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Complete Electrical Failure during Cardiopulmonary Bypass

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THE consequences of electrical failure can be particularly hazardous for the cardiac surgical patient during cardiopulmonary bypass. In addition to monitoring

equipment, electrocautery, operating room lights, air conditioning, and overhead paging, the cardiopulmonary bypass pump and heat exchanger will cease to function. This case report describes the management of a patient undergoing quadruple coronary artery bypass surgery during a 50-min loss of electrical power that occurred when the heart was arrested and the aorta cross-clamped and as the surgeon was performing the first distal coronary anastomosis.

Case Report

A 66-yr-old, 94-kg, 180-cm man was admitted through the emergency room complaining of chest pain and sustaining an acute inferior

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wall myocardial infarction. On the basis of cardiac catheterization, the patient was scheduled for coronary artery revascularization and possible aortic valve replacement 11 days after infarction.

The patient was brought into the operating room and anesthetized at 7:19 AM after standard monitoring was instituted. Monitoring included five-lead electrocardiography with continuous display of two leads; intraarterial, pulmonary arterial, and central venous pressures and waveforms; and temperature displayed on a common video monitor (model 66, Hewlett-Packard, Andover, MA). Additional monitoring consisted of noninvasive blood pressure (Dinamap 1846SX, Critikon, Tampa, FL), pulse oximetry (Nellcor, Hayward, CA), gas analysis (O.R. Saracap, PPG Biomedical Systems, Lenexa, KS), and transesophageal echocardiography (128 XP/E, Acuson, Mountain View, CA). An anesthetic gas machine (Modulus II Plus, Ohmeda, Madison, WI) and an automated anesthesia information recording system (CompuRecord, PPG Biomedical Systems, Lenexa, KS) also were employed.

Cardiopulmonary bypass was initiated with a roller pump (7000 Modular Perfusion System, Sarns, 3M, Ann Arbor, MI), and the patient was systemically cooled to 32°C. The aorta was cross-clamped at 9:32 AM, and cardioplegia was infused into the aortic root. This resulted in asystole and the first coronary arteriotomy was performed. At 9:38 AM during this first vein graft anastomosis, a power outage occurred that affected the entire hospital including the entire operating room suite and recovery room. Three power cables supplying the hospital failed in rapid succession due to the tremendous demand resulting from a record heat wave. The outside temperature on the day of surgery was 32°C with 85% relative humidity. The operating suite administrators initiated phone contact with the utility company, hospital maintenance, and the anesthesia coordinator. Power returned to the operating rooms after 30 s when the hospital generators began to operate. Immediately before the second arteriotomy, complete electrical power was lost a second time (9:53 AM), when the hospital's generators failed for 52 min. During the time of electrical power outage, the roller head in the cardiopulmonary bypass circuit was initially manually cranked at a speed that maintained a venous saturation greater than 70%, as indicated by a battery powered saturation monitor. Manual cranking continued for several minutes until a battery pack (MDX, Sarns, 3M, Ann Arbor, MI) was brought to the operating room as an alternative power supply for the cardiopulmonary bypass machine. A portable cardiovascular transport monitor (M1275A, Hewlett-Packard, Andover, MA) was brought to the operating room to measure the systemic arterial pressure.

The immediate need for the entire operating room suite was a source of light. This was initially provided with the flashlight and laryngoscope, which are standard equipment in each anesthesia stand. There were no overhead sources of light in all of the operating rooms, hallways, anesthesia workroom, or postanesthesia care unit. The darkness was an obstacle in providing and obtaining necessary equipment. Additional flashlights were obtained from the anesthesia and operating suite workrooms. Illumination for the surgical field was provided with multiple flashlights. The lack of illumination in the hallways resulted in personnel colliding with other personnel and equipment, which provided the potential for injury.

With no communication capability *via* the intercom or paging systems, all available anesthesia personnel (anesthesiologists, nurse anesthetists, residents, and workroom technicians) began a check of each operating room to determine priority needs. The anesthesia providers were evaluated periodically for possible heat exhaustion in the face of increasing temperatures and humidity. A battery-op-

erated suction device was obtained from paramedics in the emergency department, and an oxygen-driven suction was brought to the operating room. Measurement of activated clotting time in the cardiac rooms was performed manually with a flashlight and stopwatch.

