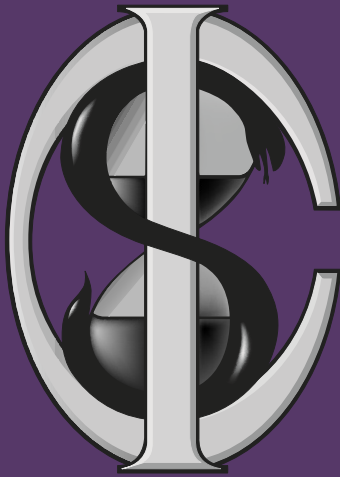# The Intensive Care Society

Standards for Capnography in Critical Care

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CONTENTS

Standards for Capnography in Critical Care

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Executive Summary

Critically ill patients are often dependent on the correct placement, continued patency and positioning of an endotracheal or tracheostomy tube. Capnography (the measurement of CO_2 in expired breath) has been an accepted standard to ensure correct tube position during induction and maintenance of anaesthesia for many years. Capnography has, however, been less consistently applied in intensive care practice.

A recent review of airway associated incidents in critical care reported to the National Patient Safety Agency suggested that a number of patients had been harmed as a result of airway misadventures in critical care. The free text descriptions of the reports of these incidents did not describe the use of capnography in helping to establish the position of the endotracheal or tracheostomy tube. The Standards Committee of the Intensive Care Society therefore developed these recommendations and standards for the use of capnography in critical care to improve the safety of patients who require endotracheal or tracheostomy tubes.

Recommendations:

1. Capnography should be used for all critically ill patients during the procedures of tracheostomy or endotracheal intubation when performed in the intensive care unit.

    Grade of recommendation: Strong.

2. Capnography should be used in all critically ill patients who require mechanical ventilation during inter-hospital or intra-hospital transfer.

    Grade of recommendation: Strong.

3. Rare situations in which capnography is misleading can be reduced by increasing staff familiarity with the equipment, and by the use of bronchoscopy to confirm tube placement where the tube may be displaced but remains in the respiratory tract.

    Grade of recommendation: Strong.

Other findings:

1. Capnography offers the potential for non-invasive measurement of additional physiological variables including physiological dead space and total CO_2 production.

2. Capnography is not a substitute for estimation of arterial CO_2.

3. Careful consideration should be given to the type of capnography that should be used in an ICU. The decision will be influenced by methods used for humidification, and the advantages of active or passive humidification should be reviewed.

4. Capnometry is an alternative to capnography where capnography is not available, for example where endotracheal intubation is required in general ward areas.

Important areas for further research

The use of continuous Capnography for monitoring critically ill patients during mechanical ventilation in the ICU needs further research. Current evidence supporting continuous capnography in the critical care unit is both weak and indirect. In view of this no consensus was reached and no recommendation is given.

Introduction

The use of capnography is a standard for anaesthesia for patients undergoing endotracheal intubation or placement of a laryngeal mask and subsequently while airway devices remain in place. [1], [2].

These recommendations were made primarily as a result of studies reporting anaesthetic deaths and neurological injuries associated with unrecognised misplacement of endotracheal tubes, including oesophageal intubation, extubation and disconnection from mechanical ventilation. Such incidents have caused death or brain damage as a result of hypoxia [3] [4] [5] [6]. These incidents are now less common, [7] [8] and this improvement may have been due to improvements in monitoring during anaesthesia, including the adoption of capnography as a standard for anaesthetic monitoring.

Capnography has also been widely accepted as a standard for monitoring during transport of critically ill patients [9] [10], in part because of the increased risk of extubation during patient movement and also because of the problems with other methods of diagnosing tube placement in noisy, dark and otherwise unsatisfactory environments.

