Review article

The role of routine pulmonary imaging before hyperbaric oxygen treatment

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Abstract

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Respiratory injury during or following hyperbaric oxygen treatment (HBOT) is rare, but associated pressure changes can cause iatrogenic pulmonary barotrauma with potentially severe sequelae such as pneumothoraces. Pulmonary blebs, bullae, and other emphysematous airspace abnormalities increase the risk of respiratory complications and are prevalent in otherwise healthy adults. HBOT providers may elect to use chest X-ray routinely as a pre-treatment screening tool to identify these anomalies, particularly if a history of preceding pulmonary disease is identified, but this approach has a low sensitivity and frequently provides false negative results. Computed tomography scans offer greater sensitivity for airspace lesions, but given the high prevalence of incidental and insignificant pulmonary findings among healthy individuals, would lead to a high false positive rate because most lesions are unlikely to pose a hazard during HBOT. Post-mortem and imaging studies of airspace lesion prevalence show that a significant proportion of patients who undergo HBOT likely have pulmonary abnormalities such as blebs and bullae. Nevertheless, pulmonary barotrauma is rare, and occurs mainly in those with known underlying lung pathology. Consequently, routinely using chest X-ray or computed tomography scans as screening tools prior to HBOT for low-risk patients without a pertinent medical history or lack of clinical symptoms of cardiorespiratory disease is of low value. This review outlines published cases of patients experiencing pulmonary barotrauma while undergoing pressurised treatment/testing in a hyperbaric chamber and analyses the relationship between barotrauma and pulmonary findings on imaging prior to or following exposure. A checklist and clinical decision-making tool based on suggested low-risk and high-risk features are offered to guide the use of targeted baseline thoracic imaging prior to HBOT.

Introduction

Hyperbaric oxygen treatment (HBOT) is generally very safe, but adverse events may occur during treatment.[1] Changes in atmospheric pressure during HBOT may cause pulmonary barotrauma (PBt) during the decompression phase of the treatment.[2,3] Isolated case reports have documented several pressure-change-related respiratory complications with HBOT, including arterial gas embolism (AGE), tension pneumothorax (PTX), and pneumomediastinum.[4–6] While uncommon, these adverse events are associated with significant morbidity and mortality.

PULMONARY COMPLICATIONS DURING HYPERBARIC OXYGEN TREATMENT

Pulmonary barotrauma during HBOT is rare. Our combined five-year experience (2016–2021) of three North American HBOT referral centres in Toronto, Canada (University Health Network and Rouge Valley Medical Centre) and Lebanon, NH, USA (Dartmouth-Hitchcock Medical Center), comprising 62,040 treatments performed on 2,250 patients, includes only a single case of PBt. This equates to an incidence of 0.0016% per treatment, or 0.044% per patient.

To review the utility of pre-treatment screening for predicting or preventing PBt during HBOT, we searched for articles describing patients undergoing pressurised treatment/testing in a hyperbaric chamber who had significant findings on pulmonary imaging either before hyperbaric exposure (i.e., pre-existing blebs, bullae, cysts) or afterwards (i.e., barotrauma, gas emboli). The search included several major databases (MEDLINE-Ovid, Embase, Cochrane CENTRAL, and CINAHL) and is detailed in *Appendix 1. A total of 1800 articles were screened independently by two

authors (CB and SK) to identify relevant reports, which are described in Tables 1 and 2.

