Diving after SARS-CoV-2 (COVID-19) infection: Fitness to dive assessment and medical guidance

Charlotte Sadler[1], Miguel Alvarez Villela[2], Karen Van Hoesen[1], Ian Grover[1], Michael Lang[1], Tom Neuman[1], Peter Lindholm[1]

[1] Department of Emergency Medicine, School of Medicine, Division of Hyperbaric Medicine, University of California, San Diego, California, USA
[2] Montefiore Medical Center/Albert Einstein College of Medicine, Department of Medicine, Division of Cardiology, Bronx, NY, USA

***Corresponding author:** Dr Charlotte Sadler, Department of Emergency Medicine, Division of Hyperbaric Medicine, School of Medicine, University of California, San Diego, California, USA*
csadler@health.ucsd.edu

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Abstract

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Scuba diving is a critical activity for commercial industry, military activities, research, and public safety, as well as a passion for many recreational divers. Physicians are expected to provide return-to-diving recommendations after SARS-CoV-2 (COVID-19) infection based upon the best available evidence, often drawn from experience with other, similar diseases. Scuba diving presents unique physiologic challenges to the body secondary to immersion, increased pressure and increased work of breathing. The long-term sequelae of COVID-19 are still unknown, but if they are proven to be similar to other coronaviruses (such as Middle East respiratory syndrome or SARS-CoV-1) they may result in long-term pulmonary and cardiac sequelae that impact divers' ability to safely return to scuba diving. This review considers available literature and the pathophysiology of COVID-19 as it relates to diving fitness, including current recommendations for similar illnesses, and proposes guidelines for evaluation of divers after COVID-19. The guidelines are based upon best available evidence about COVID-19, as well as past experience with determination of diving fitness. It is likely that all divers who have contracted COVID-19 will require a medical evaluation prior to return to diving with emphasis upon pulmonary and cardiac function as well as exercise capacity.

Introduction

Scuba diving is a passion for many recreational divers, but also represents a critical component of the commercial diving industry, scientific research, military operations and public safety diving. Severe acute respiratory syndrome coronavirus two (SARS-CoV-2 hereafter referred to as 'COVID-19') affects the lungs with potential sequelae in the lung parenchyma.[1] During descent to depth gas-containing anatomic spaces will be compressed, and during ascent, any compressed gas introduced to these spaces will expand. These potential gas volume changes create a risk of barotrauma, hence the general consensus that healthy lungs are a requirement for diving.[2,3] Diving also poses significant stressors on the cardiovascular system resulting from increases in systemic blood pressure, centralisation of blood volume, thermal stress from water immersion and increases in systemic oxygen consumption.[4] Physical challenges similar to those of other sports would require similar evaluation while keeping in mind the added physiologic changes from immersion.[5] There are currently widespread concerns in the diving and medical communities on fitness to return to dive post COVID-19. Research examining the origins and structure of the virus, its pathogenesis, and the clinical features of its acute presentation is growing, creating a foundation of evidence from which to draw while evaluating divers. However, the long-term sequelae are still unknown.

University of California San Diego diving medicine practitioners released guidelines for return to diving based upon decades of diving medical experience and the currently available literature about COVID-19.[6] Our objective here is to review the available literature considered when generating these guidelines, as well as to discuss the potential implications of COVID-19 sequelae in divers and draw relevance from fitness to dive implications of similar diseases.

Background

In a pre-COVID-19 underwater world, decompression sickness (DCS) and pulmonary barotrauma with resultant arterial gas embolism (AGE) were the dominant diving-related injuries originating from breathing compressed air under pressure and requiring treatment with hyperbaric oxygen treatment in a pressurised chamber. The overall per capita DCS rate among recreational divers has been reported as 20.5 per 10,000 person years.[7] Although DCS is a rare and usually self-limiting injury, permanent disability can occur. The risk of dying from recreational diving activities is small with Divers Alert Network (DAN) reporting 1.8 deaths per 100,000 divers per year.[8] Common factors associated with diving fatalities include insufficient breathing gas, panic, rapid ascent and equipment malfunction/problems.[8] In the 2018 DAN Annual Diving Report, the leading cause of death was drowning while the leading 'disabling injury' that led to death was cardiovascular-related problems.[8] COVID-19 exhibits a pathophysiology acutely relevant to diving with potentially increased susceptibility to DCS, AGE, or immersion pulmonary oedema from cardiac, pulmonary and haematological events. This pandemic may precipitate a much larger demand for diving medical examinations.

Magnitude of the problem

Gathering reliable data to assess the number of active scuba divers has eluded the diving industry since its inception. There are no available tools to track diver participation in this sport. Further, a case definition of what constitutes an active scuba diver remains subject to diverse interpretations.

The generally accepted range of ‘active’ scuba divers in the US by the Diving Equipment and Marketing Association (DEMA) is from 2.5 to 3.5 million.[9] The Sports and Fitness Industry Association (SFIA) reports 2,351,000 million casual participants in scuba diving and 823,000 core participants.[10] DAN, a diving safety organisation, likely has a representative active segment of the recreational scuba diving community with members who regularly participate in scuba diving activities and, therefore, procure DAN membership and diving accident insurance. With the caveat that DAN represents recreational divers and a large market share in the USA and Europe, DAN reports the following 2019 membership numbers worldwide: DAN US/Canada, 274,708; DAN Europe, 123,680; DAN Japan, 18,137; DAN World Asia Pacific, 12,163; DAN World Latin America/Brazil, 8,008; DAN South Africa, 5,894.

The true active segment of the US diving population could be fewer than 1,000,000, possibly as low as 500,000, depending on the definition of ‘active’. SFIA does not track global numbers and there is no equivalent organisation outside the US.

Entry of non-divers into the sport through certification courses also introduces a level of uncertainty when attempting to assess the magnitude of the diving medical examination need. Before COVID-19, three reporting scuba training/certification organisations (Professional Association of Diving Instructors PADI, Scuba Diving International, Scuba Schools International) submitted to DEMA a combined average of 22,325 entry-level certifications per quarter (personal communication, Tom Ingram, CEO DEMA, YEAR). At the leadership level, deriving the number of active scuba instructors in the US and internationally is equally difficult. Thirteen US organisations train and certify scuba instructors. Globally, over 300 individual certifying organisations train and certify divers and instructors. The Professional Association of Diving Instructors (PADI) reported 137,000 professional members worldwide in 2019. If PADI represents 70% market share, then the number of instructors globally reasonably approximates 195,000.

