Returning to diving and hyperbaric exposure after pulmonary vein isolation for atrial fibrillation

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Abstract

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Pulmonary vein isolation (PVI) is an established rhythm-control therapy for atrial fibrillation (AF), yet the electrophysiological response of post-PVI individuals exposed to hyperbaric environments remains undocumented. Similarly, the in-vivo performance of implantable loop recorders (ILRs) and external patch-based electrocardiographic (ECG) devices under increased ambient pressure has never been reported. We describe the first hyperbaric electrophysiology assessment in a post-PVI diver undergoing both underwater immersion and dry hyperbaric exposure with dual-modality cardiac rhythm monitoring. A 46-year-old experienced diver with successful PVI underwent: a scuba dive to 42 m in a warm water pool, monitored with a marinised 12-lead ECG Holter system; and a stepwise hyperbaric chamber compression to 284 kPa (2.8 atmospheres absolute) in ambient air, with single-lead surface ECG recordings obtained at static pressure plateaus. In both cases, the subject was monitored as well by his ILR. No AF recurrence or other dysrhythmias were detected during either exposure, with stable heart rate trends. The ILR maintained full functional integrity after both the 42 m dive and the 284 kPa chamber compression. The external ECG patch yielded interpretable tracings during static phases. Telemetry failed due to electromagnetic shielding by the steel chamber walls. This case suggests that carefully selected post-PVI individuals may tolerate controlled underwater and hyperbaric exposure without rhythm destabilisation. Both implantable and external monitoring devices preserved operational integrity under moderate hyperbaric conditions, providing a foundation for the emerging field of hyperbaric electrophysiology monitoring and informing fitness-to-dive assessment in post-ablation patients.

Introduction

Atrial fibrillation (AF) is the most common sustained arrhythmia in adults,[1,2] usually treated with rhythm or rate control, lifestyle modification, and risk factor management. Catheter ablation via pulmonary vein isolation (PVI) is a well-established, second-line therapy for symptomatic paroxysmal or persistent AF not responding to antiarrhythmic therapy, with demonstrated efficacy in maintaining sinus rhythm and reducing arrhythmic burden.[3,4] In selected cases, PVI may also be considered as first-line treatment, such as for patients with heart failure or specific occupational requirements.[4–6]

AF is increasingly prevalent in older adults,[7] a population well represented among active divers,[8] but no evidence-based guidelines address fitness-to-dive evaluation in divers with AF or post-ablation clearance to resume diving.[9] Here we describe a post-PVI scuba diver assessed under wet (underwater) and dry (hyperbaric chamber) conditions using dual-modality cardiac monitoring, aiming to characterise rhythm stability, evaluate monitoring device performance under hyperbaric conditions, and propose a conceptual framework at the intersection of electrophysiology, diving medicine, and biomedical engineering to assist in the fitness-to-dive evaluation.

Methods

The study was approved by the Ethics Committee of the Department of Biomedical Sciences, University of Padova – HEC-DSB/06-2023. The subject provided written informed consent for the experiment, and consented for the publication of his case details and data.

The subject, one of the authors, was a 46-year-old male recreational diver and diving physician. He developed unstable, symptomatic AF in 2021, initially managed with rhythm control including two electrical cardioversions. An implantable loop recorder (ILR) was implanted in April 2022 for long-term rhythm surveillance; successful PVI followed in October 2022 after shared decision-making with the electrophysiology team. Since serial ILR interrogations confirmed sustained sinus rhythm without AF recurrence, transthoracic echocardiography showed normal cardiac structure and function, and he was not taking antiarrhythmic medications, he was cleared to resume diving and hyperbaric work, and elected to self-monitor on first returning to each activity.

ELECTROPHYSIOLOGICAL MONITORING SYSTEMS

Implantable loop recorder

A Biomonitor IIIm ILR (BIOTRONIK, Berlin, Germany), implanted subcutaneously on the left anterior chest in April 2022, records single-lead electrocardiograms (ECGs) with patient-activated and automated arrhythmia detection (AF, bradycardia, tachycardia, pauses). Telemetry uses the medical implant communication system band (402–405 MHz). Patient-activated recordings capture approximately seven minutes before and one minute after activation, via a rolling memory buffer. Manufacturer guidelines advise against hyperbaric exposure exceeding 150 kPa (1.5 bar);[10] however, the company reported structural integrity after testing the device through 40 cycles at approximately 450 kPa (≈4.5 bar). The pressures in this study remained within those laboratory-tested limits, though off-label.

Conventional ECG monitoring

A single-lead Cardionica patch (Medical International Research S.p.A., Rome, Italy) was used for rhythm monitoring during chamber compression. Acquisition was limited to static pressure plateaus, as the device lacks hyperbaric certification.

