ORIGINAL ARTICLE

Crisis management during anaesthesia: desaturation

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Background: Desaturation occurs for many reasons under anaesthesia, some rare and obscure, and many potentially life threatening. The rapidity with which the cause is determined and appropriate management is instituted varies considerably between anaesthetists.
Objectives: To examine the role of a previously described ''core'' algorithm COVER ABCD–A SWIFT CHECK, supplemented by a specific sub-algorithm for desaturation, in the management of incidents of desaturation occurring in association with anaesthesia.
Methods: The potential performance of this structured approach for each of the relevant incidents among the first 4000 reported to the Australian Incident Monitoring Study (AIMS) was compared with the actual management as reported by the anaesthetists involved.
Results: Amongst the first 4000 incidents reported to AIMS there were 584 episodes of desaturation in association with general anaesthesia; 41% were dealt with by COVER, 48% by ABCD, and 11% required a specific desaturation sub-algorithm. Nearly a fifth of all desaturations were caused by endobronchial intubation. Within the specific desaturation subgroup, half were due to pulmonary problems in the form of underlying lung disease, excessive secretions or obesity and a third could not be diagnosed.
Conclusion: Desaturation may have many causes, some of which are obscure, and failure to respond promptly may place the patient at risk. In the face of persistent desaturation, management should consist of hand ventilation with 100% oxygen, completion of COVER ABCD–A SWIFT CHECK, and a return to a supine posture. Blood gases, chest radiography, and bronchoscopy may be required where desaturation is persistent and/or no apparent causes can be found.

The introduction of pulse oximetry into general use in the perioperative setting revealed the occurrence of desaturation, in varying degrees, more commonly than was expected. Desaturation may be present preoperatively due to pre-existing illness, airway compromise, or the effects of premedication drugs. It may occur in relation to anaesthesia from a myriad of causes—some rare and obscure, but nearly all potentially life threatening[1]—and has been shown to be a significant problem in the postoperative period for several days. The degree and duration of desaturation that mandates treatment has not been clearly defined and is, to some extent, dependent on the context in which it occurs. Is a long period of mild desaturation more acceptable than a short period of severe desaturation?

Within the context of anaesthesia, the oximeter is used to provide both an absolute measure and a trend, and provides rapid warning of a decline in oxygenation. In clinical situations such as laryngospasm or difficult intubation, oximetry provides an invaluable measure of the adequacy of ventilation. In other situations such as endobronchial intubation or intrapulmonary shunt, the oximeter provides the first warning of a problem. The occurrence of desaturation needs to be interpreted in the light of the prevailing clinical situation and a cause rapidly found.

In 1993 a ''core'' crisis management algorithm, represented by the mnemonic COVER ABCD–A SWIFT CHECK (the AB precedes COVER for the non-intubated patient), was proposed as the basis for a systematic approach to any crisis during anaesthesia where it is not immediately obvious what should be done or where actions taken have failed to remedy the situation.[2] This was validated against the first 2000 incidents reported to the Australian Incident Monitoring Study (AIMS). AIMS is an ongoing study which involves the voluntary anonymous reporting of any unintended incident which reduced or could have reduced the safety margin for a patient.[3]

It was concluded that, if this algorithm had been correctly applied, a functional diagnosis would have been reached within 40–60 seconds in 99% of applicable incidents, and the learned sequence of actions recommended by the COVER portion would have led to appropriate steps being taken to handle the 60% of problems relevant to this portion of the algorithm.[1] However, this study also showed that the 40% of problems represented by the remainder of the algorithm ABCD–A SWIFT CHECK were not always promptly diagnosed or appropriately managed.[1–3] It was decided that it would be useful, for these remaining problems, to develop a set of sub-algorithms in an easy-to-use crisis management manual.[4] This study reports on the potential place of the COVER ABCD–A SWIFT CHECK algorithm in the diagnosis and initial management of desaturation, provides an outline of a specific crisis management algorithm for this problem, and provides an indication of the potential value of using this structured approach.

