensitive Troponin T, measuring 16 ng/L and 30 ng/L, respectively. Cardiac MRI was performed and was negative in both cases. Higher ferritin (172±146 μg/L vs. 105±17 μg/L) and vitamin D levels (39 ±15 ng/mL vs. 27±7 ng/mL) were found in female athletes compared to males. Other examinations did not reveal any pathological abnormalities. All swimmers were able to return to training.

4.3. Participants – 19th AQUA World Championship

The 19th AQUA World Championship in Budapest had 9631 accredited participants, including 2097 (21.8%) athletes from 181 countries, 5764 (59.8%) technical staff and local crew members, 1252 (13.0%) team officials, 246 (2.6%) National Federation Representatives, 212 (2.2%) AQUA Committees and Family members, and 60 (0.6%) Future Organization Committee members. Out of 2097 accredited athletes, 907 filled out the COVID-19 questionnaire. A total of 812 athletes' answer sheets (39% of accredited athletes) were used to analyze the questionnaire, as 95 responses had to be excluded: 92 participants did not permit anonymous data use, and 3 data sheets were inconsistent. The competitors' mean age was 22.7 ± 5.9 years, with 57.5% of them being female. The average weekly training time was 22.7 ± 10.1 hours with 14.6 ± 5.8 years of training history. In terms of aquatic discipline, most respondents were swimmers (n = 333, 41%), followed by artistic swimmers (n = 162, 20%), water polo players (n = 133, 16.4%), divers (n = 124, 15.3%), and open water swimmers (n = 60, 7.4%).

4.4. Medical Service at the 19th AQUA World Championship

4.4.1. Non-COVID-related Medical Issues

During the event, 830 medical issues were reported involving 418 participants. These included 427 hotel visits, 373 on-site issues, and 67 emergency department visits. Nearly half of the medical care (404, 49%) was provided to athletes, affecting 205 (10%). Only 16 (4%) athletes withdrew from the competition for medical reasons. Figure 3 shows that most treatments occurred during the middle of the Championship.

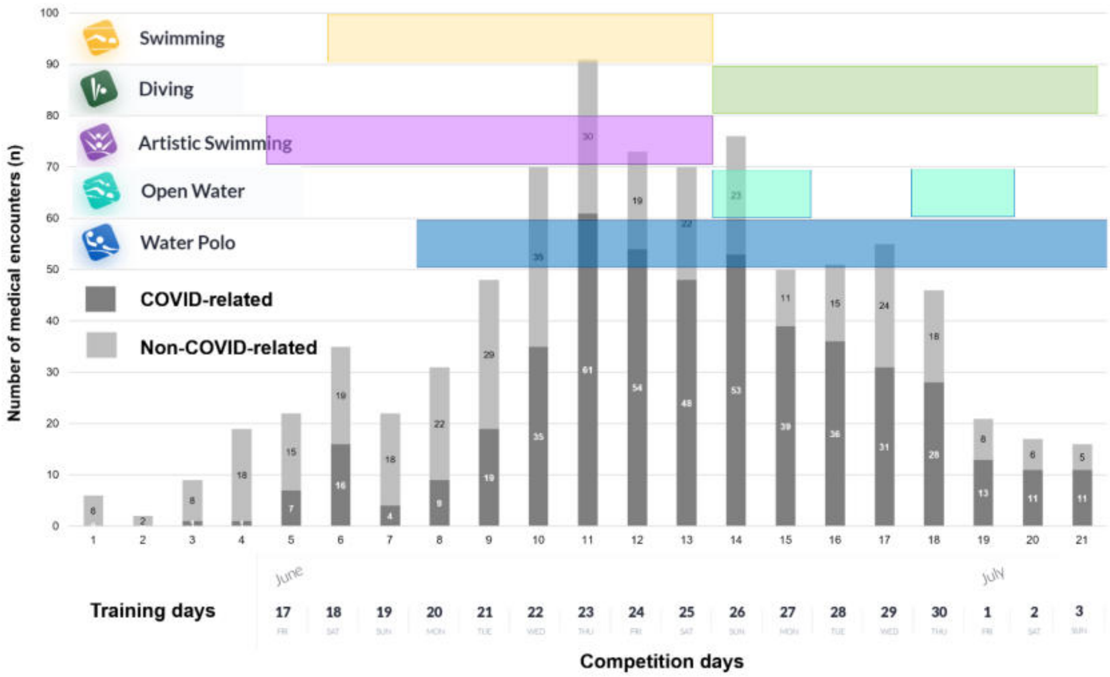

Figure 3. Distribution of medical encounters by event days and COVID status.
Legend: The figure illustrates the number of medical encounters according to COVID status by event days. The timeline indicates training and competition days, while the duration of the different sport disciplines is highlighted with colored bars. Official FINA logos were used from the FINA website (96).

The number of medical treatments by sports discipline is shown in Figure 4. Medical treatment was provided to 13.8% (n=61) of water polo players, 12.1% (n=41) of artistic swimmers, 9.9% (n=20) of open water swimmers, 8.2% (n=19) of divers, and 6.5% (n=64) of swimmers. Regarding visit frequency, swimming had the highest number of control visits, while water polo had the most treated athletes.

