Special Report

Explosion of an Ether Vaporizer

Carl W. Walter, M.D.*

AN EXPLOSION of anesthetic gases is rare in modern anesthesiology because of a complex of precautions to confine combustible gases and prevent ignition. Accidents that do occur are seldom reported in the medical literature; newspaper accounts mark the incidents and usually omit technical details. As a result, there are little data available for refining preventive regulations or correcting errors or deficiencies in existing codes or equipment. This report of an accident emphasizes the unique characteristics of an electrostatic circuit that stored energy sufficient to ignite an ether vaporizer. Experiments on a reconstructed gas transmission system exposed the role of the electrostatic charge in an explosion which might otherwise have been credited to spontaneous combustion of ether peroxides.

The surgeon's and anesthetist's reports describe the setting for the accident which occurred at 8:30 A.M. in a room with a temperature of 84° F. and a relative humidity of 23 per cent calculated from meteorologic data.

Abstract From Operative Note

A Davis mouth gag was inserted and the patient's head was suspended in the Rose position from a draped Mayo stand. The ether tube was attached to the tongue blade. The adenoids and the right tonsil were removed. The left tonsil was then grasped with a tenaculum and the mucous membrane incised to delineate the fauces. The suction dissector was used to mobilize the left tonsil. A tonsil snare was positioned and tightened. At this point a loud explosion was heard in the region of the ether vaporizer. Fire broke out on the anesthetist's cart and the anesthesia tray.

The mouth gag was immediately removed. The surgeon and his assistant carried the patient out of the room. The operation was completed in another room. Examination of the mouth and pharynx showed no evidence of foreign bodies or burns. Laryngoscopic examination revealed the epiglottis and larynx to be normal with no foreign body or burn. Superficial excoriation was present in front of the left tragus. There were three 2 × 1 cm. areas of hyperemia of the skin on the left of the neck. These appeared to be first degree burns. The hair was scorched in several areas on the left side of the head, but no other damage was seen. The patient recovered normally from anesthesia. The lungs were clear to auscultation and percussion. No central nervous system abnormalities were found.

Abstract from Statement by Anesthesiologist

Before putting on my conductive shoes, I moistened my socks with water and cleaned the soles of my shoes with a wet paper towel. The shoes were tested and found to be conductive.

There was a flash of fire between the patient and me, that is, between the Richardson vaporizer on the porcelain tray of the anesthesiology machine and the patient. I am not sure where it began. The flash was about two or three feet long and about eight to ten inches in diameter—it was a big flame. This flash lasted about one second, then there was an explosion.

Before the flash was seen, I had shut off the nitrous oxide and increased the flow of oxygen to 8 liters per minute. Also, I had checked the patient's blood pressure. I was either reaching for the control on the Richardson vaporizer or removing my hand from it after having decreased the ether vapor concentration when the flash-explosion sequence occurred.

* Clinical Professor of Surgery, Harvard Medical School; Surgeon, Peter Bent Brigham Hospital; Chairman, Committee on Hospitals, National Fire Protection Association.

Received from the Department of Surgery, Harvard Medical School and Peter Bent Brigham Hospital, Boston, Massachusetts; accepted for publication February 17, 1968.

681
After the explosion, I observed the surgeon and his assistant carrying the patient away from the area of the fire. I saw my anesthesia cart in flames. A colleague tried to smother the flames; the flames were contained until the fire was completely extinguished with carbon dioxide.

As I walked to the doorway to the scrub room, I noticed that I was dripping blood although prior to that time I had felt no injury. I had only seen the flash and heard the loud explosion. I noticed that the vision in my right eye was very dim, almost absent. There was a loud ringing and deafness in my right ear. About this time, a burning sensation developed in the medial aspect of my right arm and forearm. I was taken to the Recovery Room and given medical attention.

