Cardiac Pacing under Hyperbaric Conditions

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ABSTRACT **Temporary external pacemakers have been reported to fail under hyperbaric conditions. In this study we investigated cardiac pacing under hyperbaric conditions. Permanent hermetically sealed pacemakers were found to function well under hyperbaric conditions, while several models of temporary external pacemakers failed. The electrical characteristics of pacing leads did not change under hyperbaric conditions. External pacing under hyperbaric conditions may be accomplished safely by using a permanent pacemaker attached to the patient's temporary external leads.**

In a report of the use of the hyperbaric chamber for treatment of massive arterial air embolism occurring after open-heart operations, Tomatis and associates [1] noted an incidental finding of failure of a Medtronic temporary external pacemaker.* Indeed, three temporary external pacemakers were tested, and all failed to work when exposed to hyperbaric conditions. This report raises several important questions.

1. Do temporary external pacemakers fail under hyperbaric conditions, and if so, are all manufacturers' pacemakers susceptible to this problem?
2. Do permanent pacemakers fail under hyperbaric conditions?
3. Do electrical thresholds for pacing change under hyperbaric conditions?
4. How can patients undergo safe, temporary pacing under hyperbaric conditions when this is required for treatment of arterial air embolism?
5. Can patients with permanent pacing systems safely participate in activities such as scuba diving that expose them to hyperbaric conditions?

A search of the literature did not reveal any data that would help to answer these questions. We therefore undertook the testing of pacemakers and pacing leads under hyperbaric conditions in the laboratory to obtain our own data.

Materials and Methods

The first phase of this investigation involved the testing of both permanent and temporary pacemakers under hyperbaric conditions. All of the pacemakers tested were placed in a Bethlehem 1836H small animal hyperbaric chamber and exposed to a pressure of 100 pounds per square inch (psi) above atmospheric pressure with 100% oxygen. While under pressure, the pacemakers were tested for function by measuring voltage, output, pulse width output, rate, sensitivity, and refractory period. Twenty permanent pacemakers and 18 temporary pacemakers produced by various manufacturers were tested.

In the second phase of this investigation, we studied possible changes in electrical thresholds and characteristics of leads while under hyperbaric conditions. Four dogs weighing between 18 and 22 kg were anesthetized with 25 mg per kilogram of body weight of pentobarbital sodium. A Medtronic 6971 unipolar ring-tipped tined electrode was passed through the right external jugular vein and positioned under fluoroscopic control in the apex of the right ventricle. The dogs were then placed in the hyperbaric chamber and gradually pressurized to 100 psi above atmospheric pressure with 100% oxygen. Threshold, resistance, and R wave sensing were checked during compression and decompression.

Results

The results of evaluation of the various permanent and temporary pacemakers are shown in

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Table 1. Results of Testing of Permanent and Temporary Pacemakers under Hyperbaric Conditions

Type	Company	Model	No. Tested	Type of Case	Result
Permanent	Medtronic	5950	4	Epoxy plastic	Normal function at 100 psi
Permanent	Medtronic	5951	4	Epoxy plastic	Normal function at 100 psi
Permanent	Medtronic	5985	2	Titanium	Normal function at 100 psi
Permanent	Medtronic	5973	2	Titanium	Normal function at 100 psi
Permanent	Medtronic	5989	2	Titanium	Normal function at 100 psi
Permanent	Telectronic	155	1	Titanium	Normal function at 100 psi
Permanent	CPI	0503	1	Titanium	Normal function at 100 psi
Permanent	Pacesetter	Vivelith 5	1	Titanium	Normal function at 100 psi
Permanent	Intermedics	253-02	1	Titanium	Normal function at 100 psi
Permanent	Intermedics	259-01	2	Titanium	Normal function at 100 psi
Temporary	Medtronic	5880 A	4	Open plastic	All failed completely at 50–55 psi
Temporary	Medtronic	5375	5	Open plastic	All failed completely at 45–60 psi
Temporary	Medtronic	5330	3	Open plastic	2 failed at 50–60 psi; 1 functioned normally at 100 psi
Temporary	Intermedics	240-01	1	Open plastic	Normal function at 100 psi
Temporary	Intermedics	240-02	5	Open plastic	Normal function at 100 psi

Table 2. Threshold Testing

Dog No.	Pressure (psi)	Voltage Threshold (V)	Resistance (Ω)	R Wave Amplitude (mV)
1	0 psi	0.9	350	6.1
	100 psi	0.9	355	6.0
2	0 psi	0.8	550	5.8
	100 psi	0.8	540	5.9
3	0 psi	1.0	380	7.4
	100 psi	1.1	390	7.1
4	0 psi	0.8	410	5.6
	100 psi	0.9	400	5.5

Table 1. All permanent pacemakers were found to function well, without change in any variable during pressurization to 100 psi.

