The role of routine cardiac investigations before hyperbaric oxygen treatment

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Abstract

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Cardiac complications are a rare but potentially serious consequence of hyperbaric oxygen treatment (HBOT), resulting from increased blood pressure and decreased heart rate and cardiac output associated with treatment. These physiologic changes are generally well-tolerated by patients without preexisting cardiac conditions, although those with known or undetected cardiac disease may be more vulnerable to treatment complications. Currently, there are no universally accepted guidelines for pre-HBOT cardiac screening to identify these patients at heightened risk, leading to variability in practice patterns. In the absence of HBOT-specific evidence, screening protocols might be adapted from the diving medicine community; however, given the important differences in physiological stressors, these may not be entirely applicable to patients undergoing HBOT. Traditional cardiac investigations such as electro- and echo-cardiograms are limited in their ability to detect relevant risk modifying states in the pre-HBOT patient, stymieing their cost-effectiveness as routine tests. In the absence of strong evidence to support routine cardiac investigation, we argue that a comprehensive history and physical exam – tailored to identify high-risk patients based on clinical parameters – may serve as a more practical screening tool. While certain unique patient groups such as those undergoing dialysis or with implanted cardiac devices may warrant specialised assessment, thorough evaluation may be sufficient to identify many patients unlikely to benefit from cardiac investigation in the pre-HBOT setting. A clinical decision-making tool based on suggested low-risk and high-risk features is offered to guide the use of targeted cardiac investigation prior to HBOT.

Introduction

Hyperbaric oxygen treatment (HBOT) has several unique effects on human physiology, resulting from the combination of breathing pure (100%) oxygen and exposure to heightened pressure.[1] These effects serve as therapeutic mechanisms for its use in the treatment of a variety of medical conditions, but are also responsible for treatment complications in a rare minority of patients undergoing HBOT. As with other medical interventions, treatment decisions are made on the basis of a relative balance of expected benefits and risks, and these are estimated by way of thorough patient evaluation (e.g., to identify those at greatest risk) in combination with the best available evidence (e.g., to quantify or ameliorate that risk).

Currently, there are no widely accepted guidelines for screening patients prior to the initiation of HBOT. In the absence of expert recommendations, this process is usually undertaken at the discretion of individual providers. Typically, the initial assessment includes a thorough history and physical examination to substantiate the indication for which HBOT is considered, as well as other potentially relevant medical comorbidities and/or known contraindications to treatment. Many centres also routinely perform pre-HBOT screening with chest X-ray and/or pulmonary function testing to rule out pre-existing airways disease, which may portend an increased risk of pulmonary complications of HBOT,[2] although we have previously demonstrated the limited utility of these investigations in low-risk patient population.[3,4] Similarly, many centres including our own have been performing cardiac investigations such as electrocardiograms (ECGs) or echocardiograms as a matter of routine,[5] although the utility and value of these tests in the pre-HBOT setting has not been previously characterised.

Cardiac investigations in fitness-to-dive testing

The diving medicine community has been more methodical in developing and operationalising standard fitness-to-dive assessments, and these have undoubtedly influenced pre-HBOT screening practices. For example, the South Pacific Underwater Medicine Society has articulated clear guidelines for cardiac evaluation, including the performance of an ECG for all diving candidates older than age 45, as well as more comprehensive tests like cardiac stress tests, computed tomography angiograms, or echocardiograms for those with higher cardiovascular risk.[6] For others, a focused questionnaire is accepted as a reasonable screening tool.[7] Many hyperbaric medical units have conformed to similar practices; however, the relevant cardiac risks of diving do not necessarily extend to hyperbaric treatment, calling into question whether screening practices should be shared without modification between these communities.

Cardiac conditions are the second most common cause of diving-related deaths.[8,9] However, these are largely attributed to increased myocardial oxygen demand during the metabolically taxing activity of swimming, in combination with increases in both cardiac preload (resulting from immersion-induced increases in central venous return) and afterload (resulting from cold-induced peripheral vasoconstriction).[8] Thus, fitness-to-dive assessments focus on the detection of coronary artery disease (CAD) to identify divers who cannot tolerate the additional cardiac demands associated with exertion under pressure.[9,10] However, the metabolic demands of HBOT are minimal and, with greater dissolved oxygen in the blood, the risk of acute coronary syndrome (ACS) during treatment is very small. On the contrary, HBOT has been proposed as a treatment for ACS and small trials suggest morbidity and mortality benefits.[11] Some have also argued for cardiac screening in the fitness-to-dive assessment to detect a patent foramen ovale,[12] which may serve as a direct conduit for small venous nitrogen bubbles (formed while surfacing) to enter the systemic circulation as paradoxical gas emboli.[12–14] However, this is not widely practiced and, similarly to CAD, the concern is not relevant to HBOT. Therefore, HBOT providers should tailor cardiac investigations according to modifiable risks material to HBOT.