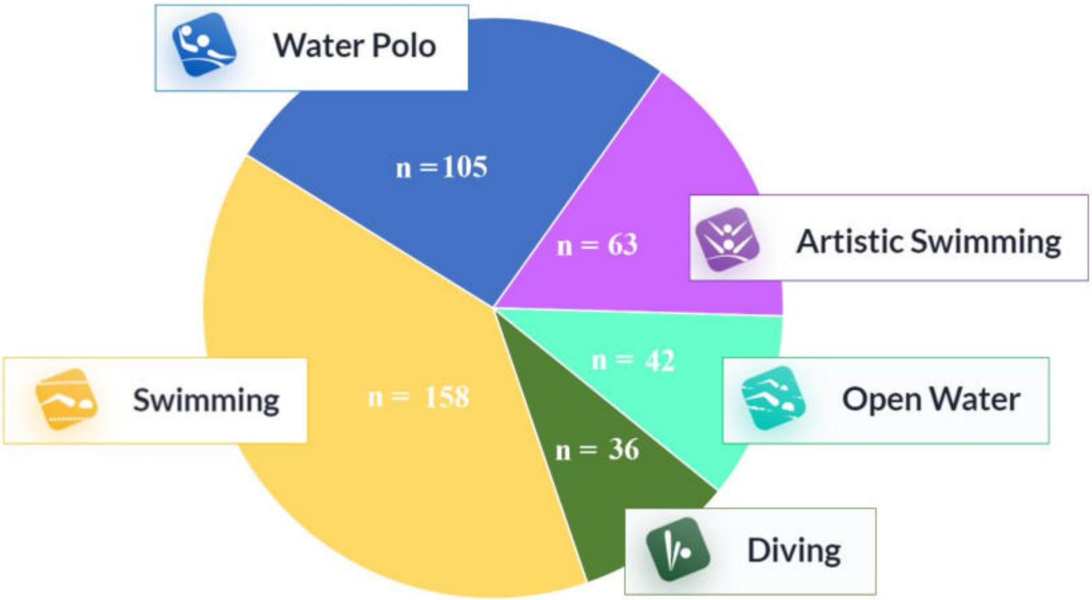

Figure 4. Distribution of athletic medical encounters by sport discipline.
Legend: The figure illustrates the distribution of athletic medical encounters by sport discipline. The chart presents absolute case numbers (n) for each discipline. Official FINA logos were used from the FINA website (96).

Medical treatments for athletes (n=404) were associated with COVID in 56% of cases and with non-COVID issues in 44%. Trauma and injury were the most common non-COVID-related problems, followed by upper respiratory tract infections, ear-nose-throat issues, and eye problems. Water polo players experienced the highest injury rate among sports at 43% (Figure 5).

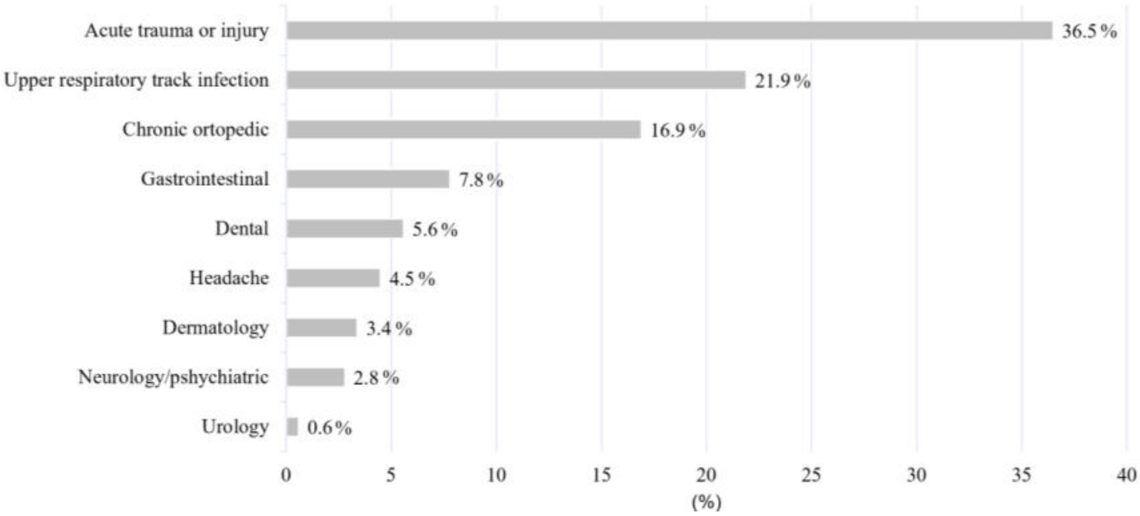

Figure 5. Distribution of non-COVID-related medical treatments in athletes.
Legend: The figure illustrates the percentage distribution of non-COVID-related medical treatments among athletes.

Of 181 countries, only 29 (16%) had at least one team physician or medical personnel, while 56 (31%) countries had a physiotherapist. Overall, 84 accredited medical personnel and 170 physiotherapists participated in the Championship. The largest participating countries had at least one doctor and one physiotherapist, but the number of medical treatments they performed remained low. Among high-participating countries with over 30 accredited athletes, six (3%) had no medical personnel, while 16 countries had more than two (Table 4).

Table 4. Medical personnel and encounters in countries with more than 30 accredited athletes.

	Countries with > 30 athletes	Athletes (n)	Team doctors and medical personnel (n)	Physio and massage therapists (n)	Support staff (n)	Medical encounters (n)
1.	USA	107	13	8	12	**4**
2.	Australia	92	4	10	8	**14**
3.	Italy	85	7	8	8	**2**
4.	Brazil	82	3	8	1	**6**
5.	Hungary	81	4	6	3	**5**
6.	Canada	79	2	9	9	**51**
7.	China	75	9	12	5	**50**
8.	Japan	60	2	8	1	**12**
9.	Greece	59	1	4	10	**16**
10.	France	56	7	10	9	**4**
11.	Spain	51	5	8	2	**1**
12.	Kazakhstan	50	1	1	0	**14**
13.	Germany	46	5	5	5	**4**
14.	Great Britain	46	2	6	6	**1**
15.	New Zealand	46	0	2	3	**10**
16.	South Africa	46	0	1	3	**17**
17.	Netherlands	39	1	3	4	**3**
18.	Thailand	39	0	4	2	**7**
19.	Mexico	36	0	1	2	**11**
20.	Korea	36	0	2	3	**6**
21.	Ukraine	32	2	2	1	**0**

22.	**Colombia**	31	1	1	1	**4**
23.	**Singapore**	30	0	2	1	**11**
	Summary	**1198**	**69**	**121**	**99**	**253**

Legend: The table lists countries with more than 30 accredited athletes, alongside the number of team doctors/medical personnel, physiotherapists/massage therapists, and support staff. The total number of medical encounters per country is indicated in the last column. The summary row shows the total numbers for athletes, staff, and encounters.

4.4.2. COVID-related Medical Issues

COVID-19 infection accounted for 226 (56%) of the 404 medical encounters involving athletes. Participants with mild symptoms received only on-site treatment (n = 32). One hundred ninety-two hotel visits were made, and two athletes were treated in the emergency department. COVID testing results are shown in Figure 6. A total of 616 exams (12.2% of all tests) were performed for symptoms. There were 104 confirmed positive cases during the competition, with 47% involving athletes. Of these, 29% were detected through entry testing, 53% due to symptoms, and 18% were linked to close contacts. On the fifth day of testing non-vaccinated participants, no COVID-19 infections were detected. Among participants with acute illnesses, 34% of the 104 COVID-positive cases had no symptoms. The most common symptoms in the remaining cases included cough (30%), fever (29%), sore throat (28%), runny nose (15%), headache (15%), and fatigue (12%). No patients showed significant COVID-19 symptoms such as chest pain, dyspnea, or thrombosis, and no hospitalizations were needed.

