



Major complications of airway management in the UK: results of the Fourth National Audit Project of the Royal College of Anaesthetists and the Difficult Airway Society. Part 2: intensive care and emergency departments[†]

T. M. Cook^{1*}, N. Woodall², J. Harper³ and J. Benger⁴, on behalf of the Fourth National Audit Project

¹ Department of Anaesthesia and Intensive Care, Royal United Hospital, Combe Park, Bath, UK

² Department of Anaesthesia, Norfolk & Norwich University NHS Foundation Trust, Norwich, UK

³ Department of Anaesthesia and Intensive Care, Royal Liverpool University Hospital, Liverpool, UK

⁴ University of the West of England, Bristol, UK

* Corresponding author. E-mail: timcook007@googlemail.com

Background. The Fourth National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society (NAP4) was designed to identify and study serious airway complications occurring during anaesthesia, in intensive care unit (ICU) and the emergency department (ED).

Methods. Reports of major complications of airway management (death, brain damage, emergency surgical airway, unanticipated ICU admission, prolonged ICU stay) were collected from all National Health Service hospitals over a period of 1 yr. An expert panel reviewed inclusion criteria, outcome, and airway management.

Results. A total of 184 events met inclusion criteria: 36 in ICU and 15 in the ED. In ICU, 61% of events led to death or persistent neurological injury, and 31% in the ED. Airway events in ICU and the ED were more likely than those during anaesthesia to occur out-of-hours, be managed by doctors with less anaesthetic experience and lead to permanent harm. Failure to use capnography contributed to 74% of cases of death or persistent neurological injury.

Conclusions. At least one in four major airway events in a hospital are likely to occur in ICU or the ED. The outcome of these events is particularly adverse. Analysis of the cases has identified repeated gaps in care that include: poor identification of at-risk patients, poor or incomplete planning, inadequate provision of skilled staff and equipment to manage these events successfully, delayed recognition of events, and failed rescue due to lack of or failure of interpretation of capnography. The project findings suggest avoidable deaths due to airway complications occur in ICU and the ED.

Keywords: airway; audit; brain damage; complications; cricothyroidotomy; death; emergency department; intensive care; tracheostomy

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Active airway management takes place most frequently in anaesthetic practice, but is often required outside the operating theatre. Several studies of airway management outside the operating theatre have identified higher rates of complications, including failed intubation, oesophageal intubation, hypoxia, and cricothyroidotomy. These include studies in intensive care units (ICU)^{1–4} and emergency departments (EDs).^{4–8} Differences in factors such as case mix, availability of skilled and trained staff, levels of assistance, and working environment all likely contribute. Recent data from analysis of the National Reporting and Learning System (NRLS) of the National Patient Safety Agency (NPSA) indicated that ICU may be an area where airway complications are relatively frequent,⁹ but the data were limited by the nature of NRLS reporting, which numerically focuses on low impact events.^{9 10}

The Fourth National Audit Project of the Royal College of Anaesthetists and Difficult Airway Society (NAP4) had the

primary aim of identifying the incidence of major complications of airway management during anaesthesia. At an early stage in planning NAP4, it was decided that it would be important to study similar complications in the environments of ICUs and EDs for the reasons stated above. This paper describes the major findings of this section of the NAP4 project.

For reasons of space, this paper cannot explore many facets of events that were reported. This paper should be read in conjunction with the accompanying paper¹¹ and the full report of the project is available on <http://www.rcoa.ac.uk/index.asp?PageID=1089>.

Methods

The full methodology of the NAP4 project is described in the accompanying paper.¹¹ In brief, a multi-speciality group was established to plan delivery of NAP4 (see Supplementary

[†]This article is accompanied by the Editorial.

Appendix). The project leads established a network of local reporters in all anaesthetic departments in UK National Health Service (NHS) hospitals believed to be performing surgery. Efforts were made to also recruit a local reporter in every ICU and ED. The local reporters were tasked with supporting the project at the local level and assisting in ensuring all cases meeting inclusion criteria were identified and fully reported to the project.

For patients in ICU and EDs, the main aim of the project was to study the nature of major airway events in the two identified non-anaesthetic environments. No formal census was planned to identify a denominator for such events. However, during the project, such a census for ED activity was completed by one of the authors of this paper.¹²

A registry of the major complications of airway management was established to collect detailed reports on such cases over a 12 month period. Discussions with the National Research Ethics Service indicated that ethics committee approval was not required. The project was examined by the Patient Information Advisory Group of the Department of Health and a methodology was agreed that ensured patient confidentiality. Data were not sought from private hospitals or Independent Sector Treatment Centres (ISTCs), but were collected from treatment centres attached to NHS hospitals. The project was widely advertised.

Inclusion criteria for complications in ICU and the ED were the same as for complications during anaesthesia. 'A complication of airway management that led to death, brain damage, the need for an emergency surgical airway (including a needle, cannula, open cricothyroidotomy or tracheostomy), unanticipated ICU admission or prolongation of ICU admission'.

