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ORIGINAL ARTICLE

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See end of article for authors' affiliations

Correspondence to: Professor W B Runciman, President, Australian Patient Safety Foundation, GPO Box 400, Adelaide, South Australia, 5001, Australia; research@apsf.net.au

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Background: Embolism with gas, thrombus, fat, amniotic fluid, or particulate matter may occur suddenly and unexpectedly during anaesthesia, posing a diagnostic and management problem for the anaesthetist.
Objectives: To examine the role of a previously described core algorithm ''COVER ABCD–A SWIFT CHECK'' supplemented by a specific sub-algorithm for embolism, in the management of embolism 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: Among the first 4000 incidents reported to AIMS, 38 reports of embolism were found. A sudden fall in end-tidal carbon dioxide and oxygen saturation were the cardinal signs of embolism, each occurring in about two thirds of cases, with hypotension and electrocardiographic changes each occurring in about one third of cases.
Conclusion: The potential value of an explicit structured approach to the diagnosis and management of embolism was assessed in the light of AIMS reports. It was considered that, correctly applied, it potentially would have led to earlier recognition of the problem and/or better management in over 40% of cases.

Embolism may result from intravascular gas, (for example, air, carbon dioxide, oxygen), thrombus, amniotic fluid, fat, bone marrow, aggregated blood products, and a variety of foreign bodies (for example, cannula fragments). Although the healthy pulmonary vascular bed offers a protective filter from moderate systemic venous embolism from these sources, as well as from nitrogen bubbles after dysbaric exposure,[1] it has a finite capacity.[2] Significant embolism to the right side of the heart and the pulmonary circulation may cause acute heart failure, and even small arterial emboli that access the cerebral and coronary circulations may produce disastrous results. The presence of right-to-left shunting (for example, with a patent foramen ovale and a high right sided pressure) poses the risk of such access with venous embolism.[3]

Venous or arterial emboli may produce sudden cardiovascular decompensation with rapidly developing falls in end tidal carbon dioxide, haemoglobin saturation, and blood pressure associated with heart rate and rhythm changes.[4 5] Air may be entrained from any venous sinus or large vein (particularly during or immediately after surgery on the brain, head and neck, and spinal cord[6]) or may be forced under high pressure into a vein from poorly primed infusion devices, the re-use of part empty blood infusion bags, and high pressure tissue dissection devices. Carbon dioxide or air may be forced into the circulation via a vascular tear or perforation during minimum access surgery employing insufflation of a body cavity under pressure.[7] Also embolic air may gain access to the cerebral circulation during problems with cardiopulmonary bypass procedures. In addition to occurring in these well recognised situations, embolism may occur suddenly and unexpectedly under a variety of less usual circumstances (for example, central line disconnection, joint replacement surgery,[8] IPPV on low compliance lungs[6]). Coupled with the relatively non-specific signs which herald its onset, an anaesthetist may be presented with a difficult diagnostic and management problem.

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.[9] 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.[10]

It was concluded that if this algorithm had been correctly applied, a functional diagnosis would have been reached in 40–60 seconds in 99% of applicable incidents, and that 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.[9] 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.[5 9–10] 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.[11] This study reports on the potential place of the COVER ABCD–A SWIFT CHECK algorithm in the diagnosis and initial management of embolism, provides an outline of a specific crisis management sub-algorithm for embolism during anaesthesia, and provides an indication of the potential value of using this structured approach.

METHODS

Of the first 4000 incidents reported to AIMS, those which made reference to embolism were extracted and analysed for relevance, presenting features, causes, diagnosis, management, and outcome. The COVER ABCD–A SWIFT CHECK algorithm, described elsewhere in this set of articles,[11] 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 embolism is not adequately dealt with by this algorithm, a specific sub-algorithm for embolism was developed (see fig), and its putative effectiveness was tested against the reports. How this was done is described elsewhere in this set of articles.[11] The potential value of this structured approach (that is, the application of COVER ABCD–A SWIFT CHECK to the diagnosis and initial management of the problem, followed by the application of the embolism sub-algorithm) was assessed in the light of AIMS reports by comparing its potential effectiveness for each incident with that of the actual management, as recorded in each report.

RESULTS

There were 67 reports that contained the word ''embolism''. Twenty nine of these referred to a past history of embolism (usually pulmonary thromboembolism), or mentioned the diagnosis only to dismiss it. The remaining 38 reports were analysed for this study.

The nature of the embolus was considered to be air in 32 reports, carbon dioxide in four, thrombus in one, and fat in one. The source was the surgical field in 27 cases (71%), a venous catheter in eight cases (21%) (peripheral in six and central in two cases), and a radial arterial catheter, ''deep veins'' and fat embolism in one case each. The patient's ASA grade was available in 36 cases: ASA I, seven (five emergency) cases; ASA II, 14 (six emergency) cases, ASA III, 13 (five emergency) cases, and ASA IV, two (no emergency) cases.