Our search identified 11 reports of respiratory complications after HBOT/hyperbaric exposure with relevant radiological findings as specified above. For those reports where the patients were receiving HBOT, one detailed 126 patients undergoing mechanical ventilation and concurrent HBOT (for a variety of indications), of whom six experienced patient-ventilator asynchrony while in the hyperbaric chamber.[7] An additional six single-case studies documented a heterogeneous group of patients aged 5–80 (one female and five males) for whom HBOT was complicated by tension PTX,[6,8] pulmonary oedema,[9] pneumomediastinum,[10] acute pulmonary embolism,[11] and AGE.[12] A final report described a survey of 98 HBOT centres, reporting a combined incidence of PBt of 0.00045%.[13] For those cases that involved hyperbaric air exposure (e.g., pressure tolerance testing), one case series described two otherwise healthy individuals who sustained AGE while undertaking routine pressure tolerance testing in a hyperbaric chamber,[14] while another report described a single case of AGE during decompression from a 'dry dive' in a patient with previously undiagnosed pulmonary sarcoidosis.[5] A final, single case reported the discovery of a bronchopulmonary sequestration determined to contraindicate diving but not HBOT.[15] Isolated case reports of underwater divers and passengers on commercial airline flights describe otherwise asymptomatic adults experiencing fatal complications, such as air emboli, when exposed to variable changes in ambient pressure.[14–19]

Approximately half of the case reports described patients with pre-existing pulmonary comorbidities such as acute respiratory distress syndrome (ARDS), chronic obstructive pulmonary disease (COPD), or pulmonary sarcoidosis, pointing to possible associations with the risk of PBt during HBOT. None of the identified studies reported a significant impact of pre-treatment pulmonary screening on the decision to proceed with HBOT. In fact, in some cases pulmonary pathology was identified prior to HBOT but did not deter treatment (presumably because the centres had previously treated patients with similar pulmonary pathologies, without incident).

CURRENT PRE-HYPERBARIC OXYGEN TREATMENT SCREENING PRACTICES FOR AIRSPACE ABNORMALITIES

The hyperbaric medicine community wants to identify features that predict respiratory injury during treatment, to prevent this adverse event for those at increased risk. Pulmonary bullae, blebs, or cysts – emphysematous pockets of air within the lung parenchyma,[20,21] may be among these features.[13] Less commonly, congenital respiratory anomalies such as bronchogenic cysts and/or bronchopulmonary sequestration can be identified on imaging studies and may be associated with elevated risk of barotrauma with rapid changes in atmospheric pressure.[15,22,16–19]

Airspace abnormalities are remarkably common in the general population (Table 3). Emphysematous changes and air trapping, once thought to represent high-risk features for pressure-related respiratory complications, are frequently present in individuals without lung disease.[23] Airspaces within the visceral pleural or the subpleural lung itself are classically delineated as blebs or bullae on the basis of diameter (smaller or larger than 1 cm, respectively).[24] The prevalence of pulmonary blebs among adults without known pulmonary disease has been reported in two cohort studies, one quoting 6.0% using diagnostic thoracoscopy[25] and the other reporting 24.6% using postmortem computed tomography (CT).[26] Similarly, pulmonary bullae have been reported in 2.3–5.3% of asymptomatic patients,[26,27] often coincident with blebs. Other emphysematous changes can be found in the lungs of 14.2–16.1% of adults.[27,28] A variety of reports have described incidental findings of pulmonary nodules in 0.4–12.8% of adults,[28–33] and one quoted as many as 48.4% in a population of cardiac patients imaged using CT angiography.[27] Other pulmonary pathologies identified in patients who have experienced barotrauma during HBOT or air dives include pulmonary fibrosis[4] and sarcoidosis,[5] which occur in 0.1%–0.8%[34,35] and 0.03–0.09%[36,37] of the general population, respectively. Airspace disease may be even more common among patients undergoing assessment for HBOT than in the general population. For example, the main applications for HBOT are in treating radiation injury for patients who received radiation treatment for head and neck cancers, and these patients are likely to have a smoking history and hence potentially also some degree of COPD.

