Environmental emergencies in theatre and critical care areas: power failure, fire, and explosion

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Key points

Environmental emergencies in the operating theatre and intensive care unit (ICU) pose a risk to the critically ill.

Fire requires the presence of an oxidant, a fuel, and an ignition source.

Despite the presence of multiple levels of redundancy, power failures in hospitals still occur.

Design of operating theatres and ICUs should take into account the possibility of an environmental emergency.

Successful outcomes from environmental emergencies are predicated on regular staff simulation and training. Staff should be familiar with and follow institutional guidelines.

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In 2012, a fire broke out in the intensive care unit (ICU) of the Royal United Hospital, Bath, when a faulty oxygen cylinder placed on a patient bed ignited. The patient sustained burns to the lower limbs, the cubicle sustained substantial structural damage, and the ICU rapidly filled with smoke, necessitating evacuation.[1] Recent studies have highlighted weaknesses in a number of London ICUs due to failures of unit design, equipment, escape routes, drills, and evacuation planning.[2] In the 11 yr between 1994/5 and 2004/5, some 10 662 fires were reported in National Health Service (NHS) facilities costing an estimated £14.6 million. Roughly 500 per annum involved acute care facilities and resulted in 651 injuries and 17 fatalities. In addition to burns and smoke inhalation, a number of other traumatic injuries were sustained during evacuations.[3]

These incidents show that environmental emergencies such as power failure, fire, and explosion have the potential to lead to substantial patient morbidity and mortality, and also endangering staff and facilities. Key to the successful management of these environmental emergencies are comprehensive and regular staff training and credentialing, inspections and auditing for environmental risks and evacuation obstacles, and simulations and exercises designed to reveal shortcomings in institutional protocols.

Fire and explosion

The ASA Practice Advisory Committee for the Prevention and Management of Operating Room Fires[4] notes that fire requires the presence of three components, referred to as the 'fire triad'. These are:

(i) an oxidizer;
(ii) an ignition source;
(iii) fuel.

Oxidizers

A compound is classified as an oxidizer if it may, generally by providing oxygen, cause or contributes to the combustion of another material more than air does. The oxidants involved in the clinical environment are usually oxygen and nitrous oxide. Less likely are nitric oxide and hydrogen peroxide.

Ignition sources

Any device capable of creating a spark or flame may become an ignition source. This includes defibrillators, electrocautery devices, lasers, heated probes, drills and burrs, argon beam coagulators, fibreoptic light cables, tourniquet cuffs, buildup of static electricity, and faulty or incorrect use of power sockets.

Fuel

A fuel is a substance that stores potential energy that may be released as heat energy and that is capable of participating in a combustion reaction with an oxidant. The ease with which a solid, liquid, or gas will ignite and burn is described by its flammability. This is increased by the presence of oxygen.

The interaction of the three components of the fire triad produces the combustion reaction, which leads to the production of heat and a number of potentially toxic chemical species.

Prevention

Operating theatres

While the introduction of halogenated anaesthetic agents has improved safety, the surgical process may also produce flammable substances. Ignition of gastrointestinal gases, byproducts of electrostatic prostate resection, equipment

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lubricants, and surgical preparation solutions have been reported.

Prevention of operating theatre fires requires attention to the 'fire triad', and involves the following described below.

Minimizing an oxidant-rich atmosphere near the surgical site

High concentrations of oxygen allow ignition of a wide range of substances not usually combustible in room air. An oxidant-rich environment may be created by a closed or semi-closed breathing system with an $F_{IO_2} > 23.5\%$. A similar risk can be created with an open breathing system if poor positioning of blankets or surgical drapes trap a gas mixture containing high concentrations of oxygen.

Safety measures include minimizing the F_{IO_2} around the surgical site, a surgical drape configuration that prevents formation of localized pockets of oxygenated gas from forming, or isolating the surgical site from the oxygen source. If an ignition source is to be used in close proximity to an oxygen source, the surgeon must alert the anaesthetist. Decreasing F_{IO_2} and eliminating nitrous oxide from the gas mixture before use of a potential ignition source may limit risk without substantially affecting patient oxygenation.

Safe management of ignition sources

This includes judicious use of lasers, diathermy or other ignition sources, and vigilance. The presence of a nearby fuel of sufficient flammability may be all that is needed to cause ignition, even in room air.