The use of capnography during airway placement and mechanical ventilation in critical care is, however, not covered by guidelines issued by anaesthetic societies, including the American Society of Anesthesiologists [11] and the European Society of Anaesthesia [12] or by critical care societies including the Society of Critical Care Medicine [13], the Canadian Society of Intensive Care [14], or the European Society of Intensive Care Medicine [15]. Surveys of practice have also suggested that capnography has not been universally used in critical care in the UK [16] or abroad [17]. These findings were confirmed by a survey we conducted during the preparation of these guidelines which showed that 44% of intubations performed in UK ICUs were carried out without the use of capnography to confirm tube placement [*In Press*]. The AAGBI has recently recommended that capnography should be used during critical care during intubation and mechanical ventilation [18] and the American Society of Respiratory Therapists has issued guidance that although capnography should not be mandated for all patients receiving mechanical ventilatory support, it may be indicated to confirm correct tracheal tube placement [19]. The Australasian Joint Faculty of Intensive Care Medicine have recommended capnography should be used during intubation and should be available at each bed area in intensive care [20].

There is therefore an apparently illogical situation where societies recommend the use of capnography during airway placement and mechanical ventilation of otherwise healthy patients having minor procedures under anaesthesia but they have not consistently issued similar guidance for the monitoring of critically ill patients during airway placement and mechanical ventilation. The Standards, Safety and Quality Committee of the Intensive Care Society felt this inconsistency should be reviewed to consider what guidelines on the use of capnography during intensive care could be issued. In producing this guideline we have conducted a number of structured literature reviews to answer the following questions:

1. Do airway incidents occur during intensive care, particularly during airway placement (endotracheal intubation, and tracheostomy) and subsequent mechanical ventilation (unplanned disconnection or removal of endotracheal tubes or blockage of endotracheal tubes)?

2. Can we estimate how frequently these incidents occur?

3. Can we estimate the frequency of actual or potential harm to patients as a result of these incidents?

4. Can capnography help in the identification of the correct placement of an endotracheal tube in critically ill patients?

5. Apart from conformation of endotracheal tube placement, what additional benefits are there for using capnography in critical care?

6. What are the potential disadvantages of using capnography?

7. What methods of capnography are appropriate in critical care?

8. If capnography is appropriate in critical care, how can it be introduced to an intensive care unit?

Methodology

Definitions

The identification of carbon dioxide in expired breath has been used in clinical practice since the 1960s and 1970s [21]. There is an extensive literature on the subject, which is well reviewed in many anaesthetic texts and in textbooks written specifically about capnography [22] [23]. The following definitions are used in this literature:

Capnography. The measurement of inspired and expired carbon dioxide concentration and the graphical display of the CO_2 concentration.

Time capnography. CO_2 concentration displayed against time during inspiration and expiration, this is commonly used in clinical practice. A time capnograph trace is shown in figure 1

Volume capnography. The expired CO_2 waveform plotted against expiratory flow rate to establish the relationship between CO_2 and flow. This allows calculation of total CO_2 production and respiratory dead space; it is not widely used in clinical practice.

Capnometry. The measurement of CO_2 in expired breath without a graphical display. Capnometry normally utilises the fact that CO2 dissolved in an aqueous solution will dissociate to reduce the pH. The resultant acidity can then be used to change the colour of an indicator dye. This gives a semi quantitative measure of the presence of CO_2 in expired gas.

Side stream and mainstream capnography. Most capnographs use the absorption of infra red light by the vibrating CO_2 molecules to estimate CO_2 concentrations. This can be done by shining a light directly through the gas flow of the ventilator circuit against an absorber, a process known as "main stream" capnography. A side stream of gas can also be removed from the ventilator circuit to a separate analyser, a process known as 'side stream capnography'. Both methods are commercially available and used in critical care.

Respiratory Gas Analyser (RGA). Capnographs are part of a group of equipment used to measure respiratory gases known as respiratory gas analysers. There are published international standards for the manufacture of these devices and equipment should conform to these standards [24].

End tidal CO2 concentration ($_{ET}CO_2$) The highest concentration of expired CO_2 measured in the expired breath, normally at the end of the breath (see figure one). With no respiratory dead space this would normally be only slightly less than the arterial CO_2 [25].