A decision was made to terminate the coronary artery surgery until power was restored. When the aortic cross-clamp was removed, the heart was asystolic and the patient's temperature was 33°C. The patient could not be warmed *via* the heater/cooler unit of the bypass circuit because this was dependent upon electrical power. A dopamine infusion was begun *via* a battery-operated infusion pump (Flo-Gard 6200, Baxter, Deerfield, IL), and with the return of adequate cardiac function, the patient was separated from bypass (10:35 AM). The lungs were manually ventilated with 100% O₂, and monitoring continued with the battery-operated pulse oximeter and transport monitor, which displayed the electrocardiogram and arterial and pulmonary arterial waveforms and pressures. Oxygen concentration was measured with the oxygen analyzer on the anesthesia machine. Anesthesia information recording was performed with a handwritten record. The ambient temperature and humidity of the operating room continued to increase until electrical power was restored (10:45 AM). Cardiopulmonary bypass was reinstated (10:53 AM), and the operation proceeded uneventfully.

Representatives of the operating room personnel met with and reassured family members who were in waiting rooms at the time of the power outage. The patient was awake later the same day, and the trachea was extubated the next morning. He did not suffer any neurologic complications and was discharged from the hospital 8 days after surgery.

Discussion

All hospitals have alternative provisions for electrical power supply. It is possible, however, for these backup systems to fail, producing the potential for catastrophic consequences. Although it is assumed that the likelihood for such an occurrence is rare, power failures occur and provisions must be made to reduce the potential for significant patient morbidity and mortality. These provisions include emergency equipment and battery-operated monitors, physical plant changes, light sources, and a specific protocol identifying a plan of action. Although previous reports describe provisions for power failure in the general operating room¹ and the intensive care unit,²⁻⁴ there is a lack of information regarding the frequency of such occurrences.

There are particular considerations and requirements for the patient receiving cardiopulmonary bypass during a power failure. First, systemic perfusion must be restored. When the pump stops, it is important to remember that venous return will continue into the reservoir and the patient will exsanguinate unless a clamp is placed on the venous tubing. If the heart is contracting at the time of power failure and able to sustain adequate contractility, limitation of the venous return

to the pump will allow the heart to resume systemic perfusion. Manual ventilation is begun as the patient is separated from bypass. If contractility is inadequate or the heart is cold and asystolic, mechanical perfusion by hand-cranking the pump is necessary. Additional help for performing this task should be sought early, because it is physically demanding. A perfusionist can hand-crank an average pump for about 15 min before beginning to tire. The adequacy of hand-cranking can be judged initially by the venous saturation monitor, which is usually battery-operated. Hand-cranking must continue until a battery source is provided or until electrical power is restored. Portable battery packs, as used in the present case report, should be available or built into the bypass machine. Besides the pump unit, which provides arterial perfusion, additional units are routinely employed during cardiopulmonary bypass. One unit is used for each of the following functions: cardioplegia administration, cardiotomy suctioning, and venting the left ventricle. These units are also inoperable unless they are connected to a battery pack or hand-cranked. If continued battery power is required, these units should be hand-cranked to avoid the additional drain on battery power, allowing more battery time for the arterial perfusion unit. Our experience with the portable battery unit used in the case report has demonstrated that it will provide 50–55 min of power when the battery pack drives the arterial perfusion unit alone and 30–35 min when it supplies power to three units and the reservoir lamp. Newer bypass machines have built-in battery supplies, which reportedly provide 60 min to a fully loaded system and 120 min to a minimal system.[†] The duration of electrical power provided by battery units is variable depending on the size of the unit, the age of the unit, the degree of charge, and whether the unit has been maintained properly with periodic deep-discharge. The heater/cooler unit of the bypass circuit requires electrical power for pumping water to the oxygenator and for generating heat for rewarming. Consequently, the patient cannot be rewarmed or cooled. The unit could be powered by the portable battery unit but is a considerable drain on power, especially during rewarming.

