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ORIGINAL ARTICLE

The impact of hyperbaric oxygen treatment for cardiovascular implantable electronic devices

Kentaro Goto MD[1] | Shinsuke Miyazaki MD[1] | Takuya Oyaizu MD[2] | Miho Negishi MD[1] | Takashi Ikenouchi MD[1] | Tasuku Yamamoto MD[1] | Iwanari Kawamura MD[1] | Takuro Nishimura MD[1] | Tomomasa Takamiya MD[1] | Susumu Tao MD[1] | Masateru Takigawa MD[1] | Kazuyoshi Yagishita MD[2] | Tetsuo Sasano MD[1]

[1]Department of Cardiovascular Medicine, Tokyo Medical and Dental University Hospital, Tokyo, Japan

[2]Department of Hyperbaric Medical Center, Tokyo Medical and Dental University Hospital, Tokyo, Japan

Correspondence
Kentaro Goto, Department of Cardiovascular Medicine, Tokyo Medical and Dental University, 1-5-45 Yushima, Bunkyo-ku 113-8510, Tokyo, Japan.
Email: ken-goto@umin.ac.jp

Abstract

Introduction: The safety of hyperbaric oxygen treatment (HBO_2) in patients with cardiovascular implanted electronic devices (CIED) remains unclear.

Methods: We conducted a retrospective analysis of seven CIED patients (median age 79 [73–83] years, five males [71.4%]), including five with pacemakers and two with implantable cardioverter defibrillators (ICD), who underwent HBO_2 between June 2013 and April 2023. During the initial session, electrocardiogram monitoring was conducted, and CIED checks were performed before and after the treatment. In addition, the medical records were scrutinized to identify any abnormal CIED operations.

Results: All seven CIED patients underwent HBO_2 within the safety pressure range specified by the CIED manufacturers or general pressure test by the International Organization for Standardization (2.5 [2.5–2.5] atmosphere absolute × 18 [5–20] sessions). When comparing the CIED parameters before and after HBO_2, no significant changes were observed in the waveform amplitudes, pacing thresholds, lead impedance of the atrial and ventricular leads, or battery levels. All seven patients, including two with the rate response function activated, exhibited no significant changes in the pacing rate or pacing failure. Two ICD patients did not deactivate the therapy, including the defibrillation; however, they did not experience any arrhythmia or inappropriate ICD therapy during the HBO_2.

Conclusion: CIED patients who underwent HBO_2 within the safety pressure range exhibited no significant changes in the parameters immediately after the HBO_2 and had no observable abnormal CIED operations during the treatment. The safety of defibrillation by an ICD during HBO_2 should be clarified.

KEYWORDS
cardiovascular implantable electronic devices, hyperbaric oxygen treatment

1 | INTRODUCTION

Hyperbaric oxygen treatment (HBO_2) involves the inhalation of 100% oxygen in an environment with two to three times the atmospheric pressure, temporarily increasing the dissolved oxygen levels in the blood to enhance the peripheral oxygen supply.[1] Appropriate indications for HBO_2 include sudden hearing loss,[2] nonhealing wounds related to peripheral arterial diseases,[3] late effects of radiation exposure,[4] and refractory infections such as gas gangrene, necrotizing fasciitis, and osteomyelitis.[5]

While HBO_2 is applied in various medical conditions,[6] patients may sometimes have cardiac implantable electronic devices (CIEDs). However, there is a lack of comprehensive reports on the safety of utilizing HBO_2 in patients with CIEDs. Medical institutions worldwide are presumed to administer HBO_2 to patients with CIEDs based on general pressure tests by the International Organization for Standardization (ISO) and results from individual pressure tests performed by CIED manufacturers (Table 1). However, pressure test requirements by the ISO standard do not consider the conditions of HBO_2, and individual pressure tests by CIED manufacturers did not follow a common protocol. In addition, the safety of implantable cardioverter defibrillator (ICD) therapy during HBO_2 has not been clarified so far. Further investigation is warranted to assess the safety of CIED treatment under HBO_2 in real-world settings.