Events occurring during transfer to or from the ICU or ED were included.

The process of notification, confirmation of inclusion criteria, submission, and case review was identical to that for anaesthesia cases: see accompanying paper.¹¹ As with anaesthesia cases, the NAP4 moderator was available to discuss cases where a clinician was uncertain about inclusion criteria. The same high levels of data protection and confidentiality that applied to all of the NAP4 project were applied to cases submitted from ICU and the ED.

An event was included if it occurred in the period from September 1, 2008, to August 31, 2009. Notification of events was accepted until June 2010.

Case review panel

An expert review panel examined each submitted clinical report. The panel incorporated representatives from all specialities involved in the project including the College of Emergency Medicine and the Intensive Care Society. Case review was a structured process; the review panel specifically considered cases under the categories described (Supplementary Table S1). Contributory or causative factors were identified as were factors considered to have had a positive effect. The degree of harm caused was graded using the National Patient Safety Agency (NPSA) severity of outcome scale for

patient safety incidents (Supplementary Table S2).¹³ Aspects of the care were analysed for learning points and pertinent cases were selected to act as illustrations of clinical care for inclusion in a detailed report of the project. Airway management was classified as good, poor, mixed (i.e. elements of both good and poor management), or unclassifiable.

Incidence calculations

No attempt was made to calculate the incidence of events in the ICU and EDs due to both lack of denominators and the fact that not all hospitals had specific local reporters for the ICU and ED.

Missing reports

No formal attempt was made to identify the extent of missing cases, as it was never the expectation of this part of the project that all cases meeting inclusion criteria would be reported.

Results

Agreement to participate and appointment of a local reporter was confirmed in all 309 hospitals by September 2008. In total, 286 anaesthesia local reporters were appointed with some representing more than one hospital. In addition, 118 ICU local reporters (for 253 UK ICUs: 47%) and 115 ED local reporters (for 239 major UK EDs: 48%) were recruited. Anaesthesia local reporters were encouraged to report cases from ICU and the ED when there were no additional local reporters.

Complications reported

A total of 286 cases were reported to the RCoA-lead or discussed with the moderator. Seventy-nine reports were withdrawn after discussion with the moderator or the reporter reviewed the inclusion criteria sent by the RCoA-lead: 207 cases were reviewed by the review panel. During the review process, additional information, using the methods described in the accompanying paper,¹¹ was requested from the reporters of 12 of the cases. After final review, 184 reports met the inclusion criteria. Of the 184 reports, 133 complicated the management of anaesthesia, 36 occurred in patients on ICU, and 15 in the ED. The results of the anaesthesia cases are presented in the accompanying article.¹¹

Patient characteristics

Of the ICU cases, the male:female ratio was 21:15 (58% males), 22% were ASA grade I–II, and 61% aged <60 (Table 1). In ICU, 19 patients were receiving invasive ventilation, eight non-invasive ventilation, eight were not receiving mechanical ventilation before the airway event: in one case, this information was not provided. Supplemental oxygen was being given in 94% before the event and in 35% the $F_{I_{O_2}}$ was ≥ 0.6 . Thirteen had organ failure other than respiratory and nine were receiving vasoactive drugs or continuous renal replacement therapy. A BMI of $>30 \text{ kg m}^{-2}$ was recorded in 47% of ICU cases and a BMI of $<20 \text{ kg m}^{-2}$

Table 1 Incident reports classified: by ASA grade and type of event; by age and type of event; and by inclusion criteria provided by the reporter. More than one inclusion criterion could be chosen. Note that some deaths were considered by the review panel not to be causally related to the event, in other cases patients reported with an inclusion criterion of brain damage either made a full recovery at the time of reporting or died. Therefore, figures in this table do not exactly match final outcomes in Table 2.

*Prolongation of stay in the case of patients already in ICU

	ICU (n=36)	Emergency department (n=15)
ASA		
I	1	2
II	7	4
III	14	5
IV	13	3
V	1	0
Not recorded	0	1
Age		
<10	1	1
11–20	2	0
21–40	6	7
41–60	11	4
61–80	14	2
>80	2	1
Not recorded	0	0
Reporter provided inclusion criteria		
Death	16	3
Brain damage	6	1
ESA	10	11
ICU admission*	12	10
Sum	44	25

in 6%. In the ICU, 46% of events for which a time was recorded took place out-of-hours (18:01–08:00). Although consultants were present for 58% of all events, there was a notable difference between events in hours (80%) and out-of-hours (36%). Several events were managed by doctors who would not be expected to have airway expertise because of lack of seniority [e.g. specialist trainee (ST) year 2] or primary speciality (e.g. ST2 in medicine).

