Short communication

Considerations for scuba and breath-hold divers during the COVID-19 pandemic: A call for awareness

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Abstract

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In late 2019, a highly pathogenic novel coronavirus (CoV), severe acute respiratory syndrome (SARS)-CoV-2 emerged from Wuhan, China and led to a global pandemic. SARS-CoV-2 has a predilection for the pulmonary system and can result in serious pneumonia necessitating hospitalisation. Computed tomography (CT) chest scans of patients with severe symptoms, show signs of multifocal bilateral ground or ground-glass opacities (GGO) associated with consolidation areas with patchy distribution. However, it is less well known that both asymptomatic and mild symptomatic patients may exhibit similar lung changes. Presumably, the various pathological changes in the lungs may increase the risk of adverse events during diving (e.g., lung barotrauma, pulmonary oedema, etc.), thus these lung manifestations need to be considered prior to allowing resumption of diving. Presently, it is not known how the structural changes in the lungs develop and to what extent they resolve, in particular in asymptomatic carriers and patients with mild disease. However, current evidence indicates that a month of recovery may be too short an interval to guarantee complete pulmonary restitution even after COVID-19 infections not demanding hospital care.

Introduction

Coronaviruses (CoVs) are large enveloped non-segmented positive sense RNA viruses associated with respiratory disease in humans.[1] Although COVID-19 is caused by a new virus, severe acute respiratory syndrome-(SARS)-CoV-2, genomic analysis shows that it, (*i*) belongs in the same beta-coronavirus clade as Middle Eastern Respiratory Syndrome (MERS) and SARS-CoV-1, (*ii*) shares a homological sequence with SARS-CoV, (*iii*) and like SARS-CoV-1, enters human host cells via the angiotensin-converting enzyme 2 receptor.[1] Moreover, similarly to MERS-CoV and SARS-CoV, SARS-CoV-2 has a predilection for the pulmonary system and can result in severe pneumonia, induce serous fluid, fibrin exudates and hyaline membrane formation in the alveoli.[2,3] Although the magnitude of these pathological manifestations are largely dictated by the severity of the disease, low-dose computed tomography (CT) chest scans indicate that both mild symptomatic patients and asymptomatic carriers commonly exhibit similar lung lesions and airway abnormalities (ground glass opacities [GGO], fibrotic streaks, diffuse consolidation, etc.).[4,5] The pathological manifestations exhibited by severe but also mild symptomatic patients and asymptomatic carriers raise serious safety concerns regarding people involved in diving-related activities and accordingly warrant further consideration. Thus, the purpose of this communication is to raise awareness of the effects of COVID-19 on the pulmonary system and the possible risks associated with exposure to diving-related activities during and/or following COVID-19 infection.

COVID-19 and the pulmonary system

SEVERE SYMPTOMATIC CASES

The most common pulmonary CT-imaging feature in severe COVID-19 patients is the presence of multifocal bilateral GGO associated with consolidation areas with patchy distribution, mainly in peripheral/subpleural lung regions and with greater involvement of the posterior regions and lower lobes.[3,6,7] These areas of GGO may be admixed with focal consolidation and/or associated with superimposed intralobular and/or interlobular reticulations of septal thickening, resulting in a ‘crazy paving pattern’. Additionally, vacuolar and microvascular dilation signs, fibrotic streaks, air bronchograms and bronchus distortion have also been documented.[7] Linear consolidations and

other signs suggesting organising pneumonia such as the reverse halo sign are frequently observed.[3,8] The number of lung segments involved was found to relate to the severity of the disease and with the opacities tending to thicken with its progression.[3,6]

MILD SYMPTOMATIC CASES AND ASYMPTOMATIC CARRIERS

The literature is currently overwhelmed by a plethora of studies delineating the clinical manifestations of severe symptomatic COVID-19 patients. In contrast, limited data are available for asymptomatic carriers and patients with only mild clinical symptoms. Mainly owing to these discrepancies, there is presently limited awareness regarding the alarming lung alterations commonly observed in individuals who have undergone less severe versions of the infection. Newly published data highlighted that out of 932 patients with mild clinical symptoms, 581 (62%) exhibited lung lesions in a low-dose-CT-scan.[5] Similarly, lung GGO, fibrotic streaks and/or diffuse consolidation were also reported in asymptomatic carriers.[4,9,10] Although the CT-scan scores are higher in severe and mild symptomatic than asymptomatic cases, these observations should be considered prior to allowing resumption of diving.

PULMONARY SEQUELAE IN DISCHARGED COVID-19 PATIENTS

To the best of our knowledge, to date, only one study exists that investigated the pulmonary sequelae in discharged COVID-19 patients.[11] In this study, 149 patients (mean age: 43 years) underwent CT-scans at discharge and thereafter at one-week intervals up to three-weeks post. At discharge, CT-scans showed signs of GGO (84%), fibrous stripes (54%), and thickening of the adjacent pleura (22%). Although these residual abnormalities gradually decreased, with pulmonary lesions being completely absorbed by week three in 53% of these patients, in more than 40% GGO and fibrous stripes manifestations persisted throughout the three-week radiological follow-up, implying that a three-week recovery is insufficient to guarantee complete pulmonary restitution.