Cardiac effects of hyperbaric oxygen treatment

While the presence of CAD is less informative of cardiac risk in the context of hyperbaric medicine, HBOT does have several known effects on cardiovascular function.[15] In the peripheral circulation, high partial pressures of oxygen cause transient vasoconstriction which increases left ventricular afterload, as well as peripheral vascular resistance and arterial blood pressure (ABP).[16] Suggested mechanisms include the formation of reactive oxygen species which interfere with nitric oxide's vasodilating effect, and/or hyperoxic inhibition of prostaglandin synthesis.[17] This can be clinically relevant for patients with hypertension, although the effect is generally small: recent studies demonstrate that HBOT is associated with an average increase of ABP by 4–11 mmHg, with larger changes in systolic than diastolic components.[16,18] The existing literature has demonstrated that patients with preexisting hypertension may experience greater increases in ABP during HBOT, while there is more controversy surrounding the cumulative effects of long treatment courses on this haemodynamic parameter.[16,18]

The other major cardiac effect of HBOT relates to heart rate (HR), which decreases due to both oxygen-dependent and oxygen-independent physiologic mechanisms.[15] Bradycardia appears to result predominately from indirect effects of HBOT on the heart (e.g., mediated by baroreceptor activation),[19] possibly compounded by direct effects of pressure on the myocardium.[20,21] An ordinary bradycardic response to HBOT may be a decrease in HR of approximately 20%, occurring gradually over the course of treatment.[17,19] Coronary perfusion is also decreased during HBOT, but this is balanced by a decrease in myocardial work and demand.[15,22] The reduction in HR is associated with, and possibly the main cause of a decrease in cardiac output (CO) for some patients.

Previous studies have reported a decrease in CO between 8% and 18% during HBOT.[23–25] However, for many patients, haemodynamic compensation can limit the impact of these changes. For example, bradycardia facilitates better ventricular filling during diastole, increasing left ventricle (LV) preload and maintaining stroke volume.[15] Recent studies have even reported that HBOT may improve LV ejection fraction (LVEF) for some patients without cardiac symptoms,[26] and increase global longitudinal strain to improve LV systolic function recovery in patients suffering from post-COVID-19 syndrome.[27] Furthermore, because the dissolved oxygen content of blood increases dramatically during HBOT, tissue oxygen requirements can be met despite a decreased CO.

However, patients with heart failure may have limited reserve to compensate for decreases in CO, and may experience further deterioration of prior LV dysfunction during HBOT, including the development of acute pulmonary oedema immediately after HBOT.[28,29] One explanatory hypothesis may involve the relative decrease in oxygen tension immediately following HBOT, leading to acute heart strain and a transient increase in physiological stress. This may affect cardiac function; however, the impact of this return to normoxia on cardiac strain has not yet been well characterised in the literature. Vincent and colleagues performed a retrospective review of 23 patients with a past medical history of heart failure and reduced LVEF (< 40%), and reported that two patients experienced acute heart failure within 24 hours of HBOT.[30] Nevertheless, both cases included significant potential confounding features such as takotsubo cardiomyopathy and septic shock, and current evidence suggests that pulmonary oedema is unlikely to be triggered by HBOT alone in the absence of other predisposing factors. These findings are consistent with our own data suggesting that a minority of patients with heart failure may experience deterioration of symptoms following HBOT.[25] Consequently, heart failure may not be an absolute contraindication to HBOT; however, caution and close monitoring of these patients are warranted.[25,30]

Cardiac investigations for hyperbaric oxygen treatment

In accordance with the principle "*do no harm*", cardiac screening before HBOT should be based on the balance of expected risks and benefits. The various haemodynamic changes of HBOT appear to be well tolerated by patients with no preexisting cardiac disease.[31] Over the past decade, our major North American HBOT referral centre in Toronto, Canada has performed approximately 26,000 treatments: in our experience, we have not observed any unexpected cardiac complications among patients without a previously known cardiac history. However, identifying those at heightened risk remains an important challenge for the mitigation of cardiac complications, and severe hypertension, advanced CAD, and symptomatic heart failure appear to be relevant conditions.