Patients with these pulmonary aberrations are often clinically asymptomatic, although they have an increased baseline risk of developing a PTX when the volume of gas in these spaces increases, commensurate with a decrease in atmospheric pressure (e.g., when an airplane is ascending to altitude or a hyperbaric chamber is being depressurised).[38] Given the increased compliance of these intrathoracic air pockets, patients with these findings who are subjected to pressure changes during HBOT are thought to be at a heightened risk of barotrauma.[13]

Some HBOT centres require a routine chest X-ray (CXR) prior to initiation of treatment to identify patients with pulmonary bullae, blebs, or PTX.[39,40] Certain centres also pursue additional investigations, such as CT imaging or spirometry, to characterise the nature of pre-existing respiratory disease and assess the risk of injury, while others routinely use CT chest imaging before HBOT.[8] Other

Footnote: *Appendix 1 is available on DHM Journal's website:
https://www.dhmjournal.com/images/Appendices/52_3/Brenna_Pulmonary_Appendix1_2022-523.pdf

investigations which may be available to providers evaluating patients for the presence of absence of gas trapping include whole body plethysmography[41] and ventilation scans using xenon,[42] nitrogen, or helium,[43] although these tests may not be available in all centres and the evidence supporting their use in pre-HBOT screening is currently limited. Despite the common practice of obtaining CXR or CT imaging as a screening tool prior to HBOT, the basis for this approach remains unclear. Presently, specific guidance on the use of pulmonary imaging prior to HBOT is not provided by the Undersea and Hyperbaric Medicine Society, the Canadian Undersea and Hyperbaric Medical Association, or the European Committee for Hyperbaric Medicine.

SENSITIVITY AND SPECIFICITY OF PRE-TREATMENT PULMONARY IMAGING

Chest X-ray is the mainstay of pre-HBOT pulmonary screening tools, largely because of its relatively low cost and minimal radiation dose.[20,44] Its diagnostic sensitivity for minor airspace abnormalities (including bullous and bleb disease) is low,[44] and relevant pathology may go unrecognised despite screening. CXRs are valuable tools for the diagnosis of pathologies such as consolidation and pleural effusion,[44] but have poor interrater reliability and limited specificity for pathologies which do not vary greatly in density.[20] The sensitivity of a CXR for even moderately severe and severe emphysematous changes is only 41%,[45] and minor airspace abnormalities like bullae and blebs can easily be missed. For example, one study describes three cases of pulmonary air cysts missed on CXR, and subsequently found on chest CT scans, in divers who had experienced PBt.[46] CXR is similarly limited in its ability to detect PTX, with a pooled diagnostic sensitivity of only 52%.[47]

In fitness-to-dive assessments CXR had a false negative rate of 32% for the identification of relevant intrapulmonary pathology.[48] The routine use of CXR for the detection of blebs, bullae, cysts, and other airspace disease may not add more to the pre-dive assessment than the individual's medical history.[46,48] This is likely also true for pre-HBOT screening in patients without any risk factors. In patients for whom a significant concern for pulmonary pathology exists, CT imaging has superior diagnostic accuracy.[44]

High-resolution CT has been proposed as a substitute for CXR in pre-HBOT screening, particularly in subjects with clinical indications.[8,12,14,48] The radiation exposure associated with high-resolution CT varies dramatically based on imaging parameters but, if performed conservatively, is comparable to a CXR.[49] While CT is a superior diagnostic tool for airway abnormalities such as pulmonary cysts,[21] it frequently identifies findings of unknown medical significance.[23,48] One study conducted in the emergency department setting noted that 33.4% of the general population had some form of incidental findings on CT imaging, such as pulmonary nodules.[50] Another, conducting postmortem CT chest scans in a sample of the general population (ages 21–71, without lung disease) reported a 33.8% prevalence of small bullae and/or blebs.[26] Incidental, clinically insignificant CT findings may be more prevalent in older patients,[51] and complicate the potential role of CT imaging in 'clearing' patients for HBOT. Additionally, while CT provides information on the presence and size of any relevant pulmonary pathology, it cannot provide guidance on whether the structure can equalise pressure during compression or decompression. While size is an important consideration (larger bullae have higher wall stress and are more likely to rupture than small ones), the relevant consideration for HBOT is whether the structure communicates with the bronchial tree during pressure changes.