METHODS

Of the first 4000 incidents reported to AIMS, those that made reference to desaturation were extracted and analysed for relevance, presenting features, type of surgery, cause, management and outcome. The COVER ABCD–A SWIFT CHECK algorithm, described elsewhere in this set of articles,[4] was applied to each relevant report to determine the stages at which the problem might have been diagnosed and to confirm that activating the COVER portion would have led to appropriate initial steps being taken. As desaturation is not adequately dealt with by this algorithm, a specific sub-algorithm for desaturation was developed and its putative effectiveness was tested against the reports. How this was done is described elsewhere in this set of articles.[4] The potential value of this structured approach—that is, the application of COVER ABCD–A SWIFT CHECK to the diagnosis and initial management of this problem, and the

application of the sub-algorithm for desaturation—was assessed in the light of the AIMS reports by comparing its potential effectiveness for each incident with that of the actual management, as recorded in each report.

RESULTS

Amongst the first 4000 AIMS reports there were 706 incidents containing the keyword ''desaturation''. Of these, 86 were excluded because they occurred before induction, in the recovery ward, or under regional anaesthesia. A further 36 did not involve desaturation but mentioned it specifically to exclude it in situations where it would have been expected. Examples are rapidly detected circuit disconnections or successful bag and mask ventilation during a difficult intubation. This left 584 incidents for analysis.

The COVER algorithm

The COVER algorithm adequately diagnosed 237 of the 584 incidents (41%). The distribution of these figures is shown in fig 1. Two incidents were diagnosed by cardiac arrest (C1) and 10 were diagnosed at O (five involved the delivery of hypoxic gas mixtures, four involved preoxygenation or mask ventilation with no gas flow, and one was a common gas outlet disconnection). Over 90% of the COVER incidents were diagnosed at V1 or E1. Most of these would have been detected at the ''CHECK'' phase—that is, during ventilation by hand and/or checking the position and patency of the endotracheal tube. Most of the V1 incidents involved leaks and disconnects. Common gas outlet disconnects accounted for many of these due to a failure to reconnect the hoses after a change of circuit. This also implies a failure to check the circuit before use as well as a failure to watch respiratory movements in the rebreathing bag during preoxygenation. Either of these manoeuvres would have immediately drawn attention to the disconnection.

There were 138 incidents diagnosed at E1 (checking the endotracheal tube), of which 103 were due to endobronchial intubation. In spite of increased awareness of the problem, endobronchial intubation remains a major cause of desaturation during general anaesthesia. The diagnosis was made very late in some of these incidents, with consequent morbidity for the patient. One patient was reported to have suffered a perioperative infarct, possibly as a result of prolonged desaturation, and at least one had postoperative radiographic evidence of lobar collapse. A further three patients had their endobronchial intubation diagnosed by a postoperative CT scan or chest radiograph in the ICU. In none of these incidents did the narrative record any attempt to specifically exclude endobronchial intubation. It is therefore tempting to conclude that, with earlier recognition—for example, by use of the COVER algorithm—much of this morbidity could have been avoided. Given that endobronchial intubation accounts for nearly one fifth of all reported desaturation incidents, it should be actively sought and excluded early in the evolution of the desaturation.

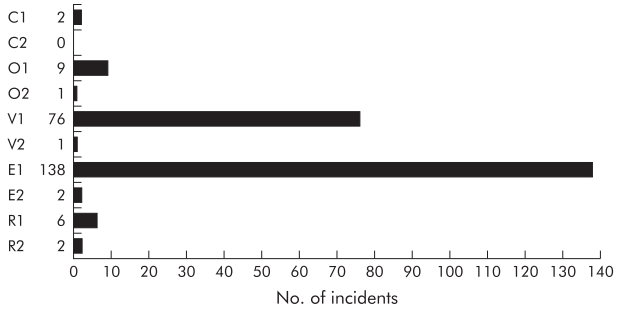

Figure 1 Desaturation diagnosed by COVER (n = 237).