In the broader clinical arena, it is recognised that screening tests are widely misused (i.e., implemented when they will not change management).[32] For example, the resting 12-lead ECG has very limited application in detecting arrhythmias or other cardiac pathology in otherwise healthy individuals. The sensitivity of an ECG for the diagnosis of left ventricular hypertrophy is a mere 7%.[33] Electrocardiographic criteria alone are not reliable for the confirmation or exclusion of important heart disease,[34] particularly the presence or absence of suspected heart failure. Transthoracic echocardiography is a preferred test for the detection of heart failure,[35] but a low incidence of heart failure in the general population[36] limits the cost-effectiveness of this test as a routine screening tool. Blood tests such as N-terminal pro b-type natriuretic peptide (NT-proBNP) have been applied in the diagnosis of heart failure, but are similarly limited as a first-line screening tool due to a lack of consensus regarding diagnostic thresholds.[37]

The value proposition of routinely applying any investigation with limited predictive value comes into question when considering the major expense associated with population screening. Choosing Wisely presents Canadian guidelines aimed at limiting unnecessary testing in the perioperative context,[38] which currently recommend that asymptomatic, low-risk patients undergoing non-cardiac surgery are not subjected to a baseline ECG,[39–41] resting echocardiography,[42,43] or cardiac stress testing.[44–47]

In contrast, a detailed history and physical exam may be the most reliable and cost-effective screening tools for heart failure. For example, a large cross-sectional diagnostic accuracy study of 721 patients (of whom 29% had heart failure) demonstrated a strong predictive model using nine key pieces of data collected from a patient history and physical exam. Those data included: age, history of CAD, pulse rate and rhythm, displaced apex beat, rales or heart murmur on auscultation, increased jugular vein pressure, and the use of loop diuretics.[48] Furthermore, rapid bedside screening tests, when performed correctly, can detect LV dysfunction with respectable accuracy. For example, a single Valsalva maneuver (specificity 91%, sensitivity 69%)[49] or hepatojugular reflex (specificity 96%, sensitivity 12%)[50] can be performed in under one minute to assess for heart failure.

Suggested guidelines

Currently, there is no robust evidence relating to the use of any cardiac investigations prior to HBOT. There is a pressing need for future studies to characterise the efficacy and cost-effectiveness of available cardiac tests in the pre-HBOT context. In the meantime, we suggest a pragmatic approach and offer a practical clinical risk tool drawing on the available literature surrounding risk factors for the development of congestive heart failure,[51] the diagnostic utility of information acquired through history and physical examination,[48,49] guidelines for perioperative cardiovascular risk assessment[38,52] and for the management of known heart failure,[53] and clinical intuition (Figure 1). This tool is presented in the form of a questionnaire which stratifies patients as low- or high-risk with respect to modifiable cardiac risk and is intended to support decisions to either pursue or forego cardiac investigations prior to HBOT. This tool will require further internal and external validation.

Limitations and future directions

There are several important caveats for any clinical risk assessment tool. Principally, it should augment but not replace the clinical judgement of a hyperbaric physician. Unique circumstances may present special cardiac risks deserving of pre-HBOT investigations. One example of a potentially high-risk group is patients undergoing dialysis, given their unique risks of fluid overload and electrolyte disturbance. Investigations may stand to inform management of these patients, as significant fluid overload would favor performing HBOT immediately after dialysis sessions, rather than immediately before them. Another example is patients with implanted devices like permanent pacemakers, defibrillators, or intrathecal pumps, for which pre-treatment device interrogation is extremely important as some of these devices may bear unique risks of fire hazard or damage during exposure to HBOT.[54,55] Finally, some indications for HBOT may be intricately associated with increased cardiovascular risk. For instance, carbon monoxide poisoning is itself associated with myocardial ischaemia and LV dysfunction;[56] however, the urgency and likely benefit of HBOT in this scenario would take priority over a delayed approach to facilitate cardiac risk assessment.