A total of 217 participants (2.3%) were unvaccinated, including 105 athletes (5% of athletes). However, 99% of those infected had been vaccinated.

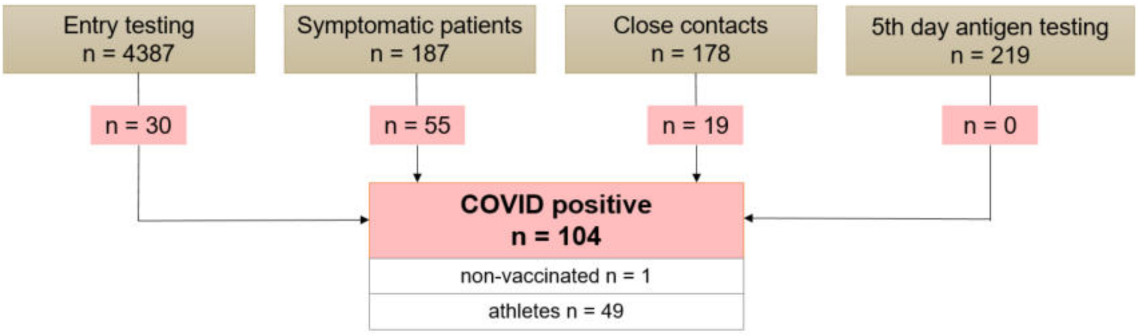

Figure 6. COVID-19 testing results.

Legend: The figure illustrates the distribution of all COVID-19 tests performed across four groups: entry testing, fifth-day antigen testing, testing due to symptoms, and testing of close contacts (represented by brown boxes). In total, 104 positive cases were identified, including 49 athletes. The numbers shown in red boxes indicate the positive cases detected in each subgroup.

4.5. Findings of the COVID-19 Questionnaire

Regarding the incidence of COVID-19 among aquatic athletes who participated in the 19th AQUA World Championships and completed the COVID-19 questionnaire, 398 (49%) reported at least one instance of infection. An additional 52 athletes (13%) had a COVID-19 infection twice. COVID-19 first and reinfection rates, along with vaccination rates over time, are shown in Figure 7.

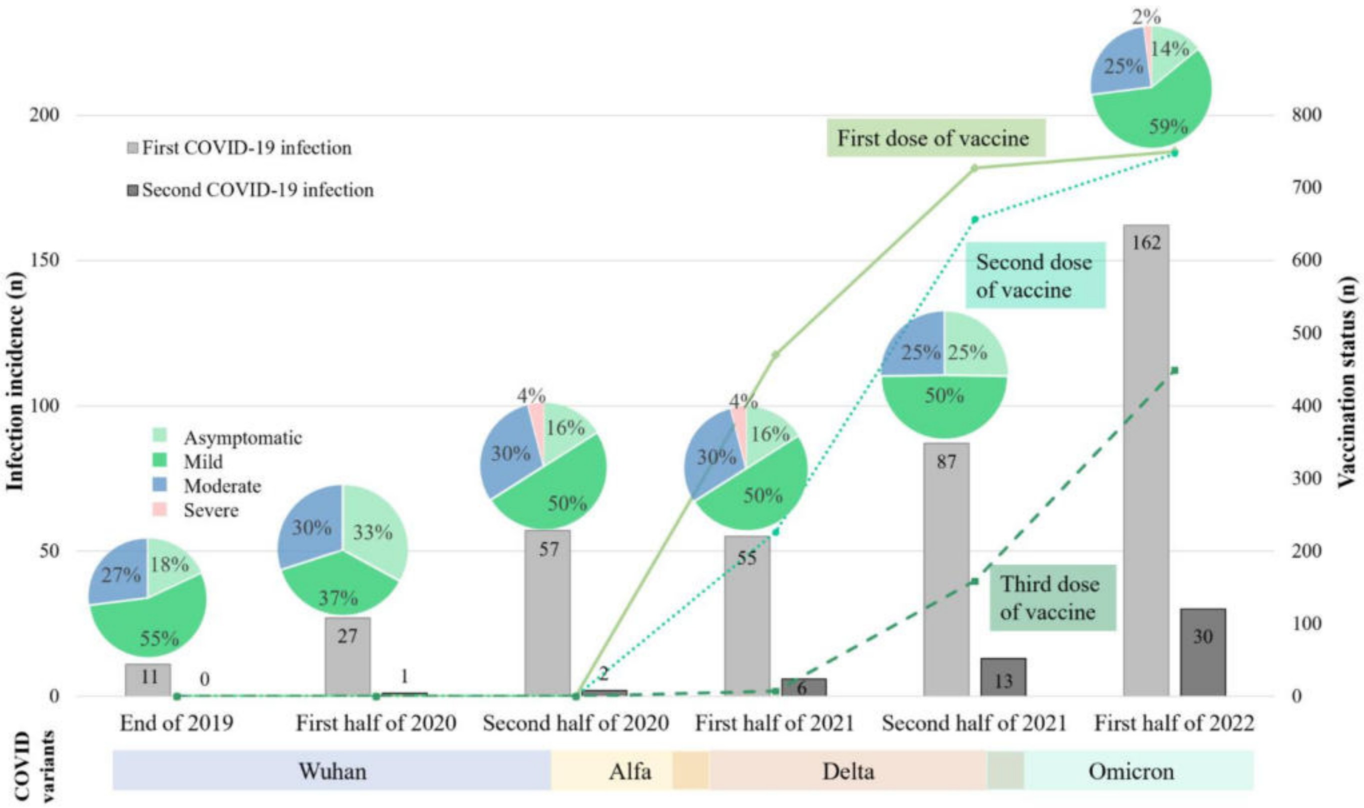

Figure 7. COVID-19 infection incidence and vaccination status over time.
Legend: The diagram illustrates the incidence of first and second infections in half-year intervals, the severity distribution of symptoms for first infections (shown in pie charts), and the number of vaccinations. COVID variants are also displayed along the timeline at the bottom of the figure. Most athletes experienced asymptomatic, mild, or moderate symptoms. The highest case numbers, including reinfections, were observed in the first half of 2022. Although case numbers increased over time, the spread of vaccination and the emergence of the Omicron variant were associated with overall milder clinical outcomes.