2 | METHODS

2.1 | Purpose of this study

This study constituted a case series of patients with CIEDs who underwent HBO_2 at Tokyo Medical and Dental University (TMDU) hospital. The primary objective of this study was to assess the potential impact of HBO_2 on CIED parameters by comparing the results of the CIED checks before and after the HBO_2. Additionally, we analyzed the electronic medical data to investigate the CIED operation, including the pacing rate and ICD therapy, under HBO_2.

2.2 | Management of CIED patients during HBO_2

The HBO_2 treatment protocol at TMDU Hospital is determined by the physicians in the department of the hyperbaric medical center based on the patient's pathology and condition. The selected treatment pressure is typically 2.5 or 2.8 atmospheres absolute (ATA). During the initial HBO_2 session for patients with CIEDs, electrocardiogram monitoring was conducted, and CIED data checks were performed before and after the HBO_2. If the initial HBO_2 session was completed without any issues related to the CIED, subsequent sessions with the same protocol were conducted without electrocardiogram monitoring and CIED checks and only assessed patient symptoms.

2.3 | Study population

Between June 2013 and April 2023, a total of 12 CIED patients underwent HBO_2 at TMDU hospital (Figure 1), including nine with pacemakers and three with ICDs. One pacemaker patient experienced difficulty equalizing the pressure in the ears, leading to the discontinuation of the initial HBO_2 session. Additionally, four patients were excluded due to the unavailability of CIED data in their medical records. As a result, seven CIED patients (five with pacemakers and two with ICD) were included in the analysis.

2.4 | Data collection

The CIED parameters, including the waveform amplitudes, stimulation thresholds, impedance for each lead, battery levels, and ICD therapy settings and log, were evaluated. These parameters were

TABLE 1 Safety pressure range for each CIED type and CIED manufacturers.

CIED type	Medtronic	Abbott	Boston	Microport	Biotronik
Pacemaker	4.0	7.0	5.0	3.0–4.0	2.5–3.0
Transvenous ICD	4.0	7.0	5.0	4.0	2.5–3.0
Subcutaneous ICD	-	-	3.0	-	-
CRT-P/D	4.0	7.0	5.0	4.0	2.5–3.0
ILR	4.0	5.0	-	-	1.5

Note: The safety pressure range for CIEDs from Biotronik (Berlin, Germany) is determined by the general pressure test requirements set by the International Organization for Standardization. For other CIEDs from manufacturers such as Medtronic (Minneapolis, MN, USA), Abbott (Chicago, IL, USA), Boston Scientific (Marlborough, MA, USA), and Microport (Irvine, CA, USA), the safety pressure range is established based on individual pressure tests conducted by the respective CIED manufacturers. It is important to note that this table is based on the results of pressure tests submitted by each CIED manufacturer and is applicable to current and general CIED models; it does not cover all CIED models from each CIED manufacturer.

Abbreviations: CIED, cardiovascular implantable electronic device; CRT-P/D, cardiac resynchronization therapy–pacemaker/defibrillator; ICD, implantable cardioverter defibrillator; ILR, implantable loop recorder.

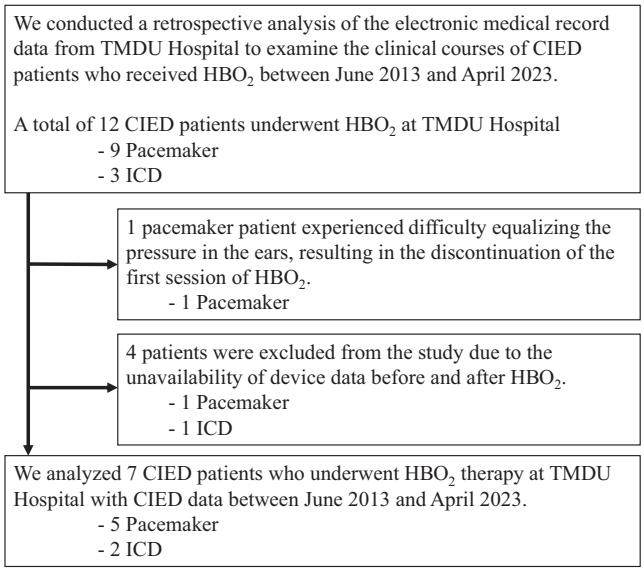


FIGURE 1 Study population. Between June 2013 and April 2023, a total of 12 CIED patients underwent HBO_2 at TMDU Hospital. Seven CIED patients (five with pacemakers and two with ICD) were included in this analysis. CIED, cardiovascular implantable electronic device; HBO_2, hyperbaric oxygen treatment; ICD, implantable cardioverter defibrillator; TMDU, Tokyo Medical and Dental University.