Scientific divers reported by the American Academy of Underwater Sciences (AAUS) number 4,500 at 150 organisational member scientific diving programmes.[11] The Centers for Disease Control and Prevention (CDC) and Bureau of Labor Statistics reported 3,380 commercial divers in the US.[12] The true number of active public safety divers is similarly unknown, but estimated to be between 3,000 and 5,000 in the US (personal communication, R Sadler, Medical Director of Dive Rescue International, 2019).

Recreational diver medical certification by a physician before undertaking diver training is a requirement in some countries, driven by insurance regulations. In the US, evaluation before recreational and governmental certification courses is done in the form of a screening medical questionnaire (the World Recreational Scuba Training Council (WRSTC) diver medical participant questionnaire). An evaluation by a physician is required for those who have positive responses on the questionnaire or for those engaged in any professional diving leadership training or certification programme (i.e., dive guide, divemaster, assistant instructor or instructor).[13] Diving medical certification for scientific divers and commercial divers in the US is required and regulated by the Occupational Safety and Health Administration (OSHA).[14] These divers are subject to routine diving medical examination intervals as mandated by their organisations and the AAUS. Most scientific divers are exempt from OSHA, but still have required exams regulated by AAUS.

Development of fitness to dive guidelines in the COVID-19 pandemic

There has been much recent discussion in the diving and medical communities on the evaluation of new diving candidates or return to diving by existing divers who have had COVID-19. Segments of the diving community (e.g., recreational instructors, commercial, military, scientific and public safety divers) may be required under certain circumstances by employers, or if they have tested positive for COVID-19, to undergo diving medical (re)certification to identify or mitigate potential risks from COVID-19 sequelae.

The diving medicine community is presented with the challenge of performing fitness to dive evaluations in the context of a disease in which the natural history is currently unknown. In what is known of its pathophysiology the pulmonary, cardiac, and thromboembolic/hypercoagulable effects seem to be very relevant to divers. Potential long-term sequelae will primarily relate to structural changes of the lung parenchyma such as the fibrosis reported in severe acute respiratory syndrome (SARS-CoV-1) and Middle East respiratory syndrome (MERS) potentially increasing risk of barotrauma, and also decreased exercise tolerance, increased susceptibility to cardiac events such as heart failure, pulmonary oedema, and arrhythmias.[1] Effects of COVID-19 on other organ systems are less specific or less relevant for the specific challenges of diving.

The recommendations promulgated here are based on knowledge of similar conditions and the limited specific knowledge of COVID-19. It should be noted some of the conditions discussed below may be automatically disqualifying in the more conservative proscriptive approach to evaluating for commercial, military, public safety or scientific divers, and some of these recommendations may only apply to recreational divers. It is not within the scope of this paper to dissect the nuances between these organisations.

Pulmonary

PATHOPHYSIOLOGY OF COVID-19 AND RELEVANCE TO DIVING

Although COVID-19 has many clinical manifestations, the primary mechanism of infection, morbidity and mortality has been in the form of a respiratory illness, ranging from mild to severe. The mechanism of pulmonary damage from the virus is thought to be related to a cytokine-mediated inflammatory response, possibly compounded by iatrogenic injury from mechanical ventilation, high airway pressures and exposure to hyperoxia.[1]

There have been many reports describing some of the characteristic acute changes seen on lung imaging in these patients. In a retrospective case series,[15] the changes seen on computerised tomography (CT) scans in patients with COVID-19 and mild to moderate disease were most commonly ground glass opacities (GGO), crazy-paving pattern, and consolidations, with subpleural (peripheral) abnormalities being more common than central. The majority of patients had bilateral disease. These radiographic abnormalities seemed to peak around day 10 of the illness and then gradually resolved. At the time follow-up ended (approximately 26 days after onset of illness), the crazy-paving pattern had resolved, but there were still extensive GGO present.[15] Similar illnesses from other members of the coronavirus family have been seen, specifically in SARS-CoV-1and MERS.[16] Similar to these other diseases, COVID-19 patients may initially have normal chest radiographs (15–20%) and then go on to develop peripheral, multifocal airspace disease (GGO and/or consolidation), cavitation, and lymphadenopathy. Spontaneous pneumothorax is rare. COVID-19 is more often bilateral (similar to MERS) and follow-up imaging (as noted above) will often show progressive opacities.[16]

The chronic phase of COVID-19 has not been described yet; but one may hypothesise it will behave similarly to the other coronaviruses. In a small case series, follow-up chest radiographs showed pulmonary fibrosis in one in three MERS patients (median time of follow-up 43 days).[17] Persistent radiographic findings were associated with a history of a more severe acute clinical course. The follow-up of SARS-CoV-1 patients has been slightly better described. Two-hundred and fifty-eight patients were followed for three months after discharge and all had serial chest imaging and pulmonary function tests (PFTs) performed.[18] If either were abnormal, the patients proceeded to CT imaging. Fifty patients had abnormal diffusion capacity for carbon monoxide (D_{LCO}) (defined as < 80% of predicted value) and 48 patients had residual abnormalities on chest radiography (CXR). The initial follow-up was done at approximately one month and both PFTs and imaging continued to improve at repeat examinations. It should also be noted these patients were symptomatic at the time of follow-up, describing generalised weakness and decreased exercise tolerance due to shortness of breath. Abnormalities of pulmonary diffusion testing were found to be more sensitive than CT scans and imaging seemed to lag behind the clinical course.