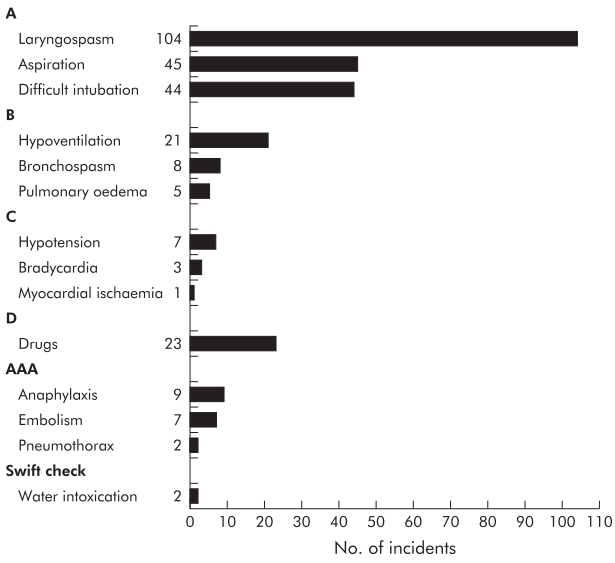

Figure 2 Desaturation diagnosed by ABCD–A SWIFT CHECK (n = 281).

Eight incidents were resolved when monitors and equipment were reviewed and found to be at fault (R).

ABCD algorithm

A further 281 incidents were dealt with by the ABCD algorithm. Figure 2 shows the distribution of causes among these categories. The majority (193 of 281) came under ''A'' in the form of laryngospasm, aspiration, or difficult intubation. Most of these situations presented no diagnostic challenge but required a sub-algorithm for further management. There were 34 incidents under ''B'' due to hypoventilation, bronchospasm, or pulmonary oedema. Hypoventilation was responsible for most of these. Many were due to coughing, straining or breath-holding, some with mask ventilation, some with laryngeal masks, some after intubation, and some after extubation. Half of these arose in intubated patients, with the degree of straining sufficient to prevent adequate ventilation. Some of these patients desaturated profoundly (50%) and needed to be re-anaesthetised to regain control of the situation. These incidents are dealt with by specific sub-algorithms that are covered in other papers in this series.

Desaturation algorithm

There remained 66 incidents (11%) in which neither COVER nor ABCD had adequately managed the problem. These were

Table 1 Causes of desaturation in which neither COVER nor ABCD adequately dealt with the problem

Causes	No
Excessive secretions	11
Underlying lung disease	11
Obesity syndrome	10
Monitor error	5
Cardiovascular	4
Suspected embolism	4
Could not determine	21
Total	66

DESATURATION

EMERGENCY MANAGEMENT
Complete COVER ABCD–A SWIFT CHECK **(1)***
Hand ventilate with 100% oxygen
Confirm the FIO_2 is appropriate
Confirm the $ETCO_2$ is appropriate, if it is low consider:
Anaphylaxis → page 48**
Pneumothorax → page 46**
Air (or other) embolism → page 44**
Auscultate again, specifically exclude endobronchial intubation **(2)**

REVIEW AND TREAT OTHER POSSIBLE CAUSES
Underlying cardiopulmonary problems
If bronchial secretions or plugs are suspected **(3)**
Posture and suction ETT/bronchi
Give a "long slow blow" especially in children
If cardiovascularly stable consider PEEP/CPAP
If acute shunt is suspected **(4)**
Ensure the patient is supine and level
If a pneumoperitoneum is present, deflate the abdomen
Consider gas embolism **(5)**

Pulse oximeter malfunction (6)
Consider: polycythaemia, methaemoglobinaemia, acute tricuspid incompetence, probe sited distal to an AV fistula.

The sub-algorithm forms a facing page of the *Crisis Management Manual*[12].
*** Numbers in brackets refer to Notes in right hand panel.**
**** Page references refer to the *Crisis Management Manual*[12].**

FURTHER CARE
Reassess the situation
If persistent/unstable desaturation consider:
Completing/abandoning surgery
Chest X-ray, blood gases
If stable and well saturated, see (5) on page 17*
Wake the patient up and extubate
If unstable or desaturated, see (5) on page 18*
Admit to ICU/HDU