compared before and after the initial session of HBO_2 to determine the influence of HBO_2 on the CIED. Electrocardiogram monitoring was conducted throughout the initial HBO_2 session, and the medical records were scrutinized to identify any observable abnormalities in the CIED operation during the entire session. The study was approved by the Institutional Review Boards of TMDU. Informed consent for this study was obtained through an opt-out form in accordance with the Declaration of Helsinki.

2.5 | Statistical analysis

Continuous variables are presented as the median (interquartile range) for nonparametric data and as the mean ± standard deviation for parametric data. Categorical variables are expressed as absolute numbers (percentages). The comparison of continuous data before and after HBO_2 was conducted using the paired *t*-test to assess any significant changes. A *p*-value of .05 was considered statistically significant. Analyses were performed using JMP statistical software version 11.0.0 (SAS Institute, Cary, NC, USA).

3 | RESULTS

3.1 | Patient characteristics and the protocols of the HBO_2

A total of seven patients with CIEDs (median age 79 [73–83] years, five males [71.4%]), comprising five with pacemakers and two with ICDs, were analyzed (Table 2). The primary indications for the CIEDs were three cases of complete atrioventricular block, two cases of sick sinus syndrome, and two cases of ventricular arrhythmias. Regarding the indications for the HBO_2, sudden hearing loss was the most common indication in three patients [42.9%], followed by two cases for peripheral arterial disease, and one each for osteomyelitis and radiation enteritis. The HBO_2 was conducted at pressures adhering to the safety pressure range specified by the ISO or the CIED manufacturer (2.5 [2.5–2.5] ATA). The median therapy cycle was 18 [5–20] sessions.

3.2 | CIED parameter comparison before and after the HBO_2

Regarding the atrial lead data, the wave amplitude (3.23 ± 1.61 vs. 3.36 ± 1.76 mV, $p = .66$), pacing threshold (0.62 ± 0.22 vs. 0.54 ± 0.17 V/0.4 or 0.5 ms, $p = .22$), and lead impedance (568.6 ± 149.1 vs. 559.3 ± 133.1 Ω, $p = .57$) did not exhibit any significant change when comparing before and after the HBO_2 (Figure 2A–C). Similarly, the ventricular lead data also did not exhibit a significant change in the wave amplitude (9.68 ± 5.76 vs. 8.34 ± 4.60 mV, $p = .33$), pacing threshold (0.71 ± 0.19 vs. 0.70 ± 0.17 V/0.4 or 0.5 ms, $p = .85$), or lead impedance (567.2 ± 251.1 vs. 540.0 ± 201.6 Ω, $p = .33$) (Figure 3A–C). The remaining battery capacity did not demonstrate any significant change between before and after the HBO_2 in all seven cases. None of the seven CIED patients experienced any issues related to the CIED, even after completing the entire HBO_2 session.

3.3 | Pacing and ICD therapy under the HBO_2

Two pacemaker patients underwent HBO_2 with the rate response setting activated, which included an accelerometer sensor. However, as carefully observed by one cardiologist and the other medical staff, among all seven patients, no significant changes in the pacing rate, pacing failure, or symptoms, clearly related to the changes in the pacing rate were observed during the initial session based on the electrocardiogram monitoring. Additionally, two patients with ICDs did not deactivate their therapy settings, including the defibrillation, during the HBO_2. These two patients did not experience any appropriate or inappropriate ICD therapy activity during the entire HBO_2 session.

4 | DISCUSSION

4.1 | Safety of CIEDs during HBO_2

While a Japanese study from 2002 addressed the safety of pacemakers during HBO_2,[7] and there have also been reports on the impact of simple hyperbaric conditions on pacemakers[8] and ex vivo tests assessing the ICD operation with HBO_2,[9] there is a lack of comprehensive reports in the English literature evaluating the safety of patients with CIEDs undergoing HBO_2.

TABLE 2 Patient and CIED characteristics, and HBO_2 protocols.