COVID-19 infection was detected in 68% of athletes due to symptoms, 24% without symptoms during routine screening, and 8% during competition screening. Aquatic team sports had the highest infection rates, with 67% in water polo and 61% in artistic swimming, while open water swimmers had the lowest incidence at 24% ($p < 0.0001$). A logistic regression model based on biological plausibility was used to predict the incidence of COVID-19 infection. Older age (OR 1.04, CI 1.01–1.06) and participation in team sports (OR 2.18, CI 1.58–3.00) were identified as independent predictors, while gender and training amount did not influence infection risk (overall model performance AUC 0.639, CI 0.61–0.67, $p < 0.0001$). The highest incidence occurred in the first half of 2022, at 40.2%. No significant difference was found in symptom severity between the studied 6-month periods. Overall, 83% of athletes experienced COVID-19-related symptoms, with only 2% (n = 8) having severe symptoms that required hospitalization. More than half (54%) had mild symptoms, and 27% experienced moderate disease. Asymptomatic cases accounted for 17%. Table 5 displays the distribution of specific symptoms during initial infections.

Table 5. The first COVID-19 infection's symptom frequency

n=370	The end of 2019 (n=11)	First half of 2020 (n=27)	Second half of 2020 (n=56)	First half of 2021 (n=55)	Second half of 2021 (n=76)	First half of 2022 (n=145)
Smell disturbance	3 (27%)	11 (41%)	20 (36%)	17 (31%)	17 (22%)	12 (8%)
Taste disturbance	2 (18%)	10 (37%)	14 (25%)	20 (36%)	20 (26%)	14 (10%)
Headache	4 (36%)	8 (30%)	28 (50%)	22 (40%)	43 (57%)	78 (54%)
Fever	5 (45%)	10 (37%)	23 (41%)	18 (33%)	43 (57%)	70 (48%)
Severe weakness	4 (36%)	7 (26%)	22 (39%)	8 (15%)	24 (32%)	44 (30%)
Palpitation	1 (9%)	2 (7%)	5 (9%)	3 (5%)	2 (3%)	10 (7%)
Eye pain	2 (18%)	7 (26%)	8 (14%)	9 (16%)	10 (13%)	14 (10%)
Cough	3 (27%)	9 (33%)	23 (41%)	17 (31%)	46 (61%)	83 (57%)
Loss of consciousness	0 (0%)	1 (4%)	2 (4%)	2 (4%)	0 (0%)	2 (1%)
Chest pain	1 (9%)	5 (19%)	11 (20%)	7 (13%)	15 (20%)	16 (11%)
Shortness of breath	2 (18%)	5 (19%)	12 (21%)	10 (18%)	17 (22%)	28 (19%)

Legend: Percentages are calculated in the context of the total number of the respective half-yearly first infection cases. The absolute number of symptomatic cases per half-year period is shown in brackets.

Long COVID syndrome developed in 40 athletes (10%) after the initial infection and was more prevalent in females (n=25). Fatigue (65%), shortness of breath (48%), cough (35%), and concentration problems (28%) were the most common symptoms linked to long COVID. Independent predictors of long COVID syndrome were identified using a multivariate logistic regression model (AUC 0.76, CI 0.72–0.80, $p < 0.0001$). Results indicated that the number of symptoms reported during the acute stage of infection served as the only dependable independent predictor (OR 1.4, CI 1.18-1.7).

The reinfection rate was 13% (n = 52), with more than half involving females (n = 28) or team athletes (n = 26). It mainly occurred in the second half of 2021 (25%) and the first half of 2022 (58%). Reinfections had a milder disease course, with 46% of cases being asymptomatic, 37% mild, 13% moderate, and 4% severe, compared to the first infection (Table 6). Symptom count, symptom severity, and missed training time were significantly lower during the second infection. The median number of symptoms was 3 (IQR 1-4) for the first infection and 1 (IQR 0-3) for the second infection ($p < 0.0001$). The median symptom severity category for both infections was 2 (mild symptoms). Still, the interquartile ranges were significantly different, at 2-3 (mild-intermediate) for the first infection and 1-2 (asymptomatic-mild) for the second infection ($p = 0.0001$). Due to reinfection, 65% of the athletes missed only six days of training. The median missed training time was 1-2 weeks (IQR 3-4) during the first infection and 4-6 days (IQR 2-4) during the second infection ($p=0.0001$). Four percent of athletes had ongoing symptoms for over four weeks following their second infection.

Table 6. Characteristics of the first COVID-19 infection in terms of symptom severity

	Asymptomatic (n=66)	**Mild (n=216)**	**Moderate (n=108)**	**Severe (n=10)**	**p**
Age (years, IQR)	23 (18-28)	23 (19-27)	22 (19-25.5)	22 (17-23)	
Training volume (hours/week, IQR)	24 (20-30)	23 (20-27)	21 (17-27)	20 (20-21)	
Training history (years, IQR)	15 (12-20)	15 (11-19)	15 (12-18)	12 (6-19)	Ns
Female, n=252 (n, %)	42 (64%)	131 (60%)	74 (69%)	5 (50%)	
Male n=147 (n, %)	24 (36%)	85 (50%)	33 (31%)	5 (50%)	
Long COVID (n=40/400) (n, %)	1 (2%)[2,3]	15 (7%)[4]	22 (20%)[2,4]	2 (20%)[3]	<0.0001
Swimming (n=145/334) (n, %)	22 (33%)	72 (33%)	44 (41%)	7 (70%)	
Open water swimming (n=17/60), (n, %)	5 (8%)	9 (4%)	3 (3%)	0 (0%)	
Water polo (n=89/134) (n, %)	17 (26%)	45 (21%)	26 (24%)	1 (10%)	Ns
Diving (n=50/124) (n, %)	8 (12%)	33 (15%)	9 (8%)	0 (0%)	
Artistic swimming (n=99/163), (n, %)	14 (21%)	57 (26%)	26 (24%)	2 (20%)	
No days missed (n=21)	7 (11%)[2]	11 (5%)	2 (2%)[2]	1 (10%)	0.0019