Figure 1. Capnograph Trace
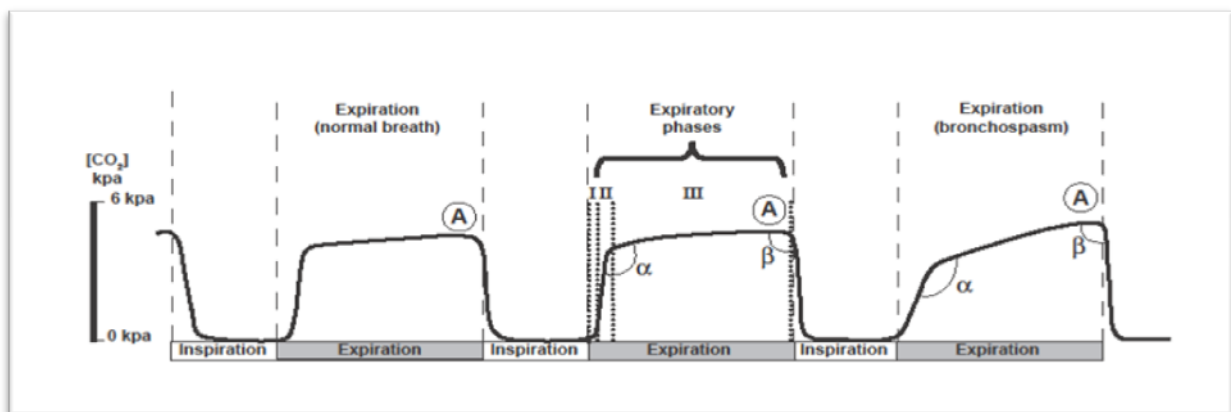
Figure one shows a capnograph trace produced during 3 breaths. The expiratory component is normally divided into 3 phases; I is the start of the phase before CO_2 starts to appear in the breath, phase II shows the rapid increase in CO_2 as the expired breath now starts to contain breath from the alveoli. Phase III (plateau phase) represents the emptying of alveolar space. The angle (α) between phase II and phase III may be increased in bronchospasm, the gradient of phase III may also be increased in brochospasm as shown in the last expiratory phase shown in figure one. The end tidal CO_2 is the highest concentration of CO_2 seen at the end of each breath and is marked as A on the figure.

Search strategies

The reviews have been conducted using the following search strategy, based on guidance issued by the Scottish Intercollegiate Guidelines Network guideline developer's handbook (Sign 50) [26]. The process includes the following steps:

1. Are there already evidence based literature reviews on the subject, for example: Cochrane collaborative reviews [27]?

2. Are there previous systematic reviews or meta-analyses or are there trials registered in the Cochrane register of clinical trials?

3. If not, the literature was reviewed using specific subject headings in Medline, searching for MEsH terms appearing in the titles or abstracts of papers. These terms are contained in appendix 1. For some subjects all abstracts were reviewed. For others the search was initially limited to core journals, again, as listed in appendix 1.

It is well recognised that this technique of literature review will miss a considerable amount of relevant material. For this reason we used the Science Citation Index [28] to identify papers that cited publications from the initial review. Additionally, publications were identified from the reference lists of papers identified in the initial review. Publications were then included in the review if they were relevant to one of these specific questions:

1. Do airway incidents occur in critical care?

2. How common are they?

3. How commonly do patients suffer harm or potential harm?

These broad topic areas were further defined into the following review questions.

Literature Review Questions

i) How commonly are airway incidents reported in general series of critical incidents that occur in intensive care?

Reviews of all types of critical incidents occurring in critical care were identified to estimate how commonly airway incidents were reported.

The search strategy is outlined in appendix 1 and a summary of the review is shown in appendix 2, table 1. It was possible to estimate that 16% (Range 7% to 33%) of all critical incidents reported in critical care involve the airway and that there were 11 airway associated deaths in 6780 reported critical incidents. There were very inconsistent methods of reporting the population sizes in which these incidents were occurred. Some reported patient days, others the number of ICU beds and others periods of time, so it is not possible to estimate the total sample size of patients or patient days from which these incidents were reported.

ii) How common are incidents associated with percutaneous tracheostomy?