The operative procedures which generated the 38 reports are shown in table 1, the clinical feature which first alerted the anaesthetist in table 2 and those features which subsequently also became apparent in table 3. The clinical management is presented in table 4.

Sixteen of the 38 reports involved emergency cases. Seven reports involved a head up posture, and seven incidents involved children or infants. Six of the reports involved patients who were awake, four of whom sustained peripheral venous air embolism before induction of anaesthesia from unprimed heat exchange coils. Four reports involved liver surgery, of which the hepatotome dissector was the source in two cases. Doppler monitors were not in use for any of the cases in this series. There were no deaths clearly directly attributable to embolism, although a possible contributory role was played in two cases (a pneumonectomy and a head injury).

When the COVER ABCD–A SWIFT CHECK algorithm was applied to each report, it was considered that the problem would have been detected in all cases at the C1 (circulation) or C2 (colour) stage of COVER or, failing that, at the R1 (review monitors) stage of COVER. If the diagnosis had not been made at the SCAN or CHECK levels of COVER, then it was considered that it would have been made when the **A** (Air embolism, Air in the pleural cavity, Allergy/Anaphylaxis, and Awareness) of A SWIFT CHECK was considered, particularly in conjunction with the SWIFT CHECK portion

AIR (AND OTHER) EMBOLISM

SIGNS (1)*
A sudden fall in $ETCO_2$
Desaturation and/or central cyanosis
Air in surgical field or vascular line
Hypotension
A sudden change in spontaneous breathing pattern
A change in the heart rate
A change in the ECG configuration
Raised CVP or distended neck veins
A cardiac murmur or mottled skin

EMERGENCY MANAGEMENT
Inform the surgeon **(2)**
Prevent further entrainment/infusion of gas **(3)**
Flood the field with fluid
Aspirate central venous line if already in situ
100% oxygen and hand ventilate
Consider valsalva or PEEP
Level the patient

Do not hesitate to treat as a cardiac arrest → page 38**

Turn the vaporiser off
If hypotensive:
Volume expansion with crystalloid 10 ml/kg
Consider adrenaline; give 0.001 mg/kg IV bolus (adult dose 1 ml of 1:10,000) followed if necessary by an adrenaline infusion starting at 0.00015 mg/kg/min (1 ml/min of 1 mg in 100 ml = 10µg/min) **(4).**

The sub-algorithm forms a facing page of the *Crisis Management Manual*[15].
*** Numbers in brackets refer to Notes in the right hand panel.**
**** Page reference refers to the *Crisis Management Manual*[15].**

FURTHER CARE
Careful postoperative review of the patient to:
Confirm nature/source of embolism **(3)**
Stabilise long bone fractures
Consider admission to ICU
If there is confirmed cerebral gas embolism
Give IV lignocaine at 0.06 mg/kg/min
Early hyperbaric oxygen therapy

NOTES:
It was judged that correct use of the algorithm would have led to earlier recognition of the problem and/or better management in 41% of the 38 relevant incidents reported to AIMS.
(1) The following changes were documented in the AIMS reports: A fall in $ETCO_2$ 68%, desaturation – 60%, hypotension – 36%, a change in heart rate – 24%, a change in ECG configuration – 27%.
(2) In the AIMS reports, in 22% the source of embolus was via intravascular lines. The remainder were from the surgical field, most commonly: intracranial, hepatobiliary and maxillofacial.
(3) Sources of embolism include:
(a) Entrainment of air, from venous sinuses or large veins, high risk procedures include those where the operative site is above the level of the right atrium. Procedures most commonly implicated included neurosurgical and maxillofacial. Others: spinal, intrathoracic, and hepatic.
(b) Infusion of air or carbon dioxide; from "unprimed" vascular lines such as warming coils or infusion devices, insufflation of body cavities, "pressure" operated dissection devices and re-use of part empty blood bags.
(c) Thrombotic embolism; most commonly from pelvic veins.
(d) Fat embolism; occurring after any trauma, or long bone surgery.
(4) In some reported cases, noradrenaline has been effective (P. Mackay, personal communication).

These notes comprise a reverse side of a page of the *Crisis Management Manual*[15].

Figure 1 Air (and other) embolism.