Persistent abnormalities were also seen in SARS-CoV-1 patients on CT with paired inspiration-expiration views at follow-up.[19] Imaging done at an average of 140 days post onset of symptoms showed persistent abnormalities, including GGO, reticulations, and air trapping in 16 out of 20 patients. A 15 year follow-up study of SARS-CoV-1 patients showed a rapid improvement in radiographic lesions over the first year followed by a plateau and relatively stable PFTs.[20]

The above described sequelae of other coronaviruses are certainly worrisome and if COVID-19 behaves similarly, it may have potential implications for divers. First is the potential for decreased exercise capacity because of residual lung disease. Pulmonary demands of diving are distinct from those of exercise on land, being affected by increased breathing resistance from diving equipment, immersion, and gas density.[21] This is discussed in further detail in the cardiac section below, but an appropriate exercise capacity will be required for return to diving. Second, there is the possibility that these residual changes would potentially expose the diver to a higher risk of barotrauma. The increased risk of pulmonary barotrauma, potentially because of decreased lung compliance from residual scarring or fibrosis, structural abnormalities such as bullae or blebs or residual air trapping may be a significant issue for divers. Additionally, residual lung disease from COVID-19 could interfere with the pulmonary vasculature enough to allow asymptomatic venous gas emboli to more easily cross the pulmonary capillary filter leading to their arterialisation.

FITNESS TO DIVE IN OTHER PULMONARY CONDITIONS

Pneumonia (lobar, viral). A CXR should be performed after six weeks to ensure no underlying structural abnormality is present. Exercise tolerance should be back to the patient's baseline and oxygen saturation with exercise should be normal. PFTs should be back to baseline; this usually occurs within three to five weeks following a pulmonary infection.[22]

Organising pneumonia (OP). COVID-19 bears resemblance to OP on chest CT, which is an inflammatory process rather than an infectious one.[23,24] OP is usually non-necrotizing but often takes longer to resolve than infectious pneumonias. However, there is no known distinction or prior data separating OP from other forms of pneumonia related to diving. Thus, a CXR is indicated after the clinical resolution of disease.

Pulmonary fibrosis. Pulmonary fibrosis is considered a contraindication for scuba diving because of the increased risk of barotrauma due to decreased lung compliance. There is also concern that the fibrotic lung tissue will interfere with gas exchange. However, this is based on expert opinion and not evidence, as noted in the British Thoracic Society guidelines.[25]

Blebs and bullae. Traditional teaching has been blebs and bullae should be contraindications to scuba diving because of increased risk of overexpansion injury and subsequent barotrauma, including the potential for pneumothorax and arterial gas embolism. Indeed, there have been case reports of individuals who have suffered barotrauma and subsequently were found to have pulmonary bullae.[26,27]

Many of the lesions described in these case reports are relatively large (> 20 mm) and it seems reasonable that patients with large bullae and blebs should be excluded from diving.[27] It is a disqualifying condition for military, commercial, and scientific divers. However, the guidance on small blebs and bullae in recreational divers is less clear. Asymptomatic blebs and bullae have been found in a large portion of the population. In a case series of autopsies performed on otherwise healthy individuals without lung disease, the incidence was approximately 33%.[28] Some describe it as so frequent a finding that "*radiologists in my institution do not routinely report on small blebs on CT scans as they are so common as to be considered normal findings in the patient population seen by a major hospital radiology department*".[29] Given the large number of active divers, the high incidence of blebs and bullae in the population and the relatively low incidence of pulmonary barotrauma and arterial gas embolism in divers, it seems reasonable to conclude there are many individuals scuba diving with blebs and bullae without injury. Indeed, this is the basis for not recommending routine screening CT scans in professional divers, as it would unnecessarily disqualify many divers.[29] Thus, it has been the practice at our institution for recreational divers with incidentally discovered small blebs and bullae to continue diving, though with a discussion of potential risks and risk mitigation.

Pneumothorax. While a history of spontaneous pneumothorax remains a contraindication to diving because of the increased risk of recurrent pneumothorax, patients with a history of post-traumatic and uncomplicated iatrogenic pneumothoraces may be candidates to dive if they have normal PFTs and follow-up imaging.[25] For individuals with a history of significant lung injury or surgery, in which there is concern for air trapping, a high-resolution chest CT scan with inspiratory and expiratory views can confirm or rule out air trapping.

Asthma. Controversy exists in the diving community with regard to whether asthmatics should dive.[25] Theoretical risks to the asthmatic diver include increased risk of barotrauma, decreased exercise tolerance and potentially cold/exercised induced bronchospasm while diving.[21] However, review of retrospective data shows there are many asthmatics diving without significantly increased risk of morbidity. Current recommendations suggest asthmatics with normal PFTs are candidates for diving. With exercise and cold-induced asthma, they require appropriate exercise/cold challenged PFTs.[21,30–32]

Cardiac

PATHOPHYSIOLOGY OF COVID-19 AND RELEVANCE TO DIVING

COVID-19 manifests primarily as atypical pneumonia, but cardiac involvement is increasingly recognised as a prominent feature. There are no uniform patterns of cardiovascular manifestations in patients with COVID-19. They constitute a spectrum with significant clinical overlap that includes isolated elevations in cardiac biomarkers, acute coronary syndrome (ACS), arrhythmias, and myo- or myopericarditis.[33] Published autopsy series have shown myocyte necrosis, lymphocytic myocardial infiltrates and dilated right ventricles.[34] Despite the virus's cardiotropic potential, direct myocardial invasion has not been proven, suggesting that most of the myocardial damage is secondary to systemic inflammation or a general hypercoagulable state.[35] Direct invasion of the virus has been shown, however, in the endothelial cells.[36] This may have significant long-term implications, particularly for divers, because DCS appears to cause endothelial dysfunction. Troponin elevation is reported to occur in 8–28% of patients with COVID-19 and is associated with a higher mortality risk.[37] Isolated elevations in brain natriuretic peptide (BNP) have also been reported in patients with increased mortality.[38] The mechanisms underlying cardiac injury in these patients are complex and the following have been proposed:

- COVID-19 uses the angiotensin converting enzyme II (ACE-2) receptor as a port of entry to human cells and in turn leads to its down-regulation. This results in an increase of circulating angiotensin-II levels leading to vasoconstriction, inflammation and a prothrombotic state.[39]
- Systemic hyperinflammation resulting from uncontrolled amplification of cytokine production following the initial immunologic response against viral replication may lead to direct myocardial injury, microvascular dysfunction or atherosclerotic plaque rupture.[35]
- Cardiac damage may result from direct invasion of the virus into the myocardium or the endothelium.[36]
- Myocardial damage may simply result from increased metabolic demands coupled with systemic hypoxia due to respiratory failure.