Harm associated with tracheostomy has been systematically reviewed in preparation for the Trac-man study, and this is described in the trial protocol [29], the review estimated an interoperative mortality of 0.8%. It is clear that immediate complications of tracheostomy have reduced in the years following the original descriptions of percutaneous tracheostomies due to a better understanding of the technique [30,31,32] so the current risk should be no higher than that estimated in the Trac-man review.

iii) How common are incidents associated with endotracheal intubation?

Reports of problems associated with endotracheal intubation in critical care were reviewed using the search terms set out in appendix 1, while appendix 2, table 4, summarises the papers identified.

Studies reporting on 8450 intubations were identified, 966 of 4399 intubations were associated with harm. The rate of aspiration of gastric contents was 116 in 4250 intubations, the oesophageal intubation rate was 354 in 4442 intubations and the cardiac arrest rate was 59 arrests in 3702 intubations. 10 patients died in the 862 intubations where death rates were reported. More detailed information describing complication rates in different studies is contained in appendix 2, table 2.

The complication rate associated with intubation is determined by:

1. The number of patients who are critically hypoxic or difficult to intubate.

2. The experience or the staff conducting the procedure.

3. The technique used (for example drugs, equipment, use of rapid sequence induction).

The considerable variation in the complication rates associated with endotracheal intubation can be partly explained by differences in these three variables in different studies. We believe that most UK ICUs have only allowed anaesthetists with at least a basic level of training to conduct endotracheal intubation using rapid sequence techniques. Complication rates in UK practice should therefore be towards the lower end of internationally described rates. However there were 125 intubation incidents reported to the NPSA in the 2 years from September 2005, with 31 incidents associated with more than temporary harm [33].

iv) How commonly do airway incidents occur after tube placement?

a) Unplanned extubation: There is an extensive literature describing unplanned extubation and device removal in Intensive Care. The search strategy to review this literature is shown in appendix one and summary of publications are shown in appendix 2, table 2. The median rate of unplanned extubation was 12 per 1000 intubated days (range 2-21 per 1000 days). A median of 48% of extubations required

reintubation (range 30-88%) with a median of 35% (range 20%-46%) requiring reintubation in the first hour. It is reasonable to assume that these reintubations would be challenging, and would be helped by the provision of capnography. There were 12 deaths directly associated with the episode of extubation described in 888 tube displacements giving an approximate death rate of 1 death every 6000 days. Unplanned extubation followed by reintubation is associated with an increased ICU mortality, however, this is probably because this sequence of events identifies a high risk patient population and it is unlikely that this late mortality would be reduced by the use of capnography during re-intubation.

b) Other Incidents: Studies summarising rates and complications from blocked tubes are shown in appendix 2 table 3. The rate of tube blockage was described at 1 per 1000 days in all three studies with 5 deaths or cardiac arrests described in the three studies. The study reported by Siempos [34] was itself a meta-analysis and the death rate of approximately 1 per 23,000 patient days reported in this study seems to be the best available estimate of the death rate associated with blocked endotracheal and trachesotomy tubes. In UK practice partially displaced and blocked tubes are also associated with significant morbidity [33].

v) Do airway incidents occur during intra hospital transport of critically ill patients?

The search strategy is contained in appendix 1 and a summary of the identified papers is shown in appendix 2, table 5. Of a total of 1393 identified intrahospital transfers 7 were associated with displacement of the endotracheal tube, 52 with hypoxia and 21 with cardiac arrest.