NOTES:
It was judged that correct use of the algorithm would have led to earlier recognition of the problem and/or better management in 16% of the 584 relevant incidents reported to AIMS.
(1) The use of COVER ABCD accounted for 89% of applicable incidents reported to AIMS. Use of the desaturation sub-algorithm accounted for a further 9% of applicable incidents.
(2) Endobronchial intubation was the commonest cause of desaturation in anaesthetised patients reported to AIMS. It should be specifically excluded early. Further details may be found in **(6)** below.
(3) 2% of incidents were due to bronchial plugs or excessive bronchial secretions, which can produce marked desaturation, especially in young children. A shunt effect is produced, which may be unmasked by abolition of hypoxic pulmonary vasoconstriction with induction of anaesthesia.
(4) "Obesity syndrome" refers to the rapid desaturation which may be seen at induction when anaesthetising obese patients, or those with tightly distended abdomens, and accounted for 2% of relevant incidents. Drug-induced abolition of hypoxic pulmonary vasoconstriction and an acute reduction in functional residual capacity resulting in sudden V/Q mismatching is thought to be the cause. The lithotomy and Trendelenberg positions, spontaneous ventilation and hypovolaemia all may exacerbate the problem, resulting in sudden desaturation at the start of a case and progressive desaturation during the maintenance phase.
(5) 0.8% of incidents involved suspected gas embolism.
(6) 1% of incidents involved unusual causes of pulse oximeter malfunction, including acute tricuspid incompetence, polycythaemia and methaemoglobinaemia. Acute tricuspid incompetence may lead to the oximeter sensing the venous pulse. A large plethysmographic wave form and a saturation of 70-75% is commonly seen. Arterial saturation, when directly measured, may be quite adequate. Polycythaemia may lead to artefactually low saturation readouts with high directly measured arterial oxygen saturations or tensions. Methaemoglobinaemia, depending on its extent, will cause the saturation to approach 85%.

These notes comprise a reverse side of a page of the *Crisis Management Manual*[12].
*** Page references refer to *Crisis Management Manual*[12].**

Figure 3 Desaturation.

incidents in which desaturation occurred with no obvious cause from equipment, airway, circulation, etc. By definition, this was a more challenging group of incidents. The main causes of desaturation unaccounted for by COVER or ABCD are shown in table 1.

Secretions (n = 11)
Most of these incidents had one or more of the following features: heavy smoker (including recent ex-smoker), recent upper respiratory tract infection, child requiring grommets (middle ear ventilation tubes) or adenoidectomy, Down's syndrome or other congenital neurological conditions.

Bronchial plugs or excessive secretions can produce a shunt effect which may be unmasked by the abolition of the homeostatic mechanism of hypoxic pulmonary vasoconstriction with the induction of anaesthesia, resulting in marked desaturation. Also included in this category was the case of a child undergoing nephrectomy for a perinephric abscess in whom the sudden deterioration was later explained by the finding that the abscess had extended into the lung and ruptured during surgery, soiling the bronchial tree with copious amounts of purulent fluid.

Underlying lung disease (n = 11)
All of these patients had some lung pathology that was either undiagnosed or underestimated before surgery. For example, a baby with known bronchopulmonary dysplasia and subglottic stenosis was turned on his side for insertion of a spinal with no monitoring in place. When the spinal block was completed and the child turned supine again, he was found to be profoundly cyanosed (Spo_2 50%). Care with preoperative evaluation and anaesthetic technique may have averted some of these problems.

''Obesity syndrome'' (n = 10)
This refers to the rapid desaturation that may occur when obese patients or those with tightly distended abdomens are anaesthetised. It is exacerbated by spontaneous ventilation and by the lithotomy position. All of the patients in this category were obese and all but two were in the lithotomy position.

Monitor error (n = 5)
There were five incidents in which the reported desaturation was spurious. In one the oximeter showed marked desaturation, both with a finger probe and an ear probe, but a simultaneous blood gas analysis showed a Po_2 of 458. A falsely low reading occurred in a patient with polycythaemia and one in a patient who was very cold. The remaining false readings occurred in a patient with tricuspid incompetence in whom the oximeter was sensing a venous pulse, and in a patient with an old arteriovenous fistula.

Cardiovascular (n = 4)

There were four incidents in which desaturation occurred in conjunction with hypotension and arrhythmias. In one of these it was felt that the child may have reversed the flow across his known atrial septal defect, and in another a coarctation of the aorta was diagnosed in the recovery ward.