Our knowledge of these manifestations derives mostly from reports of hospitalised patients with higher disease severity.[40,41] The incidence of cardiac involvement in patients with mild or moderate illness managed in ambulatory settings is largely unknown. Attention should be paid to the potential lack of work-up patients may have received during the acute phase of their illness. In this pandemic, resources are strained and patients convalesce at home in circumstances where they may otherwise be hospitalised. If there is a history of potential cardiac involvement, the physician should attempt to clarify what type of cardiac manifestations were present and to what degree they were evaluated. Examples of potential cardiac manifestations include myocarditis, myocardial injury (evidenced by elevated biomarkers), cardiomyopathy, arrhythmias, thromboembolic disease, and acute coronary syndrome.[42]

This will help answer important questions such as:

- What was the right and left ventricular function?
- Was there evidence of myocardial inflammation on MRI or other testing modalities? and
- Was epicardial coronary disease diagnosed with coronary angiography and/or treated with percutaneous coronary intervention (PCI)?[33] Establishing the severity of the viral illness and the nature of cardiac involvement will be paramount in guiding the clearance to dive process.

Recreational and commercial diving to a greater degree, may demand a work-rate of 6–7 MET (approximately 21 $ml \cdot kg^{-1} \cdot min^{-1}$ oxygen consumption) or higher when managing common contingencies. Hence, adequate cardiac reserve needs to be established before diving. Current guidelines recommend at least 10 MET (approximately 35 $ml \cdot kg^{-1} \cdot min^{-1}$ oxygen) for commercial divers and 6 MET for recreational divers.[13,43] Thorough cardiac evaluation should be done in patients recovering from a disease with complex pathophysiology such as COVID-19.[33] Silent residual cardiac inflammation could be unmasked by the stresses of the underwater environment resulting in decompensated heart failure or cardiac arrhythmias, among others.

FITNESS TO DIVE IN OTHER CARDIAC CONDITIONS

Coronary artery disease

Coronary artery disease and hypertension are well known risk factors for fatalities associated with diving.[44] Clearance for future diving will depend on the overall burden of disease and, if a coronary intervention was performed, on the burden of residual disease. Some modality of exercise stress testing should be performed before returning to dive to rule out ongoing ischaemia and demonstrate adequate exercise capacity.[45]

Myocarditis/pericarditis/congestive heart failure

In general, heart failure and cardiomyopathies are considered a contraindication to diving because of the increased cardiovascular demands placed on the heart from diving.[44] Clearing patients to dive after pericarditis or myocarditis has not been comprehensively discussed in the literature, but one would presumably need a normal echocardiogram and likely a normal stress echo. Diving is known to be high risk for precipitating arrhythmias, and cases of Takotsubo cardiomyopathy have been reported.[43,46,47] The effects of immersion and centralised shunting of blood also place the diver at risk for immersion pulmonary oedema.[48,49] A depressed left ventricular ejection fraction or impaired exercise tolerance during an exercise stress test limited by symptoms or arrhythmias should disqualify a candidate from diving.

Thromboembolic disease

PATHOPHYSIOLOGY OF COVID-19 AND RELEVANCE TO DIVING

The incidence of venous thromboembolism (VTE) has been reported to be significantly increased in COVID-19 compared to other similar illnesses, but the true incidence is unknown.[50] COVID-19 is thought to induce a hypercoagulable state and although the mechanism remains to be elucidated (potentially via ACE-2 receptors and increased levels of Angiotensin II), there have been reports of elevated D-dimers and troponins, which are associated with worse outcomes.[50] In the acute phase, this predisposes the patient to multiple complications, including VTE and ACS. The question has been raised whether or not this would predispose a diver who had COVID-19 to DCS, which is also thought to be an inflammatory, prothrombotic state. The chronic effects are unknown, but it seems unlikely the hypercoagulable state would remain after the acute phase of the illness is over. The more likely consequence to divers would be the complication of ACS (see above in cardiac section) or pulmonary embolism.

FITNESS TO DIVE IN OTHER THROMBOEMBOLIC CONDITIONS

Pulmonary embolism. Pulmonary embolism is not an absolute contraindication to diving. An echocardiogram and exercise tolerance test could be performed to evaluate for any residual right heart strain or development of chronic thromboembolic pulmonary hypertension. Caution should be taken when diving on anticoagulant medication due to the increased risk of bleeding from even minor trauma.

Current recommendations for evaluation of divers or diving candidates after COVID-19

We have developed working guidelines based on the limited evidence of sequelae of COVID-19 available and experience with other diseases which share similar features (see above). We have categorised divers based on the history and severity of their illness and determined their return to dive evaluation accordingly. As with any illness, ultimately the work-up is left to the discretion of the evaluating physician. The guidelines which follow explicitly pertain to divers who are asymptomatic after their illness, including normal exercise tolerance (see exercise tolerance section). We currently recommend following CDC guidelines for screening of an employee for any diver prior to diving.[51] Measuring vital signs or oxygen saturation routinely before diving is not practical, but no diver should dive if they currently have or within 14 days have had any cough, shortness of breath or difficulty breathing, fever, chills, myalgias or new loss of smell or taste.

DEFINITIONS OF TERMS USED IN GUIDELINES

COVID-19 suspected illness

We define a COVID-19-suspected illness as symptoms consistent with COVID-19 with or without a positive polymerase chain reaction (PCR) or antibody test, as testing is currently unreliable. As more accurate antibody testing is developed and becomes widely available it will likely be useful in guiding these evaluations. In defining ‘symptoms consistent with COVID-19’ we are currently using the CDC case definition of COVID-19 for those patients who did not have PCR or antibody confirmed illness.[51]

Thus, a COVID-19 illness is suspected when there have been at least two of the following symptoms:

- fever (measured or subjective), chills, rigors, myalgia, headache, sore throat, new olfactory and taste disorder(s);
- OR at least one of the following symptoms: cough, shortness of breath, or difficulty breathing;
- OR severe respiratory illness with at least one of clinical or radiographic evidence of pneumonia, or acute respiratory distress syndrome (ARDS);
- AND no alternative more likely diagnosis.

