

Central oxygen pipeline failure

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Abstract:

Anaesthetic and critical care staff play a governing role in the comprehension of a hospital's oxygen delivery system and associated contingency plans for internal disaster management. Therefore, staff must be thoroughly prepared and properly trained to support an institution-wide emergency response in the event of central oxygen pipeline failure.

Keywords: oxygen, pipeline, failure, anaesthesia, hospital

Introduction

Anaesthetic and critical care staff play a governing role in the comprehension of a hospital's oxygen delivery system and associated contingency plans for internal disaster management. Therefore, staff must be thoroughly prepared and properly trained to support an institution-wide emergency response in the event of central oxygen pipeline failure. Although routine checking and maintenance of anaesthetic equipment is increasingly delegated to non-physician staff, such as theatre technologists, the responsibility still remains that of the anaesthetist to personally complete a routine equipment check and to be vigilant, able and prepared to adequately manage equipment-related crises as they arise.

Case study

Mid-morning on 25 August 2012, a sudden, unanticipated and complete central oxygen pipeline failure occurred throughout Tygerberg Hospital. It transpired that a maintenance employee was welding in the presence of an unidentified oxygen leak, which caused an explosion and the subsequent failure of the main oxygen valve. This happened while I was on duty in the surgical intensive care unit (ICU), with two patients on full ventilation and four patients breathing spontaneously on 40% oxygen face masks. Given the number of patients in the ICU, only one back-up ventilator was available in the event of an additional need for ventilatory support. The hospital superintendent and the hospital's oxygen suppliers were notified immediately. However, at the time it was neither apparent what the cause or extent of the oxygen pipeline failure was, nor when the oxygen supply would be restored. The ICU was inundated with requests for help from the various divisions of the hospital, and given the uncertainty around the cause of the failure and the restoration, there was general confusion and concern as some patients' lives were in danger.

To manage the extent and impact of the failure, the following actions were immediately taken. All elective procedures were cancelled and operating theatres placed on standby to deal with

emergencies only. Mobile oxygen cylinders were deployed. The clinical technologist ordered more oxygen cylinders [10 x 700 l (0.94 kg) and 7 x 350 l (0.47 kg)] from the medical gas stores. At approximately 16h45, almost seven hours after the initial failure, the newly replaced main oxygen valve was slowly opened to allow pipeline pressure to build. However, the maximum rate of flow that was delivered from the wall sockets was 5 l oxygen/minute, with a maximum pressure of 2.7 bar (normally 3.5–4.5 bar). The low rate of oxygen flow and low pressure were investigated, and it was discovered that the main high-pressure oxygen pipeline had ruptured. This rupture was repaired within the next hour, and by 18h30 all of the technical problems relating to the central oxygen supply had been resolved. The oxygen pressure and the flow rate were once again normal. The failure of the central oxygen supply led to the entire hospital being without oxygen for approximately eight hours. Fortunately, there were no deaths or serious consequences for any patient as a result of the central oxygen pipeline failing.

The Tygerberg Hospital medical gas pipeline system consists of one main bulk liquid oxygen tank with a capacity of 14 tons, and one back-up bulk liquid oxygen tank with a capacity of six tons. The two tanks are linked with automatic changeover valves. This bulk medical oxygen supply is stored as a liquid in a vacuum-insulated evaporator system at a cryogenic temperature. Ambient-heated vaporisers convert the cryogenic liquid into gas for distribution throughout the medical gas pipeline system.

The gas then passes through high-pressure regulators, which regulate the system pressure down to 1 200 kPa. Up to this point, the central oxygen supply system is maintained by a private company, with the rest of the system being the responsibility of the Tygerberg Hospital Engineering Department. The oxygen pipeline system then continues into inline regulators, which further reduce the pressure to 450 kPa. As a back-up, these regulators are interlinked with a standby manifold consisting of 40 oxygen cylinders (10.2 kg each). Once the pressure has been reduced to 450 kPa, the oxygen pipeline enters the hospital basement, splitting into various hospital blocks. The oxygen pipeline system splits into shafts to each floor in each of the blocks. The oxygen supply then runs along the passages

Table 1: The anaesthetic machines and intensive care unit ventilators in use at the time of the central oxygen pipeline failure at Tygerberg Hospital

