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ORIGINAL ARTICLE

Patent Foramen Ovale Influences the Presentation of Decompression Illness in SCUBA Divers

Kevin Liou, MBBS, MPH [a*], Darren Wolfers, FANZCA, Dip DHM [b], Robert Turner, FANZCA, Dip DHM [b], Michael Bennett, MD, FANZCA [b], Roger Allan, FRACP [a], Nigel Jepson, FRACP [a], Greg Cranney, FRACP [a]

[a]Eastern Heart Clinic, Prince of Wales Hospital, Barker Street, Randwick, 2031, Australia
[b]Australian Diving and Hyperbaric Medicine Research Group, Prince of Wales Hospital, Barker Street, Randwick, 2031, Australia

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Background Few have examined the influence of patent foramen ovale (PFO) on the phenotype of decompression illness (DCI) in affected divers.

Methodology A retrospective review of our database was performed for 75 SCUBA divers over a 10-year period.

Results Overall 4,945 bubble studies were performed at our institution during the study period. Divers with DCI were more likely to have positive bubble studies than other indications ($p < 0.001$).
Major DCI was observed significantly more commonly in divers with PFO than those without (18/1,000 v. s. 3/1,000, $p = 0.02$). Divers affected by DCI were also more likely to require a longer course of hyperbaric oxygen therapy (HBOT) if PFO was present ($p = 0.038$). If the patient experienced one or more major DCI symptoms, the odds ratio of PFO being present on a transoesophageal echocardiogram was 3.2 ($p = 0.02$) compared to those who reported no major DCI symptoms.

Conclusion PFO is highly prevalent in selected SCUBA divers with DCI, and is associated with a more severe DCI phenotype and longer duration of HBOT. Patients with unexpected DCI with one or more major DCI symptoms should be offered PFO screening if they choose to continue diving, as it may have considerable prognostic and therapeutic implications.

Keywords Patent foramen ovale • Decompression illness • Hyperbaric oxygen therapy • Transoesphageal echocardiography • Bubble studies

Introduction

Patent foramen ovale (PFO) is present in approximately 27% of the adult population [1]. It is a vestige of the foetal circulation which persists beyond the early stages of life as a result of failed fusion between the septum primum and secundum. The one-way flap valve that forms over the fossa ovalis allows right-to-left shunting of blood flow when the right atrial pressure exceeds the left. Mechanistically, it has been implicated in various clinical syndromes including cryptogenic stroke [2–5], migraine [6,7], and neurological decompression illness (DCI) [8,9].

DCI occurs when there is a reduction in the ambient pressure surrounding the body, for example when a diver surfaces after a dive. It could either be caused by formation or expansion of existing inert gas bubbles (usually nitrogen) in the tissue causing local damage (decompression sickness, DCS), or intravascular gas bubbles passing into the arterial

*Corresponding author. at: Eastern Heart Clinic, Prince of Wales Hospital, Barker Street, Randwick, 2031. Tel.: +61 423 778 504; fax: +61 2 9382 0799.,
Email: k_liou@hotmail.com

circulation with subsequent embolic complications (arterial gas embolism, AGE). The latter could either result from direct pulmonary barotrauma, or presence of a right to left shunt within the body such as a PFO.

Amongst all widely available diagnostic modalities, the trans-oesophageal echocardiogram (TOE) remains the investigation of choice for many institutions for the diagnosis and characterisation of PFO. PFO is detected via positive transeptal colour Doppler flow, transeptal flow of gas bubbles during bubble studies, or both, with or without the aid of Valsalva manoeuvres. In this report we reflect on our experience in 75 SCUBA divers referred for assessment following an episode of DCI treated at a major centre for Diving and Hyperbaric Medicine. Other studies to date have looked at divers as a whole and have not singled out divers affected by DCI as a group. It is our intention to characterise this specific subgroup in order to understand the relationship between DCI and PFO in these divers. To our knowledge this is the first time this specific group of patients has been studied in a moderate size cohort.

Methodology

This is a retrospective case series based on a review of our echocardiogram database and medical records between January 2004 and May 2013. All agitated saline bubble studies performed during the study period were identified. Clinical indications for the bubble studies were noted and divided into three groups: the ''source study'' group, where TOE was performed primarily to identify possible causes of cerebrovascular accident (CVA) and peripheral thromboembolic diseases, for divers with DCI, and for other miscellaneous indications. The latter group encompasses all other indications for TOEs including valve studies, TOE guided cardioversions, exclusion of endocarditis etc. For the purpose of this study these indications were grouped into one to distinguish them from studies aimed at identifying left-right shunts within the heart. All echocardiographic features were recorded.

The clinical notes of patients who underwent TOE following DCI were reviewed. Pertinent information including patients' demographics, co-morbidities, diving profiles, and details of decompression illness were recorded. Minor and major DCI are defined in Table 1. Divers with DCI were referred for TOE at the discretion of their diving physician; generally this was when the severity and/or symptoms of their DCI were incongruous with their dive profile and accumulated nitrogen load. Patients received treatment for their DCI prior to their TOE, so the need to treat and duration of treatment was determined without knowledge of their PFO status. TOE was performed in a single institution under sedation with midazolam and fentanyl, and following lignocaine anaesthetic spray to the oropharynx. The inter-atrial septum was interrogated with colour Doppler by sweeping the probe from the transverse to the longitudinal plane, looking for transeptal blood flow. Bubble studies were performed in the imaging plane where inter-atrial septum was most resolved, and by injection of 10 mL of contrast through an upper limb cannula. The echo-contrast medium consists of a mixture of saline, air and 1 mL of the patients' own blood taken from the intravenous cannula. When transeptal bubble flow was not immediately apparent, patients were asked to perform a Valsalva manoeuvre. A positive bubble study is defined as crossing of bubbles from right to the left atrium within four heartbeats.

Table 1 Definition of major and minor DCI.

Major DCI	Minor DCI
Cognitive Impairment	Dermatological manifestations
CNS dysfunction (cerebral cortex, cerebella, spinal cord)	Parasthaesia
Visual disturbances	Musculoskeletal Pain
Loss of consciousness	Abdominal discomfort
Amnesia to event	Constitutional symptoms (dyspnoea, headache, nausea, fatigue, unwell, light-headedness, and insomnia)
Inner ear disturbances	

Data collected was analysed using IBM SPSS Ver 20. Categorical data are expressed in absolute numbers and proportions, and statistical significance is tested with chi-square test. Continuous data are expressed as medians +/- inter-quartile ranges (IQR) if they are not normally distributed or mean+/- standard deviation (SD) if they are. Intergroup comparison of normally distributed data was tested with two-tailed student T test, while comparison of non-normally distributed data was performed through a two-tailed Mann-Whitney test. Statistical significance is defined as $p < 0.05$.

Results

Bubble Studies

Overall, 4,945 bubble studies were performed between January 2004 and May 2013 (Table 2). Seventy-five bubble studies (1.5%) were performed in patients with DCI, 1,385 (28%) in the ''source study'' group, and the remaining for other indications. Bubble studies were positive in 682 TOE (13.8%) overall. However, significantly more patients had positive bubble studies in the DCI group compared to the ''source study'' group and studies performed for other indications (52% v.s. 21% and 10% respectively, $p < 0.001$). When the bubble studies were positive, resting unprovoked transeptal flow of bubbles was more likely to be observed in patients with DCI, as compared with the ''source study'' group and studies performed for other indications ($p = 0.001$ and 0.03 respectively).