Table 1 Operative procedures in which embolism occurred

Procedure	Number*	%
Intravascular lines†	9	22
Intracranial	8	19
Hepatobiliary	4	10
Maxillofacial	4	10
Orthopaedic	4	10
Endoscopic surgery‡	4	10
Intrathoracic§	3	7
Spinal	2	5
Other abdominal	2	5
Obstetric	1	2
Total	41	100

*In one report simultaneous air embolism was observed from both the surgical field and a peripheral venous catheter. In another, three separate episodes of air embolism occurred during one operation.
†Four from intravenous warming coils, two from peripheral venous catheters, two from central venous catheters, and one from a radial artery catheter.
‡Three gynaecological and one general surgical procedure.
§Includes cardiopulmonary bypass procedures.

of the algorithm (see Discussion). It was considered that the cause would have been detected during the SWIFT CHECK portion of the algorithm, and that the actions recommended by COVER would have constituted appropriate immediate steps for air embolism. It was also considered that carrying out the recommendations of the embolism sub-algorithm outlined in figure 1 would have constituted appropriate management in all cases.

When the potential effectiveness of the structured approach represented by the COVER ABCD–A SWIFT CHECK algorithm and the special sub-algorithm for embolism[10] (see fig) was compared with that of the actual management, as documented in each of the 38 incident reports, it was considered that, properly applied, the structured approach recommended would have led to a quicker and/or better resolution of the problem in 16 cases (42%). There was significant delay in diagnosis in 11 of these patients (see below) and incomplete management in 15. For example, the patient was not placed in an appropriate posture in five cases, entrainment of air was not controlled in five cases, and in two cases no specific steps were taken.

There was delay in recognition of embolism in 11 cases: four cases presented with and were treated as desaturation for some time before other signs were elicited (in one of these cases ventilation was progressively reduced because of a low end tidal carbon dioxide, before it was realised that ongoing air embolism from the surgical field was causing the changes in both saturation and end tidal carbon dioxide), one presented with and was initially treated as bradycardia, and three cases presented as cardiac arrests. In five of these cases diagnosis was delayed in spite of the fact that several cardinal signs were noted. Diagnosis was delayed in four cases because no oximetry was in use and in three cases because no capnography was in use.

DISCUSSION

Embolism must be considered immediately whenever a fall in end tidal carbon dioxide and saturation occur in rapid succession. It should also be considered with hypotension, a change in heart rate or rhythm, a change in configuration of the electrocardiogram waveform, and with any of the clinical signs listed in figure 1 (left hand panel). It was considered that the COVER ABCD–A SWIFT CHECK algorithm would have detected a problem in all cases in this series at the C1 or C2, or failing that, the R1 stages of COVER at the SCAN level, had it been applied in the recommended manner.

Table 2 Primary means of detection of embolism

Means of detection	Number (n = 38)	%
Fall in $ETCO_2$*	13	34
Desaturation	10	26
Human detection†	7	18
Arterial catheter	4	11
Electrocardiogram‡	4	11

*End tidal carbon dioxide concentration.
†In two reports an alteration in the spontaneous breathing pattern of the patient was the first sign.
‡Three changes in heart rate, one ST segment change.

However, it was considered that the use of COVER at the SCAN or CHECK level would not necessarily identify embolism as the cause of the problem. When the COVER ABCD algorithm has been completed at the CHECK level, and the cause of the problem is still not evident, the four As of A SWIFT CHECK must be specifically considered. In the "reminder" for the four As, "Be Aware of Air and Allergy", Air serves as a reminder for Air (or other) embolism and for Air in pleura (pneumothorax). The four As each represent about 0.5–1.5% of incident reports, and share the feature that certain clinical signs and/or situations should immediately be searched for when certain combinations of changes are evident on the monitors. Thus, consideration of the four problems represented by the A preceding SWIFT CHECK provides a further primary chance to diagnose air (or other) embolism.

The SWIFT CHECK portion of the algorithm may also play a role in establishing the diagnosis and cause of embolism. In addition to reviewing the monitors, a careful check should be made of the patient, of what the surgeon is doing, and of all intravascular lines and infusions. Embolism should be considered even when only one of the signs or high risk situations, listed in the figure, is present and remains unexplained, although a disconnection or leak in the gas sampling system to the capnograph should be considered when there is a sudden fall in end tidal carbon dioxide with no other sign.

If embolism is thought to have taken place, the COVER algorithm should be invoked in its full EMERGENCY form, including turning off the vaporiser, with the exception that it is not necessary to separate the patient from the anaesthetic machine if the oxygen analyser reads 100% and vapour concentrations fall to zero after turning off the vaporiser. The

Table 3 Additional features reported after primary detection of embolism

Feature	Number (n = 38)*	%
Fall in $ETCO_2$†	13	34
Desaturation	13	34
Hypotension	10	26
ECG change‡	6	16
Heart rate change§	6	16
Air seen or aspirated	5	13
Weak or absent pulse	3	8
Tachycardia	2	5
Heart murmur	2	5
Mottled tissues	2	5
Other¶	4	11

*Many reports specified several additional features.
†End tidal carbon dioxide concentration.
‡Electrocardiogram change (two ST segment elevations, one widened QRS complex, one nodal rhythm, one premature ventricular contraction, one bigeminal rhythm).
§Bradycardia in four cases and tachycardia in two.
¶Rising central venous pressure; poor cardiac output with internal cardiac compression; increased alveolar-arterial oxygen gradient; confusion (fat embolus).