**Inspection**

The author inspected the operating room nine hours after the explosion. Photographs of the scene had been taken, various measurements had been made and statements of personnel involved in the accident had been recorded. The gas transmission system is of chief interest in the photograph of the undisturbed site of the explosion (fig. 1). Several noteworthy items are indicated by arrows: (1) the improvised nonconductive rubber adapter that connected the vaporizer on the anesthesia machine to the conductive tubing of the portable Richardson vaporizer; (2) the nonconductive, enameled porcelain anesthesia tray, which before the accident supported the portable ether vaporizer; (3) the top of the Richardson vaporizer; (4) the Davis mouth gag;
(5) the conductive strap for connecting the patient electrically to the table; (6) charred supplies on the anesthetist’s cart. Fragments of the glass vaporizer scattered over the floor can also be seen.

The Richardson vaporizer is a quart size, glass jar fitted with a metal screw cap (fig. 2). A disc mixing valve in the cap directs the flow of gas. The discs are loosely coated by an adjustable nut and gas leakage is possible particularly during manipulation of the valve. In use, the vaporizer jar is usually placed in a pan of warm water to volatilize the ether.

Immediately after the explosion the members of the team were found to be properly clothed and shod with the exception of the anesthetist whose shoes were not conductive. Conductive rubber plugs inserted in the soles and heels of his leather shoes had lost their conductivity and his routine of dampening his socks and shoe soles only temporarily re-established conductivity through a capillary film of moisture around the plugs.

The patient had been connected electrically to the table with a conductive rubber strap, one end of which was tucked between the metal top and the mattress, the other between the skin of the patient’s back and the insulating bedding. Presumably, circumstances at the time of investigation were those existing at the time of the accident. A conductive system was found throughout with a resistance of 20 megohms between the patient’s pathway and the floor. The resistance of the floor averaged 183,000 ohms, measured between standard electrodes set three feet apart. A wide band of adhesive had been fixed across the top of the anesthetist’s stool to prevent slipping. It insulated 50 per cent of the metal top and afforded a variable electrical contact and capacitance coupling with the anesthetist.

Multiple violations of Bulletin 56, “Flammable Anesthetics Code, 1965,” promulgated by the Committee on Hospitals of the National Fire Protection Association were noted throughout the suite, ranging from lack of humidification, improper storage of gases, use of faulty cords, plugs and improvised adapters, unlisted electrical appliances and insulating surfaces on furniture and apparatus.

Fig. 2. Top of Richardson vaporizer.

Fig. 3. Reconstructed gas transmission system. Electrostatic circuit is superimposed. The gas transmission circuit is indicated by solid lines; the anesthetist’s circuit by dotted lines C1, C2, C3, C4, C5, C6, G7, C8 = Capacitance. R1, R2, R3, R4 = Resistance. R3 is the resistance in the circuit when the conductive strap is in contact with the patient’s skin. The complete pathway is through the operating table and its castors to the conductive floor. Circuit values are given in table 1. V = 6,000 electrostatic volts between the points indicated by the connections to the frame of the anesthesia machine and the metal top of the vaporizer with the connection at R3 (the conductive strap) open. The anesthetist’s shoes were nonconductive.
TABLE 1. Circuit Values of Reconstructed System

<table>
<thead>
<tr>
<th>Surfaces Measured</th>
<th>Insulation</th>
<th>Capacitance Picofarads</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 Control valves to top of vaporizer</td>
<td>Nonelective rubber adapter</td>
<td>74</td>
</tr>
<tr>
<td>C2 Top of vaporizer to pan</td>
<td>Glass jar</td>
<td>17</td>
</tr>
<tr>
<td>C3 Pan to metal of glazed tray</td>
<td>Top glaze</td>
<td>370</td>
</tr>
<tr>
<td>C4 Metal of glazed tray to anesthesia machine</td>
<td>Bottom glaze</td>
<td>113</td>
</tr>
<tr>
<td>Total capacitance/gas transmission system to anesthesia machine</td>
<td></td>
<td>80</td>
</tr>
<tr>
<td>C5 Davis gag to operating table with patient in contact with gag but with conductive strap disconnected</td>
<td>Double sheet</td>
<td>2,000</td>
</tr>
<tr>
<td></td>
<td>Double sheet plus clothing</td>
<td>3,000</td>
</tr>
<tr>
<td>C6 Anesthetist to floor</td>
<td>Nonconductive shoes</td>
<td>230</td>
</tr>
<tr>
<td>C7 Anesthetist to stool</td>
<td>Two layers of textile</td>
<td>785</td>
</tr>
<tr>
<td>C8 Stool to conductive floor</td>
<td>Contact resistance</td>
<td>300</td>
</tr>
<tr>
<td>Anesthetist to floor</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>Resistance Values</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R1, R2 Conductive tubing</td>
<td>0.35 megs/foot</td>
<td></td>
</tr>
<tr>
<td>R3 Davis gag to floor</td>
<td>20 megs</td>
<td></td>
</tr>
<tr>
<td>R4 Resistance of floor</td>
<td>0.5 megs/3 ft.</td>
<td></td>
</tr>
</tbody>
</table>