Safe management of fuels

There are a large number of potential fuels present in the operating theatre, including bedding, surgical materials, and various preparation solutions (i.e. isopropyl alcohols, tincture of benzoin, etc.). Specific measures include allowing adequate time for drying of alcoholic preparation solutions to allow dispersion of flammable vapours, moistening or minimization of surgical sponges and other potential fuels to be used near an ignition source, and the shaving or coating of body hair with water-soluble, flame-retardant sterile lubricant.[5]

Intensive care unit

As open breathing systems are often used in patient care in ICU, prevention involves minimization of ignition sources and safe management of fuels.

Minimization of ignition sources

Frequently cited sources include the buildup of flammable material within wall power outlets and oxygen cylinders, and faulty power supplies and electronic equipment.

The safe use of electronic equipment is often overlooked. It involves regular authorized maintenance and safety checks of electronic equipment, cabling and power sockets, the withdrawal from the use of suspect equipment, and the prohibition of private electronic devices until appropriately cleared for use by biomedical engineering.

Cylinder explosions may result from oil or grease coming into contact with oxygen under pressure. Sudden opening of the valve can cause an increase in temperature of a small volume of gas as the pressure suddenly increases. If any flammable material is adjacent to this, then it may ignite, with a resultant explosion. Hospitals should have in place guidelines and training for the safe use of pressurized oxygen cylinders.[6]

Safe management of fuels

The risk of hospital fires is greatly increased by the presence of flammable waste. The orderly stacking of waste and other flammable products in designated areas, and regular cleaning to prevent the buildup of such materials reduces the risk. This is especially important in hidden spaces such as behind walls and power sockets.

Facility design

The design of a new facility allows for fire prevention and control features to be incorporated. Older facilities are often compromised by inadequate fire doors, ventilation, and escape routes.

Specific guidelines for design of critical care areas have been issued by the UK Intensive Care Society.[7] When designing a new facility, consideration must be given to the separation of patient areas from fire hazards, the use of fire-resistant construction, and storage of potentially flammable materials away from fire-fighting equipment and fire exits. Specific requirements for fire alarm and sprinkler systems should be met, and water and carbon dioxide fire extinguishers should be readily available. These measures go hand-in-hand with staff education and training with yearly credentialing.

Management

Recognizing the early signs of fire

Early signs of fire include a flame or flash, unusual sounds or movement of drapes, unusual odours, smoke, and heat. If it is suspected that a fire is present, any procedure should be halted and investigatory efforts made.

Attempting to extinguish the fire

For an established fire involving the patient but not the airway or breathing circuit, the emergency alarm and fire alarms should be activated. The designated fire alarm may activate the facility fire plan and transmit a signal to the local fire service. After this, the flow of all airway gases should be stopped and all drapes, flammable, and burning materials should be removed from the patient. These may be extinguished using techniques immediately at hand including water, saline, or smothering. If these actions are successful, then the patient should be assessed for smoke inhalation or airway burns (if not intubated) and a plan devised for ongoing care.

In the event that the fire is not extinguished on the first attempt, or the fire does not involve the patient, then further measures including the use of a fire extinguisher may be required. The correct extinguisher should be selected to minimize the risk of harm to patients, equipment, and staff as per the relevant British standard (Fig. 1).

Simultaneously, patients and staff should be evacuated from the room following institutional protocols, and the door closed to contain the fire. The fire brigade should be responsible for the re-opening of the door and re-entering of the room.

If the fire is at risk of spreading, or if it involves the ceiling or pendant, the medical gas supply should be turned off using the control valve normally located immediately outside each operating theatre or within the ICU, despite the effects that this will have on patients requiring oxygenation or ventilation if portable oxygen supplies are not available. Preparations to evacuate the ICU or operating theatre suite require liaison with designated senior members of hospital administration and engineering.

Evacuation

Evacuation should be possible via three separate, clearly signposted fire escapes to different safe areas, following a predetermined plan.[7]

Preparation for evacuation requires alteration to patient management, and access to transport drugs and equipment, similar to intra-hospital transfer of the critically ill patient. Critical care areas should be self-reliant in this regard. Access to additional resources may be limited following evacuation, and staff should take all equipment necessary to maintain the patient's condition acutely without access to main medical gas, suction, or electrical supplies. This practice should be reinforced with regular training and simulation.

In an extreme emergency, the sequence of evacuation should be:

(i) those in immediate danger;
(ii) ambulant patients;
(iii) the remaining patients who are not ambulant.

Patients connected to closed breathing systems will remain safe from toxic gases until disconnected, or until the medical gas supply is interrupted. Some continuous therapies may not be able to be stopped (i.e. extracorporeal circulation) unless they have a mechanism for manual operation or battery back-up. Such patients may be forced to remain in the ICU or operating theatre until evacuation is nearly complete or the fire is controlled. In extreme circumstances, these patients may not be able to be safely evacuated from the area, and the difficult decision to leave them behind may have to be made.