Summary of evidence for the occurrence of airway incidents in Critical Care:

The literature strongly suggests that airway incidents occur in intensive care units during airway placement and during mechanical ventilation. These incidents may be associated with patient harm, including cardiac arrest and death. The rates of airway associated incidents and harm associated with the incidents are, however, too uncommon to allow then to be accurately measured. There is no reason to believe that airway incidents occur less commonly during intensive care then during anaesthesia, and the case mix and level of experience of staff mean that these incidents are likely to be more common and are more likely to result in harm for individual patients in intensive care than during the conduct of routine anaesthesia. Clearly many more patients undergo general anaesthesia than are admitted to intensive care units and this may hide the risks of airway incidents to individual patients in intensive care. The relative risks of airway incidents in critical illness may also be hidden by the other very real risks of death associated with the disease processes of critical illness when compared with the rarity of other risks associated with anaesthesia. Although many of the described international studies may not be relevant to UK intensive care practice, in a convenience sample of 44 675 patient safety incidents submitted to the UK National Patient Agency between October 2005 and September 2007, 1085 airway related incidents were identified. 61% of these incidents were associated with harm and 25 of the incidents may have contributed to the patient's death [33].

Basic principles in reviewing interventions to reduce rare events:

The reviews described above show that death associated with a misplaced endotracheal or tracheostomy tube is probably a rare occurrence in a well managed intensive care unit. If capnography was to reduce the risk of major harm associated with these rare life threatening airway events, it would be inevitable that this could not be established by randomised controlled trials (RCT), as no trial could be powered to detect a reduction of such a rare event (Table A). The statistics associated with rare catastrophic events has been well reviewed [35-37]. Tramer and McQuay's description of biological progression is particularly useful for considering death associated with airway incidents as more measurable incidents, for example oesophageal intubation rates could indicate what the mortality rate may be as a result of some of these events progressing to cause significant patient harm. Table A shows the estimated RCT sample sizes required to determine the effect of using capnography to reduce deaths or serious harm associated with airway incidents in critical care.

Table A: Example power calculations for capnography RCTs

Incidence of deaths or serious harm associated with airway procedures	Reduction in rate of harm by the use of capnography	Number of patient days required to reach 80% chance of identifying a reduction in harm
1 per 1000 days	50% reduction	100,000
1 per 1000 days	20% reduction	700,000
1 per 1000 days	10% reduction	3 million
1 per 2000 days	20% reduction	1.4 million

Is capnography useful in the identification of correct placement of a tube in the trachea?

For capnography to be useful in reducing harm associated with airway incidents in Intensive Care, it should be able to confirm correct placement of a tube in the trachea and confirm incorrect placement of a tube in the oesophagus with an accuracy that exceeds clinical examination. The options for tube placement and capnographic confirmation are shown in figure 2.