Experimental

A simplified reconstruction of the gas transmission system was assembled. The electrical circuit that stored the charge is superimposed on the illustration (Fig. 3). Each of the insulators in the circuit served as a dielectric in a capacitance circuit. The picofarad values that were measured on a capacitance bridge are listed in Table 1. In an ambient relative humidity of 14 per cent, temperature 74°F, this system could be electrified readily. An insulated individual could add incremental charges to the system by such motions as rubbing clothing, dragging shoes on the floor or pumping a sphygmomanometer. Charges as great as 6,000 volts were accumulated, measured on an electrostatic voltmeter connected between the metal top of the portable vaporizer and the frame of the anesthesia machine.

A conscious volunteer acting as patient in the reproduced gas transmission system, felt a shock each time the circuit was charged by successive increments, with an increment as slight as 800 volts causing discomfort. Once the system was charged to 6,000 volts (full scale on the voltmeter) the potential remained for six to ten seconds before gradually dissipating. The capacitance between the subject's skin and the metal table was 3,000 picofarads with three layers of textile interposed; 2,000 picofarads with two layers. The slow rate of dissipation of the charge was considered an indication of a fault in the conductive path from the subject's skin to the operating table.

Various combinations and rates of gas flow were tried, but no electrostatic charge accumulated attributable to the flow of gas.

Discussion

The initial combustion of the mixture of ether, nitrous oxide and oxygen leaking from the vaporizer was undoubtedly the result of ignition by an electrostatic spark. The flame propagated itself into the vaporizer through
the space between the valve discs; the gas mixture exploded and the glass jar burst. The significant defects in the conductive pathway were: (1) the nonconductive rubber adapter, (2) the nonconductive porcelain tray, (3) the nonconductive shoes, (4) the adhesive on the top of the stool, and (5) the limited and questionable electrical continuity between the patient and the conductive floor.

Electrification of various elements of the circuit could have occurred as a result of: (1) the flow of anesthetic gases, (2) motions of activity about the patient, and (3) actions of the anesthetist.

No evidence of electrification due to the flow of gas could be demonstrated by experiment. Flowing pure gas will not cause electrification but the motion may be indirectly responsible for charging. For example, distention of a rebreathing bag may cause friction between the bag and a contiguous object. Droplets or dust entrained in flowing gas can also accumulate an electrostatic charge.

Electrification of the patient need not be considered, if as the anesthetist stated, the conductive strap, shown in figure 1 (5) and figure 3 (R3), was properly positioned to contact the patient's bare skin and establish an electrical connection with the conductive floor. Presuming that the strap was not in contact, manipulation of the blood pressure cuff or the motion of other insulating materials such as surgical drapes against the patient's body could produce a charge on C5 (fig. 3), which would also charge C1, C2, C3, and C4. Then, even if the anesthetist were in electrical contact with the floor, he could draw a spark off the vaporizer. Negligence was introduced with the use of the nonconductive rubber adapter, the insulating porcelain tray and the insulating cotton bedding.

Actions of the anesthetist are the key to the analysis of the electrostatics. Many motions essential to his functions create an electrostatic charge. His conductive body sheathed in insulating clothing stored a large charge. This charge was released whenever his exposed skin approached an object of different potential closely enough to breach the dielectric barrier of interposed air. In figure 4, the anesthetist is stylized as the knob of a selector switch.

The various points of the switch indicate parts of the anesthesia transmission system that are either grounded or have sufficient capacity to draw an appreciable charge. When the anesthetist contacts these capacitance circuits, their charges are equalized to the potential accumulated on his body.