Anaesthetic machine	Ventilator drive type
Dräger Julian [®]	Descending bellows
Dräger Fabius [®] CE	Piston
Dräger Fabius [®] GS	Piston
Dräger Fabius [®] GS Premium	Piston
Dräger Primus [®]	Piston
Dräger Zeus [®]	Turbine
ICU ventilator	Ventilator drive type
Third VELA [®]	Pressurised oxygen (2.8–6 bar)
Dräger Savina [®]	Generates compressed air with a blower unit. It is able to ventilate without any connection to medical compressed air. If compressed, oxygen is used, whether from a wall socket or cylinder. A precise concentration is measured and delivered.

to the valve boxes. From the valve boxes, it flows to the oxygen outlets, where it is delivered to patients. There is an average of 34 oxygen outlet points per normal ward, with up to 60 oxygen outlet points in selected paediatric wards. The oxygen is filled by African Oxygen Limited (Afrox), who also issues accompanying purity certificates.

The bulk oxygen tanks are fitted with both low-pressure and high-pressure alarm systems. When one of the alarms is triggered, it registers at both the Exchange Department of Tygerberg Hospital and at Afrox in Germiston, Gauteng. As soon as an alarm is activated, the standby officer at Tygerberg Hospital is notified. The standby officer liaises with Afrox to ensure speedy oxygen delivery. Low-pressure alarms are activated as soon as the bulk tank's content falls below three tons. At this point, the standby bulk tank is filled to capacity (six tons). If there is any delay in filling the main bulk tank, the system automatically switches to the standby bulk tank with a second alarm that is triggered as soon as its level also falls below three tons. Should the standby tank also run empty, the emergency oxygen cylinder manifolds still remain as a back-up system. Tygerberg Hospital uses approximately 4.5 tons of oxygen daily. The liquid oxygen tanks are filled every second day. At the time of the incident, Tygerberg Hospital was using various types of anaesthetic machines and ICU ventilators (Table 1).

Discussion

Central oxygen pipeline failure is a relatively rare, but potentially disastrous, phenomenon for any hospital. Several reports deal with central gas supply failure.¹⁻¹⁹ Although these were due to different causes, the impact on patients and staff remains the same. Anaesthesiology and critical care practitioners are exposed to the risk of such failures, perhaps more so than other medical practitioners, and should therefore be adequately informed of and trained in the management of these emergencies. High-fidelity patient simulation training can help to identify gaps in the anaesthesia curriculum and test clinicians' responses to a vast number of critical equipment failure events. Training can assist in identifying common managerial pitfalls, and is useful in establishing appropriate future action protocols. Residents'

performance, skills and progress can be assessed and improved continuously without placing patients at risk.^{9,10}

Recommendations

Prevention

Actions which can be taken to ensure the prevention of a central oxygen pipeline failure include the following:

- Simulation training of registrars.
- Routine checks of anaesthetic work stations and equipment by anaesthetists, and specifically, an awareness of the ventilator drive type used.
- Ensuring that there is an oxygen analyser for every anaesthetic machine, which is essential.
- The oxygen supply pressure failure alarm systems should be checked every morning before starting on any theatre case.
- Full reserve emergency oxygen tanks on each machine (properly checked and closed prior to each anaesthetic).
- Self-inflating ventilation equipment, e.g. an Ambu[®] bag, within easy reach.
- Routine evaluation of the medical gas supply systems in theatre.
- Continuous quantitative measurement of cryogenic oxygen tank contents. The alarm should not only be activated by a low volume, but also by an excessive rate of volume loss.
- Awareness by hospital staff of the design and function of the medical gas pipeline system.
- Effective communication between the clinical, engineering and commercial supplying parties.

Planning

When planning how to manage a central oxygen pipeline failure, the following needs to be included:

- A thorough disaster management plan with regard to the medical gas pipeline system, which includes regular, rehearsed mock disaster drills. Hospitals must conduct an audit of their central gas supply systems regarding the rate of daily oxygen consumption and the existence and adequacy of a back-up system, and have a contingency plan in the event of an interruption.
- Ensuring that there are adequate oxygen cylinder supplies on site, as well as a contingency plan on how to obtain additional supplies if necessary.

Hospital design

The hospital's design can impact on a central oxygen pipeline failure. The following should be carried out:

- Ensure a spatial or physical barrier between the primary and secondary liquid oxygen supply tanks, with independent pipelines.
- Large medical centres with high oxygen consumption might consider having an additional reserve bulk liquid oxygen tank,

apart from the primary and secondary supply tanks, with independent pipelines.