				CIED			HBO_2		
Patient number	Age, years	Gender	Indication	CIED type (pacing mode)	Name	Safety pressure range	ATA	Cycle, times	Indication
# 1	83	Male	CAVB	PM (DDD)	Evity8 DR-T	3.0	2.0–2.5	21	Osteomyelitis
# 2	81	Male	CAVB	PM (DDDR)	Accent MRI	7.0	2.5	8	Sudden hearing loss
# 3	91	Male	CAVB	PM (DDD)	Symphony DR 2550	3.0–4.0	2.5	19	Radiation enteritis
# 4	73	Male	SSS	PM (DDD)	Advisa DR MRI	4.0	2.5	3	Peripheral arterial diseases
# 5	77	Female	SSS	PM (AAIR)	Epyra8 SR-T	3.0	2.5	5	Sudden hearing loss
# 6	79	Male	VT	ICD (DDD)	Evera MRI XT DR	4.0	2.5	20	Peripheral arterial disease
# 7	63	Female	VF	ICD (DDD)	RESONATE EL	5.0	2.0	18	Sudden hearing loss

Note: Patient characteristics of the CIED recipients who underwent HBO_2 and the treatment protocol.

Abbreviations: ATA, atmosphere absolute; CAVB, complete atrioventricular block; CIED, cardiovascular implantable electronic device; HBO_2, hyperbaric oxygen treatment; ICD, implantable cardioverter defibrillator; PM, pacemaker; SSS, sick sinus syndrome; VR, ventricular fibrillation; VT, ventricular tachycardia.

Although the patient number was small, our study found no impact on the CIED parameters due to HBO_2, and no abnormal CIED operation was observed during the HBO_2. We also confirmed with the CIED manufacturers in Japan (Medtronic Japan, Abbott Japan, Boston Scientific Japan, and Biotronik Japan) that no case reports regarding CIED issues related to HBO_2 have been acknowledged to date. It is likely that if the pressurization remains within the safety range specified by ISO and each CIED manufacturer, the likelihood of CIED issues related to the HBO_2 seems to be low.

4.2 | When pressurization beyond the safety range is required

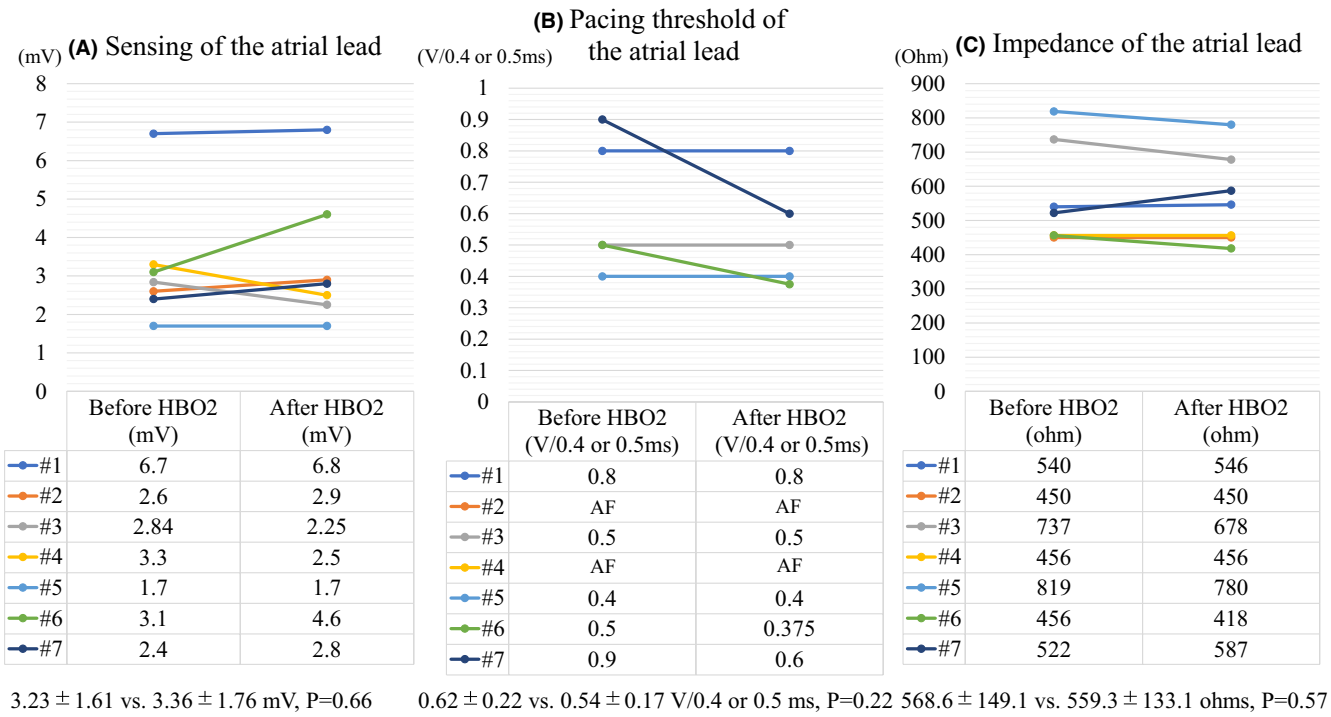
HBO_2 protocols are generally conducted under 2.5–2.8 ATA, and most CIEDs adhere to the safety pressure range. However, some reported HBO_2 protocols, such as those for gas embolisms,[10] include pressures exceeding 3.0–4.0 ATA. When pressurization beyond the safety range is necessary, the safety of CIEDs is not well established.

