
The Physical Effects Of Volatile Anesthetics On Polycarbonate Membrane Oxygenators

A Avidan, A Klein, J Nates, J Almog, Y Donchin

Citation

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Abstract

The spillage of enflurane on the outside of a membrane oxygenator during cardiopulmonary bypass resulted in a leak at the venous outlet, with nearly fatal outcome. We studied the effect of three different volatile anesthetics on the polycarbonate parts of unused and used COBE CMS membrane oxygenators with 30-HRV open filtered reservoir. The polycarbonate parts were submitted to a series of tests and then exposed to the volatile anesthetics. Intact polycarbonate was not affected by etheric volatile anesthetics, but by halothane. Internal and externally applied stress (cyclic loading or pressure) may make the polycarbonate vulnerable for etheric volatile anesthetics. The bending motion caused by the continuous vibrations of the cardiopulmonary pump may damage the polycarbonate equipment, thus making it vulnerable to the harmful activity of etheric volatile anesthetics.

INTRODUCTION

Spillage of enflurane on the membrane oxygenator during cardiopulmonary bypass resulting in a leak at the venous outlet (1) induced us to investigate the durability of oxygenators and their polycarbonate parts when these are exposed to volatile anesthetics. Although the potential hazardous effect of volatile anesthetics on the polycarbonate components of cardiopulmonary oxygenators has been reported, the findings are controversial (2,3,4). To the best of our knowledge no investigations addressing the mechanism underlying this phenomenon have as yet appeared in the literature. In the current study we performed a series of tests using polycarbonate parts of both intact and damaged membrane oxygenators and bringing them into contact with volatile anesthetic agents. The experiments were performed at the Division of Identification and Forensic Science, Israel National Police, Jerusalem and in the laboratory of Paltough Ltd./Palram Ltd., Israel's largest polycarbonate producer.

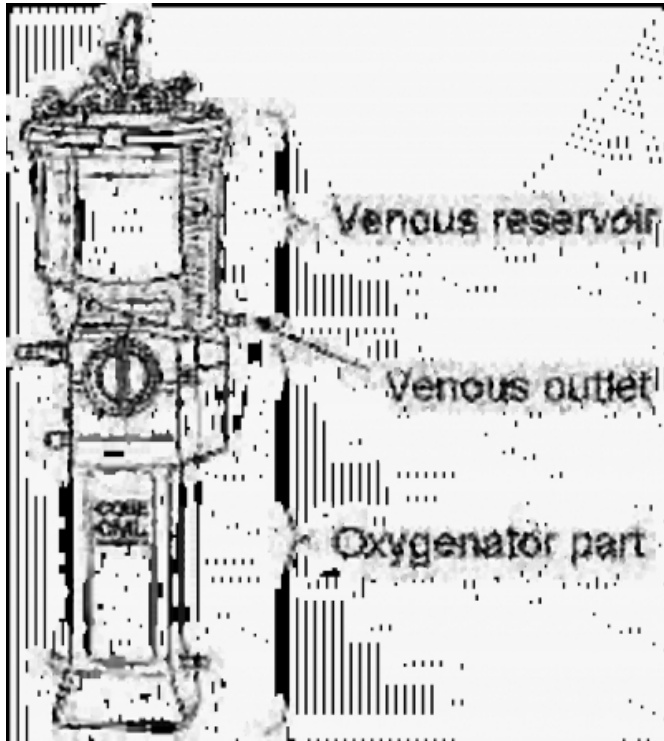
METHODS AND MATERIALS

The oxygenator unit in question can be divided into two major components: the open filtered reservoir (venous reservoir) and the membrane oxygenator with heat exchanger (oxygenator part) (Illustration 1). Most of the components of the oxygenator and the venous reservoir are manufactured from polycarbonate. This material is a special class of polyester derived from the reaction of carbonic acid

derivatives with aromatic, aliphatic or mixed diols. It melts at 215-225° C and may be shaped with sufficient pressure. It exhibits outstanding thermal stability and exceptional impact strength, ductility and transparency (5). The plasticized polyvinylchloride tubing for blood circulation is attached directly to the in- and outlets of the venous reservoir and oxygenating part.