CLINICAL INTERPRETATION OF PULMONARY FINDINGS

Because of the shortcomings of imaging modalities available for pre-HBOT screening, how to estimate the risk associated with potential findings is unclear. Many of the studies outlined in Table 1 report respiratory complications of HBOT despite adherence to pre-HBOT imaging protocols and unremarkable imaging studies prior to treatment.[5,7–10,14] The difficulty associated with interpreting incidental imaging findings is highlighted by two case reports detailing patients whose pre-HBOT imaging identified bullous or bleb disease, but who nonetheless proceeded with HBOT and sustained respiratory complications.[6,12]

Without clear evidence to discriminate abnormalities representing an elevated risk for PBt from incidental morphology, the utility of pre-HBOT imaging is limited. In a survey of practice patterns among 98 HBOT centres, a majority of centres reported choosing to proceed with treatment for patients in whom pulmonary blebs or bullous lesions were radiologically identified.[13] Of those centres which did not, 54% screened patients with a history of lung disease using CXR, while a minority screened those with known pathology using CT, high-resolution CT, or spirometry.[13] Some of the surveyed centres reported taking additional precautions when treating patients with identifiable blebs or bullous lesions (such as slower compression/decompression rates, pressure limits, and bronchodilator administration).[13] The applicability of the survey to current practice can be challenged given its age, low response rate (36.8%), and methodological limitations. But among its 98 responding centres, imaging results seldom influenced treatment decisions in a meaningful way.[13] Nonetheless, PBt was still remarkably infrequent among the surveyed centres, with a reported incidence of 0.00045% or nine instances from approximately 2,000,000 HBOT sessions.[13]

Table 1

Previous reports of pulmonary complications during hyperbaric oxygen exposures; data are reported as raw numbers unless otherwise noted. *number of responding hyperbaric centres, not numbers of patients; ARDS – acute respiratory distress syndrome; AGE – arterial gas embolism; CO – carbon monoxide; COPD – chronic obstructive pulmonary disease; CT – computed tomography; CXR – chest radiography; DCS – decompression sickness; F – female; HBOT – hyperbaric oxygen treatment; M – male; N/A – not applicable; NR – not reported; PBt – pulmonary barotrauma; PCT – prospective cohort trial; PTX – pneumothorax; PVD – peripheral vascular disease; US – ultrasound

Citation, country, and study design	Population			HBOT exposure			Pulmonary imaging		
	n	Age, Sex	Patient comorbidities	Exposure indication	Sessions	Respiratory complications	Pulmonary imaging modality	Impact on exposure	Relevant commentary on pre-exposure imaging
Bessereau et al. (2017)[7] France PCT	126	Mean Age: 57 Sex: M = 78 F = 48	ARDS (23%), mechanical ventilation (100%)	DCS, CO poisoning, AGE, soft tissue infection, chronic wounds	Mean = 1	Patient-ventilator asynchrony (*n* = 6)	Imaging modality not specified	Did not inform treatment decision	CXR is limited in identifying small or anterior PTX with certainty. Chest US and tomodensitometry are both better, and physicians should perform more relevant, non-invasive tests.
Cakmak et al. (2015)[8] Turkey Case report	1	Age: 28 Sex: M	ARDS	Lower extremity wounds	7	Tension PTX (*n* = 1)	CXR and CT prior to HBOT – no bullae or blebs. After the 7th session, CT showed total right lung collapse with left mediastinal shift.	Did not inform treatment decision	Sensitivity of the CT scan in the detection of blebs and bullae is 88%. A bleb or bullae that was not detected on CT may be the reason for PTX in the reported patient.
Cho et al. (2018)[9] Japan Case report	1	Age: 31 Sex: M	N/A	CO poisoning	2	Pulmonary oedema (*n* = 1)	Pre-HBOT CXR unremarkable. Repeat CXR after 2nd HBOT session noted pulmonary oedema.	Did not inform treatment decision	NR
Jaeger et al. (2013)[10] USA Case report	1	Age: 5 Sex: M	NR	CO poisoning	1	Pneumo-mediastinum (*n* = 1)	Post-intubation CXR normal. CXR after HBOT found occult pneumo-mediastinum	Did not inform treatment decision	Routine pre- and post-HBOT CXR in intubated patients may prevent or minimise adverse outcomes related to pneumomediastinum
Obiagwu et al. (2015)[11] USA Case report	1	Age: 80 Sex: M	Ischaemic cardio-myopathy, diabetes, PVD	Diabetic foot ulcer	NR	Acute pulmonary embolism (*n* = 1)	No pre-HBOT screening. CXR after HBOT and intubation bilateral alveolar perivascular infiltrates.	N/A	NR