Figure 1

Clinical decision-making questionnaire; a questionnaire based on current evidence to support clinicians and patients in the decision to pursue or forego cardiac investigations prior to hyperbaric oxygen treatment. [1] During a Valsalva manoeuvre (forced expiratory effort against a closed airway), a transient increase in systolic blood pressure is normal. While auscultating the brachial pulse, both persistent Korotkoff sounds throughout this manoeuvre and failure of Korotkoff sounds to resume after conclusion of the Valsalva are considered abnormal. [2] A positive hepatojugular reflex is defined by an increase in jugular venous pressure of at least 3 cm, sustained for at least 15 seconds, signifying that the right ventricle cannot accommodate the augmented venous return. [3] Four metabolic equivalents is the approximate intensity of activities like light housework/yardwork, climbing a flight of stairs, or walking on level ground at 4 miles·hour^{-1}. [4] Unexplained weight increase greater than 1 kg·day^{-1} or 2 kg·week^{-1} is considered suspicious for heart failure

SHOULD MY PATIENT HAVE CARDIAC INVESTIGATIONS?

A Pre-Hyperbaric Oxygen Therapy Questionnaire

Low-Risk Features

- Age < 75 years
- No medical history/symptoms of cardiovascular disease
- Unremarkable physical exam, with a normal pulse rate/rhythm and non-displaced apex beat
- Normal Valsalva maneuver[1] and hepatojugular reflex[2]
- Physical exercise tolerance > 4 METs[3]
- Recent NT-proBNP < 100 pg·mL^{-1}*

With all low-risk features, treatment decisions are unlikely to be influenced by cardiac investigations.

High-Risk Features

- History of exertional shortness of breath, chest pain, or increasing daily weights[4]
- Rales, murmurs, elevated jugular venous pressure, ascites, or pedal edema on physical exam
- History of congestive heart failure, coronary artery disease, and/or valvular heart disease
- Use of loop diuretics
- Significant smoking history (e.g., > 20 pack-years)
- History of hypertension and/or diabetes
- History of abnormal cardiovascular investigations (e.g., low LVEF, multivessel CAD, valve abnormality) without cardiology follow-up during the past year

With one or more high-risk features, the use of cardiac investigations should be guided by clinical judgement.

Other Protective Features*

- Recent, unremarkable cardiac investigations with no interval change in health status or medications
- Recent uncomplicated non-cardiac/non-thoracic surgery
- Recent uncomplicated diving exposure

Low likelihood to benefit from cardiac investigations, even with high-risk features.

Additional Information

For all patients a detailed history should be obtained, and a focused clinical exam should be performed. While in many circumstances cardiac investigations may not meaningfully inform HBOT treatment decisions, test results should always be reviewed if previously performed for another reason. Prior cardiac investigations, especially if recent, may obviate the need for further testing whether or not they demonstrate remarkable findings. This questionnaire is designed to assist with decision-making, but ultimately investigation and treatment decisions rest with the patient and HBOT provider.
*Within the preceding twelve months. JVP – jugular venous pressure; METs – metabolic equivalents; NT-proBNP – N-terminal pro-B-type natriuretic peptide; LVEF – left ventricular ejection fraction; CAD – coronary artery disease.

The role of cardiac investigations to elucidate cardiovascular risks prior to HBOT remains poorly defined. Future directions for this work should focus on robust clinical studies characterising the contributions of specific cardiac tests to decisions of whether to proceed or not with HBOT. Another important aspect of pre-HBOT testing is the evaluation of the cost-effectiveness of these investigations. Finally, for risk stratification to be successful, the cardiac risks of HBOT must be better understood. Current evidence suggests that acute decompensation of existing heart failure happens in a rare minority of patients undergoing HBOT, but it is not well understood why some patients decompensate while others do not, or how to predict which patients would benefit from tailored care or the consideration of alternative therapies.

Conclusions

The marginal benefit of incorporating cardiac screening investigations in the pre-HBOT care of all patients is likely to be low. While there is a paucity of evidence to guide decision-making with respect to screening for relevant cardiac disease, the existing literature demonstrates that HBOT is tolerated without complication by most patients. Specifically, normotensive patients who are not in heart failure have a very low risk of HBOT-related cardiac complications. In the absence of high-quality evidence, patients with known heart failure may benefit from limited cardiac investigations prior to HBOT, and optimal monitoring of cardiac function during and after HBOT should be ensured. For those patients without a history of heart disease, a meticulous history and physical exam should suffice prior to HBOT. Patients identified as potentially high-risk for undiagnosed cardiac dysfunction may benefit from a targeted cardiac assessment in order to answer a specific clinical question, when this will factor into decision-making and allow HBOT to be performed in the safest possible conditions.

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