Notably, such pulmonary CT-changes are not necessarily associated with subjective or verified signs of degraded physical performance. In *Pneumocystis carinii* pneumonia, a disease with similar CT-findings, and which also presents with dry cough and silent hypoxaemia, symptoms have been shown to disappear earlier than the radiological findings.[12] An example of a similar finding with COVID-19 was a fire-fighter who had recovered from a mild case of the disease and was able to complete a 17 km run, but still showed areas of GGO on a subsequent pulmonary CT during a fitness-to-dive examination. Based on the CT-scan findings the diver was not permitted to resume diving (P Ullström MD, personal communication). Similarly, inability to maintain peripheral oxygen saturation during light exercise has been reported in two out of six asymptomatic male divers 5–6 weeks after their initial diagnosis, and four of the six divers' CT-scans still showed "*impressive structural lung changes*".[13] Collectively, these findings may suggest that longer recovery periods could be necessary prior to resuming any diving-related activities. However, at present, no firm conclusions can be drawn either regarding the pulmonary sequelae in COVID-19 patients, or how long after having contracted COVID-19 one should wait before starting to dive. The diverse structural lung manifestations observed across severe, mild and asymptomatic patients suggest that recovery periods amongst patients may vary markedly. Follow-up studies including pulmonary function testing and chest CT-scans will help to clarify the extent of the sequelae on the pulmonary system but also shed some light on the timeframe(s) of recovery.

Drawing from past experiences: SARS-CoV-1

Chest CT findings in confirmed cases of COVID-19 generally resemble those associated with SARS-CoV-1, with viral pneumonia and acute lung injury that may progress to the typical imaging features of acute respiratory distress syndrome in critically ill patients.[2] Studies that investigated the pulmonary sequelae and physical performance characteristics of severe SARS-CoV-1 survivors highlighted abnormal CT findings (e.g., lung fibrotic changes) as well as persisting reductions in exercise capacity (6-min walk test) up to one-year post-discharge.[14,15] Surprisingly, although an initial rapid reduction in the percentage of pulmonary lesions was recorded one-year post discharge (from 9.40% (SD 7.83) to 3.20% (4.78)), no further improvements were documented with the percentage of lesions remaining stable 14 years later (4.60% (6.37)).[16] In contrast, limited and conflicting evidence exists regarding the long-term effects of asymptomatic and less severe SARS-CoV-1 survivors. In 14 asymptomatic young survivors (mean age 14.7 years) residual high-resolution-CT demonstrated thoracic abnormalities even 15 months after initial diagnosis.[17] On the other hand, in less severe adult SARS-CoV-1 survivors (mean age 42 years), spirometry, lung volume measures, and diffusion capacity were within normal limits at three months post-discharge.[18] Conjointly, the aforementioned studies provide further evidence to support that a month of recovery may be too short an interval to guarantee complete pulmonary restitution from a CoV infection.

Possible risks associated with diving during/after COVID-19 pulmonary infection

The various pathological changes in the lungs may increase the risk of adverse events during diving. The initial effect of the viral infection appears to be formation of a local subpleural interstitial oedema which manifests on CT as GGO. It has been pointed out that this fluid accumulation occurs mainly in lung structures where stress and strain are concentrated.[19] As the disease progresses areas of consolidation and fibrotic strands appear more frequently. These changes are considered to be associated with increased

risk of pulmonary barotrauma during scuba diving due to air trapping and stress concentration.[20] It should also be noted that in more severe cases, pneumoceles and pulmonary blebs have been observed. Also, a number of case reports of COVID-19 patients with spontaneous pneumothoraces have been published.[21] Although far from confirmed, it is conceivable that the disease leads to a reduced strength of supportive structures in the lungs.

A major fixture of the COVID-19 infection is arterial hypoxaemia. This appears to be more related to circulatory dysfunction (e.g., inflammation and/or pulmonary thromboembolism) than an inability to ventilate the lungs properly.[19] It is, of course, of major importance that normal physical exercise capacity has been restored prior to restarting breath-hold or compressed gas diving. The fact that the viral infection produces an interstitial oedema indicates that the vasculature in at least some pulmonary areas is more susceptible to fluid leakage than normal. Given that diving activities (especially breath-hold diving) often produce larger transvascular pressures in the pulmonary circulation (e.g., head-out immersion, pulmonary squeeze during deep breath-hold dives, negative hydrostatic imbalance) than normal, it is important that the integrity of the vessels has been restored before resuming diving-related activities to avoid an increased risk of immersion pulmonary oedema. Even though functional tests (e.g., exercise test with pulse oximetry and/or echocardiography[22]) can be utilised to evaluate whether recovery has restored (*i*) normal oxygenation and (*ii*) vascular integrity, complete healing of pulmonary structural defects can only be ascertained by CT-scan of the lungs.

Conclusions

It is clear from the quoted research articles and case reports that pulmonary changes visible on CT-scans are frequent in subjects with only mild symptoms of COVID-19 infection. It is not known how the structural changes in the lungs develop and to what extent they resolve in patients with mild disease. In the one published follow-up study in hospitalised patients only slightly more than half of the patients showed complete radiological resolution three weeks after discharge.[11] Present evidence suggests that a month of recovery may be too short an interval to guarantee complete pulmonary restitution even after COVID-19 infections not demanding hospital care. However, follow-up studies will help to clarify the extent of the sequelae on the pulmonary system and shed light on the timeframe(s) of recovery. In the meantime, a precautionary principle must rule when allowing return to diving.

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