- Ensure prominent labelling and shielding of the oxygen feed lines that connect the main supply vessel to the hospital, so as to avert accidental interruption.
- Ensure that there are ample valves along the oxygen supply line in the hospital, so that leaks can be isolated without interrupting the central supply.
- Incorporate an external connection to the central oxygen piping system, to which an oxygen tanker truck could attach to provide emergency oxygen for the entire institution.
- The reserve system must be of sufficient size to supply oxygen for long enough before the arrival of an oxygen tanker truck at the hospital.

Immediate action by the anaesthetist in theatre

Immediate action must be taken by the anaesthetist in theatre to:²⁰

- Confirm the oxygen supply failure. This covers the failure of oxygen alarm sounds, oxygen pressure gauge falls and oxygen and linked flow meter falls, emergency oxygen flush failure, oxygen-driven ventilators stopping and audible leaking in the event of a pipeline disconnection.
- Turn on the reserve oxygen cylinder on machine. Check the pressure gauge. Is it adequately filled? Check the oxygen analyser and confirm the return of oxygen flow.
- Close the adjustable pressure-limiting valve.
- Reduce fresh gas flows so that they are kept to a minimum (≈ 250 ml oxygen per minute).
- Manually ventilate via the circle system if the ventilator is oxygen driven.
- Maintain anaesthesia. Use volatile agents, where appropriate, as well as total intravenous anaesthesia.
- Ensure that there is an adequate fraction of inspired oxygen 2 concentration.
- Call for additional oxygen cylinders.
- Disconnect the failed pipeline from the wall, and do not re-use it until the gas composition and quality at the wall outlet have been formally tested.
- Inform the surgeon and expedite or postpone surgery.
- Allocate a competent person, other than the anaesthetist, to manually ventilate the patient if needed, e.g. an oxygen-driven ventilator on an anaesthetic machine.
- Inform personnel in other relevant hospital areas, as well as theatre management.
- Establish when the oxygen supply is likely to be restored.
- If the oxygen cylinder supply runs out, manually ventilate the patient with a self-inflating (Ambu[®]) bag on room air (21% oxygen).

Institutional operational policy in the event of central oxygen pipeline failure

The institutional operational policy in the event of central oxygen pipeline failure must incorporate the following:²¹⁻²⁴

- The person who discovers the failure must inform the switchboard and matron on duty immediately.
- The switchboard must inform the hospital superintendent on duty, the main porter and a designated authorised person of the problem. (The authorised person is one who has sufficient technical knowledge, training and experience to fully understand the dangers involved in relation to the medical gas pipeline system.)
- The details of the failure should be confirmed, i.e. the floor level, department, room numbers, gases involved and whether or not patient ventilators are in use.
- The switchboard must also notify personnel in all critical care areas.
- The matron on duty must determine which patients may have been put at risk by the failure and to arrange for immediate emergency medical action, where needed.
- Depending on the reason for the failure and its possible duration, the authorised person must decide on the most appropriate method of long-term emergency oxygen provision. This may involve establishing locally regulated cylinder supplies at ward or department entrances.
- Nursing and medical staff must attempt to keep oxygen consumption to a minimum during the emergency.
- Portering staff must monitor or replenish the cylinders at the emergency stations and at plant room emergency supply manifolds.
- The hospital pharmacy must arrange for emergency cylinder deliveries, as necessary.
- The authorised person must liaise with a designated competent person to complete emergency repairs to reinstate the oxygen supply, using the permit-to-work system. (The competent person has sufficient technical knowledge, training and experience to carry out his or her duties in a competent manner and to understand fully the dangers involved in relation to the medical gas pipeline system. The permit-to-work system is a form of declaration, or certificate used to control work on a medical gas system. Its objective is to prevent the inadvertent isolation of, or unauthorised work on, the gas system. The system states the degree of hazard involved and defines all services to be worked on and the points where isolation of the affected sections are to be carried out.)
- When the oxygen supply is fully restored, the authorised person must complete a critical incident form and report extensively to the hospital chief executive officer (CEO) within 24 hours of the incident.

In situations where it is envisaged that there will be a long-term loss of oxygen, the hospital superintendent on duty must liaise with clinical colleagues, including the matron on duty, the head of anaesthesiology and critical care, the hospital CEO and the authorised person on the need to transfer critically ill patients

to suitable facilities, as department closure may be warranted in extreme events.

Conclusion

In order to ensure patient safety during a central oxygen pipeline failure, a systematic approach to prevent and manage such an event is required. Hospital planning and disaster management strategies are essential. In addition, anaesthesiologists should be aware of and adequately trained in the practicalities of managing such an event to ensure that patient safety is not compromised.

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