Of the ED cases, the male:female ratio was 10:5 (67% males), 40% were ASA grade I–II, and 80% aged <60 (Table 1). A BMI of >30 kg m⁻² was recorded in 46% and <20 kg m⁻² in 7%. Fifty-three per cent of events took place 'out of hours'. All but three cases involved attempts at tracheal intubation, the exceptions being facemask anaesthesia for cardioversion and two surgical airways for airway obstruction. In 11 cases (73%), airway management was performed by an anaesthetist and in eight (53%) a consultant. Anaesthetist involvement decreased from 6/7 during the day (08:01–18:00) to 5/8 out-of-hours and consultant involvement was 4/7 in-hours and 4/8 out-of-hours. Several events were managed by doctors who would not be expected to have airway expertise, including two ICU trainees with

Table 2 Final outcome: Narrative outcome and NPSA classification (see Supplementary Table S2)

	ICU (n=36)	Emergency department (n=15)
Final outcome (narrative)		
Death	18	4
Brain damage	4	1
Other partial recovery	3	1
Full recovery	9	9
Unrelated death	2	0
Final outcome (NPSA definitions)		
Death	18	4
Severe	5	0
Moderate	12	11
Low	1	0
None	0	15

minimal anaesthetic experience and one Acute Care Common Stem trainee with 5 months anaesthetic experience. In a further three cases, the anaesthetist present at the start of the airway event was a year 3 specialist trainee, and in eight events, no consultant was present at the start of the airway event.

Inclusion criteria and event outcomes

The inclusion criteria indicated by reporters are presented in Table 1. The final outcome of events is presented, both focusing on outcomes of death and brain damage and by NPSA classification of severity of harm (Table 2).

Death resulting from an airway problem was the inclusion criterion for 33 reports: 16 occurred in ICU and three in the ED (Table 1). Three further cases resulted in late deaths, two in ICU, and one in the ED. In total, there were 38 deaths attributable to an airway event, 18 on ICU, and four in the ED. Hypoxia was the common theme in deaths caused by an airway problem in both ICU and the ED. Death rate for cases in ICU was 18/36 (50%) and in the ED 4/15 (27%).

Brain damage

In 13 patients, brain damage was recorded as an inclusion criterion, six in reports of events on ICU, and one in the ED (Table 1). After excluding those who died or recovered, there were four cases of persistent non-fatal brain damage in ICU and one in the ED. The combined rate of death and brain damage for ICU cases was 22/36 (61%) and in the ED 5/15 (33%).

Emergency surgical airway

An attempt at emergency surgical airway, either tracheostomy or cricothyroidotomy, was reported as an inclusion criterion in 75 cases (Table 1). Twelve attempts took place on ICU (33% of all ICU cases), with three failing to rescue the airway, a failure rate of 25%. Five needle cricothyroidotomies were attempted on ICU, three of which failed. One patient

with successful surgical airway died and one suffered persistent brain damage; two patients with failed placement of an emergency surgical airway died.

Ten emergency surgical airways were placed in the ED (67% of ED cases) with no total failures. However, in all three cases where a needle cricothyroidotomy was attempted, this failed and had to be replaced by a surgical or percutaneous technique. Of the 10 patients requiring a surgical airway in the ED, two died and one suffered persistent brain damage.

ICU admission

Of 122 cases included in NAP4 because of ICU admission or prolongation of ICU stay, 12 arose in patients already on ICU and 10 in ED cases. The most common reasons for prolongation of stay on ICU after an airway event were failure to awaken in five, aspiration of gastric contents or blood in four, and airway swelling in two. The most common reasons for ED cases to be admitted to ICU were management of airway swelling/trauma in four, failure to awaken in three, and aspiration in two.

Primary airway problem

In the ICU, tracheostomy-related events were the most frequently occurring problem ($n=18$, 50%) (Table 3). Next most frequent was failed intubation or tracheal tube misplacement (including unrecognized oesophageal intubation and inadvertent extubation). Displacement of an existing tracheostomy or standard tracheal tube combined accounted for 18 events and half of all cases of death or brain damage. These events occurred most frequently in obese patients and during patient movement, sedation holds (e.g. sudden awakening and coughing or manually removing a tube) or airway interventions (e.g. tracheal suction or nasogastric tube placement). Of all tubes that became dislodged, 13 were recorded as taped (ties, Velcro straps), two sutured, and three both taped and sutured. There were three

Table 3 Primary reported airway event

ICU ($n=36$)	
Tracheostomy-related problems	14
Tracheal tube misplacement/displacement	7
Failed intubation	7
Oesophageal intubation	3
CICV—the cannot intubate, cannot ventilate scenario	2
Iatrogenic airway trauma	2
Problems at the time of extubation	1
Emergency department ($n=15$)	
Failed intubation	7
Aspiration of gastric contents	2
Oesophageal intubation	2
CICV—the cannot intubate, cannot ventilate scenario	2
Iatrogenic airway trauma	1
Difficult or delayed intubation	1

unrecognized oesophageal intubations and two led to death (there was also one fatal oesophageal intubation as a secondary event). Displacement or obstruction of a tracheostomy and difficult intubation required a fibrescope on several occasions and delays in accessing one was a recurrent problem.