Underwater Holter recording

A Holter ECG H12+ (Welch Allyn Inc., NY, USA) was housed in a sealed steel cylinder with external cable port for underwater deployment. Standard chest electrodes were waterproofed with dual-layer transparent adhesive dressings. The 12-lead recording was interpreted by a sports medicine cardiologist.

UNDERWATER DIVING AND HYPERBARIC PROTOCOLS

Both sessions were supervised by hyperbaric and diving medicine specialists with biomedical engineering oversight.

Underwater dive

The subject completed a scuba dive to 42 metres of freshwater (mfw) at the Y-40® "*The Deep Joy*" facility (Montegrotto Terme, Italy; water 31.5 ± 0.5°C), breathing compressed air on open circuit without a diving suit. Descent was at approximately 1 m·min^{-1}; after ~5 minutes of bottom time (no-decompression profile), ascent proceeded at ~1–2 m·min^{-1} with a three-minute safety stop at 5 mfw (total dive ~40 minutes; Figure 1A). The ILR was manually activated before water entry and after resurfacing, capturing approximately the first minute and last seven minutes of the immersion. Continuous ECG was recorded simultaneously via the waterproof Holter. Depth–time data were extracted from the dive computer log.

Dry hyperbaric chamber exposure

Hyperbaric exposure was performed at the Policlinico "*Paolo Giaccone*," Palermo, in ambient air with stepwise compression to 284 kPa (2.8 atmospheres absolute [atm abs]) (equivalent depth 18 m), including three-minute plateaus at 152 kPa and 203 kPa (1.5 and 2.0 atm abs) during which the ECG patch was activated (Figure 1B). Telemetry with the ILR was unsuccessful due to steel-wall radiofrequency shielding. Decompression was completed in oxygen. The ILR was manually activated before compression and after decompression, capturing approximately the first minute and last seven minutes, respectively. Total hyperbaric exposure was ~40 minutes.

Results

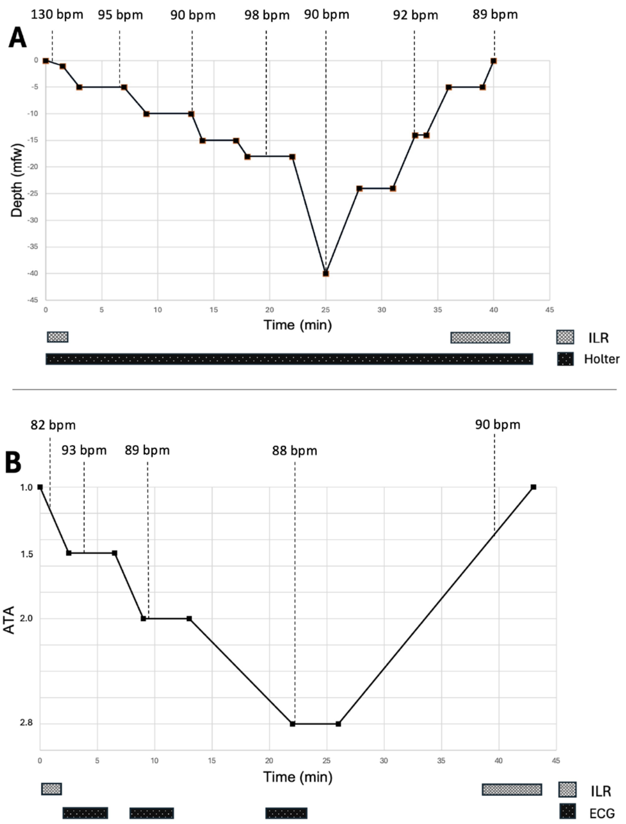
The subject completed both exposures without symptoms. During the pool dive, both the waterproof Holter ECG and start/end-immersion ILR recordings demonstrated sinus rhythm, with no dysrhythmias detected. Mild sinus tachycardia was noted on water entry, with subsequent heart rate stabilisation (Figure 1A). During the dry hyperbaric exposure, the ECG and ILR again showed sinus rhythm with stable heart rate (Figure 1B). ILR interrogation after each session confirmed the absence of events over the subsequent 48 hours and verified full device functionality.

Discussion

To our knowledge, this is the first report to describe ECG behaviour in an individual exposed to elevated

Figure 1

Depth–time and pressure–time profiles during underwater immersion (panel A) and dry hyperbaric exposure (panel B); heart rates in beats per minute (bpm) recorded at selected time points are reported above each panel. Shaded bars below each panel indicate active monitoring windows for the different devices employed. ATA – atmospheres absolute; ECG – electrocardiogram; ILR – implantable loop recorder; mfw – metres of freshwater



environmental pressure after PVI for AF, under both dry and submerged (wet) conditions. The participant's self-monitoring addresses two previously unexamined questions: (i) whether hyperbaric exposure can unmask clinically relevant dysrhythmias following an apparently successful PVI, and (ii) whether implantable and external cardiac rhythm-monitoring systems retain functional integrity and provide reliable signal acquisition during and after exposure to increased ambient pressure.