While HBO_2 is distinct, guidelines and reports related to CIED patients during diving might be informative due to the commonality of high-pressure environments.[11] Although there is also no comprehensive research on the safety of CIED operation during diving, the Undersea and Hyperbaric Medical Society advises CIED patients to avoid diving beyond 30 m (=4.0 ATA). Additionally, a prior report has revealed that a CIED submerged beyond 30–60 m (=over 4.0 ATA) in the sea exhibited deformation.[12] Based on these facts, in terms of high-pressure environments alone, when CIED patients undergo HBO_2 over 4.0 ATA, which exceeds the safety pressure range of the CIED, a careful evaluation is needed. In that case, conducting device checks during HBO_2 is ideal for evaluating the CIED operation. However, it remains uncertain whether it is truly necessary.

4.3 | CIED settings during HBO_2

Regarding the blood oxygen concentration, the impact of a high blood oxygen concentration on the pacing threshold and sensing has not been reported. A low oxygen concentration to some extent (pO_2 41.3 mmHg) has not been reported to transiently or permanently change the pacing threshold.[13] Theoretically, it might possibly affect the pacing threshold or sensing if the myocardium at the pacing site has a more insufficient oxygen supply. However, it is difficult to imagine that a high oxygen supply would worsen the pacing threshold or sensing, at least in the acute phase.

The two patients with a rate response function activated during the HBO_2 had an accelerometer sensor on the circuit board, which possibly was not affected by the deformation of the pacemaker surface. Additionally, while this accelerometer sensor is designed to sense acceleration in an anterior–posterior direction, it might not be affected by the HBO_2, when the pressure increases gradually from all directions. In addition, concerning any potential electromagnetic interference from the HBO_2 instrument, it generally complies with