Figure 2 Capnography at intubation: Diagnostic possibilities
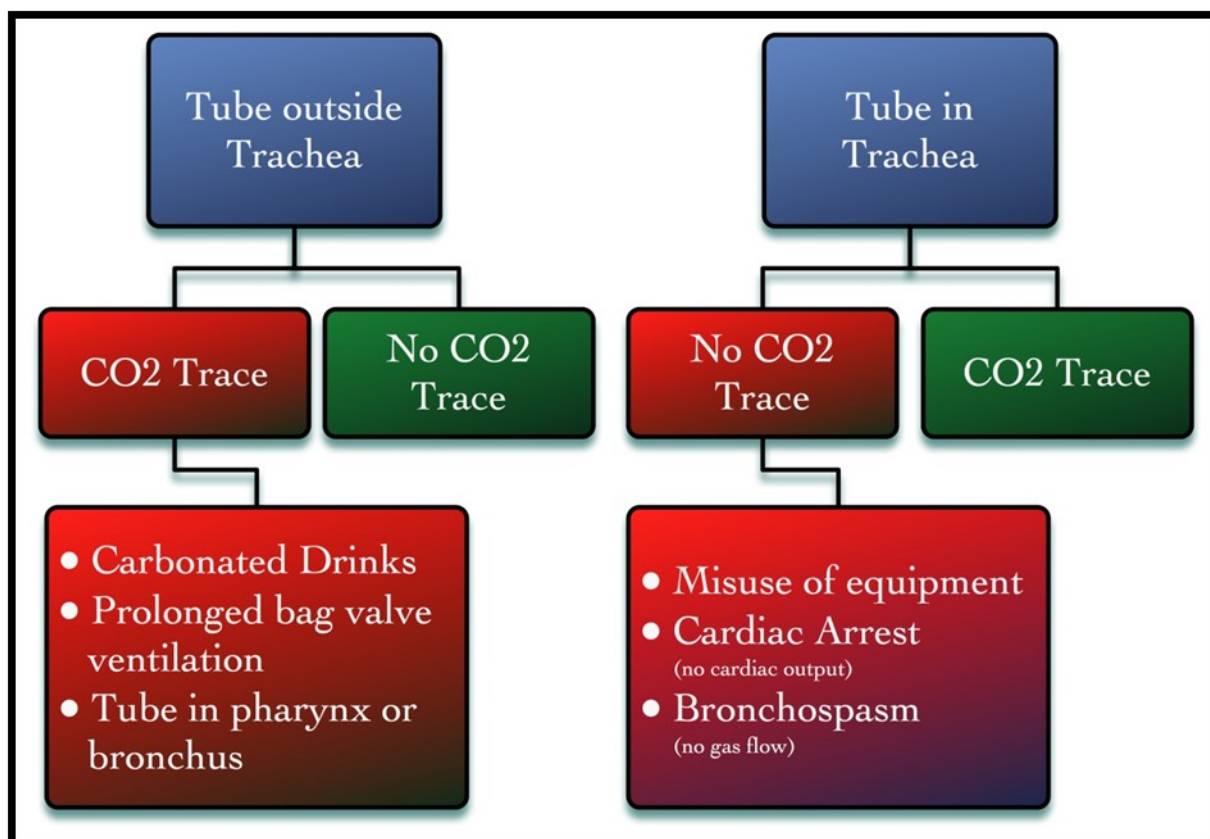
In what situations will capnography incorrectly diagnose tube placement?

Situations where capnography does not identify correct tube placement are rare and were identified using the search terms described in appendix one. These terms were also used to identify studies comparing capnography with other methods used to confirm endotracheal tube placement.

1. Are there situations where there is no capnograph trace, but the tube lies within the trachea?

Capnography will not work if there is no circulation to deliver CO_2 to the lungs or absolute bronchospasm prevents any gas exchange [38, 39]. There are many reports demonstrating that CO_2 will be produced by effective cardiopulmonary resuscitation to give a capnograph trace [40,41]. The adequacy of the capnograph trace has been used as a guide to the effectiveness of resuscitation and as a prognostic guide to the chances of survival after cardiac arrest [42, 43]. Capnometry (the use of semi-quantitative dye indicators) will, however, be less reliable than capnography in these circumstances as the device may not be sensitive enough to detect the low levels of CO_2 produced during a cardiac arrest, and may fail to identify tracheal tube placement in 75% of patients with no pulse [44]. Capnography is not 100% sensitive and specific in cardiac arrest, some authors have not been able to demonstrate that capnography predicts tracheal intubation in the emergency department during cardiac arrest [45]. This finding is supported by systematic review of a number of studies, which showed a disappointing rate of specificity and sensitivity for capnography and capnometry, where the devices were reviewed together [46].
A capnograph may not produce a reliable capnograph trace if the device is incorrectly connected to the patient or incorrectly set up. There are several points where the connections to a side stream capnograph may be interrupted, and therefore a very real possibility that staff that are not familiar with the equipment could misinterpret a flat capnograph trace as being the result of an oesophageal intubation when the tube has been correctly placed in the trachea. Similar results will be obtained with an un-calibrated inline capnograph [47 48 49]. There is a strong argument that the routine use of capnography would greatly reduce the chances of incorrect assembly of the device, and this is therefore an important argument for the routine use of capnography. However, we were unable to find evidence to support or refute this 'common sense' argument, although a review of patient safety incidents submitted to the UK National Patient Safety Agency suggested that the most common reason for equipment related patient safety incidents was the incorrect use of equipment [50].