(n, %)					
1-3 days missed (n=26) (n, %)	7 (11%)	9 (4%)	9 (8%)	1 (10%)	
4-6 days missed (n=88) (n, %)	16 (24%)	53 (25%)	19 (18%)	0 (0%)	
1-2 weeks missed (n=211) (n, %)	26 (39%)[1]	124 (57%)[1]	57 (53%)	4 (40%)	
3-4 weeks missed (n=36) (n, %)	8 (12%)	15 (7%)	11 (10%)	2 (20%)	
> 4 weeks missed (n=18) (n, %)	2 (3%)	4 (2%)[5]	10 (9%)[6]	2 (20%)[5,6]	

Legend: Percentage calculations are based on the total number of respective symptomatic categories for demographics, long COVID frequency, sports category, and missed training calculations.
The number of positive cases per sports type is marked in brackets.
[1]p<0.05 between asymptomatic and mildly symptomatic categories
[2]p<0.05 between asymptomatic and moderate categories
[3]p<0.05 between asymptomatic and severe categories
[4]p<0.05 between mildly symptomatic and moderately symptomatic categories
[5]p<0.05 between mildly symptomatic and severe categories
[6]p<0.05 between moderately symptomatic and severe categories
(Chi-squared and Fisher's exact test were used as appropriate)

Among athletes, 94% (n = 769) received at least one vaccine dose, 92% received two doses, and 55% received three doses. During the first vaccination, athletes experienced a more severe reaction with vector vaccines compared to mRNA vaccines (category 6 vs. category 8, $p < 0.0001$). No significant differences were observed between vaccine types during the second (category 9 vs. 8; p = ns) or third (category 9 vs. 8; p = ns) doses (Table 7).

Table 7. Vaccination status, side effects, and subjective experience of vaccination.

Vaccination		**First dose n (%)**	**Second dose n (%)**	**Third dose n (%)**
Type of vaccine	*Comirnaty*	511 (66.4 %)	538 (71.9 %)	345 (76.5 %)
	Spikevax	79 (10.3 %)	94 (12.6 %)	64 (14.2 %)
	Vaxzevria	64 (8.3 %)	52 (7.0 %)	30 (6.6 %)
	Jcovden	57 (7.4 %)	15 (2 %)	5 (1.1 %)
	BBIBP-CorV	33 (4.3 %)	33 (4.4 %)	5 (1.1 %)
	Gam-COVID-Vac	23 (3.0 %)	15 (2.0 %)	1 (0.2 %)
	Nuvaoxivid	2 (0.3 %)	1 (0.1 %)	1 (0.2 %)
Side effects of the vaccine	*Yes*	479 (62.2 %)	398 (53.2 %)	250 (55.4 %)
	Local pain	319 (66.6 %)	263 (66.1 %)	178 (71.2 %)
	Muscle or joint pain	194 (40.5 %)	144 (38.0 %)	94 (37.6 %)
	Fever	163 (34.0 %)	118 (29.6 %)	73 (29.2 %)
	Fatigue	148 (30.9 %)	110 (27.6 %)	73 (29.2 %)
	Headache	145 (30.3 %)	115 (30.3 %)	81 (32.4 %)
	Sleepiness	132 (27.6 %)	101 (25.4 %)	59 (23.6 %)
	Swelling of lymph nodes	40 (8.4 %)	45 (11.3 %)	32 (12.8 %)

	Palpitation	14 (2.9 %)	13 (3.3 %)	7 (2.8 %)
	Chest pain	9 (1.9 %)	8 (2.0 %)	4 (1.6 %)
	Vomiting	6 (1.3 %)	3 (0.8 %)	0 (0.0 %)
Length of side effects	*Unknown*	0	4	2
	Less than 24 hours	217	182	103
	1-3 days	234	183	122
	4-6 days	12	19	15
	1-2 weeks	7	4	6
	3-4 weeks	4	2	0
	More than 4 weeks	5	4	2
Experience of vaccination (IQR)		8 (6-10)	8 (6-10)	8 (6-10)

Legend: Data are presented as the number of participants and percentage (%). Side effects are listed separately for each vaccine dose, including type, frequency, and duration. The experience of vaccination is expressed as median (IQR), where a higher score indicates a better experience.

Psychological support was needed by 36% of athletes. However, nearly half of them did not receive the necessary help, as shown in the detailed data in Figure 8.

The median score reflecting athletes' overall well-being during the pandemic was 6 (IQR 4-7), the median for mood changes was 6 (IQR 4–8), and for the subjective drop in performance, it was 5 (IQR 3–7). Female athletes exhibited more significant mood changes (median 7 compared to 6, $p = 0.0002$). There were notable correlations between athletes' overall well-being and mood changes ($r = 0.617$, $p < 0.0001$), decreases in performance ($r = 0.466$, $p < 0.0001$), and the severity of the initial infection ($r = 0.146$, $p = 0.004$).

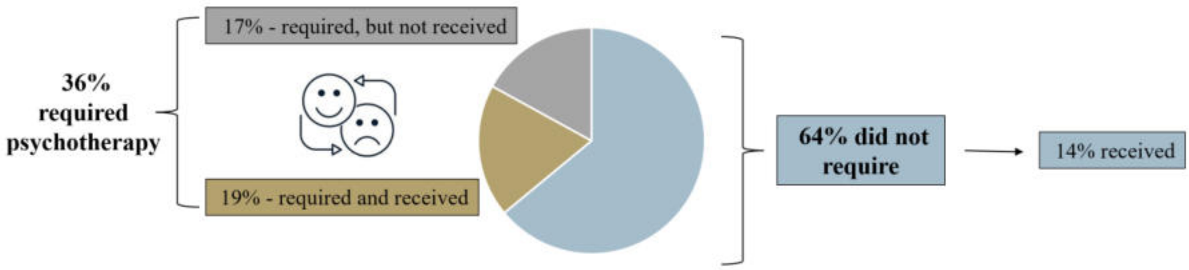

Figure 8. Psychological support needs.

5. Discussion

The COVID-19 pandemic has brought major challenges for athletes and the sporting world, affecting performance, training opportunities, and the organization of competitions. Our results provide a comprehensive overview of how the pandemic has impacted aquatic athletes and sports from different perspectives. Using sports cardiology screening results, medical encounter analyses, and survey data, we showed that despite high infection rates and widespread disruptions, the mainly mild course of infection and high vaccination rates enabled athletes to maintain their performance and physiological adaptations. Additionally, mood swings and perceived declines in performance significantly influenced the overall experience of aquatic athletes during the pandemic.