Table 1 continued.

Rivalland et al. (2010)[12] New Zealand Case report	1	Age: 72 Sex: M	COPD, oral squamous cell carcinoma	NR	1	Cerebral AGE (n = 1)	CXR prior to HBOT clearly showed bullous disease in the left upper lobe. Post-HBOT, CXR again demonstrated bullae in the left upper lobe.	Did not inform treatment decision	CXR is appropriate if abnormal respiratory history (e.g., tuberculosis, smoking, or pneumonia). CT is more sensitive for cystic change, but may find insignificant lesions in normal subjects and should probably be reserved for cases where CXR is equivocal and index of suspicion for significant lesions is high.
Toklu et al. (2008)[13] Turkey Survey	98*	NR	NR	NR	NR	PBt (n = 9) from approximately 2,000,000 exposures (0.00045%)	Only 33.7% of centres excluded patients with air cysts, and 54% of these screened patients with known lung disease using CXR. Others used CT or spirometry.	Most centres (66.3%) proceeded regardless of findings on imaging	This survey demonstrated that (1) a large proportion of HBOT centres treat patients with blebs/ bullae, (2) CXR is the most common thoracic screening tool, and (3) the prevalence of PBt is very low in HBOT.
Unsworth et al. (1973)[6] Australia Case report	1	Age: 55 Sex: F = 1	Squamous cell carcinoma, permanent tracheostomy	Wound healing	8	Tension PTX (n = 1)	Pre-HBOT CXRs showed COPD and right middle lobe (inflammatory or neoplastic) opacity. Post-HBOT CXR noted right-sided tension PTX.	Did not inform treatment decision	Some patients may be excluded from HBOT based on history or physical examination alone. CXR and pulmonary function studies using spirometry and nitrogen or helium washout patterns may add value.

Table 2

Previous reports of pulmonary complications during hyperbaric air exposures; data are reported as raw numbers unless otherwise noted. The exposure indication in all cases was routine pressure tolerance testing or a dry dive experience. AGE – arterial gas embolism; CT – computed tomography; CXR – chest radiography; HBOT – hyperbaric oxygen treatment; M – male; N/A – not applicable; PBt – pulmonary barotrauma