Events in the ED were predominantly related to tracheal intubation and included delayed or failed intubation, unrecognized oesophageal intubation, the cannot intubate, cannot ventilate (CICV) scenario, aspiration, and perforation of the trachea with a bougie. The two unrecognized oesophageal intubations led to death. Airway management in both of these cases was undertaken by a non-anaesthetist intensive care doctor, one junior and one senior, the latter with limited anaesthetic experience. The case of significant airway trauma occurred during an uneventful intubation by an emergency physician.

Paediatrics and obstetrics

There were no cases reported from ICU or the ED that involved pregnant women.

One event occurred in ICU in a child under 10 yr: a dysmorphic neonate required multiple attempts to intubate and the tracheal tube was then repeatedly displaced. Intubation became impossible and attempts were made to transfer the patient to theatre for a surgical tracheostomy, but the airway was again lost during transfer and the patient died. There was one paediatric event reported from the ED: a case of inadvertent oesophageal intubation in an infant. During cardiac arrest, a flat capnography trace was not recognized as indicating 'non-intubation'. The patient died.

Review panel analysis

Degree of harm

The outcomes ascribed to all ICU and ED cases by the review panel are presented in Table 2.

Causal, contributory and positive aspects of care

Causal and contributory factors were identified in all 36 ICU cases (Table 4). The most frequent causal and contributory factors were patient-related (69% of cases), followed by education/training (58%), judgement (50%), equipment/resource (36%), and communication (31%). Positive factors were identified in 19 cases (54%): the most frequent positive factors were communication (36% of cases) and organization/strategic (19%).

Causal and contributory factors were identified in all 15 ED cases (Table 4). The most frequent causal and contributory factors were patient-related (73% of cases), followed by judgement (57%), education/training (40%), and task (33%). Positive factors were identified in eight cases (53%), the most frequent positive factor being communication (33% of cases).

Quality of airway management conduct

Reviewers assessed airway management in ICU cases as good in 11% of cases ($n=4$), mixed in 52% ($n=19$), and poor in 36% ($n=13$) (Table 5). In the ED, airway management

Table 4 Factors assessed by review panel to contribute or cause events and factors indicating good practice. For definitions of factors listed, see Supplementary Table S2

Factors	ICU (n=36)			ED (n=15)		
	Causal	Contributory	Positive	Causal	Contributory	Positive
Communication	2	9	13	0	3	5
Education and training	2	19	2	0	6	2
Equipment and resources	0	13	4	0	4	1
Medicines	0	7	0	0	4	0
Organization and strategic	0	7	7	0	0	0
Patient	6	19	0	3	8	0
Task	0	6	2	2	3	1
Team and social	0	7	1	0	3	1
Work and environment	0	4	0	0	1	0
Judgement	3	15	4	0	8	1
Other	0	3	0	0	2	0

Table 5 Airway management and degree of harm number of cases: n (includes all reported cases—anaesthesia, ICU, and ED)

Clinical area	Airway management				Sum
	Good	Good and poor	Poor	Not classified	
All	30	79	65	10	184
All deaths	3	14	20	1	38
All death and brain damage	3	16	27	2	48
ICU	4	19	13	0	36
ICU death	0	10	8	0	18
ICU death and brain damage	0	11	11	0	22
Emergency department	2	5	7	1	15
Emergency department death	0	0	4	0	4
Emergency department death and brain damage	0	1	4	0	5

was assessed as good in 13% ($n=2$) cases, mixed in 33% ($n=5$), and poor in 46% ($n=7$) (Table 5). Airway management was assessed as poor in almost half of ICU deaths and all ED deaths.

Discussion

This project has performed a prospective study of major airway events occurring throughout the UK during anaesthesia, in ICU and the ED for the first time. In-depth structured review of these cases has identified specific issues and recurrent themes. While such a study will be ranked low in a hierarchy of research quality, it is likely to have considerable clinical relevance and importance.

There is much that could be discussed, but this discussion is structured in three sections.

- What have we observed?
- What do we learn from these observations?
- What can be done to improve airway management in the environments of ICU and the ED?

Space limits the extent of these discussions and the reader is referred to a full report of the project available at <http://www.rcoa.ac.uk/index.asp?PageID=1089>.

What have we observed?