While COVID-related medical issues were a primary concern during sports events, the risk-benefit balance shifted with the appearance of less severe variants and high vaccination rates, leading to changes in protocols for mass gatherings. Assessing the impact of COVID-related issues and treatments at the 19th AQUA World Championship, we found that although COVID-related concerns dominated medical care, no severe cases occurred, and the event was successfully held despite not having strict COVID regulations in place.

5.1. Sports Cardiology Screening and COVID-19 Infection in Elite Swimmers

Our study thoroughly evaluates how mildly symptomatic COVID-19 infection affects elite swimmers. Using a standardized sports cardiology screening protocol in 2019 and 2021, we compared adaptation and performance metrics and evaluated the impact of COVID-19 on Olympic preparation, finding no adverse effects.

All 14 COVID-positive cases (28%) had mild symptoms, enabling all athletes to return to play after about three weeks. In two cases with positive troponin results, we conducted cardiac MRI, but it did not confirm myocarditis. An Italian study involving ninety competitive athletes, either asymptomatic or with mild symptoms, examined cardiac effects of COVID-19 through detailed screening (physical exam, blood tests, spirometry, ECG, echocardiography, CPET). They found one case of perimyocarditis and two cases of pericarditis, which is similarly low as in our results (97).

Our findings indicate that vitamin D levels were notably lower in COVID-19 cases. This aligns with studies suggesting that better vitamin D status may reduce both the likelihood and the severity of the disease (98, 99). A review of more than thirty studies shows that athletes whose serum vitamin D exceeded 40 ng/mL demonstrated enhanced performance, better overall health, and a reduced susceptibility to COVID-19. Vitamin D cut-offs vary by population and region. Our study defined normal levels as 50 ng/mL or higher, based on sports-specific research (100). Conversely, the large CORONAVIT phase 3 trial (101) found no effect of vitamin D supplementation on COVID-19 incidence or severity in the general population. However, that study used a lower sufficiency cut-off of 30 ng/mL and included a highly diverse cohort, where multiple confounding factors might have masked potential effects. In elite athletes—our target group—a higher cut-off (≥50 ng/mL) may be more appropriate given the unique physiological stress from intensive training.

We performed two echocardiography exams on swimmers to evaluate cardiac morphological adaptation to sport. Since the baseline exams already revealed notable sport-related structural changes, further wall thickening or chamber enlargement was not anticipated. Researchers studied a group of aquatic athletes, consisting of twenty males and seventeen females, who observed chamber diameters and wall thicknesses similar to ours (102). In the two consecutive echocardiography examinations, we observed a trend toward concentric hypertrophy. The diameters of the left ventricle at end-diastole decreased, whereas the diameters of the right ventricle increased. Although swimming is primarily an endurance sport that usually leads to an increase in diameters, the rise of dryland strength training—particularly during the COVID-19 lockdown—may account for our observations, as static training has become more significant (103).

We aimed to explore the impact of COVID-19 on athletic performance, since even brief (<4 weeks) periods of training interruptions can result in a decline of exercise-related adaptation processes (104). Short-term detraining reduces maximum oxygen uptake and breathing efficiency, while the RER and lactate levels rise (104, 105). Our research reveals no differences in CPET outcomes between athletes with and without COVID, suggesting that detraining had no lasting effects.

Research involving 16 top-level volleyball players found that athletes showed the usual effects of three weeks of detraining, even though their maximal aerobic capacity stayed normal. However, the study was unable to determine how detraining impacted performance due to the lack of pre-COVID baseline assessments or a comparable non-COVID control group (106). Researchers also studied how an eight-week lockdown affected the performance of ten elite male handball players. During this time, athletes were instructed to keep exercising at home and completed two incremental exertion tests, once during the 2019 pre-season and again in 2020 following the lockdown. Results showed no significant differences in power output or VO_{2max} between the pre- and post-lockdown measurements. In contrast, shuttle run testing revealed reduced endurance capacity. Although a baseline measure was available, the comparisons were made with the pre-season test rather than a peak performance or CPET (107).

Dauty et al. assessed the impact of a two-month quarantine on 29 high-level adolescent football players (108). Since they were not screened for COVID-19, their infection status remained uncertain. They performed home training at less than 80% of their predicted maximal heart rate during the quarantine. Without CPET, their aerobic fitness was estimated using the Yo-Yo field test. The results showed a decline in aerobic capacity, likely due to the quarantine and submaximal intensity training. Another study examined how the lockdown period influenced soccer players' performance through the Yo-Yo test. The 20 athletes were also instructed to train at home with a submaximal heart rate (65-75%). The forty-day quarantine period affected the maximum sprinting speed, high-intensity running distance, acceleration, and deceleration; however, the estimated VO_{2max} remained unchanged (109).

Considering that the AQUA points objectively measure swimming performance regardless of gender, stroke, distance of race, and placement, we could also compare the swimmers' performances using the National Championships time-ranking points for both years. No difference was observed in AQUA points between athletes with and without COVID, indicating that all athletes enhanced their performance times.

Our research revealed no significant differences in CPET results between 2019 and 2021. The athletes performed at their peak in both years, as their primary focus was on the 2019 Gwangju World Aquatics Championships and the 2021 Tokyo Olympics. Additionally, our research emphasizes the need for regular, thorough sports cardiology screenings that incorporate echocardiography and CPET. In addition to detecting pathological conditions, these exams can also evaluate and monitor sport-related adaptations and performance.

5.1.1. Strengths and Limitations

Our study group comprised elite male and female swimmers with equivalent training levels, all of whom participated in the Tokyo Games. At present, limited detailed research exists on the effects of COVID-19 on elite swimmer performance. This study is the first to compare post-COVID outcomes of Olympic-level swimmers with both their pre-COVID baseline values and with a control group that remained uninfected. Additionally, we applied time-ranking points to assess endurance and overall swimming performance, enabling comparisons across strokes and distances.

The primary limitation of this study is the relatively small number of COVID-19-positive athletes compared to those without infection. Additionally, the affected participants experienced only mild symptoms, not requiring extended detraining or hospital admission. A further limitation was that exercise testing was conducted in a clinical setting using a treadmill ergometer, which differs from the swimmers' usual training environment. We found significant echocardiographic changes, but these might result from inter-observer variability rather than true sport adaptations.