The underwater environment imposes abrupt cardiovascular loading through central blood shift, increased cardiac filling, and atrial stretch, compounded by autonomic perturbations from concurrent sympathetic and parasympathetic activation.[11] These combined preload/afterload and autonomic perturbations may alter atrial refractoriness and conduction, increasing the likelihood of arrhythmia expression in susceptible individuals. Resuming diving after PVI raises the concern that the diving response may challenge the post-ablation atrial substrate, where recurrence and ectopy remain possible despite a successful procedure. The hyperbaric chamber exposure was designed to separate pressure effects from immersion and to support the subject's return to hyperbaric work. Exposure to 284 kPa (2.8 atm abs) breathing air is generally associated with modest cardiovascular effects;[12,13] however, the small rise in inspired oxygen partial pressure may theoretically promote a shift toward parasympathetic predominance and higher heart rate variability, based on observations under hyperoxic conditions.[14,15] The absence of AF recurrence–or other dysrhythmias sufficient to trigger the ILR alarm–suggests the participant's rhythm was not destabilised in either setting. Heart rate trends were stable in both exposures, with only transient sinus tachycardia on water entry (Figure 1 A), consistent with prior observations.[16] In the chamber, serial ECG recordings demonstrated sinus rhythm within the physiological range (Figure 1 B), possibly reflecting appropriate autonomic adaptation to the gradual compression profile.

This case also addresses whether cardiac rhythm-monitoring devices retain functional integrity under hyperbaric conditions. Prior work by some of the authors emphasised the heterogeneity in manufacturer suitability statements and pressure limits among implantable cardiac devices.[17] In many cases, regulatory disclaimers discouraging hyperbaric exposure appear to reflect limited or absent human testing rather than documented device malfunction. Here, the ILR maintained continuous operation and preserved sensing performance throughout both exposures–providing, to our knowledge, the first published in-vivo confirmation under these conditions. The waterproof Holter system supported the feasibility of rhythm assessment during diving, albeit without real-time transmission. The external ECG patch yielded good-quality tracings during static phases, but telemetry communication attempt was unsuccessful, plausibly due to radiofrequency attenuation by the steel walls. Further study is warranted to optimise external device reliability and develop remote monitoring capability–especially underwater.

These findings are relevant to the evaluation of individuals with AF, particularly given the absence of prospective evidence and dedicated consensus guidelines. In carefully selected patients with sustained sinus rhythm stability, hyperbaric exposure may be considered on a case-by-case basis after comprehensive multidisciplinary evaluation by electrophysiology, cardiology, sports medicine, and diving medicine specialists. However, individuals with residual AF burden, structural heart disease, or ongoing antiarrhythmic therapy should not be assumed to share a comparable risk profile. For individuals at elevated risk of developing AF, reversible lifestyle factors should be modified and diving restricted until these are addressed. Newly diagnosed AF warrants thorough evaluation to exclude relevant comorbidities, such as structural or ischemic heart disease, before diving clearance, and should be withheld until rhythm control and clinical stability are achieved. Antiarrhythmic drugs merit particular caution, as autonomic fluctuations during immersion can provoke benign ectopy in healthy individuals,[16] but may carry greater risk of dysrhythmias in predisposed patients. Regarding occupational hyperbaric exposure, protocols requiring pressures ≥ 304 kPa (3 atm abs) or special gas mixtures should be avoided. Finally, careful selection of candidates for AF ablation could ensure a prompt activity resumption. Future research developments should include a follow-up of divers diagnosed with AF (both ablated and not), and the integration of biomedical engineering expertise into the multidisciplinary team to develop monitoring solutions enabling direct observation during hyperbaric exposure.

As a single-subject report, these observations have limited generalisability. The pressure exposures evaluated here were moderate relative to those achieved in technical or professional diving, and neither helium-based mixtures nor prolonged hyperbaric plateaus were monitored. These more extreme conditions may entail substantially greater physiological stress in individuals with prior AF ablation, underscoring the need for systematic study.

Conclusions

This first documented ECG assessment under hyperbaric conditions in an individual after PVI suggests that, in carefully selected cases, recreational diving and hyperbaric exposure may be tolerated without clinically evident rhythm destabilisation. Although generalisability is limited to a single case, well-selected post-ablation patients may be considered for return to diving or hyperbaric chamber exposure following comprehensive, multidisciplinary evaluation. Future research should prioritise follow-up studies and real-time monitoring systems for reliable acquisition during compression, decompression, and immersion.

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