We have observed that although ICU was the setting for fewer than 20% of notified events almost half of deaths occurred there. More than 60% of events reported from ICU led to death or brain damage (compared with 14% in anaesthesia). While it is not surprising that ICU patients frequently had a high ASA grading, multi-organ failure, and were receiving high inspired oxygen fractions, the high rate of obesity (approaching 50%) of patients experiencing major airway complications is a new and notable finding. Events in the ICU in obese patients led to death or permanent brain damage more often than events in non-obese patients (12 of 17 obese and 10 of 19 non-obese). This is in contrast to anaesthesia, where events in obese patients were not associated with poorer outcomes than in non-obese patients. Primary events leading to complications were more likely than anaesthesia events to involve failed intubation or problems with tracheostomies. These events were more likely than anaesthesia events to occur out-of-hours and to be managed by inexperienced staff. NAP4 identified several cases where management of intubation was by staff who were not adequately experienced and when problems arose, they were not managed in a logical or recognized manner. Issues with equipment arose frequently and included non-availability, lack of training in the use of equipment, and failure to consider using the right equipment. When rescue techniques were used (facemask ventilation,

laryngeal mask ventilation, and cricothyroidotomy), these all had relatively high rates of failure. Issues of preparedness were also identified and included failures to identify patients at risk of complications, failures to formulate a plan for critical events in these patients and failure to ensure that such a plan could be carried out. The assessors judged airway management in the ICU to be good less frequently than in either anaesthesia or the ED.

Observations in the ED were similar, with a high proportion of events occurring out-of-hours and without consultants present; the primary airway problem was predominantly failed or problematic intubation and outcomes were similar to those in ICU, although less severe. Several reports suggested failure of preparation, failure to follow standard practices for airway protection, or airway rescue in cases of difficulty. Emergency surgical airway was required in two-thirds of cases, higher than during anaesthesia or in ICU, and in all cases was ultimately successful, also higher than other settings.

An observation in both ICU and the ED was of unrecognized oesophageal intubation. In total, there were six leading to five deaths (23% of deaths in these areas). All were performed by clinicians with very limited airway experience. Capnography was not used in five cases and in one case, it was used, but a flat capnograph trace was misinterpreted as being 'due to cardiac arrest'.

In both groups, there was a high failure rate of needle cricothyroidotomy. Of eight attempted in ICU and the ED, six failed (75%) and the airway was rescued either with a surgical approach (open or percutaneous tracheostomy) or with other non-invasive techniques. Direct surgical approaches to the trachea had high success rates.

What do we learn from these observations?

In both settings, it must be accepted that patients may present with complex conditions which are intrinsically 'high risk': in ICU because of critical illness and oxygen dependency and in the ED because of underlying pathology or injury that has precipitated their admission. An American Society of Anesthesiologists' Closed Claims Project (ASACCP) study identified claims related to difficult airway management outside the operating theatre to be considerably more likely to lead to fatal outcomes than in the operating theatre.⁴ A study of more than 10 000 emergency intubations outside the operating theatre found multiple attempts at intubation to be associated with dramatic increases and high rates of hypoxaemia (11.8% vs 70%), regurgitation of gastric contents (1.9% vs 22%), aspiration (0.8% vs 13%), bradycardia (1.6% vs 21%), and cardiac arrest (0.7% vs 11%).³ For these reasons, the staffing and equipment in both settings must be such that airway management can be timely, skilled, and where necessary utilize highly advanced techniques. This requires planning and communication. In ICU, planning should recognize that intubation sometimes fails, that tracheal tubes and tracheostomies will inadvertently fall out, and that all these events are

more likely to occur in obese patients. Tracheal tube and tracheostomy displacement in ICU was repeatedly reported after patient movement or patient interventions and this has been reported before.⁹ Similarly, delayed diagnosis of displacement, in the absence of capnography, has been reported before⁹ and was reported repeatedly in this project.

Failed intubation or difficult intubation contributed to many events on ICU and the ED. Failure to identify potential difficulty, to have a strategy for failure (plan B, plan C), to assemble the correct equipment, and intubation by inappropriately inexperienced personnel contributed to numerous events. These observations also applied to patients specifically admitted to a critical care unit for airway monitoring and management. Reviewer assessments frequently identified system, organizational, and human factor deficiencies. In a recent study, implementation of a 10-point ICU intubation management protocol ('care bundle') led to a 30–60% reduction in complications.¹⁴ There are various interpretations of this study, but it is notable that the bundle included preoxygenation with continuous positive airways pressure, presence of two operators, rapid sequence induction (RSI), capnography, and early administration of vasopressors if needed. Such a protocol, supported by a checklist is attractive in the light of this study and other checklist-driven successes in ICU.¹⁵

In the ED, predictable airway emergencies include trauma intubations, stridor, inhaled foreign bodies, and other causes of airway obstruction. The rate of difficult intubation in the ED may be as high as 8.5%, and the need for an emergency surgical airway as high as 0.5%.^{5–8} Knowledge of likely scenarios should drive preparedness of personnel, equipment, communication channels, and policies. A survey¹² identified that ~20 000 RSIs of anaesthesia are performed in UK EDs per year and therefore an average size ED will perform RSI approximately every 4 or 5 days with 80% of these performed by anaesthetists, many of whom are trainees. In this project, we identified avoidable harm, including death, caused by airway trauma or oesophageal intubation that occurred during airway management by clinicians with limited airway management experience. The implications are that emergency physicians undertaking these procedures need specific training to establish and maintain their skills, that anaesthetists and intensive care doctors need to understand the particular requirements and difficulties of airway management in the ED, and that channels of communication between the ED and anaesthesia or ICU departments need to be well established to ensure prompt attendance by an appropriately skilled senior clinician.