Exercise tolerance

Exercise tolerance is the most important definition used in our guidelines and it is vital physicians evaluate it carefully. It has been our experience that a diver with significant cardiac or pulmonary pathophysiology will most likely not have normal exercise tolerance. However, the definition of the word normal is critical. First, the diver must have returned to his or her baseline level of exercise tolerance. Even minor deviations from their baseline (‘getting more winded’, longer recovery times, etc) warrant further testing and investigation. Second, the physician must be satisfied the diver’s exercise regimen reflects an appropriate level of equivalence for the predictable demands of diving. As mentioned above, current guidelines recommend at least 10 MET for commercial divers and 6 MET for recreational divers.[13,43] If the physician is not assured the diver’s self-reported exercise level meets appropriate criteria or is concerned it would not reveal underlying cardiac or pulmonary disease, further testing is warranted.

GUIDELINES FOR DIVER EVALUATION

The following guidelines are intended for the evaluation of divers who had a COVID-19 suspected illness, are currently asymptomatic, and have subjectively returned to their baseline exercise tolerance. The tables are intended to be used in sequential fashion (i.e., Table 1, then Table 2). Table 1 requires a thorough history of the diver’s illness in order to appropriately categorise them. A diver should be placed in the highest category where they meet any (not all) of the criteria. For example, any patient who was hospitalised or required the use of supplemental oxygen is automatically categorised as moderate or severe. Any patient who required intensive care unit (ICU) admission or any assisted ventilation, such as bi-level positive airway pressure (BiPAP), continuous positive airway pressure (CPAP) or intubation, is categorised as severe. If a patient was hospitalised and there is no record of a cardiac work up, they are also placed in the severe category.

After a patient has been categorised based on their initial illness severity, Table 2 is then used to guide their work up before returning to dive. The initial imaging recommended is a chest X-ray and a CT performed if the X-ray is abnormal. A CT scan (potentially with inspiration/expiration views) would be more sensitive than a radiograph for detecting abnormalities but it is our position that a CT scan is not

Table 1

Classification of divers or diving candidates based on severity of COVID-19 suspected illness. The categories of divers are based upon presenting symptoms and severity of disease, including oxygen requirement, imaging, need for and level of hospitalisation, and cardiac involvement. A diver should be placed in the highest category where they meet any (not all) of the criteria. BIPAP = bilevel positive airway pressure support; BNP = brain natriuretic peptide; CK-MB = creatine kinase MB fraction; CPAP = continuous positive airway pressure support; CT = computed tomography; DVT = deep venous thrombosis; ECG = electrocardiogram; ICU = intensive care unit

Category 0 ***NO*** *history of COVID-19-suspected illness*	**Category 1** ***MILD*** *COVID-19-suspected illness*	**Category 2** ***MODERATE*** *COVID-19-suspected illness*	**Category 3** ***SEVERE*** *COVID-19-suspected illness*
Definition: Divers who have no history of COVID-19 suspected illness should proceed with normal evaluations. Additionally, we would use these criteria in those who may have had a positive screening PCR or antibody test, but without any history of illness or symptoms consistent with COVID-19.	Definition: ● Did not seek health care or received outpatient treatment only without evidence of hypoxaemia. ● Did not require supplemental oxygen. ● Imaging was normal or not required.	Definition: ● Required supplemental oxygen or was hypoxic. ● Had abnormal chest imaging (chest radiograph or CT scan). ● Admitted to the hospital but did NOT require mechanical (intubation) or assisted ventilation (BIPAP, CPAP) or ICU level of care. ● If admitted, had documentation of a normal cardiac work up including normal ECG and cardiac biomarkers e.g., troponin or CK-MB and BNP.	Definition: ● Required mechanical (intubation) or assisted ventilation (BIPAP, CPAP) or ICU level of care. ● Cardiac involvement defined as abnormal ECG or echocardiogram, or elevated cardiac biomarkers e.g., troponin or CK-MB and BNP (or absence of documented work up). ● Thromboembolic complications (such as pulmonary embolism, DVT, or other coagulopathy).

indicated if a patient has a normal radiograph, PFTs, and exercise tolerance. CT may be overly sensitive for clinically insignificant lesions, as well as cause unnecessary radiation exposure and cost.

The guidelines detailed above require a more rigorous and conservative workup than would traditionally be required after a viral respiratory illness. However, this disease has proven itself to be atypical in a number of ways, including multi-organ system involvement and potential long-term effects on the pulmonary and cardiovascular systems. It is impossible to provide an algorithm that encompasses all combinations of the nature and severity of apparent COVID-19 sequelae, but that decision-making is likely to be based on similar principles to those applied in evaluating similar respiratory and cardiovascular problems arising from other causes. Because of the potential risks (including barotrauma, decreased exercise tolerance, cardiomyopathy, and arrhythmia), it is prudent to do a thorough evaluation of divers who have recovered from COVID-19.

Symptomatic divers or those with abnormal test results

Symptomatic individuals or those who have abnormal testing per the guidelines above should be advised not to dive (though each will need to be evaluated on a case by case basis and exceptions are to be expected). For example, those with persistent parenchymal damage, evidence of air trapping, cardiac injury, or inadequate exercise capacity should be advised not to dive. However, there may be more subtle abnormalities, such as borderline PFTs or a subtle radiographic abnormality in an otherwise asymptomatic healthy diver. These may not necessarily represent a lifetime ban on diving as many of the sequelae which are currently disqualifying may resolve over time and re-testing may be indicated. It is beyond the scope of this paper to provide detailed recommendations for all of these possibilities and we strongly recommend that the interpretation of the results of investigation, ongoing health re-evaluation or surveillance, and related fitness to dive decisions involve a physician with training in diving medicine.