Performance of the temporary external pacemakers was not so consistent. Each of the temporary single-chamber external devices, including the 5880 A and the 5375 manufactured by Medtronic, failed suddenly and completely between 45 and 60 psi. Before reaching the level of failure, these pacemakers demonstrated completely normal function in all electrical variables. On decompression, all of these units once again began to function normally at approximately 30 to 40 psi. Three Medtronic 5330 temporary dual-chamber units were tested. Two units failed completely at 50 and 60 psi and resumed pacing at 40 psi. However, the third unit continued to function well up to 100 psi. Five temporary external pacemakers manufactured by Intermedics* were tested, and all functioned normally up to 100 psi. Those pacemakers that failed in 100% oxygen were retested in 100% nitrogen and were all found to fail at similar levels of pressure.

The electrical variables of voltage threshold, resistance, and R wave amplitude measured in the 4 dogs during hyperbaric compression to 100 psi demonstrated no marked change in values during compression or decompression (Table 2).

*Intermedics, Inc., Freeport, TX 77541.

Comment

Although it was not possible to test all the different types of permanent pacemakers now being manufactured, the group of pacemakers tested does offer a satisfactory representation of the potential behavior of permanent pacemakers. This is especially likely because all currently produced permanent pacemakers are housed in hermetically sealed titanium cans. Thus, the result of satisfactory function of these units was as expected. We suspected that the epoxy plastic sealed units of the 5950 and 5951 Medtronic type might possibly be sensitive to hyperbaric conditions, but they also functioned well under test conditions.

The temporary external pacing units all come in essentially open, porous plastic housing constructed with the electrical components within the unit directly exposed to the hyperbaric atmosphere. The sudden and completely reversible failure of function suggests the failure of a single component under hyperbaric conditions. The difficulty in determining the malfunctioning component while under hyperbaric conditions is obvious. Since these units all functioned well when returned to normal atmospheric conditions, it was impossible to identify the malfunctioning component following completion of the test.

We did not analyze the difference in construction between the Medtronic and Intermedics temporary external pacing units to determine possible characteristics in the Intermedics units that allow them to withstand hyperbaric conditions.

Our findings suggest the following answers to the questions raised at the beginning of this article:

1. Many types of temporary external pacemakers do fail under hyperbaric conditions. Indeed, one unit from a particular manufacturer may function perfectly well under hyperbaric conditions while another unit of the same model may fail at pressures as low as 30 to 40 psi. The pacemakers manufactured by Intermedics appeared to be more uniformly dependable and might work satisfactorily if the need for hyperbaric pacing should arise. However, the performance of five units is certainly not sufficient to prove that dependence on a temporary external unit under hyperbaric conditions is entirely safe.
2. Permanent pacemakers hermetically sealed within titanium cans appeared to be resistant to the effects of hyperbaric conditions, at least up to 100 psi.
3. Electrical thresholds for pacing do not change under hyperbaric conditions.
4. Standard hyperbaric treatment of air embolism is not usually carried out to pressures greater than approximately 30 psi. Thus, some types of temporary pacing units, such as the Intermedics device, may be used satisfactorily when pacing is required in patients undergoing hyperbaric treatment. However, most surgical programs that include open-heart procedures will have available working explanted permanent pacemakers in hermetically sealed titanium containers. These units should be very dependable at levels of 30 psi since they demonstrated complete dependability when tested to 100 psi.
5. The usual scuba diver seldom exceeds a depth of 100 feet, which is equal to approximately 50 psi. This depth should cause no malfunction of the pacemaker or the electrical characteristics of the lead-heart interface. Thus, the pacing system would appear to function safely during scuba diving. Other factors, such as cardiac function under strenuous activity, should also be considered for each patient. We did not actually test a patient with an implanted pacing system under hyperbaric conditions. We recommend that any patient with a permanent pacing system undergo testing in a controlled medical situation such as a hyperbaric chamber before undertaking activities such as scuba diving.

Reference

1. Tomatis L, Nemiroff M, Riahi M, et al: Massive arterial air embolism due to rupture of pulsatile assist device: successful treatment in the hyperbaric chamber. Ann Thorac Surg 32:604, 1981