Figure 1

Illustration 1: COBE CMS membrane oxygenator with 30-HRVF open filtered reservoir, divided into venous reservoir (a) and oxygenator part (b). Arrow indicates venous outlet where crack occurred



The following volatile anesthetic agents were used in the tests:

Halothane (CF₃-CHClBr) is a non-etheric (alkane), non-flammable (in clinical concentrations), highly volatile liquid. It reacts with aluminum, brass and lead in the presence of water. Copper and chromium remain unaffected. Rubber is soluble to a degree and polyethylene dissolves entirely in this agent. It is miscible with petroleum, ether, and other fat solvents (6,7).

Enflurane (CHF₂-O-CF₂-CHClF), is an etheric, non-flammable (in clinical concentrations) solvent, miscible with other organic liquids (including fat and oil) (8,9).

Isoflurane (CF₃-CHCl-O-CHF₂), an isomer of enflurane, is non-flammable (in clinical concentrations) and miscible with other organic liquids (including fat and oil). It does not react with metals under normal atmospheric conditions (10,11).

Three new and five used oxygenators were employed in the tests.

Test 1: Squares of polycarbonate (5x5 cm), cut from a unused and a used venous reservoir, were placed in covered

glass vessels, each containing one of the anesthetic agents, and soaked for 4 h.

Test 2: Polycarbonate squares (10x10 cm), cut from both used and unused venous reservoirs, were bend about 45o, after which a few drops of each of the anesthetic agents were dripped on them. The polycarbonate squares were tested by Fourier transform infrared (FTIR) spectrum analysis for their chemical composition before and after the procedures.

Test 3: A few drops of enflurane and isoflurane were dripped onto the venous reservoir outlet to the pump loop of the five used and the three new oxygenators.

Test 4: A few drops of enflurane and isoflurane were trickled onto the connection between the venous reservoir and the oxygenator of both the used and unused equipment.

RESULTS

Test 1: The polycarbonate became sticky, opaque and easily breakable after immersion in halothane, but was impervious to isoflurane and enflurane.

Test 2: The plastic pieces from both new and used venous reservoir fragmented and disintegrated within seconds of coming into contact with enflurane and isoflurane (Illustration 2). Halothane did not fragment the polycarbonate, but turned it opaque, sticky and easily breakable. The FTIR spectrum analysis failed to show any changes in the chemical composition of the polycarbonate after treatment with the etheric anesthetics.

Figure 2

Illustration. 2: Polycarbonate cracked by etheric volatile anesthetics after forced bending



Test 3: Within seconds of coming into contact with either of the two anesthetics, visible cracks formed in the venous

outlets in four the five used oxygenators and the polycarbonate material turned very soft and easily breakable (Illustration 3). This did not happen to venous outlets of the new oxygenators.

Figure 3

Illustration. 3: Cracked venous outlet of a used oxygenator after coming into contact with an etheric volatile anesthetic agent



Test 4: The base of the venous reservoir of all the used and the new oxygenators cracked.

DISCUSSION

Etheric anesthetics cause no harm to intact polycarbonate. But parts of the polycarbonate with internal stress (caused during production of the bent parts) or submitted to with external stress (for example bending) are vulnerable to the etheric anesthetics. Maltry and Eggers (2) reported that enflurane has no effect on polycarbonate compared with isoflurane. We showed that enflurane and isoflurane have the same effect on the polycarbonate.

Our findings with halothane are at variance with the results of Cooper and Levin (3) in that this agent did not dissolve the polycarbonate parts, whether from new or used equipment, but turned it sticky, opaque and breakable.

It is noteworthy that the etheric anesthetic agents distorted the venous outlet of four of the used, but of none of the new oxygenators. A plausible explanation for the vulnerability of the oxygenators during and after use is the setup and mode of use of the oxygenators and the pump. The oxygenators are held in place by a special device directly connected to the cardiopulmonary pump, and are therefore exposed to the vibrations generated by this pump during bypass. The components that make up the cardiopulmonary bypass equipment vibrate each at different frequencies and phases.

Vibrations of the oxygenator and the tubing passing through the roller pump create continuous bending of the venous reservoir outlet, the more slowly oscillating tubes acting as lever arms that create forces on the short venous outlet. This may cause damage to the polycarbonate and turn it vulnerable to etheric anesthetics by two mechanisms.

First, the cyclic load application during bypass to the venous outlet can cause its premature failure at stresses well below the tensile strength (12). This phenomena is known as "fatigue failure" and can occur via two mechanisms: at large stress amplitudes it involves thermal softening which precedes crack propagation leading to the ultimate failure, while low frequency can cause fatigue fracture by conventional crack propagation.