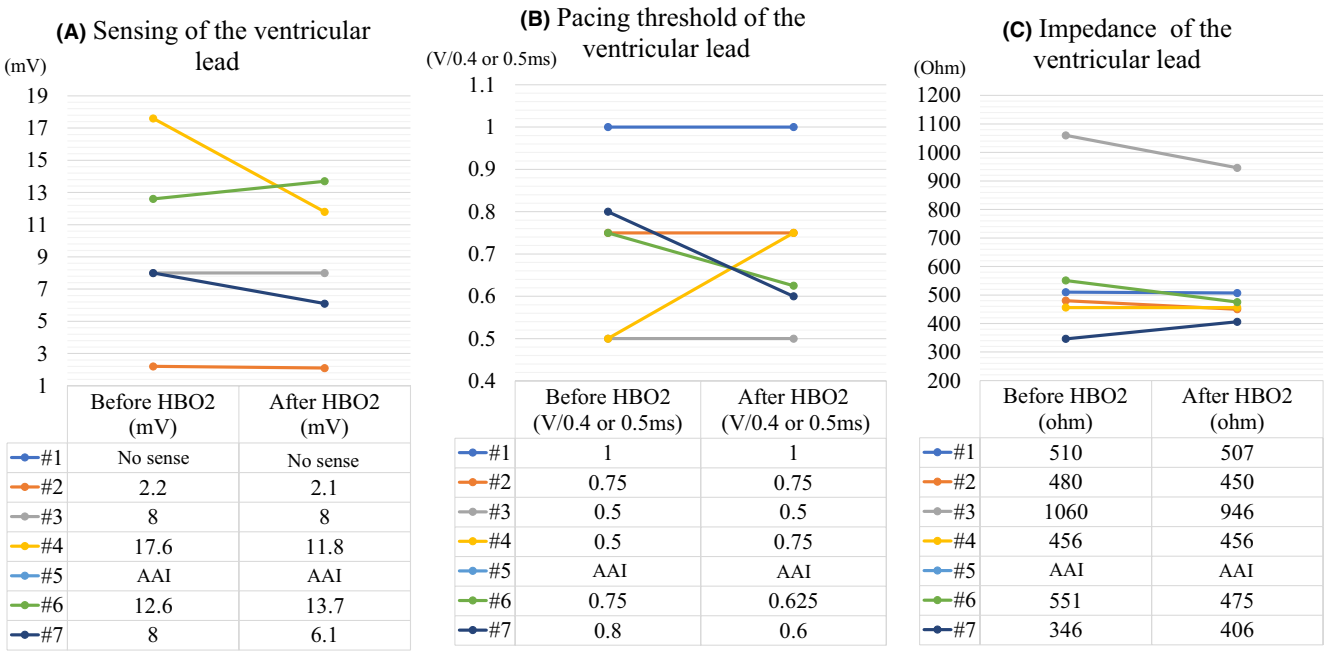
	Before HBO2 (mV)	After HBO2 (mV)
#1	6.7	6.8
#2	2.6	2.9
#3	2.84	2.25
#4	3.3	2.5
#5	1.7	1.7
#6	3.1	4.6
#7	2.4	2.8

	Before HBO2 (V/0.4 or 0.5ms)	After HBO2 (V/0.4 or 0.5ms)
#1	0.8	0.8
#2	AF	AF
#3	0.5	0.5
#4	AF	AF
#5	0.4	0.4
#6	0.5	0.375
#7	0.9	0.6

	Before HBO2 (ohm)	After HBO2 (ohm)
#1	540	546
#2	450	450
#3	737	678
#4	456	456
#5	819	780
#6	456	418
#7	522	587

3.23 ± 1.61 vs. 3.36 ± 1.76 mV, P=0.66 | 0.62 ± 0.22 vs. 0.54 ± 0.17 V/0.4 or 0.5 ms, P=0.22 | 568.6 ± 149.1 vs. 559.3 ± 133.1 ohms, P=0.57

FIGURE 2 Comparison of the atrial lead parameters before and after the HBO_2. A comparison of CIED parameters regarding the atrial lead before and after the HBO_2 did not reveal a significant change in the (A) sense amplitude, (B) pacing threshold, or (C) lead impedance. Values under the table represent the means ± standard deviation. The *p* value in each figure corresponds to the result of the paired *t*-test. CIED, cardiovascular implantable electronic device; HBO_2, hyperbaric oxygen treatment; ICD, implantable cardioverter defibrillator.



	Before HBO2 (mV)	After HBO2 (mV)
#1	No sense	No sense
#2	2.2	2.1
#3	8	8
#4	17.6	11.8
#5	AAI	AAI
#6	12.6	13.7
#7	8	6.1

	Before HBO2 (V/0.4 or 0.5ms)	After HBO2 (V/0.4 or 0.5ms)
#1	1	1
#2	0.75	0.75
#3	0.5	0.5
#4	0.5	0.75
#5	AAI	AAI
#6	0.75	0.625
#7	0.8	0.6

	Before HBO2 (ohm)	After HBO2 (ohm)
#1	510	507
#2	480	450
#3	1060	946
#4	456	456
#5	AAI	AAI
#6	551	475
#7	346	406

9.68 ± 5.76 vs. 8.34 ± 4.60 mV, P=0.33 | 0.71 ± 0.19 vs. 0.70 ± 0.17 V/0.4 or 0.5 ms, P=0.85 | 567.2 ± 251.1 vs. 540.0 ± 201.6 ohms, P=0.33