Citation, country, and study design	Population			Hyperbaric exposure		Pulmonary imaging		
	n	Age, Sex	Comorbidities	*n*	Respiratory complications	Pulmonary imaging modality	Impact on exposure	Relevant commentary on pre-exposure imaging
Buschmann et al. (2010)[14] South Africa Case series	2	Mean Age: 30 Sex: M = 2	N/A	1	AGE (*n* = 2)	Case 1: CXR on day 1 was normal. A CT chest on day 2 noted a 2.5 cm right basal subpleural bleb/bulla. Case 2: CT (chest) on day 8 was normal.	Did not inform treatment decision	CXR is commonly performed but based on weak evidence. CT more sensitive, but cost may not be justified with an overall low incidence of PBt/AGE and an unclear relationship between findings and pulmonary risk of barotrauma. Lung compliance rather than anatomical lesions (blebs/bullae), may guide risk.
Tan et al. (2020)[15] Singapore Case report	1	Age: 26 Sex: M	N/A	N/A	N/A	Lateral pre-exposure CXR revealed a left lower lobe pulmonary nodule. A chest CT then diagnosed a cavitary left lower lobe (intralobar) broncho-pulmonary sequestration.	Did not inform treatment decision	Bronchopulmonary sequestrations and other air-filled parenchymal lesions should contraindicate diving (but the patient was still considered eligible for HBOT). Although this case supports routine use of lateral CXR in pre-diving health screening, its marginal utility should be weighed against costs (financial, radiation exposure, and false positive rates).
Tetzlaff et al. (1999)[5] Germany Case report	1	Age: 46 Sex: M	Pulmonary sarcoidosis (discovered after hyperbaric exposure)	1	AGE (*n* = 1)	CXR was normal four years pre-exposure. Post-exposure CXR showed bilateral middle and upper lobe infiltrates. CT showed scarring in both lungs.	Did not inform treatment decision	Case illustrates a potential risk of PBt during hyperbaric exposure, even in asymptomatic subjects with normal imaging. Authors emphasise careful evaluation of spirometry and CXR in patients undergoing hyperbaric exposure.

Table 3

High-risk features in the general population; prevalence of high-risk features for pulmonary complications of hyperbaric oxygen treatment, including pulmonary blebs and bullae, other emphysematous changes, pulmonary fibrosis, and sarcoidosis. Data are reported as percentage of study population or number per 100,000 patients. CAD – coronary artery disease; CXR – chest radiography; CT – computed tomography; NR – not reported

High-risk feature	Study population	Screening method	Prevalence	Citation
Pulmonary blebs only	Dutch population without pulmonary disorders	Post-mortem CT imaging	24.6% (32/130)	de Bakker et al. (2020)[26]
	Young healthy adults	Thoracoscopy	6.0% (15/250)	Amjadi et al. (2007)[25]
Pulmonary blebs and bullae	Dutch population without pulmonary disorders	Post-mortem CT imaging	6.9% (9/130)	de Bakker et al. (2020)[26]
Pulmonary bullae only	Dutch population without pulmonary disorders	Post-mortem CT imaging	2.3% (3/130)	de Bakker et al. (2020)[26]
	Patients with CAD	CT angiography	5.8% (10/171)	Yorgun et al. (2010)[27]
Other emphysematous changes	Adult trauma patients	Spiral CT	14.2% (297/2092)	Barrett et al. (2009)[28]
	Patients with CAD	CT angiography	16.4% (28/171)	Yorgun et al. (2010)[27]
Incidental pulmonary nodules	Adult trauma patients	Spiral CT	10.9% (229/2092)	Barrett et al. (2009)[28]
	General population	CT angiography	12.8% (33/258)	Gil et al. (2007)[29]
	Cardiac patients	Electron-beam CT	4.8% (65/1356)	Horton et al. (2002)[30]
	Cardiac patients	Electron-beam CT	0.44% (8/1812)	Hunold et al. (2001)[31]
	Cardiac patients	Cardiac CT	2.4% (4/166)	Haller et al. (2006)[32]
	Cardiac patients	Cardiac CT	6.6% (33/503)	Onuma et al. (2006)[33]
	Cardiac patients	CT angiography	48.5% (83/171)	Yorgun et al. (2010)[27]
Pulmonary fibrosis	General Population (Quebec, Canada)	NR	0.08% (76/100,000)	Tarride et al. (2018)[34]
	General population, ages 16–84 (USA)	NR	0.0099% (9.85/100,000)	Raghu et al. (2016)[35]
Sarcoidosis	General adult population (USA)	NR	0.88% (29,372/3,340,000)	Baughman et al. (2016)[36]
	General population, ages 20–69 (USA)	CXR or histology	0.03% (259/830,891)	Rybicki et al. (1997)[37]