5.2. Medical Service at the 19th AQUA World Championship

We reviewed medical encounter data from the 2022 19th AQUA World Championship, which demonstrated that the semi-bubble system was effective in minimizing COVID-19 transmission, ensuring athletes' safety, and allowing the event to proceed successfully without the need for strict COVID-19 rules.

A semi-bubble system was implemented by the AQUA Sports Medicine Committee and the Local Organizing Committee to reduce the risk of brought-in infections. The number of COVID-19-positive cases was low (2.1%) during the 19th AQUA World Championship, with nearly one-third (30%) confirmed through the entry PCR test. Therefore, the entry PCR played a crucial role in preventing the infection from spreading widely during the competition. Although the infection rate in the "bubble" competitions was below 1% (88, 110-112), this required strict COVID-19 rules, such as using masks and maintaining social distancing, with only limited or no spectators permitted. We found that 50% of the positive cases occurred among symptomatic participants with predominantly mild symptoms, likely due to the high vaccination rate of 99%. Concerning athletic treatment types, over half of the cases (56%) involved COVID-19 infection. There is no comparable data on athletic treatments at a global sporting event during the COVID era. Team sports, such as water polo, were particularly impacted by COVID-19 infections compared to athletes in other disciplines. This could be due to the higher risk of transmission from closer physical contact compared to individual sports (56, 57, 113, 114). Our event participants had a high vaccination rate for COVID-19. A questionnaire evaluated the vaccination status of participants in the Tokyo Olympics 2020, with 12.072 individuals (38% of whom were athletes). Among them, 74% were fully vaccinated, and 81% had at least one dose (115).

Half of the medical services were provided to athletes, with swimming being the most affected sport. This is likely because it has the highest number of registered athletes, which is reflected in the large number of control treatments. This trend aligns with previous AQUA World Championships in 2009 (Rome), 2013 (Barcelona), and 2015 (Kazan), where water polo showed the highest illness rates (6.3%, 8.2%, 16.6%), followed closely by swimming (8.5%, 8.9%, 13.5%) (116).

We found that the most common non-COVID health issues were acute trauma or injury, followed by upper respiratory tract infections not related to COVID, as well as ear, nose, and ophthalmology problems. These issues are typical in aquatic sports (36). Throughout all three AQUA World Championships, the most frequent illnesses included respiratory infections (32.6% vs. 24.7% vs. 34.3%), gastrointestinal infections (20.4% vs. 23.2% vs. 23.7%), and otitis (17.1% vs. 15.5% vs. 9.6%) (116). The lower incidence of gastrointestinal infections may be attributed to improved hygiene practices among participants, such as frequent use of hand sanitizers during the pandemic and different environmental conditions at the competition venues.

Water polo had the highest number of treated athletes and injuries, consistent with its nature as a contact team sport. This aligns with previous injury reports from FINA. Additionally, in the 2016 Rio Olympics register, water polo players ranked fifth among injured athletes and were the top team sport for injuries (117-119).

Finally, we evaluated the medical staffing levels. We found that 16% of the countries had at least one accredited medical professional, while 31% had at least one physiotherapist present during the Championship. Larger countries generally had more medical staff than smaller ones. Countries with team doctors reported lower medical encounters than those without a team physician. In line with our findings, less than 20% of teams had accredited medical personnel during the 12th FINA World Championships (120). This indicates that, during the pandemic, the medical expertise within teams has not seen significant improvement.

5.2.1. Limitations

We only conducted entry COVID testing in our "semi-bubble" structure, so the total number of asymptomatic COVID-19-positive cases may be underestimated. Participants who do not report COVID symptoms after entry testing are excluded from the analysis, and we have no follow-up data post-event. We used solely the accreditation data for medical personnel, which may vary. Follow-up treatments were only given if participants appeared, so we could not assess time lost in competition or training.

5.3. Effect of the COVID-19 Pandemic on Aquatic Athletes

Our survey assessed the COVID-19 infection rates and clinical characteristics, including symptoms, reinfection rates, long COVID syndrome, vaccination experiences, and psychological impacts, within a multinational cohort of elite aquatic athletes.

According to the WHO, the general infection rate was between 8% and 10% in the population, with athletes experiencing a higher rate (121). This is due to stricter screening of athletes, exercise-related immune function impairment (55, 122), and closer physical contact, especially in team sports (56, 57). Our study found an infection rate of 49.4%, with 3% of the cases classified as severe and needing hospitalization. An extensive longitudinal study involving nearly 10.000 athletes from 13 universities found an incidence of COVID-19 infection of 30.4% (54). We found that the highest infection prevalence occurred among water polo players and artistic swimmers, whereas open water swimmers had the lowest. Our findings indicate that close physical contact contributes substantially to higher COVID-19 infection rates, especially among athletes in team sports. This aligns with previous research, showing higher infection rates in team sports (56, 57).

A Swiss COVID-19 survey examining infection rates and symptoms among elite athletes found a prevalence rate of less than 20%, with a higher incidence among males (56). In contrast, our female athletes showed higher transmission rates, although symptom severity was similar across both sexes. Other studies indicate that young female athletes are less likely to experience severe symptoms and are often asymptomatic (123, 124).

Most studies indicate that athletes typically experience mild to moderate symptoms of COVID-19 (54, 56, 125-127). Our findings highlight the most common symptoms of headache, fever, and cough. Different COVID-19 variants have been linked to distinct symptom profiles and levels of disease severity. In a college athlete registry from September to December 2020, the most prevalent symptoms were loss of taste or smell, headache, muscle pain, cough, fatigue, and fever, similar to those observed in our data from the latter part of 2020 (125).

The specific duration of the missed training time is rarely documented in athletes and likely depends on various factors. Our data indicate that most athletes missed 1–2 weeks of training, potentially due to quarantine, symptom severity, and the closure of training facilities. Krzywanski et al. found that COVID-19 resulted in greater training loss than other respiratory infections. The surveyed 1073 elite Polish athletes had 12–13% of lost training days due to COVID-19, notably lower than in our cohort (72). Schwellnus et al. linked symptom clusters to longer recovery times, with COVID-19 requiring 16–40 days, compared to 7–22 days for other illnesses. Symptom clusters tend to prolong training absences, mainly due to fatigue (128).