Power failure

Hospital power supplies are designed with two levels of redundancy in addition to the main power supply. These take the form of an onsite emergency generator and an uninterrupted power supply. Whether or not a care area has access to an alternate power supply is determined by its risk category[8] (Table 1).

Main power supply

Main power is normally derived from the municipal supply, via an electrical substation and transformer. A white or beige power socket is connected to the main power supply only. In the event that this fails, they will not function.

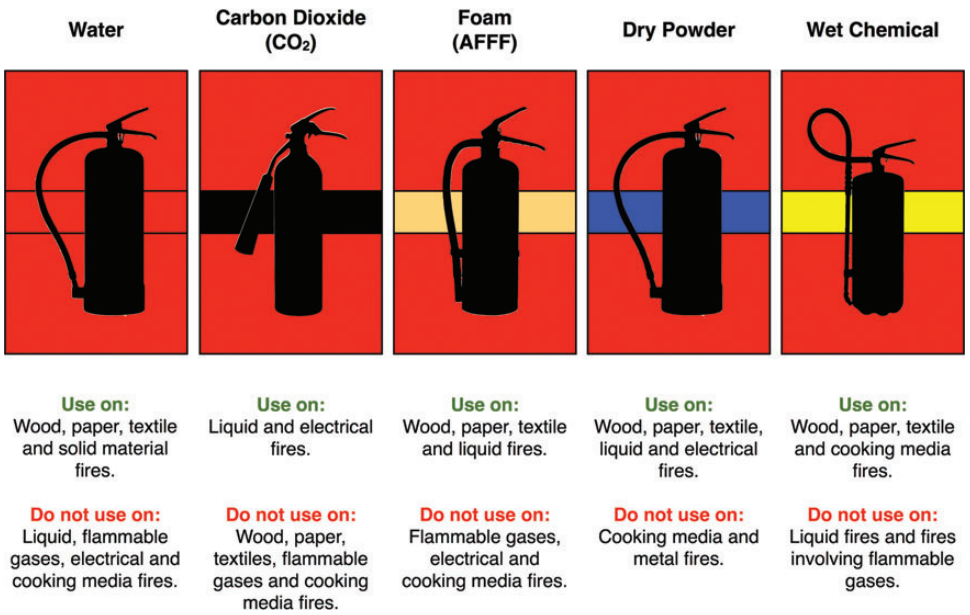

Fig 1 Current fire extinguisher colour codes as mandated by British Standards (BS EN3). Cylinder types are differentiated by their shape (demonstrated by the black outline) and body colour (demonstrated by the red background common amongst all types, and the type-specific coloured strip or panel on upper part of the cylinder body).

Table 1 NHS patient clinical risk categories for electrical services and distribution

Risk category	Descriptor	Alternate power supplies	Examples
1	Support service circulation	N/A	Waiting areas, offices, non-patient care areas, laboratories
2	Ambulant care and diagnostics	N/A	General practice, outpatient clinics
3	Emergency care and diagnostics	SPS	Mental health wards and some maternity services
4	Special medical locations	SPS ± UPS	General medical/surgical wards, radiology, haemodialysis, endoscopy suites, ambulant emergency care, birth suites
5	Life support/complex surgery	SPS and UPS	Operating theatres, ICU, trauma/resuscitation areas of emergency departments, cardiac catheter laboratories, angiography suites

Secondary power supply

The secondary power supply (SPS) is activated if the main power supply fails. Usually, this refers to single or multiple onsite diesel generators depending on the electrical load. Disruption of the main power supply is detected by the phase loss relay (Fig. 2). This is activated when voltage is <80% of normal for 2 s. Activation triggers the critical branch transfer or auto-changeover load switch, allowing the power supply for connected circuits to be drawn from the SPS. The SPS supplies power to vital circuits and delayed vital circuits, which cannot be without power for more than 15 s or 2 min, respectively.

Electrical circuits connected to the SPS are denoted by a red power socket. These should be reserved for equipment that is essential but has a battery backup which powers all device functions (i.e. ventilators with a transport function), or devices for which a short period of disruption may be tolerated (i.e. surgical diathermy).

Uninterrupted power supply

An uninterrupted power supply (UPS) is a backup battery bank that supplies circuits that cannot afford any interruption to electricity (instantaneous circuits). Depending on its size, the UPS may be used to support a single circuit, or a complete hospital. Electrical circuits connected to the UPS are denoted by a dark blue power socket, and are reserved for essential equipment without adequate battery backup.