Considering the relatively high incidence of otherwise-benign pulmonary lesions in the general population and the low incidence of pulmonary complications following HBOT, we can conclude that many patients with pulmonary abnormalities are routinely undergoing HBOT without any observed complications. A patient with relevant pulmonary abnormalities is more likely to have unremarkable pre-treatment CXR imaging than they are to experience iatrogenic pulmonary complications during HBOT. Based on an incidence for PBt during HBOT of 0.00045%,[13] the number needed to treat (NNT) to prevent one case of barotrauma would be 2,222 if there was a perfectly sensitive and specific tool to identify patients certain to experience that complication. In reality, the NNT must be much higher to account for both the limitations in CXR sensitivity and the unknown likelihood that an identified abnormality will predispose to barotrauma. In current practice, if patients identified as having radiological risk factors for PBt are not actually excluded from HBOT, the NNT of CXR is infinity.

Table 4
Low-risk features of patient history and physical exam which may be reassuring of low-risk for pulmonary complications following hyperbaric oxygen treatment. ARDS – acute respiratory distress syndrome; COPD – chronic obstructive pulmonary disease; HBOT – hyperbaric oxygen treatment PTX – pneumothorax

Possible low-risk features
No history, symptoms, or physical exam findings of asthma, COPD, pulmonary fibrosis, sarcoidosis, PTX, or ARDS
Unremarkable thoracic imaging, if previously performed and available for review
Previous HBOT without incident
History of scuba diving or air travel without incident
Age < 40 years
Non-smoker

Based on the current evidence, we suggest that thousands of patients would have to undergo pulmonary imaging – with its own associated costs and risks – to prevent one from undergoing HBOT and developing PBt. The process would also exclude patients who would not have otherwise sustained barotrauma, and could also include some who would suffer it nonetheless. Given the challenges in applying imaging findings to the clinical determination of which patients are safe to endure hyperbaric conditions, we suggest that pre-HBOT imaging adds very little to a thorough history and physical exam in low-risk populations.

RISK STRATIFICATION BEYOND PRE-TREATMENT IMAGING

Pre-HBOT imaging can (sometimes) provide information on whether a patient has intrathoracic anatomical abnormalities, but it can offer little guidance on whether those abnormalities are likely to cause problems in the hyperbaric chamber. We instead draw on common features of patients reported as having experienced PBt during HBOT in the scientific literature[4–12,14,15] to suggest a checklist of possible clinical indicators of relatively low risk for pulmonary complications of HBOT (for whom imaging may have the least to offer). These features include: the absence of pre-existing obstructive lung diseases, restrictive lung diseases, PTX, or ARDS; a history of HBOT, scuba diving, or air travel without incident; age younger than 40 years; and non-smoking (Table 4). When prior thoracic imaging is available, especially if it is recently performed, it should be reviewed.

The risk factors for spontaneous pneumothoraces or emphysematous lung changes (e.g., younger age, male sex, low body mass index, pulmonary infection, and cigarette and/or marijuana smoking),[46,52–54] which are themselves predictors of PBt during HBOT, may also indirectly inform hyperbaric exposure risk. Based on the available evidence, and clinical experience, a practical clinical risk tool is provided in *Appendix 2 (in the form of a questionnaire) to support clinicians' and patients' decisions to pursue or forego chest imaging prior to HBOT.