Diagnosis of oesophageal intubation was hampered by lack of capnography. The current situation in ICU and the ED can be compared with the 1980s when capnography was not universally used for intubation in anaesthesia. The ASACCP identified numerous cases of litigation after oesophageal intubation:¹⁶ delays in diagnosis of more than 5 min were almost universal, auscultation routinely gave false positives, cyanosis was often absent, and it was cardiovascular disturbance or collapse that alerted clinicians to the

problem in more than 80% of cases. The authors commented on 'preconceived notions of likelihood', 'reflex clinical behaviours', 'conflicting environmental data', 'the inherent limitations of diagnostic tests', and 'the potential for a rapid and poorly reversible clinical cascade'. These comments act as a potent reminder of the problem and the potential for human factors to impede correct clinical diagnosis. A more recent study of emergency intubation outside the operating theatre noted that reliance on indirect clinical tests for diagnosing oesophageal intubation during emergency tracheal intubation led to more hypoxaemia, severe hypoxaemia, regurgitation, aspiration, cardiac dysrhythmia, and cardiac arrest.¹⁷

An important recurrent finding was misinterpretation of capnography when oesophageal intubation occurred during cardiac arrest or cardiac arrest occurred as a consequence of it. This was also noted in anaesthesia cases. Clinicians, mostly anaesthetists, failed to recognize that a flat capnograph trace indicated absence of ventilation and a misplaced tracheal tube. Nevertheless, it has been recognized for many years that during cardiopulmonary resuscitation (CPR) capnography is not flat but indicates a low concentration of expired gas (Fig. 1).¹⁸ The 2010 International Consensus guidelines on Cardiopulmonary Resuscitation specifically addressed the use of capnography to confirm advanced airway placement during CPR.¹⁹ The report describes two studies which included 21 oesophageal intubations in 297 patients at cardiac arrest and in which waveform capnography was 100% sensitive and 100% specific in identifying correct tracheal tube placement.^{20 21} In contrast, studies of colorimetric expired carbon dioxide detectors, non-waveform expired capnometers, and oesophageal detector devices (both syringe aspiration and self-inflating bulb types) had similar accuracy to clinical assessment for confirming the tracheal tube position during cardiac arrest.²²⁻³⁰ The report concludes that 'waveform capnography is recommended to confirm and continuously monitor the position of a tracheal tube in victims of cardiac arrest...it should be used in

addition to clinical assessment...if not available, a non-waveform carbon dioxide detector or oesophageal detector device in addition to clinical assessment is an alternative'.¹⁹

Capnography, or rather the failure to use it, likely contributed to 17 outcomes of death or brain damage on ICU, including four oesophageal intubations and 14 inadvertent tube displacements: these account for 82% of events leading to death or brain damage in ICU.

In the ED, capnography use was higher, being definitely used 50% of intubation attempts, although this question was poorly completed. Despite this, its use was not universal and failure to use, or misinterpretation of, capnography led to two fatal unrecognized oesophageal intubations in the ED. Correct use and interpretation of capnography would have prevented half of the deaths in the ED.

The contrast between rates of use of capnography in anaesthesia and in ICU and the ED is stark and is reinforced by this project's findings. The use of capnography in ICU has been recommended by various authors and organizations.^{9 14 31-35} The breadth of these recommendations has ranged from that it should be available for intubation to recommending its routine use 'from intubation to extubation'. Surveys repeatedly show current use fails even to meet the narrowest recommendation. This project has shown that full implementation would save lives.

In both areas, needle cricothyroidotomy had an unexpectedly high failure rate. It has been widely discussed as to whether needle or Seldinger or surgical approaches to direct tracheal access are best and it may be argued that this project provides evidence that needle cricothyroidotomy has a high failure rate and therefore should be abandoned, particularly as surgical approaches were generally successful (even when following failed needle cricothyroidotomy). There are several reasons to be cautious about such a conclusion. The NAP4 project specifically studied events with poor outcomes and although we did seek reports of all airway complications requiring emergency surgical airway, it is possible that a disproportionate