The UPS always supplies the designated sockets, and is continually recharged by the main power supply or the SPS. The duration for which a UPS can continue to supply power in isolation is dependent on battery size, the level of charge when power is lost, and the load on the device.

For faults between the UPS and the power socket, there will be no flow of power to instantaneous circuits. A recent fire in a theatre electrical control panel in our institution resulted in interruption of all power supplies to that operating theatre.

Consequences

Power failures may affect an entire facility or an isolated operating theatre or ICU bedspace. Potential equipment losses after power failure include the anaesthesia machine and respiratory support, physiological monitoring, lights, fluid delivery and warming devices, surgical tools, extracorporeal circulation, imaging, communications, electronic medical records, laboratory testing, humidity and temperature control, and laminar flow.

Functions lost depend on the power supplies affected (main, SPS/UPS, or both) and the adequacy of battery backup. A battery backup may only supply the most essential functions of a device. Case reports have highlighted the response of anaesthetic machines in which the battery backup powered only the ventilator, gas, and vapour delivery for 20–30 min at maximum load.[9] All other functions of the machine were lost.

Preparation

Preparatory steps to ensure the continued supply of electricity in the event of main power failure involve minimizing the load on the UPS and ensuring adequate battery backup.[10] Only essential equipment should be connected to the blue power sockets, and unless a device has an essential function that cannot be supplied by battery, equipment with battery backup should not be connected to the UPS. Devices not essential to the function of the clinical environment (i.e. domestic equipment) should be connected to the beige and white power sockets.

Critical care environments should be equipped to manage complete power failure. Alternate, battery powered, fully charged light sources should be available in each operating theatre and for each ICU bedspace. A self-inflating, bag–valve resuscitator, portable pulse oximeter, manual sphygmomanometer, and portable oxygen supply should also be available for each patient. An institutional guideline for power failure should be readily accessible and contained in staff training packages and simulations in a similar fashion to fires and other environmental emergencies.

Immediate management

Immediate management should focus on the individual patient followed by an institutional response.[10] The hospital internal disaster response system should be immediately activated and a single clinician not directly involved in patient care (logically the anaesthetic consultant-in-charge in theatre and the consultant intensivist in ICU) should liaise with the hospital control centre.

For clinicians directly involved in patient care, assistance should be sought, and additional light obtained if ambient light is inadequate. If a flashlight is not available, a laryngoscope or mobile telephone may be used. Do not use naked flames. Any procedure in