FIGURE 3 Comparison of the ventricular lead parameters before and after the HBO_2. Comparison of the CIED parameters concerning the ventricular lead between before and after the HBO_2 did not reveal any significant change in the (A) sense amplitude, (B) pacing threshold, or (C) lead impedance. The values under the table represent the means ± standard deviation. The *p* value in each figure corresponds to the result of the paired *t*-test. CIED, cardiovascular implantable electronic device; HBO_2, hyperbaric oxygen treatment; ICD, implantable cardioverter defibrillator.

electromagnetic compatibility regulations, ensuring that the instrument does not interfere with other medical devices. Regarding pacing settings alone, HBO_2 would not require changes, at least under the secure pressure ensured by each CIED manufacturer, in terms of high pressure, high oxygen concentration, or electromagnetic interference.

However, determining whether ICD therapy should be ON or OFF during HBO_2 poses a challenging decision. In this study, two patients with ICDs had their therapy settings left ON throughout the entire course of the HBO_2. However, there were no appropriate or inappropriate ICD activities. In the event of a life-threatening arrhythmic event during the HBO_2, there is a potential delay in treatment due to the emergency decompression of the chamber. From this perspective, it is considered reasonable to keep the ICD therapy ON. However, similar to temporarily interrupting the oxygen supply during external defibrillation, although it is extremely rare, in oxygen-rich environments, arcing between two electrodes has been known to cause fires.[14] Regarding extracorporeal defibrillators, risks of fire and an inappropriate operation under high-pressure environments have been reported in prior studies,[15,16] and a recent comprehensive review of cardiopulmonary resuscitation during HBO_2 also recommended that extracorporeal defibrillators should not be stored inside the pressure chamber. The use of biphasic devices placed outside the chamber with a connection to chest panels inside should be preferred.[17]

Further, the safety of defibrillation with transvenous or subcutaneous ICDs during HBO_2, conducted under high pressure and 100% oxygen administration, remains unclear. While the risk is presumed to be low, especially for transvenous and subcutaneous ICDs with shock leads/devices inserted into the body and a low output compared to extracorporeal defibrillators, the safety of defibrillation, particularly with the subcutaneous ICDs with shock leads closer to the skin, needs further investigation in the HBO_2.

5 | LIMITATIONS

This analysis was conducted with a small sample size at a single center, so it may not provide robust enough clinical evidence to demonstrate the safety of CIEDs under HBO_2. A subsequent HBO_2 session was performed without electrocardiogram monitoring. Although we conducted CIED checks only before and after the first session of HBO_2, repetitive HBO_2 sessions could affect the CIED. It is advisable to perform a CIED check at least at the end of each treatment series. We did not have any detailed data on the heart rate variability during HBO_2 in patients with the rate response function activated. No arrhythmia events or ICD therapies occurred during the HBO_2, and as a result, the safety of ICD defibrillation during HBO_2 could not be evaluated. Patients with CIEDs who underwent HBO_2 at our institution were referred specifically for HBO_2 treatment, and after the completion of the treatment, they returned to their previous hospital. Therefore, we do not have any data on the CIED performance in the chronic phase.

6 | CONCLUSION

The seven cases of CIED patients who underwent HBO_2 under the safety pressure range specified by the ICD manufacturers exhibited no significant changes in the CIED parameters before or immediately after the HBO_2, and there were no observable abnormalities in the CIED operation. Further investigation is required to assess the safety of defibrillation by ICDs during HBO_2.

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CONFLICT OF INTEREST STATEMENT

Dr. Goto, Dr. Takigawa, and Dr. Miyazaki belong to the endowed departments of Medtronic and Boston Scientific. Dr. Miyazaki received speaker honoraria from Medtronic.

DATA AVAILABILITY STATEMENT

The datasets used in the current study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study was approved by the Institutional Review Boards of Tokyo Medical and Dental University.

PATIENT CONSENT STATEMENT

Informed consent for this study was obtained through an opt-out form in accordance with the Declaration of Helsinki.