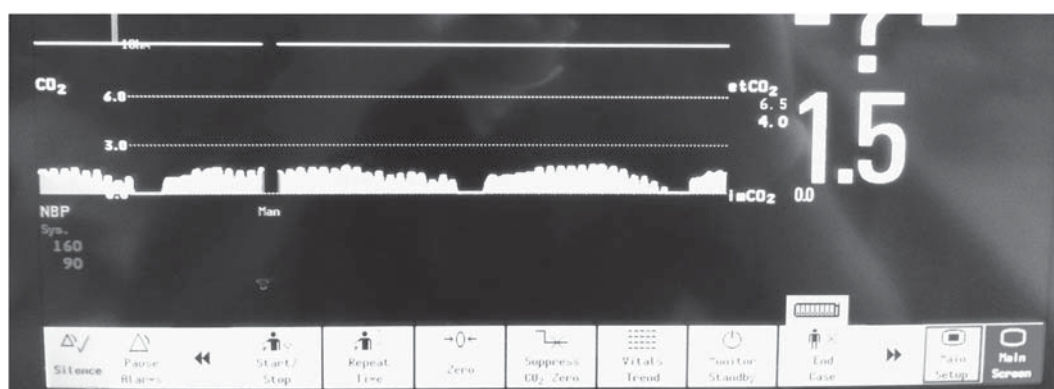


Fig 1 Capnograph trace during cardiac arrest with on-going CPR. The positive trace is an indicator of correct (i.e. tracheal) placement of the tracheal tube.

number of successful rescue needle cricothyroidotomies were not reported. Even if this explanation is not correct, it is not reasonable to abandon the needle cricothyroidotomy technique without a much more robust explanation of failures, which may have been due to failures of training, use of inappropriate equipment, design problems with appropriate equipment, or technical failures during use. Examples of each of these observed in NAP4 include cephalad placement of the device, use of an i.v. cannula for cricothyroidotomy, mechanical failures of a Ravussin cannula, and successful passage of a fine bore needle followed by unsuccessful (and inappropriate) attempts to ventilate with a low-pressure gas source.

Emergency surgical airway is the 'final common pathway' for all difficult airway algorithms. While much emphasis is placed on the choice of device and technique, there is relatively little written about the decision-making process and timing of emergency surgical airway. An anaesthetic litigation review found that 42% of 179 difficult airway cases terminated in CICV.⁴ Errors of technique were frequent causes of failure, particularly failure to ventilate with a high-pressure source when a narrow cricothyroid cannula was inserted.³⁶ Of equal importance, persistent attempts at intubation occurred before rescue techniques and the authors noted that 'our data suggest the rescue ability of (supraglottic airways) may have been reduced by the effects of multiple preceding attempts at conventional intubation' and that 'in 2/3 of the claims where CICV occurred a surgical airway was obtained but was too late to avoid poor outcomes'. In NAP4, there were also cases, in anaesthesia and also in the ICU and ED, where persistent attempts at intubation perhaps precipitated CICV, likely led to failure of rescue techniques and definitely delayed emergency surgical airway.

What can be done to improve airway management in the environments of ICU and the ED?

Intensive care unit

Capnography

- Capnography should be used for intubation of all critically ill patients irrespective of location.
- Continuous capnography should be used in all ICU patients with tracheal tubes (including tracheostomy) who are intubated and ventilator-dependent. Cost and technical difficulties may be practical impediments to the rapid introduction of routine capnography. However, these need not prevent its implementation.
- Where capnography is not used, the clinical reason for not using it should be documented and reviewed regularly.
- Training of all clinical staff who work in ICU should include interpretation of capnography. Teaching should focus on identification of airway obstruction or displacement. In addition, recognition of the abnormal (but not flat) capnograph trace during CPR should be emphasized.

Intubation

- An intubation checklist should be developed and used for all intubations of critically ill patients. A checklist might usefully identify preparation of patient, equipment, drugs, and team. A checklist should include identification of back-up plans.

Recognition of difficulty and back-up planning

- Every ICU should have algorithms for management of intubation, extubation, and re-intubation. National efforts should be made to develop evidence-based algorithms for ICU.
- Patients at risk of airway events (i.e. those patients at increased risk of problems or for whom the standard algorithms are not appropriate) should be identified and clearly identifiable to those caring for them.
- A plan for such patients should be made and documented. The planning should identify primary and back-up plans. The plan should also identify any additional equipment and skills necessary to carry out the plan. The plan should be communicated to on-coming staff at each staff handover, including confirmation that the plans can still be carried out.

Tube displacement

- Staff education should recognize and emphasize the risks of airway displacement. Airway displacement may occur at any time but is more frequent in obese patients, in patients with tracheostomy, during or after patient movement, and during sedation holds.

Obesity

- Obese patients on ICU should be recognized as at increased risk of airway complications and at increased risk of harm from such events. Plans to manage the airway should be particularly meticulous.
- Responsible bodies (e.g. Royal College of Anaesthetists, Intensive Care Society) should work with other stakeholders and manufacturers to explore two aspects of tracheostomies for obese patients. (i) Can design be improved to reduce risk of displacement? (ii) Can the optimal mode of fixation be determined?

Airway equipment

- Every ICU should have immediate access to a difficult airway trolley. This should have the same content and layout as the one used in that hospital's operating department.
- The airway trolley needs regular checking, maintenance, and replacement of equipment after use which should be appropriately documented.
- A fibrescope should be immediately available for use on ICU.