Limitations

As evidenced by the above discussion, there is relatively little fitness to dive literature in general and what is available consists of case series and reports, as well as workshop proceedings. Most recommendations are the results of consensus and opinion. The long-term effects of COVID-19 are even less well understood and the recommendations above are made with the expectation that they will be revised as more evidence becomes available.

Conclusions

The potential implications of COVID-19 on fitness for diving are real, though the chronic sequelae of this disease are not yet known. Diving physicians are mandated to proceed

Table 2

Recommendations for evaluations of divers or diving candidates. Recommendations for evaluation are based upon the divers' severity of COVID-19 suspected illness (see Table 1). If results are unknown or unavailable, recommendations are for more extensive cardiac and pulmonary evaluations. BNP = brain natriuretic peptide; CK-MB = creatine kinase MB fraction; CT = computed tomography; ECG = electrocardiogram; PA = posterior-anterior; RSTC = Recreational Scuba Training Council. * If there is doubt that the diver's self-reported exercise level meets appropriate criteria or concern it would not reveal underlying cardiac or pulmonary disease, further testing is warranted

Category 0 ***NO*** *history of COVID-19-suspected illness*	**Category 1** ***MILD*** *COVID-19-suspected illness*	**Category 2** ***MODERATE*** *COVID-19-suspected illness*	**Category 3** ***SEVERE*** *COVID-19-suspected illness*
● Initial/periodic exam per professional group or RSTC guidelines. ● Chest radiograph only if required per professional group or RSTC guidelines. ● No additional testing required.	● Initial/periodic exam per professional group or RSTC guidelines. ● Spirometry. ● Chest radiograph (PA and lateral); if abnormal, obtain chest CT. ● If unknown (or unsatisfactory) exercise tolerance*, perform exercise tolerance test with oxygen saturation.	● Initial/periodic exam per professional group or RSTC guidelines. ● Spirometry. ● Chest radiograph (PA and lateral); if abnormal, obtain chest CT. ● ECG. ● Echocardiogram (if no work up was done as an inpatient. Can forgo if had negative work up). ● If unknown (or unsatisfactory) exercise tolerance*, perform exercise tolerance test with oxygen saturation. ● Investigation and management of any other complications or symptoms per provider and professional group or RSTC guidelines.	● Initial/periodic exam per professional group or RSTC guidelines. ● Spirometry ● Chest radiograph (PA and lateral); if abnormal, obtain chest CT. ● ECG. ● Repeat cardiac troponin or CK-MB and BNP to ensure normalization. ● Echocardiogram. ● Exercise Echocardiogram with oxygen saturation. ● Investigation and management of any other complications or symptoms per provider and professional group or RSTC guidelines.

with fitness to dive evaluations despite this lack of evidence and thus must draw upon past experience with similar conditions. The above guidelines represent our current opinion on best practice and will continue to be updated as a better understanding of the novel COVID-19 is gained. The updated guidelines will be available at:
https://health.ucsd.edu/coronavirus/Documents/UC%20San%20Diego%20Guidelines%20for%20Evaluation%20of%20Divers%20during%20COVID-19%20pandemic.pdf.

References

1 Spagnolo P, Balestro E, Aliberti S, Cocconcelli E, Biondini D, Casa GD, et al. Pulmonary fibrosis secondary to COVID-19: A call to arms? Lancet Respir Med [Online ahead of print]. 2020 May 15. doi: 10.1016/S2213-2600(20)30222-8. PMID: 32422177. PMCID: PMC7228737.

2 Pougnet R, Pougnet L, Dewitte J-D, Loddé B, Lucas D. Temporary and permanent unfitness of occupational divers. Brest Cohort 2002–2019 from the French National Network for Occupational Disease Vigilance and Prevention (RNV3P). Int Marit Health. 2020;71:71–7. doi:10.5603/IMH.2020.0014. PMID: 32212151.

3 Neuman T. Pulmonary fitness to dive. In: Lundgren CEG, Miller JN, editors. The lung at depth. New York: Marcel Dekker; 1999. p. 73–91.

4 Bove AA. The cardiovascular system and diving risk. Undersea Hyperb Med. 2011;38:261–9. PMID: 21877555.

5 Phelan D, Kim JH, Chung EH. A game plan for the resumption of sport and exercise after Coronavirus disease 2019 (COVID-19) Infection. JAMA Cardiol [Online ahead of print]. 2020 May 13. doi: 10.1001/jamacardio.2020.2136. PMID: 32402054.

6 Sadler C, Alvarez Villela M, Van Hoesen K, Grover I, Neuman T, Lindholm P. UC San Diego guidelines for evaluation of divers during COVID-19 pandemic [Internet]. University of California, San Diego; 2020 May. Available from: https://health.ucsd.edu/coronavirus/Documents/UC%20San%20Diego%20Guidelines%20for%20Evaluation%20of%20Divers%20during%20COVID-19%20pandemic.pdf. [cited 2020 June 01].

7 Denoble PJ, Ranapurwala SI, Vaithiyanathan P, Clarke RE, Vann RD. Per-capita claims rates for decompression sickness among insured Divers Alert Network members. Undersea Hyperb Med. 2012;39:709–15. PMID: 22670551.

8 Buzzacott P, Denoble PJ, editors. DAN Annual Diving Report 2018 edition: A report on 2016 diving fatalities, injuries, and incidents. Durham (NC): Divers Alert Network; 2019.

