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CASE REPORT

Carbon dioxide: making the right connection

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Carbon dioxide has been used in anaesthesia since the late 1920s, principally to stimulate breathing after a period of hyperventilation in the era before routine use of capnography. The authors' tertiary academic hospital still has the infrastructure for pipeline delivery of carbon dioxide. A case is reported of accidental administration of carbon dioxide to a patient under anaesthesia, who was found to have end-tidal carbon dioxide ($EtCO_2$) concentrations of greater than 25 kPa immediately after induction. This was confirmed on arterial blood-gas analysis. After successful resuscitation using an alternative oxygen source, it was discovered that the high concentrations were due to misconnection of gas pipelines during the refurbishment of a theatre. This highlights safety issues concerning pipeline provision of carbon dioxide, and that it is of utmost importance to confirm correct gas connections and supply before a new theatre is commissioned.

Keywords: anaesthesia equipment, capnography, hypercarbia, medical error

Case report

A 58-year-old woman presented with cholangiocarcinoma with a background of Type 2 diabetes mellitus and human immunodeficiency virus infection. The emergency anaesthesia team was requested to provide general anaesthesia for percutaneous transhepatic cholangiogram and drainage of multiple intra-abdominal collections under radiological guidance. The procedure was to be performed in a recently refurbished and commissioned angiography suite. While previous general anaesthesia had been performed in the same theatre without incident, the required specific position of the patient led to the anaesthesia workstation being moved from its usual position, and an alternative set of wall gas outlets (unused since theatre refurbishment) being employed.

A rapid-sequence induction was planned due to clinical signs of sepsis and a history of gastro-oesophageal reflux. After preoxygenation with 100% O_2, anaesthesia was induced with propofol, neuromuscular blockade with suxamethonium, and endotracheal intubation was performed. The patient was initially ventilated with a mixture of air (2 $l.min^{-1}$) and oxygen (2 $l.min^{-1}$). Bilateral chest rise and equal air entry on auscultation confirmed correct placement of the endotracheal tube (ETT). However, the capnograph showed no value or visible waveform, despite normal waveforms existing during preoxygenation. Vital signs at this stage were normal, except for an initial temperature of 38.2 degrees Celsius. Oxygenation remained normal. Over the next 15 min, however, the patient became progressively more hypotensive and bradycardic, requiring small doses of inotrope.

During this period, ETT placement was rechecked and senior help obtained. Occasional $EtCO_2$ values were displayed, mostly in the region of 25 kPa. On close inspection, a consistently high, flat $EtCO_2$ trace at the display maximum was visible. Assuming equipment malfunction, the heat and moisture exchange filter, capnograph sample line, gas analysis unit, water trap and soda lime were all changed. Due to suspicion of malignant hyperthermia (MH), volatile anaesthesia was discontinued, and a total intravenous anaesthesia (TIVA) technique commenced.

A new, clean anaesthesia workstation machine was obtained. During the changeover of machines, the patient was manually ventilated with a bag-valve-mask resuscitator and 100% oxygen. This resulted in return of a normal CO_2 waveform. Resumption of ventilation with the new anaesthesia workstation resulted in a return to the original problem. An arterial blood gas sample demonstrated a pH of 6.69, pO_2 of 20 kPa and a pCO_2 of 25 kPa. Fearing residual contamination of the new machine with volatile agents, an ICU ventilator was obtained, which for expediency was connected to a different set of wall gas outlets. The problem again appeared to resolve. Subsequent blood gas analysis showed a significant improvement in arterial CO_2 levels and pH. The procedure was continued uneventfully under propofol TIVA, and the patient was successfully extubated upon completion of the procedure.

A post-incident investigation was initiated, during which gas analysis was performed using the original wall gas outlet and both anaesthetic machines. When a mixture of air and oxygen was selected, persistently high values of CO_2 (up to 27 kPa) were obtained. This resolved when oxygen and nitrous oxide were selected. Connecting the anaesthesia machine to the two other sets of wall gas outlets in the angiography suite showed no aberrant behaviour. As neither medical oxygen nor medical grade air should contain any carbon dioxide, it was then suspected that the third set of wall gas outlets was contaminated with CO_2.

Access was obtained to the interfloor service level containing the gas pipelines supplying the angiography theatre. On inspection, it was found that during the installation process, a new set of outlets had been installed, providing a total of three sets for the theatre. To save costs and avoid drilling new holes, the existing carbon dioxide pipeline had been disconnected, and then reused for the new medical air outlets. Two of the three were correctly connected and repainted, but the third was accidentally reconnected to the carbon dioxide supply. Although repainted grey to designate its new planned role to carry medical air, specks of green paint revealed its original nature (see Table 1 for

Table 1: Medical gas colour coding in use at Groote Schuur Hospital, based on South African National Standard (SANS) 7396-1

Gas	Pipeline colour	Cylinder colour
Oxygen	White	Black with white shoulder
Low-pressure air	Grey	Grey with black-and-white shoulder
High-pressure air	Salmon pink	
Carbon dioxide	Green	Green with grey shoulder
Medical vacuum	Primrose yellow	
Nitrous oxide	Royal blue	Royal blue
Entonox	Royal blue and white bands	
Scavenging	Orange	

Figure 1: Anaesthesia workstation being tested after the event; connected to faulty wall gas outlet and ventilating a test lung. While supplying only medical air, note the lack of oxygen or other gas on the analyser display, subtle high flat line EtCO2 trace and lack of capnograph reading.

pipeline colour standards). This was not apparent inside the theatre to the anaesthetic team. When pure oxygen was administered during preoxygenation, the patient was indeed receiving 100% oxygen. However, when an oxygen/air mixture was selected, the patient received a mixture of oxygen and carbon dioxide instead.