Suspected embolism (n = 4)

There were four cases in which the most likely diagnosis was an embolism, one of fat and three of gas. In each case a fall in saturation was associated with hypotension and a moderate to severe fall in end-tidal carbon dioxide. One of the cases occurred during hydrogen peroxide irrigation of a freshly curetted frontal lobe abscess cavity, one occurred during a laparoscopic cholecystectomy, and one during a nephro-ureterectomy.

Don't know (n = 21)

Many of these were complex incidents involving already sick patients where the underlying problem was never resolved. In some the information provided by the reporter was inadequate while, in others, no conclusions were possible despite detailed reporting of the incident.

When the potential effectiveness of the structured approach, represented by the COVER ABCD–A SWIFT CHECK algorithm and the special sub-algorithm for desaturation (fig 3), was compared with that of the actual management as documented in each of the 584 relevant reports it was considered that, properly applied, the structured approach would have led to a quicker and/or better resolution of the problem in 16% of the incidents. A further 42% of all incidents required other specific sub-algorithms to manage the problem, such as laryngospasm,[5] difficult intubation,[6] and aspiration/regurgitation.[7]

There were a significant number of incidents in which use of the structured approach was deemed not to have outperformed the actual management described, in which the COVER algorithm had effectively been used by the reporting anaesthetist.

Within the subgroup of 66 incidents that required the specific desaturation sub-algorithm, it was felt that 15% of these would have been better handled by correct application of the algorithm. In most incidents this referred to failure to clearly work through a logical sequence, ventilate by hand on 100% oxygen, suction the airway, or check blood gases. There was a haphazard approach to finding a cause, an acceptance that desaturation had occurred and the fraction of inspired oxygen increased with no further attempt to elucidate a cause. In 14% it was not possible to determine what the cause of the desaturation was because of inadequate information in the reports. Overall, the majority of incidents in this subgroup were handled well even if the underlying cause could not be found. There were no incidents where use of the desaturation sub-algorithm was thought to have been likely to make the situation worse.

Table 3 Desaturation as a first or second warning presentation

Stage of algorithm	First	Second
COVER	189	48
A:		
Laryngospasm	9	95
Aspiration/regurgitation	2	43
Difficult intubation	2	42
B:		
Hypoventilation	6	15
Bronchospasm	4	4
Pulmonary oedema	2	3
C:		
Hypotension	2	5
Bradycardia	1	2
Myocardial ischaemia	0	1
D:		
Drugs	5	18
"A":		
Anaphylaxis	4	5
Embolism	5	2
Pneumothorax	1	1
Water intoxication	0	2
Desaturation	53	13
Total	285	299
Percentage	49%	51%

DISCUSSION

Desaturation is a common occurrence during general anaesthesia. It occurs for many reasons related to anaesthetic equipment and to the patient. There have been very few

Table 2 Timing of desaturation: number of incidents by cause and phase of anaesthetic

	Induction	Maintenance	Emergence	Total
COVER	59	165	13	237
A:				
Laryngospasm	37	21	46	104
Aspiration/regurgitation	19	20	6	45
Difficult intubation	37	6	1	44
B:				
Hypoventilation	7	9	5	21
Bronchospasm	5	2	1	8
Pulmonary oedema	0	3	2	5
C:				
Hypotension	1	6	0	7
Bradycardia	0	2	1	3
Myocardial ischaemia	0	1	0	1
D:				
Drugs	7	10	6	23
"A":				
Anaphylaxis	3	6	0	9
Embolism	0	7	0	7
Pneumothorax	0	2	0	2
Water intoxication	0	2	0	2
Desaturation	22	40	4	66
Total	197	302	85	584
Percentage	34%	52%	15%	

publications examining the causes of desaturation under anaesthesia; a recent publication had findings consistent with those discussed here.[8]

Among the first 4000 incidents reported to AIMS there were 706 incidents (17.7%) with the key word ''desaturation''. This makes desaturation one of the most frequently reported incidents under anaesthesia. For the purposes of this paper, only those incidents that occurred in the context of a general anaesthetic were considered. Incidents which occurred in patients undergoing regional or local anaesthesia, or which occurred before induction or after emergence, were excluded. Thus, there were 584 incidents for analysis.