The second mechanism can be described as crazing and/or cracking (13). Its prime cause is selective plasticization of the polymer matrix ahead of craze or crack where a polyaxial stress field is developed by stress concentration. The failure of the polycarbonate initiates or grows as a result of plasticization-induced weakening of the polymer matrix in this region. This mechanism may be compared with the windshield of a car damaged by impact. The glass, being produced such that it causes stress between its different layers, will change its polymer matrix upon being hit by even a small projectile (e.g., a stone) traveling at moderate speed, resulting in further cracking of the windshield and its disintegration into thousands of small pieces. Even water spilled on polycarbonate which is under high stress (bending or pressure) can destroy polycarbonate (personal communication, Mr. Guy Ben Zvi, General Director Paltough Ltd./Palram Ltd., Israel).

As we learned, contact between plasticized polyvinylchloride and polycarbonate should be avoided (personal communication, Mr. Guy Ben Zvi, General Director Paltough Ltd./Palram Ltd., Israel). It is known that under certain conditions (contact under pressure and heat) even polyvinylchloride exerts an adverse effect on polycarbonate. Although the ambient temperature in the operating room is low, the heating of the patient's blood during the warming up period before the end of cardiopulmonary bypass combined with the heat produced by the mechanical parts of the equipment (vibrations, which are converted into heat due to the low thermal conductivity of the polycarbonate (13)) may bring the temperature to a critical point where the plasticized polyvinylchloride tubing is concerned. Although no reports relating to oxygenator failure due to malfunctioning of the tubing could be found, it

might very well be that the latter is implicated in cases of unexplained breakdown of the oxygenators.

The instructions provided by the manufacturers of the various oxygenators available on the market sometimes fail to caution the user that polycarbonate should not come in contact with volatile anesthetics. Thus no warnings are attached to the COBE CMS 30-HVRF oxygenator, the COBE CML Duo Flat Sheet Open System oxygenator or the Maxim hollow fiber oxygenator with filtered hard-shell reservoir. On the other hand, the instruction booklets for the Polestar Safe II and Dideco D703 membrane oxygenator, the Baxter 10 plus bubble through and the Baxter Univox-IC membrane oxygenators do contain warnings regarding these dangers. The literature pertaining to cardiac anesthesia also scarcely mentions the risk of handling volatile anesthetic agents in the vicinity of oxygenators (14,15,16). As far as could be ascertained by us, neither the literature nor the product information sheets carry any mention of the possible deleterious effect of plasticized polyvinylchloride on polycarbonate.

We tested only the Cobe CMS 30-HVRF membrane oxygenator, since this apparatus was used almost exclusively in our hospital. However, we presume that the polycarbonate components of other such systems would react in the same manner. With regard to the three anesthetics tested in the present work, sevoflurane and desflurane could not be included, as they are not yet available in Israel. It is to be expected, however, that these two ethers will have the same effect on polycarbonate.

Based on our experience and taking into consideration the results of our tests, it is concluded:

1. The vaporizer should not be placed above or near the oxygenator.
2. The vaporizer should be refilled before the oxygenator is installed.
3. A clear warning should be affixed to all oxygenators; the anesthetic literature, including textbooks, should advise the reader of the inherent hazards of the combination of volatile anesthetics, or of plasticized polyvinylchloride (i.e., the tubing), and the polycarbonate components of the cardiac-pulmonary bypass system;
4. Although halothane has not the immediate

devastating effect on polycarbonate as etheric anesthetics, the same precautions as for etheric anesthetics are warranted;

5. The employment of materials impervious to volatile anesthetics and plasticized polyvinylchloride in the operating room should be considered.

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Author Information

Alexander Avidan, M.D.

Department of Anesthesiology and Critical , Hadassah Medical School, Hebrew University/Hadassah University Hospital

Asné Klein, M.Sc.

Headquarters, Division of Identification and Forensic Science, Israel National Police

Joseph L. Nates, M.D.

Department of Anesthesiology and Critical Care Medicine, Hadassah Medical School, Hebrew University/Hadassah University Hospital

Joseph Almog, Ph.D.

Headquarters, Division of Identification and Forensic Science, Israel National Police

Yoel Donchin, M.D.

Department of Anesthesiology and Critical Care Medicine, Hadassah Medical School, Hebrew University/Hadassah University Hospital