Once systemic perfusion has been restored, either manually or with batteries, efforts should be directed to providing hemodynamic monitoring. Blood pressure determination with a manual cuff as described in a pre-

vious report¹ is not useful during bypass because of the absence of pulsatile flow. A sphygmomanometer may be used to determine mean arterial pressures if the end is adapted for connection to pressure tubing as shown in figure 1. A portable battery-operated monitor can provide electrocardiographic and pulmonary artery pressure monitoring in addition to arterial pressure monitoring. A portable cardiovascular transport monitor offers the further advantage over a sphygmomanometer in permitting observation of the pressure waveform in addition to the numeric value of the pressure. Battery power is limited for these portable units, and they should be kept fully charged and properly maintained, including periodic deep discharge. The

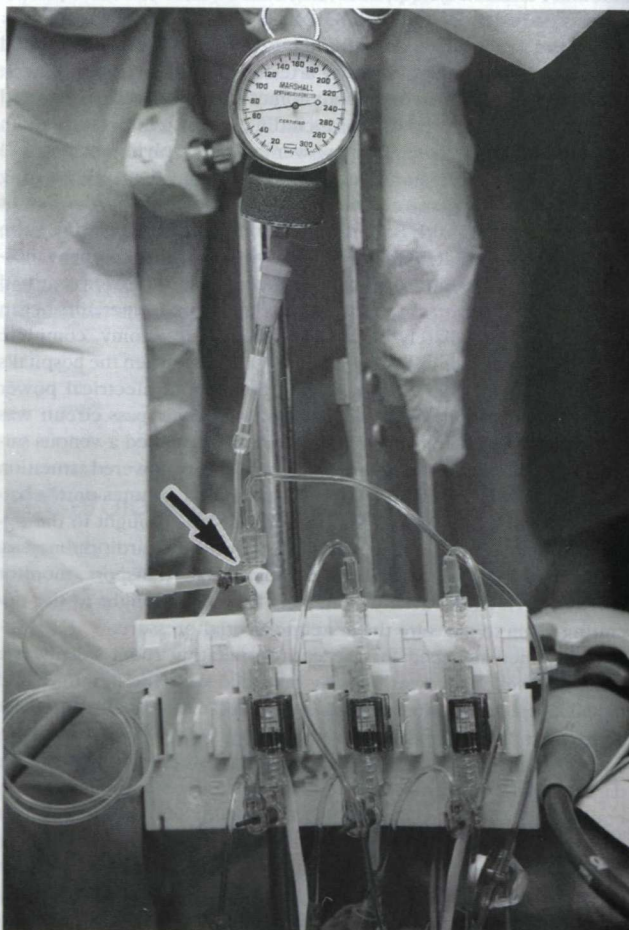


Fig. 1. A method for measuring mean arterial blood pressure during nonpulsatile cardiopulmonary bypass with a sphygmomanometer, a flash bulb, and pressure tubing. Arrow indicates attachment of pressure tubing from sphygmomanometer to stopcock in the arterial pressure line. Stopcock is turned off to the electrical transducer.

[†] Sarns 9000 Perfusion System Operators Manual. Ann Arbor, Sarns 3M Health Care, 1991, 20.13–20.14.

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availability of a second portable monitor is beneficial if the need for prolonged use of the first monitor becomes apparent.

Measurement of heparin effect is required during cardiopulmonary bypass to maintain an adequate level of anticoagulation. Automated versions of the activated coagulation time are inoperable during a power failure. Manual determination of the activated coagulation time must be conducted. This procedure requires a light source (e.g., flashlight), a stopwatch, and the constant attention of the observer looking for the first signs of clot formation.

If restoration of electrical power is not imminent, surgical efforts should be directed at restoring cardiac function and separating the patient from cardiopulmonary bypass. Battery power to the bypass machine is obviously limited, and it is therefore safer for the patient if the heart is contracting so that systemic perfusion is not completely dependent on the bypass machine. If a coronary arteriotomy has been performed just before the power failure, the anastomosis to that artery must be completed before the aortic cross-clamp can be removed. Restoration of cardiac function will be difficult if the heart is cold and not completely revascularized. Vasoactive infusions should be started early, because a more expedient restoration of adequate cardiac function will permit earlier separation from cardiopulmonary bypass. Most, if not all, modern infusion pumps have a built-in battery supply, further emphasizing that these pumps should remain plugged-in and fully charged when not in use. A summary outlining our protocol for care during power failure during bypass is shown in figure 2.