Table 4 Clinical strategies documented for the management of embolism

Clinical strategy	Number (n = 38)*	%
Change FIO_2† to 1.0	21	55
Communicate with surgeon	12	32
Change to manual IPPV‡	11	29
Control the source of air	11	29
Administer drugs§	10	26
Head down posture	9	24
Increase IV fluids	8	21
Turn off inhalation agents	7	18
Flood surgical field	5	13
Aspirate gas via line	5	13
Commence CPR¶	4	11
Other**	4	11

*Combinations of clinical strategies were used in most cases.
†Inspired oxygen fraction.
‡Intermittent positive pressure ventilation.
§Adrenaline in three cases, ephedrine in two, and atropine, calcium, dopamine, metaraminol, and an unspecified drug in one case each.
¶Cardiopulmonary resuscitation (includes one report of internal cardiac compression).
**DC cardioversion; bilateral carotid compression; alveolar arterial oxygen gradient measurement; call for help.

additional steps that should be taken for the embolism sub-algorithm are listed in the figure under ''Emergency Treatment'', including the use of Doppler or transoesophageal echocardiography if available.[12] On the available evidence, if these steps and those listed under COVER-EMERGENCY are taken, we consider that appropriate crisis management would have taken place.

In the recovery phase, the patient should undergo a thorough survey of all systems, and should be reviewed each day for 2–3 days. For proven cerebral arterial gas embolism, early hyperbaric oxygen therapy is indicated.[13 14] An intravenous infusion of lignocaine (0.06 mg/kg/min initially) may also be beneficial, especially if hyperbaric oxygen therapy is delayed.[15]

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.

In summary, embolism is a potentially life threatening complication which may occur unexpectedly. Anaesthetists should have a high index of suspicion in known risky situations such as the now commonplace surgical techniques involving body cavity insufflation. Continuous monitoring of end tidal carbon dioxide concentrations and of saturation (both with appropriate alarm settings) should allow the rapid diagnosis of this problem. The algorithm presented in the figure provides an outline for the immediate emergency management, with recommendations for follow up. It was considered that had the structured approach recommended been carried out (that is, the application of COVER ABCD–A SWIFT CHECK for diagnosis, followed by activating the COVER portion of this algorithm and then carrying out recommendations for the embolism sub-algorithm outlined in the figure), it would have led to earlier recognition of the problem and/or better management in 41% of cases.

Key messages

- Thirty eight embolism incidents associated with anaesthesia were found among the first 4000 reports to the AIMS.
- The types of emboli were air (32 reports), CO_2 (four reports), thrombus (one report), and fat (one report). There were no deaths directly attributable to embolism in this series.
- The sources of the emboli were the surgical field in 27 cases (71%) (NB liver surgery), a venous catheter in eight cases (21%; peripheral in six cases, central in two cases), and one case each of a radial arterial catheter, deep venous thrombosis, and ''fat embolism''.
- Sixteen of the 38 cases involved emergency cases.
- Three cases presented as cardiac arrests. Doppler monitoring was not used in any of the cases in this series.
- The commonest of the 10 operative procedures implicated were intravascular line placement and intracranial surgery.
- Primary detection was most commonly by a fall in $ETCO_2$ (34%), desaturation (26%), and ''human'' detection (18%).
- Of the 15 different clinical strategies reported, many used in combination, the most common were ''change FIO_2 to 1.0'', ''communicate with the surgeon'', ''change to manual IPPV'', and ''control the source of air''.
- There was delay in recognition of embolism in 11 cases, in five of which several cardinal signs were noted.
- Continuous monitoring with both capnography and oximetry (with alarm settings) should allow rapid diagnosis of embolism in the absence of Doppler monitoring.
- It was considered that the use of the core algorithm combined with the specific sub-algorithm for embolism would have constituted appropriate management in all cases in this series.

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Authors' affiliations

J A Williamson, Consultant Specialist, Australian Patient Safety Foundation; Visiting Research Fellow, University of Adelaide and Royal Adelaide Hospital, Adelaide, South Australia, Australia
S C Helps, Department of Medical Biochemistry, School of Medicine, Flinders University, Bedford Park, South Australia, Australia
R N Westhorpe, Deputy Director, Department of Paediatric Anaesthesia and Pain Management, Royal Children's Hospital, Parkville, Victoria, Australia
P Mackay, Consultant Anaesthetist, Royal Melbourne Hospital, Parkville, Victoria, Australia; Chairman, Victorian Consultative Council on Anaesthetic Mortality and Morbidity

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