ROUTINE PULMONARY SCREENING BEFORE OTHER VOCATIONAL OR RECREATIONAL HYPERBARIC EXPOSURES

While the present article focuses on pulmonary screening prior to HBOT, its findings are applicable to medical assessments preceding other hyperbaric exposures. Pulmonary barotrauma occurring in divers is well described,[55,56] and the risk can be extrapolated to others working in environments prone to rapid atmospheric compression and decompression, such as caisson or compressed air workers. The incidence of PBt in these groups has not been clearly defined, but reports of affected divers have identified several risk factors including airway obstruction, pre-existing respiratory disease or structural parenchymal abnormality (e.g., bullae or blebs), or a reduced mid-expiratory flow at 25% of vital capacity.[57–59]

Despite the risk of PBT associated with compression and decompression in these contexts, whether pulmonary imaging is required as part of the standard medical assessment of prospective commercial or recreational divers remains controversial. Recognising the low yield of a screening CXR, the guidelines of some national organisations (such as the UK Health and Safety Executive)[60] and many major sources of knowledge in the field suggest that CXR is not a requirement unless justified by heightened individual risk.[61,62] Others, in contrast, have suggested that there is a role for routine CXR screening for all prospective divers,[63] or at least for professional divers/diving instructors.[46,64] When pulmonary screening is warranted by local policy or a high index of suspicion for PBT-predisposing factors, high-resolution CT imaging has been advocated as a potential tool for the initial examination of divers,[46,65] although this is not currently practical in many settings.

The pre-HBOT risk stratification checklist presented in Table 4 overlaps with, and can be supplemented by, the known risk factors identified for PBt among divers such as pre-existing respiratory disease and blebs/bullae.[57,58] However, the precise risk profiles of HBOT and other hyperbaric exposures may differ. For example, compression/

Footnote: *Appendix 2 is available on DHM Journal's website:
https://www.dhmjournal.com/images/Appendices/52_3/Brenna_Pulmonary_Appendix2_2022-523.pdf

decompression injury during diving typically involves much faster pressure change and relates largely to nitrogen, which is inert and less soluble, while oxygen (in HBOT) is more soluble and metabolically consumed. These differences may help explain the relative rarity of AGE during HBOT, which we found reported in only two case studies.[4,12]

LIMITATIONS

The core limitation of this review is its susceptibility to publication bias. Cases where pulmonary complications were avoided via the identification of bullae or blebs on pre-HBOT imaging are almost certainly under-reported in the literature, although survey data suggest most centres do not consider CXR findings of bullae or blebs to be an absolute contraindication to HBOT, and routinely proceed with treatment – with a very low overall incidence of PBt.[13] This core limitation could be overcome in the future by using an international multicentre hyperbaric oxygen treatment registry[66] designed to collect and analyse outcomes and complications related to HBOT exposures.

Conclusions

This review highlights the limitations of routine pulmonary imaging as a screening tool prior to HBOT. Reports of PBt during HBOT often describe patients with known pre-existing pulmonary pathology (e.g., asthma, COPD, pulmonary fibrosis, sarcoidosis, PTX, or ARDS) or occult intrathoracic abnormalities (e.g., bullous lesions or blebs). Abnormalities which might be considered to increase the risk of pulmonary complication during HBOT are common, even among otherwise healthy individuals without any pulmonary disease. Importantly, normal pre-HBOT CXR does not preclude patients from developing barotrauma. The use of routine imaging prior to HBOT does not provide a reliable way to reduce the risk of iatrogenic injury in low-risk populations. In high-risk patients or when clinical findings are unclear (e.g., unable to rule out a PTX), high-resolution CT imaging may be a superior test for the identification of airway or parenchymal lung disease in carefully selected patients. The presence of an abnormality on CT scan, however, does not provide a dependable measure of whether the lesion might rupture or leak with changes in atmospheric pressure. Ultimately, the provider will need to use clinical judgement when determining how to proceed for patients deemed high-risk for respiratory complications of HBOT.

A thorough approach to patients' past medical histories and physical examinations are more relevant steps in assessing the risk for iatrogenic respiratory complications related to HBOT. Further research is needed to characterise how specific features of patients' demographic and past medical history may influence the risk of iatrogenic lung injury during HBOT. This review suggests that, for low-risk individuals, HBOT can proceed without pre-treatment chest imaging.

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Conflicts of interest and funding

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