After cardiopulmonary bypass, the emphasis shifts to ventilation, monitoring, and pharmacologic support of the circulation. Electronic ventilators and alarms will not be operational in the face of a power failure unless the anesthesia machine is equipped with battery power. Ventilators will be operational for 30–60 min from a battery source that is fully charged and has been properly maintained. It is important that anesthesia providers become aware of how their particular equipment functions during a power failure. The newer anesthesia machines have built-in battery backup, while older machines do not. Manufacturers recommend testing of

the backup battery system daily and not using the system unless the battery is fully charged.†§ Electrical power to the anesthesia machine is automatically cut off when the battery voltage decreases to less than a specified threshold. Deep discharge damages lead-acid batteries. Ventilation was performed manually in this case to conserve energy for the alarms and oxygen analyzer. Pneumatic ventilators will continue to function during a power failure because they are driven by oxygen. Dedicating one person to manual ventilation ensures adequate and continued ventilation without distraction. Ventilation can be monitored *via* an esophageal stethoscope and by visual inspection of lung expansion in the open mediastinum. In the absence of capnography and a battery-powered spirometer, a mechanical spirometer can be used for the determination of tidal volume and adequate ventilation.

Oxygen analyzers and pulse oximeters can operate with battery power and provide very important information regarding oxygen delivery and tissue oxygenation. This is especially important in the cardiac surgical patient who cannot be readily monitored visually because of surgical drapes and the dark operating room environment. Pulse oximeters also provide heart rate information.

Visual inspection of the heart provides an estimate of contractility in the absence of power to the cardiac output monitor and transesophageal echocardiography machine. A portable monitor, previously described, which provides hemodynamic data, can infer ventricular performance by measurement of pulmonary artery pressure and by observing the upstroke on the arterial pressure waveform.

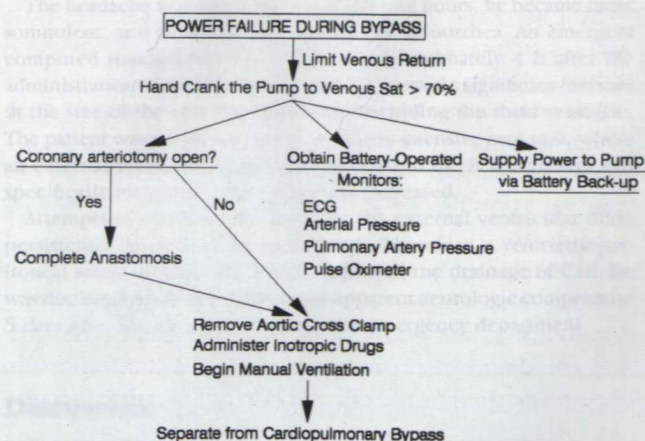


Fig. 2. Protocol outlining intraoperative plan of action for complete electrical failure during cardiopulmonary bypass.

† Modulus II Plus Anesthesia Machine Operating and Maintenance Manual. Madison, Ohmeda, 1991, 3-33.

§ Narcomed 2B Anesthesia System Operator's Instruction Manual. Telford, North American Drager, 1993, 23-34.

Additional considerations include the loss of lighting, electrocautery, and suction. In the absence of battery-powered floodlights, several flashlights were required in the case described, for both the operative field and for walking around and visualizing equipment in an otherwise dark environment. Although loss of electrocautery and suction may seemingly only involve the surgeon, continued bleeding and the inability to localize the bleeding will affect anesthetic management as hemodynamic deterioration develops.

Failures of the normal electrical supply to health-care facilities occur and must be considered unavoidable. Interruption of normal electrical service may be caused by catastrophes, such as storms, floods, fires, earthquakes, or explosions; by failures of the systems supplying electrical power; or by incidents within the facility.⁵ Building codes require that the electrical supply to a hospital consists of two separate full-capacity services, each independent of the other. These services should be connected in such a manner that one will pick up the load automatically upon loss of the other and so arranged that the load of the system will be transferred to the alternate source (generator) only when both utility services are interrupted.⁵ Furthermore, the electrical supply should be divided into essential and nonessential branches. The essential branch should include wiring to the operating rooms and intensive care unit and be provided with power from more than one source, as mentioned.⁶

In conclusion, although rare, complete electrical power failures do occur in modern hospitals. The keys to appropriate management and avoidance of potential catastrophes include having a plan of action and the

availability of nonelectrical or battery-operated equipment with fully charged batteries that have been properly maintained. Battery-operated overhead lighting, which was not available in our operating room suite, is extremely important in operating rooms, hallways, recovery rooms, and equipment storage areas. This type of lighting source requires regular maintenance, including periodic deep-discharge so that the back-up lighting will be available when needed. Following these recommendations and provisions will maximize the likelihood of successful outcomes and minimize the occurrence of potentially significant morbidity and mortality.

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