ORCID

Kentaro Goto https://orcid.org/0000-0002-0089-9779
Masateru Takigawa https://orcid.org/0000-0002-8473-7514
Tetsuo Sasano https://orcid.org/0000-0003-3582-6104

REFERENCES

1. Tibbles PM, Edelsberg JS. Hyperbaric-oxygen therapy. N Engl J Med. 1996;334(25):1642–8.
2. Chandrasekhar SS, Tsai Do BS, Schwartz SR, Bontempo LJ, Faucett EA, Finestone SA, et al. Clinical practice guideline: sudden hearing loss (update). Otolaryngol Head Neck Surg. 2019;161(1_suppl):S1–S45.
3. Conte MS, Bradbury AW, Kolh P, White JV, Dick F, Fitridge R, et al. Global vascular guidelines on the management of chronic limb-threatening ischemia. Eur J Vasc Endovasc Surg. 2019;58(1S):S1–109.e33.
4. Lin ZC, Bennett MH, Hawkins GC, Azzopardi CP, Feldmeier J, Smee R, et al. Hyperbaric oxygen therapy for late radiation tissue injury. Cochrane Database Syst Rev. 2023;8(8):CD005005.
5. Memar MY, Yekani M, Alizadeh N, Baghi HB. Hyperbaric oxygen therapy: antimicrobial mechanisms and clinical application for infections. Biomed Pharmacother. 2019;109:440–7.
6. Mathieu D, Marroni A, Kot J. Tenth European Consensus Conference on Hyperbaric Medicine: recommendations for accepted and non-accepted clinical indications and practice of hyperbaric oxygen treatment. Diving Hyperb Med. 2017;47(1):24–32.

7. Utsunomiya S, Iwata K, Abe K. Safety of pacemakers under hyperbaric oxygen therapy [Kouatsu sanso ryouhou ni okeru pacemaker no anzensei] (in Japanese). Nichi Kou Atsu Igakushi. 2002;37(4):249–56.
8. Trigano A, Lafay V, Blandeau O, Levy S, Gardette B, Micoli C. Activity-based rate-adaptive pacemakers under hyperbaric conditions. J Interv Card Electrophysiol. 2006;15(3):179–83.
9. Guenneugues R, Henckes A, Mansourati V, Mansourati J. Effects of hyperbaric exposure on mechanical and electronic parameters of implantable cardioverter-defibrillators. Europace. 2023;25(5):euad134.
10. Bessereau J, Genotelle N, Chabbaut C, Huon A, Tabah A, Aboab J, et al. Long-term outcome of iatrogenic gas embolism. Intensive Care Med. 2010;36(7):1180–7.
11. Undersea and Hyperbaric Medical Society. Diving medical guidance to the physician. 2021. Available from: https://www.uhms.org/images/Recreational-Diving-Medical-Screening-System/forms/Diving_Medical_Guidance_EN_English_2021-09-16.pdf
12. Lafay V, Trigano JA, Gardette B, Micoli C, Carre F. Effects of hyperbaric exposures on cardiac pacemakers. Br J Sports Med. 2008;42(3):212–6.
13. Weilenmann D, Duru F, Schönbeck M, Schenk B, Zwicky P, Russi EW, et al. Influence of acute exposure to high altitude and hypoxemia on ventricular stimulation thresholds in pacemaker patients. Pacing Clin Electrophysiol. 2000;23(4 Pt 1):512–5.
14. Link MS, Atkins DL, Passman RS, Halperin HR, Samson RA, White RD, et al. Part 6: electrical therapies: automated external defibrillators, defibrillation, cardioversion, and pacing: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2010;122(18 Suppl 3):S706–S719.
15. Pitkin A. Defibrillation in hyperbaric chambers: a review. J R Nav Med Serv. 1999;85(3):150–7.
16. Wright KT, Praske SP, Bhatt NA, Magalhaes RM, Quast TM. Treatment of cardiac arrest in the hyperbaric environment: key steps on the sequence of care—case reports. Undersea Hyperb Med. 2016;43(1):71–8.
17. Schmitz J, Liebold F, Hinkelbein J, Nöhl S, Thal SC, Sellmann T. Cardiopulmonary resuscitation during hyperbaric oxygen therapy: a comprehensive review and recommendations for practice. Scand J Trauma Resusc Emerg Med. 2023;31(1):57.

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