Discussion

Anaesthesiologists naturally assume that the wall outlets will deliver the correct medical gas, on the presumption that gas outlets have been tested on commissioning. In this instance, it is understandable that a thorough machine check did not highlight the problem encountered. During the machine check, it is customary to flow 100% oxygen to check O_2 supply, and calibrate the capnography to room air. As the problem was with the medical air pipeline, neither action would detect the error. Only flowing air alone, and testing the oxygen concentration, would have elucidated the elevated CO_2. This is not a commonly performed test. Careful attention to displayed pipeline pressures may, however, hint at a misconnection. In our hospital, CO_2 is supplied at 1.8–2.0 bar, whereas the low-pressure air is supplied at 4.0–4.2 bar.

The capnography on the anaesthetic monitor did not display numerical values during most of the incident, as the value was well above the normal reference range. On close inspection during re-enactment of the scenario, it could be seen that the capnography trace displayed a flat line at the top of the screen, but this was very difficult to observe, as demonstrated in Figure 1. When the soda lime was replaced, a carbon dioxide trace was seen briefly, before disappearing again, as the soda lime became overwhelmed by the high flows of carbon dioxide. This case highlights the necessity of checking installed gas pipelines in any newly commissioned theatre, and checking each gas individually during a machine check.

A review of the literature shows that, whilst rare, the administration of the incorrect gas to a patient under an anaesthetic does happen on occasion. This is the first case we can find in the literature where carbon dioxide has been erroneously connected to a medical air pipeline. As oxygenation was never a concern – even in the face of impressive respiratory acidosis – the patient was initially very stable. Jerusalem and Starling showed in 1910 that hypercarbia resulting from an administration of a 20% CO_2 mixture produced significant cardiac depression.[1] Thus, the combination here of myocardial depression, vasodilation, sepsis and volatile agent, eventually led to bradycardia and hypotension.

Other cases reported include cylinders incorrectly filled with CO_2.[2–4] In these cases, cardiac arrest or cardiac arrhythmias were prominent features. In another more recent case, a nitrous oxide pipeline was forced into a carbon dioxide outlet during an anaesthetic performed in Saint Louis, Missouri. This error was attributed to the similarity of the Diameter Index Safety System (DISS) between the two pipes, and the lack of experience of the technician involved.[5] This cause of error was excluded in the particular interventional radiology theatre concerned, as the CO_2 DISS outlets had been replaced entirely.

Due to the use of relative hyperventilation in the era before routine capnography, CO_2 was often used to stimulate breathing on completion of anaesthesia. CO_2 delivery systems were included on Boyle's anaesthesia machines from 1927. Despite concerns over safety, as late as 1988 a survey of carbon dioxide use by 1 100 British anaesthetists showed that 60.9% still used it daily, and a similar proportion considered having carbon dioxide cylinders on the machine as not being hazardous. Despite this, 200 anaesthetists knew of an adverse incident involving CO_2, of which 29% resulted in death.[6]

The heat generated by the chemical reaction between soda lime and carbon dioxide is spectacularly demonstrated when carbon dioxide is passed through fresh soda lime (see Supplemental video 1). This heat can be transmitted to the patient, as demonstrated in a case where the oxygen cylinder was filled with pure carbon dioxide and used during an emergency Caesarean section. The patient developed extensive respiratory burns distal to the tip of the endotracheal tube, and unfortunately subsequently died of respiratory complications four months post-incident.[7] Our patient was probably protected because of the high proportion of oxygen mixed with the carbon dioxide, mitigating the heat production and avoiding harmful temperatures. Indeed, the increased fraction of inspired oxygen also prevented hypoxia despite the severe hypercarbia.

Despite the use of colour codes, clear labelling, diameter index and pin index safety systems, it is still possible to provide the wrong gas to the patient, if installation of lines is not checked and adequately supervised. As it is no longer routinely used for anaesthesia, discontinuation of pipeline CO_2 supply has been proposed. However, it is still used for specific applications such as endoscopic surgery and fire suppression systems.

Recognition of sudden hypercarbia after induction should always stimulate the anaesthesiologist to consider hypermetabolic states such as malignant hyperthermia and thyroid storm. In this instance, the clinical findings did not match either condition, and a search for another source was appropriate. When doubt exists, it is prudent to switch to provision of 100% oxygen through a clean circuit or alternate delivery method. Our patient fortunately did not suffer any negative long-term sequelae, partly due to the quick action taken by the staff involved.

Important learning points:

- Engineering short cuts do not save costs in the long run.
- New theatres should be thoroughly checked, and all medical gas outlets analysed before commissioning.
- Bizarre high readings of $EtCO_2$ – in the absence of other factors suggestive of malignant hyperthermia or circuit valve malfunction – should make the anaesthesiologist consider exogenous carbon dioxide administration.
- A manual bag-valve-mask resuscitation bag connected to separate source of oxygen is an essential lifesaving piece of equipment and helped identify the cause in this case.

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Supplementary material

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