When both foot-to-ground and body-to-stool resistances are high, the anesthetist's motions on the grounded stool cause electrification. When he rises and increases the distance between his body and the stool, or if he slides off an edge of the stool and decreases the area of contact, the voltage between him and ground will climb because the capacitance of C7 will drop. The strip of adhesive tape on the seat of the stool restricted contact with metal and made this factor critical.

Rising from a sitting position reduces the capacitance to ground anywhere from 1,000 picofarads to 230 picofarads and the voltage climbs proportionately. Rising also generates electrostatic charge. If the standing anesthetist then touches anything, a spark will jump just before contact releasing sufficient
energy to ignite a combustible mixture of anesthetic gases.*

Two other sequences could be held accountable for the spark and each could be demonstrated repeatedly in the laboratory.

For one, it is assumed that the gas transmission system was at zero potential as its charge either leaked through the patient to the conductive floor or was dissipated to the conductive floor via the anesthetist during simultaneous manipulations of the vaporizer and the conductive anesthesia machine. The insulated anesthetist subsequently became electrified by motions attendant upon management of the anesthesia. Discharge to the electrically depleted gas transmission system resulted in the igniting spark.

The other mechanism assumes that the charges generated by the anesthetist were transferred, by contact, to the conductive portions of the isolated gas transmission system, i.e., the conductive tubing from the nonconductive rubber adapter to the metal parts of the portable vaporizer, the conductive tubing to the metal Davis mouth gag. Contact between the charged anesthetist and this isolated conductive gas transmission system was necessarily frequent. The result was the incremental accumulation of electrostatic charge in the capacitance of the gas transmission system, (fig. 3, C1 + [C2 + C3 + C4]). This voltage discharged (sparked) to the anesthetist's fingers when he adjusted the vaporizer while being momentarily at zero potential as a result of touching the valves on the anesthesia machine.

In any one of the three situations, the anesthetist supplied the energy to generate the charge by pumping a sphygmomanometer, reaching for the controls of the anesthesia machine or vaporizer or fidgeting on the stool.

He was negligent in wearing nonconductive shoes and compounded the situation by tolerating the adhesive strip on his stool.

This analysis of an explosion illustrates the value of reporting and consultation. Recital of the experience has educational value, dispels mystery, adds to knowledge of anesthetic explosions and helps overcome complacency in hospital staffs. Confidence in the concepts of prevention as outlined in The Code of the National Fire Protection Association is reaffirmed. In particular, the importance of an electrically conductive gas transmission system (Paragraph 2542), conductive footwear (Paragraph 3512A), conductive metal surfaces (Paragraph 2531), and electrical continuity between the patient and conductive floor (Paragraph 3512B) is emphasized by this near disaster.¹

Summary

An explosion of an anesthetic mixture of nitrous oxide, oxygen and ether is reported. Breaches in the conductive pathway that permitted the accumulation of an electrostatic potential sufficient to ignite the flammable mixture of gases around and within a Richardson vaporizer are described. A small capacitance electrostatic circuit that can be easily electrified with a charge of 6,000 volts is described. Maintenance of a conductive pathway to ensure equalization of electrostatic potential is urged.

The prompt reporting of all explosions and fires of anesthetizing gases is solicited to aid in understanding and elimination of the hazard. The merits of the Bulletin of the National Fire Protection Association are re-emphasized as essentials in preventing catastrophes related to ignition of anesthetic gases.

References


4. Sereda, P. J. and Morse, R., National Research Council, Ottawa, Canada (Personal communication, August 29, 1965.)

---

* To ignite the combustible mixture of anesthetic gases, approximately 6.1-10.0 millijoules of electrostatic energy "E" are required.

\[ E = \frac{1}{2} CV^2 \]  (joules, farads, volts)

\[ V = \text{easily obtained} = 6-10 \text{ Kilovolts} \]

\[ C = \frac{2E}{V^2} = \frac{2 \times 1 \times 10^{-2}}{100 \times 10^4} \text{ farads} \]

\[ = \frac{2 \times 10^2}{10^4} \text{ pf} = 20 \text{ picofarads} \]

Values of this order were measured in the reconstructed electrostatic circuit.