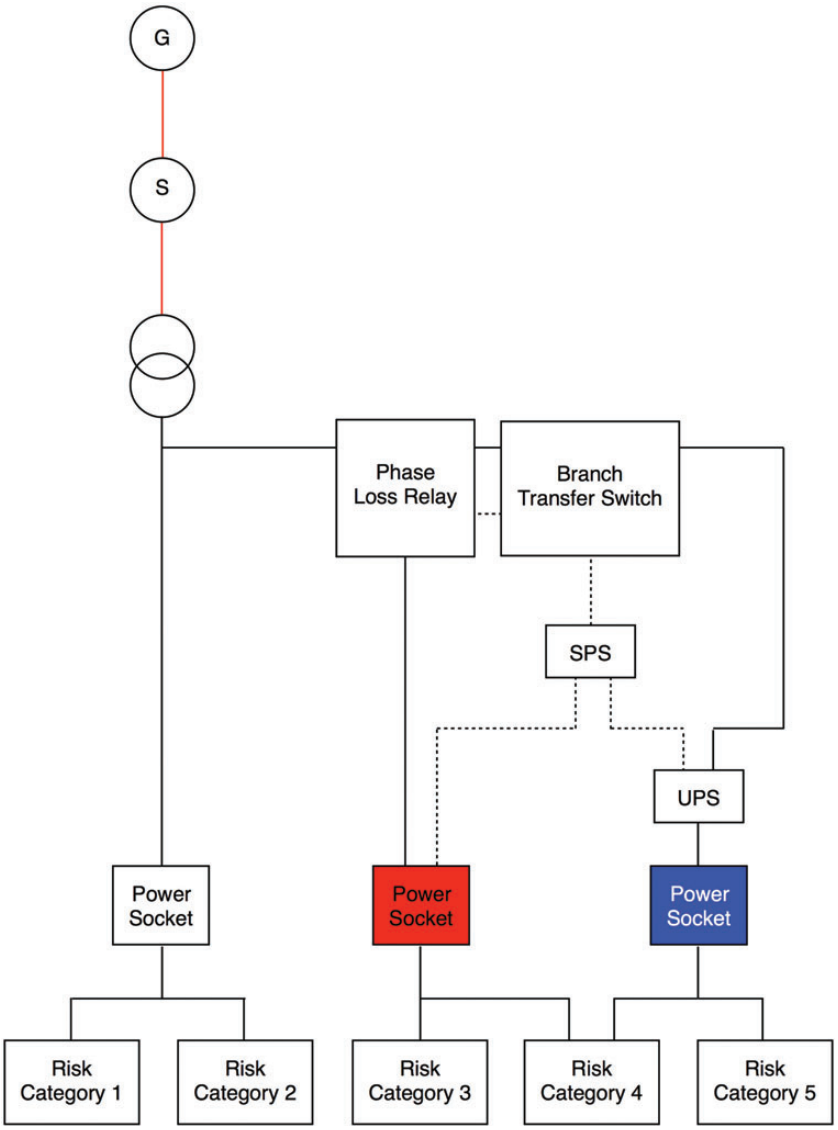

Fig 2 Simplified schematic of the distribution of power, and the availability of SPS and UPS in various areas of a hospital as described by their risk category. G, high-voltage power generating station; S, electrical substation; interlocked circles, electrical transformer; solid red line, high-voltage power line; solid black line, low-voltage power line (main); broken black line, low-voltage power line (alternate).

progress should be suspended if safe to do so while the patient and situation are assessed. If the patient requires extracorporeal circulation then hand-cranking should be started if necessary. The pulse should be manually palpated and a manual sphygmomanometer used to assess arterial pressure. Adequate ventilation and oxygenation should be established using portable oxygen and a manual bag–valve resuscitator if need be. Ventilation may be assessed by observing the colour of the patient, fogging of the airway device, and the rise and fall of the chest. If a mechanical ventilator is being used, placing a hand over the common gas outlet and observing the rise and fall of the bellows may assess continued function.

Once the basic physiological state of the patient has been stabilized, an alternative means of anaesthesia or sedation must be ensured. If inhalation agent delivery is questionable (measured flow and Aladin^{TM} cassette vaporizers are unreliable without electrical power), then total i.v. anaesthesia with battery backup should be established. If infusion pumps fail, then the measurement of drip rates using volumetric burettes may be required.

Essential monitoring should be re-established as soon as possible. Portable transport monitors, pulse oximeters, and end-tidal capnographers are ideal for this purpose. If emergency power is available via the UPS, efforts should be made to minimize the electrical load, potentially by discontinuing mechanical ventilation. Spontaneous ventilation or hand ventilation may be considered if safe, although this will not be possible if the patient has complex ventilatory requirements.

Subsequent management

Operating theatre

A decision must be made whether or not to continue the procedure in consultation with the surgical team. The reliability of the power supply, the duration of the surgery remaining, and the stability of the patient should be considered. If the decision is made to expedite or abort the surgery, this may require leaving surgical packs *in situ* or leaving the operative site open for a return to theatre, once power is restored. If the decision is made to continue surgery, a gas-powered or pneumatic anaesthetic machine may be used if the medical gas supply is intact. The battery supply on an entirely electronic anaesthetic machine may be limited.

Once the procedure is concluded, the safest location for continued patient care should be considered. This may not be the recovery room. The availability of staff, space, and equipment for patient transfer to the chosen location, and also the risks and benefits of extubation should be considered. If the patient is to remain intubated for any length of time, it may be wise not to use neuromuscular block in the event of a subsequent power or ventilator battery failure. A dedicated, self-inflating, bag–valve resuscitator must be available at all times.

Intensive care unit

Key concerns are the provision of organ support, the maintenance of adequate staffing and equipment for each bedspace, and the potential need to transfer patients to other areas within the facility or other hospitals.

After the patient has been stabilized, it should be ensured that there is adequate equipment and staff to provide care and monitoring for each ICU bedspace.

If the expected duration of power failure is short, there may be areas that would be able to provide a similar level of care to the ICU until power is restored. These could include coronary care wards, post-anaesthetic care units, geographically distant critical care areas, or emergency departments. However, if all areas of the hospital are similarly affected and restoration of power is not possible, preparations should be made to transfer patients to other hospitals until the crisis is over.

Conclusion

Because of the need for organ support and sedation and limited physiological reserve and mobility, the critically ill are vulnerable to the sequelae of environmental emergencies. Anaesthetists and intensivists must appreciate the causes of such events, that these should be minimized by appropriate actions and that institutional guidelines are in place to handle them if they occur. Individual staff members should have an understanding of these events, and undergo regular training and credentialing, so that the consequences of these potentially life-threatening occurrences may be prevented.

Declaration of interest

None declared.

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