9 Hornsby A. Models for estimating the diver population of the

United States: An assessment. In: Vann R, Lang M, editors. Recreational diving fatalities workshop proceedings. Durham (NC): Divers Alert Network; 2011. p. 165–9. Available from: https://www.diversalertnetwork.org/files/Fatalities_Proceedings.pdf. [cited 2020 June 29].
10 Scuba diving participation report 2019. Silver Spring (MD): Sports and Fitness Industry Association; 2019. Available from: https://www.sfia.org/reports/796_Scuba-Diving-Participation-Report-2019. [cited 2020 Jun 01].
11 American Academy of Underwater Sciences. DCI incidence rates [Internet]. Available from: https://aaus.org/AAUS/AAUS/Statistics/DCI_Incidence_Rates.aspx. [cited 2020 Jun 01].
12 Bureau of Labor Statistics. Occupational employment and wages, May 2018: 49-9092 Commercial Divers [Internet]; 2019. Available from: https://www.bls.gov/oes/current/oes499092.htmExternalexternal icon. [cited 2020 Jun 01].
13 Diver Medical Screening Committee. Recreational diving medical screening system [Internet]; 2020. Available from: https://www.uhms.org/resources/recreational-diving-medical-screening-system.html. [cited 2020 Jun 01].
14 Department of Labor. Occupational safety and health administration. 29 CFR 1910, Subpart T. Commercial diving operations [Internet]. Available from: https://www.osha.gov/sites/default/files/enforcement/directives/CPL_02-00-151.pdf. [cited 2020 Jun 01].
15 Pan F, Ye T, Sun P, Gui S, Liang B, Li L, et al. Time course of lung changes at chest CT during recovery from Coronavirus disease 2019 (COVID-19). Radiology. 2020;295:715–21. doi: 10.1148/radiol.2020200370. PMID: 32053470. PMCID: PMC7233367.
16 Hosseiny M, Kooraki S, Gholamrezanezhad A, Reddy S, Myers L. Radiology perspective of Coronavirus disease 2019 (COVID-19): Lessons from severe acute respiratory syndrome and middle east respiratory syndrome. AJR Am J Roentgenol. 2020;214:1078–82. doi: 10.2214/AJR.20.22969. PMID: 32108495.
17 Das KM, Lee EY, Singh R, Enani MA, Al Dossari K, Van Gorkom K, et al. Follow-up chest radiographic findings in patients with MERS-CoV after recovery. Indian J Radiol Imaging. 2017;27:342–9. doi: 10.4103/ijri.IJRI_469_16. PMID: 29089687. PMCID: PMC5644332.
18 Xie L, Liu Y, Xiao Y, Tian Q, Fan B, Zhao H, et al. Follow-up study on pulmonary function and lung radiographic changes in rehabilitating severe acute respiratory syndrome patients after discharge. Chest. 2005;127:2119–24. doi: 10.1378/chest.127.6.2119. PMID: 15947329. PMCID: PMC7094359.
19 Chang Y-C, Yu C-J, Chang S-C, Galvin JR, Liu H-M, Hsiao C-H, et al. Pulmonary sequelae in convalescent patients after severe acute respiratory syndrome: Evaluation with thin-section CT. Radiology. 2005;236:1067–75. doi: 10.1148/radiol.2363040958. PMID: 16055695.
20 Zhang P, Li J, Liu H, Han N, Ju J, Kou Y, et al. Long-term bone and lung consequences associated with hospital-acquired severe acute respiratory syndrome: A 15-year follow-up from a prospective cohort study. Bone Res. 2020;8:8. doi: 10.1038/s41413-020-0084-5. PMID: 32128276. PMCID: PMC7018717.
21 Neuman T. Pulmonary disorders. In: Bove AA, Davis JC, editors. Bove and Davis' diving medicine. Philadelphia: Saunders; 2004.
22 Hall WJ, Hall CB. Clinical significance of pulmonary function tests. Chest. 1979;76:458–65. doi: 10.1378/chest.76.4.458. PMID: 225132. PMCID: PMC7094698.
23 Polak SB, Van Gool IC, Cohen D, von der Thüsen JH, van Paassen J. A systematic review of pathological findings in COVID-19: A pathophysiological timeline and possible mechanisms of disease progression. Mod Pathol. 2020 Jun 22;1–11 [Online ahead of print]. doi: 10.1038/s41379-020-0603-3. PMID: 32572155. PMCID: PMC7306927.
24 Lu J, Yin Q, Zha Y, Deng S, Huang J, Guo Z, et al. Acute fibrinous and organizing pneumonia: Two case reports and literature review. BMC Pulm Med. 2019;19(1):141. doi: 10.1186/s12890-019-0861-3. PMID: 31382933. PMCID: PMC6683570.
25 British Thoracic Society Fitness to Dive Group, Subgroup of the British Thoracic Society Standards of Care Committee. British Thoracic Society guidelines on respiratory aspects of fitness for diving. Thorax. 2003;58:3–13. doi: 10.1136/thorax.58.1.3. PMID: 12511710. PMCID: PMC1746450.
26 Reuter M, Tetzlaff K, Warninghoff V, Steffens JC, Bettinghausen E, Heller M. Computed tomography of the chest in diving-related pulmonary barotrauma. Br J Radiol. 1997;70:440–445. doi: 10.1259/bjr.70.833.9227223. PMID: 9227223.
27 Germonpré P, Balestra C, Pieters T. Influence of scuba diving on asymptomatic isolated pulmonary bullae. Diving Hyperb Med. 2008;38:206–11. PMID: 22692754.
28 de Bakker HM, Tijsterman M, de Bakker-Teunissen OJG, Soerdjbalie-Maikoe V, van Hulst RA, de Bakker BS. Prevalence of pulmonary bullae and blebs in postmortem CT imaging with potential implications for diving medicine. Chest. 2020;157:916–23. doi: 10.1016/j.chest.2019.11.008. PMID: 31759963.
29 Millar IL. Should computed tomography of the chest be recommended in the medical certification of professional divers? Br J Sports Med. 2004;38:2–3. doi: 10.1136/bjsm.2003.010413. PMID: 14751933. PMCID: PMC1724731.
30 Van Hoesen KB, Neuman TS. Asthma and scuba diving. Immunol Allergy Clin North Am. 1996;16:917–28. doi: 10.1016/S0889-8561(05)70278-2.
31 Lippmann J, Taylor D McD, Stevenson C, Williams J, Mitchell SJ. Diving with pre-existing medical conditions. Diving Hyperb Med. 2017;47:180–90. doi: 10.28920/dhm47.3.180–190. PMID: 28868599. PMCID: PMC6159622.
32 The South Pacific Underwater Medical Society Guidelines on medical risk assessment for recreational diving, SPUMS Medical 5th ed [Internet]. Melbourne: South Pacific Underwater Medical Society; 2020. Available from: https://www.spums.org.au/content/spums-full-medical-0. [cited 2020 Jun 01].
33 Akhmerov A, Marbán E. COVID-19 and the heart. Circ Res. 2020;126:1443–55. doi: 10.1161/CIRCRESAHA.120.317055. PMID: 32252591.
34 Fox SE, Akmatbekov A, Harbert JL, Li G, Quincy Brown J, Vander Heide RS. Pulmonary and cardiac pathology in African American patients with COVID-19: An autopsy series from New Orleans. Lancet Respir Med. 2020;8:681–6. doi: 10.1016/S2213-2600(20)30243-5. PMID: 32473124. PMCID: PMC7255143.
35 Libby P. The Heart in COVID19: Primary target or secondary bystander? JACC Basic Transl Sci. 2020;5:537–42. doi: 10.1016/j.jacbts.2020.04.001. PMID: 32292847. PMCID: PMC7151324.
36 Varga Z, Flammer AJ, Steiger P, Haberecker M, Andermatt R, Zinkernagel AS, et al. Endothelial cell infection and endotheliitis in COVID-19. Lancet. 2020;395:1417–8. doi: 10.1016/S0140-6736(20)30937-5. PMID: 32325026. PMCID:

PMC7172722.
37 Shi S, Qin M, Shen B, Cai Y, Liu T, Yang F, et al. Association of cardiac injury with mortality in hospitalized patients with COVID-19 in Wuhan, China. JAMA Cardiol. 2020;5:802–10. doi: 10.1001/jamacardio.2020.0950. PMID: 32211816. PMCID: PMC7097841.
38 Guo T, Fan Y, Chen M, Wu X, Zhang L, He T, et al. Cardiovascular implications of fatal outcomes of patients with coronavirus disease 2019 (COVID-19). JAMA Cardiol. 2020;5:1–8. doi: 10.1001/jamacardio.2020.1017. PMID: 32219356. PMCID: PMC7101506.
39 Oudit GY, Kassiri Z, Jiang C, Liu PP, Poutanen SM, Penninger JM, et al. SARS-coronavirus modulation of myocardial ACE2 expression and inflammation in patients with SARS. Eur J Clin Invest. 2009;39:618–25. doi: 10.1111/j.1365-2362.2009.02153.x. PMID: 19453650. PMCID: PMC7163766.
40 Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: A retrospective cohort study. Lancet. 2020;395(10229):1054–62. doi: 10.1016/S0140-6736(20)30566-3. PMID: 32171076. PMCID: PMC7270627.
41 Yang X, Yu Y, Xu J, Shu H, Xia J ’an, Liu H, et al. Clinical course and outcomes of critically ill patients with SARS-CoV-2 pneumonia in Wuhan, China: A single-centered, retrospective, observational study. Lancet Respir Med. 2020;8(5):475–81. doi: 10.1016/S2213-2600(20)30079-5. PMID: 32105632. PMCID: PMC7102538.
42 Driggin E, Madhavan MV, Bikdeli B, Chuich T, Laracy J, Biondi-Zoccai G, et al. Cardiovascular considerations for patients, health care workers, and health systems during the COVID-19 pandemic. J Am Coll Cardiol. 2020;75(18):2352–71. doi: 10.1016/j.jacc.2020.03.03. PMID: 32201335. PMCID: PMC7198856.
43 Association of Diving Contractors International. International consensus standards for commercial diving and underwater operations: Section 2 diving personnel medical and training requirements [Internet]; 2016. Available from: https://www.adc-int.org/files/ADCI%20PHYSICAL%20&%20MEDICAL%20REQUIREMENTS%202_0(1).pdf. [cited 2020 Jun 01].
44 Sadler CA, Nelson C, Grover I, Witucki P, Neuman T. Dilemma of natural death while scuba diving. Academic Forensic Pathol. 2013;3:202–12. doi: 10.23907/2013.026.
45 Mitchell SJ, Bove AA. Medical screening of recreational divers for cardiovascular disease: Consensus discussion at the Divers Alert Network Fatality Workshop. Undersea Hyperb Med. 2011;38:289–96. PMID: 21877558.
46 Baber A, Nair SU, Duggal S, Bhatti S, Sundlof DW. Stress cardiomyopathy caused by diving: Case report and review of the literature. J Emerg Med. 2016;50:277–80. doi: 10.1016/j.jemermed.2015.09.045. PMID: 26589557.
47 Demoulin R, Poyet R, Castagna O, Gempp E, Druelle A, Schmitt P, et al. Epidemiological, clinical, and echocardiographic features of twenty “Takotsubo-like” reversible myocardial dysfunction cases with normal coronarography following immersion pulmonary oedema. Acta Cardiol. 2020 Feb 24;1–7. doi: 10.1080/00015385.2020.1726627. PMID: 32089094.
48 Wilmshurst PT. Immersion pulmonary oedema: A cardiological perspective. Diving Hyperb Med. 2019;49:30–40. doi: 10.28920/dhm49.1.30-40. PMID: 30856665. PMCID: PMC6526048.
49 Lindholm P, Swenson ER, Martínez-Jiménez S, Guo HH. From ocean deep to mountain high: Similar computed tomography findings in immersion and high-altitude pulmonary edema. Am J Respir Crit Care Med. 2018;198:1088–9. doi: 10.1164/rccm.201803-0581IM. PMID: 30044644.
50 Bikdeli B, Madhavan MV, Jimenez D, Chuich T, Dreyfus I, Driggin E, et al. COVID-19 and thrombotic or thromboembolic disease: Implications for prevention, antithrombotic therapy, and follow-up: JACC State-of-the-Art Review. J Am Coll Cardiol. 2020;75(23):2950–73. doi: 10.1016/j.jacc.2020.04.031. PMID: 32311448. PMCID: PMC7164881.
51 Centers for Disease Control and Prevention. Coronavirus disease 2019 (COVID-19) 2020 interim case definition, Approved April 5, 2020 [Internet]. 2020. Available from: https://wwwn.cdc.gov/nndss/conditions/coronavirus-disease-2019-covid-19/case-definition/2020/. [cited 2020 June 01].

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