Regarding the long COVID syndrome, we found it in 10% of athletes. According to a systematic review and meta-analysis of 43 studies involving 11.518 athletes, a prevalence of 8.3% was reported (129). Our previous cohort of 322 athletes demonstrated an 8% rate, with adults and master athletes being more likely to develop persistent symptoms (130). According to our current findings, which primarily involve young adults, only the number of acute symptoms independently predicted the development of long-standing symptoms. Reinfection of COVID-19 among athletes has been poorly researched, primarily through small studies (131, 132). Good et al. found a reinfection rate as low as 0.8% in a cohort of student-athletes during the Delta wave, before the emergence of Omicron (132). In our research, the reinfection rate was 13%, with fewer and milder symptoms, and fewer missed training days than the initial infection. This may be due to the different virus variants (133-135) or athletes' immune priming from prior infection or vaccination. Furthermore, the development of vaccines may also reduce the severity of the disease. Our relatively high reinfection rate could also be attributed to most infections in early 2022 during the Omicron outbreak. Moreover, elite athletes typically underwent strict medical monitoring and pre-competition screenings, making it more probable that mild or asymptomatic reinfections were detected. Conversely, reinfection rates among the general population stayed relatively low until the emergence of the Omicron variant (123, 136).

In our study, we observed a high vaccination rate, with nearly all of our athletes (94%) receiving at least one COVID-19 vaccine dose and 92% getting the second dose. Post-vaccination adverse effects, similar to those observed within the general population (137), were rare and mild, typically lasting less than four days. An infographic paper by Rankin et al. showed that vaccination in athletes was also well tolerated, with mild side effects, and an average of 4 missed days (138). Oudjedi et al. found that 55% of 273 Algerian athletes experienced side effects, mainly fever and local pain (139). These results are consistent with our findings. However, for athletes who rely heavily on their upper extremities, the timing of vaccination may be necessary due to potential local side effects (140). Despite rising vaccination rates, COVID-19 cases increased, possibly indicating lower vaccine efficacy against newer Omicron variants, as noted in the literature (135, 141, 142).

The COVID-19 pandemic caused mental health issues among athletes, including stress, anxiety, and depression (143). A study of 310 athletes from several sports and continents showed that maladaptive perfectionism was linked to many mental health problems. Furthermore, competitive athletes showed negative emotional states during the pandemic, but those with better coping strategies experienced less anxiety, stress, and depressive symptoms (144). Our findings indicate that mood shifts and perceived declines in performance were closely related to the overall pandemic experience, with 36% of athletes requiring psychological support. Female athletes experienced slightly more negative mood changes than males, consistent with other studies (124, 144-146). Half the athletes did not need support, possibly due to effective coping skills. However, 17% of those who needed support could not access it, emphasizing the need for providing proper psychological assistance to athletes.

5.3.1 Limitations

This retrospective study relies on self-reported data from an English-only survey, which may affect responses from non-native speakers due to language barriers. We also lack details about the types and methods of COVID-19 testing and cannot confirm the accuracy of other health-related information that has been reported. As a result, potential inaccuracies or incomplete responses might have slightly impacted data quality. Furthermore, the exact dates of positive tests could not be confirmed using institutional medical records.

6. Conclusions

The COVID-19 pandemic has significantly impacted the sports world, creating unique challenges for athletes and professionals, while the importance of sports cardiology screening has been outlined. It has become essential to rule out COVID-related cardiac consequences and return-to-play decisions. However, the emerging evidence and the appearance of milder variants did not indicate an increased cardiac risk; the detailed screening programs provided a good practice for safer sport eligibility decisions. Our research reveals a high rate of COVID-19 infection among aquatic athletes, with most experiencing mild to moderate symptoms and a low rate of complications. Furthermore, elite swimmers preparing for the Tokyo Olympics maintained their performance levels. Higher transmission rates were observed in team sports, highlighting the importance of implementing effective preventive measures. Vaccination acceptance was high among aquatic athletes, with mostly mild side effects, emphasizing the importance of encouraging vaccination within sports communities for a safer environment. The increased awareness and hygiene practices from the pandemic may continue to help athletes by reducing infections. Psychological factors significantly affected athletes' experiences, emphasizing the need for ongoing mental health support. After the quarantine era, mass competitions could be safely and successfully organized without complications and relevant transmission of the COVID-19 infection, as Hungary outlined with the first organized World Championship without strict preventive countermeasures. Overall, our findings highlight the importance of adaptable training, targeted medical monitoring, mental health support, and evidence-based organizational strategies in protecting athlete health and maintaining competitive sports during future public health crises.

7. Summary

The COVID-19 pandemic has introduced unforeseen challenges to the sporting world, affecting athletes' health, training, and event organization. Prioritizing the protection and enhancement of elite athletes' health and performance is essential. Comprehensive sports cardiology screening is crucial in identifying potentially life-threatening conditions, evaluating performance-limiting factors and the effects of COVID infections, and facilitating a safe return to play.

Our findings comprehensively assess the pandemic's impact on aquatic athletes through three studies. We investigated how the COVID-19 infection influenced Olympic swimmers' performance and cardiovascular health by analyzing pre- and post-infection screening data alongside a group of non-infected control swimmers. Additionally, we reviewed the mitigation strategies and medical encounters related to the 19 AQUA World Championship. We also surveyed this multinational cohort of aquatic athletes during the 19th AQUA World Championship to examine infection rates, disease course, symptoms, vaccination experiences, and psychological well-being.

Our findings demonstrate that the COVID-19 infection rate was high in aquatic athletes and was associated with mostly mild to moderate symptoms. Moreover, transmission rates in team sports were higher relative to individual disciplines. Vaccination acceptance was also high among aquatic athletes, and adverse effects were limited to mild and transient symptoms. The post-infection cardiology assessment was crucial for a safe return to training. Neither short-term detraining nor COVID infection significantly affected the elite swimmers' performance or Olympic preparation. However, psychological factors influenced athletes' experiences during the pandemic, underscoring the relevance of sustained mental health support. Finally, implementing a semi-bubble structure enabled the safe and successful hosting of the 19th AQUA World Championships without overly restrictive measures. Our findings show that aquatic athletes have handled the physical effects well and the psychological effects moderately during the COVID-19 pandemic.

These findings underscore the importance of adopting flexible training approaches, implementing focused medical monitoring, providing psychological support, and implementing evidence-based organizational procedures to protect athletes' health and maintain competitive sports during future public health challenges.

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