Cricothyroidotomy

- Training of staff who might be engaged in advanced airway management of these potentially difficult patients should include regular, manikin-based practice in the performance of cricothyroidotomies. Correct identification of the landmarks, especially on obese patients, should be encouraged.
- Research is required to identify the equipment and techniques most likely to be successful for direct tracheal access in critically ill patients. This research should specifically address whether the same solutions are effective in obese patients.

Transfers

- Recognizing that transfers, whether inter- or intra-hospital, are high-risk episodes, an airway assessment that includes patient, equipment, back-up, and staff skills should be made before transfers.

Staffing

- Trainee medical staff who are immediately responsible for management of patients on ICU need to be proficient in simple emergency airway management. They need to have access to senior medical staff with advanced airway skills at all hours.
- Where senior intensivists do not have an anaesthetic background with advanced airway management skills, it is recommended that specific protocols are in place to ensure experienced anaesthetic cover can be called on to assist in management of difficult cases. Trust management should support the financial implications.

Education/training

- Junior medical staff who are to be immediately responsible for management of patients on ICU need airway training. This should include basic airway management, familiarization with algorithms for management of predictable airway complications, and use/interpretation of capnography. Training should identify the point at which trainees reach the limit of their expertise and mechanisms for summoning more experienced clinicians. Such training is likely to include simulation and team training.
- Regular audit should take place of airway management problems or critical events in the ICU.

Emergency department

Many of the above recommendations apply equally to the ED. To these are added:

- Capnography should be used for all intubations in the ED.
- Capnography should be used for all anaesthetized patients in the ED.
- Capnography should be used for intubated patients during transfers from the ED to other departments.

- An intubation checklist should be developed and used for all intubations of ED patients. A useful checklist may identify preparation of patient, equipment, drugs and team, and also back-up plans.
- EDs should perform a risk assessment to identify the type of patients and their airway problems that they can anticipate receiving. Equipment, training, and strategies should be planned around, although not restricted to, the anticipated patient groups.
- Every ED should have the airway equipment necessary to manage the anticipated clinical scenarios. This needs regular checking, maintenance, and replacement of equipment after use.
- Every ED should also have a difficult airway trolley. This should have the same content and layout as the one used in that hospital's operating department and also needs regular checking, maintenance, and replacement of equipment after use.
- In cases of airway compromise, it is generally preferable to secure the airway before moving the patient out of the ED, but local considerations apply. Any decision to move a patient with a threatened airway should be made by a senior clinician.
- Robust processes should be established to ensure the prompt availability of appropriately skilled and senior staff at any time to manage the airway within a reasonable timeframe.
- Joint training of emergency physician and anaesthesia/ICU staff is recommended—as described above.
- Staff training should focus on the anticipated clinical presentations. Training should also include management of failed intubation and emergency surgical airway techniques using the airway equipment available in the ED.
- Strong links and good communication between senior clinicians in the ED, anaesthesia, ICU, ear, nose, and throat surgery, and other relevant specialities are essential in planning for, and managing, the emergency airway problems that present to the ED. Consideration should be given to designating consultant leads from each involved speciality to agree and oversee the management of emergency airway problems presenting to the ED.
- Regular audit should take place of airway management problems or events in the ED.

Research

- NAP4 has identified numerous areas of concern and potential improvement in airway management in ICU and EDs. Airway management on ICU and in the ED is as suitable an area for future research as many other interventional areas. It is currently under-explored. Grant awarding bodies should recognize this. Several areas of potential research are indicated above.

The main limitations of the NAP4 project are described in the accompanying paper.¹¹ In contrast to the anaesthesia

events where every UK NHS hospital had a local reporter, our network of local reporters for ICU and EDs likely covered only 50% of hospitals. Although many cases in these areas will have been reported by anaesthesia local reporters, it is likely that a higher proportion of events arising in ICU and EDs were not notified. We cannot quantify these, but it is certainly possible that the cohort of patients we studied represent only the 'tip of the iceberg' of such cases in ICU and EDs.

Before surgery, airway management is generally a necessary part of the process of anaesthesia to facilitate an operation, while in both ICU and the ED, the primary aim may be securing the patient's airway, with anaesthesia a necessity for that. Owing to preceding patho-physiological disturbance, it may be difficult in these patients to determine to what extent an adverse airway event was the cause of a poor outcome and this was relevant to several cases in NAP4. At the reviewing stage, we aimed only to include those cases where the outcome was judged likely to be related to the airway event.

In conclusion, at least one-quarter of major complications of airway management in hospitals are likely to occur in the ICU and ED. These complications are more likely to lead to permanent harm or death than events in anaesthesia. Case review has identified avoidable deaths and areas of care that need improvement. We have outlined recommendations on which to base such improvements.

Supplementary material

Supplementary material is available at *British Journal of Anaesthesia* online.

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Conflict of interest

T.M.C. has been paid by Intavent Orthofix and the LMA Company (manufacturers of laryngeal mask airways) for lecturing. He has never had and has no financial interest in these or any anaesthetic equipment companies.

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