Most desaturations (52%) occurred during the maintenance phase as shown in table 2. Those which occurred at induction were largely those where the cause was immediately obvious (for example, laryngospasm, difficult intubation, inadequate ventilation). However, these observations emphasise the importance of preoxygenation.[9 10] Similarly, the greater proportion of the emergence desaturation incidents were due to obvious causes such as aspiration, laryngospasm, coughing, and breath holding. Again, 100% oxygen at emergence clearly represents good practice. The much bigger group of incidents occurring during the maintenance phase were from more obscure causes. More than half of these were diagnosed by the COVER algorithm and include a large contribution from endobronchial intubation. Numerous equipment related problems accounted for the rest.

Within the specific desaturation subgroup (the small group of difficult incidents not handled by COVER or ABCD), two thirds occurred during maintenance. This gives the lie to the popular notion that, once the anaesthetic has reached ''cruising altitude'', all will remain well. These incidents were frequently difficult for the anaesthetist to unravel. Half of these were clearly due to pulmonary problems in the form of underlying lung disease which was unknown or underestimated before anaesthesia, to excessive secretions related to smoking or respiratory tract infection, and from the so-called ''obesity syndrome''. In those patients with known lung disease, desaturation may occur for any number of reasons totally unrelated to their disease; the normal COVER algorithm should therefore be worked through to exclude other causes.

The widespread availability of pulse oximetry highlights the fact that anaesthetists may not observe cyanosis until there is marked desaturation. Thus, the Australian and New Zealand College of Anaesthetists requires that a pulse oximeter be available for the exclusive use of every anaesthetised patient.[11] The importance of oximetry is highlighted by the fact that, in half the reported incidents, desaturation was the first warning that all was not well. Table 3 shows the pattern of desaturation as a first or second warning: 80% of the COVER related incidents were heralded by desaturation (table 3, fig 1), as were 80% of the specific desaturation sub-algorithm incidents. Even in the anaphylaxis and embolism incidents included in this paper, desaturation was often the first warning, rather than bronchospasm or hypocarbia, as would be expected. The incidents where desaturation was the second presentation were largely those where it was obvious that a problem had occurred, such as laryngospasm, aspiration, or difficult intubation.

There remained a third of the desaturation sub-algorithm group in which the underlying cause was not found. Some of these were due to inadequate information on the forms, but many were because the reporting anaesthetist was faced with a complex clinical situation in which a number of potential factors were involved. In most of these the management of the incident was good, in that all attempts were made to maintain oxygenation while finding a cause.

The resulting structured approach to managing clinical desaturation, as appears in the Crisis Management Manual,[12] is detailed in fig 3. Finally, it is important that a full explanation of what happened be given to the patient and the problem clearly documented in the anaesthetic record. If a particular precipitating event was significant or a particular action was useful in resolving the crisis, this should be clearly explained and documented.

Key messages

- There were 584 analysable episodes of desaturation (15%) among the first 4000 incidents reported to AIMS.
- Another 86 occurred before induction, in recovery, or under regional anaesthesia; these are excluded from this series.
- With half of the incidents analysed, desaturation was the first warning, emphasising the importance of pulse oximetry.
- Almost a fifth of all the desaturation incidents were caused by endobronchial intubation. This cause was often associated with late diagnoses and consequent patient morbidity.
- Profound desaturation occurred in some intubated patients in association with coughing, straining, or breath holding.
- Sixty six incidents (11%) were not managed adequately by the core algorithm COVER ABCD. The most common causes in this group were excessive secretions (e.g. in heavy smokers), underlying lung disease, and obesity syndrome.
- 15% of the 66 incidents would have been better handled by correct application of the specific sub-algorithm for desaturation.
- Most desaturation incidents (52%) occurred during the maintenance phase.
- In all desaturation situations, ventilation with 100% oxygen represents good practice. Always attempt to maintain oxygenation while a cause for the desaturation is being sought.

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