2. Are there situations where a capnograph trace can be present when the tube is not in the trachea?

i. Where the stomach contains CO2: Difficult bag mask valve ventilation will cause respiratory gas to be pushed into the stomach. The CO_2 in this gas can then be measured in the first few breaths after an oesophageal intubation, however the capnograph trace will show a rapidly decreasing CO_2 trace with each breath [51].
Capnometry will be less reliable than capnography in differentiating gastric and pulmonary CO_2 production in this situation [52]. The recent ingestion of carbonated drinks or antacids will also cause similar problems with CO_2 production

from the stomach [53], this may also be more likely to cause a problem with the use of capnometry [54].

ii. The tube is in some other part of the respiratory tract: There are a number of case reports where the tip of the endotracheal tube was thought to sit above the glottic opening, but to remain in continuity with expired respiratory gases, so that a capnograph trace has continued to be produced [55, 56]. The capnograph will also fail to diagnose endobronchial intubation. In both of these types of tube misplacement the additional use of a bronchoscope will aid with rapid identification of the position of the tube.

3. Is the capnograph more reliable than clinical examination in establishing correct endotracheal placement?

It is well established that the clinical diagnosis of oesophageal intubation using breath sounds and chest movement and 'feel' of the breathing circuit may be unreliable in anaesthetic practice [57], and reliance only on clinical findings was one of the reasons for a higher anaesthetic associated mortality in the 1970s and 1980s. Grmec has shown in two observational studies that capnography was superior to auscultation in emergency intubation [58] [59] with a sensitivity and specificity of 100%. In comparison, auscultation had a sensitivity of 100%, 94% and 94% and specificity of 80%, 84% and 66% in different series. In a blinded, randomised controlled trial where patients were intubated with endotracheal and oesophageal tubes, medical staff were accurate in all cases in identifying tube position using capnography but inexperienced examiners were inaccurate when using auscultation in 68% of cases [60]. We would conclude that capnography is therefore superior to clinical signs in the identification of endotracheal tube placement.

4. Does the introduction of capnography decrease the rate of undetected oesophageal intubation?

We were unable to find studies addressing this question in ICU. There is a significant literature about the use of capnography in out of hospital and emergency medicine. We identified one paper published in this literature [61], where the introduction of capnography across an urban area resulted in no undetected oesophageal intubations in 93 patients who were monitored with capnography while there were 13 cases of unrecognised oesophageal intubation in 60 patients were capnography was not used.
Lack of additional evidence to support a reduction of undiagnosed oesophageal intubation in critical care with the use of a capnography is predictable, given the rarity of the event, and obvious ethical problems, which make randomised controlled trials of the benefit of capnography impossible. A similar situation would have existed in anaesthesia before the widespread adoption of capnography into anaesthetic practice, it is of note that the rate of anaesthetic airway associated deaths has decreased significantly since the widespread adoption of capnography as a standard of care [7] [8], although a direct cause and effect is, again, not be possible to identify.

Grading the strength of Recommendations

The grading of the strength with which recommendations are made has been subject to detailed review. The development of the GRADE system to categorise the strength of evidence with which an intervention can be recommended is now commonly used [62] [63] [64] [65]. This system uses 3 levels of recommendation:

Strong recommendation: Most people in this situation would want this recommendation and only a small proportion would not.

Weak recommendation: Most people in this situation would want this intervention but many would not.

No specific recommendation: The advantages and disadvantages are equivalent.

The grade of recommendation is based on:

1. The quality of evidence which is defined as;

 a) High quality,

 b) Moderate quality

 c) Low quality

 d) Very low quality.

2. The balance between the advantages and disadvantages of the recommendation. For capnography the advantages would include a reduction in the number of deaths associated with airway incidents whereas the disadvantages would include the potential for incorrect use of the equipment causing patient harm.

3. How patients would view the advantages and disadvantages of an intervention and balance the benefits and side-effects in reaching a preference.

4. The economic and other costs of the intervention.

We have graded our recommendations using this system. The following statements can be made:

1. Airway incidents occur in critical care and they cause harm to patients. The level of harm is not quantifiable, but significant harm is rare enough to mean that strategies to reduce this harm cannot be evaluated by randomised controlled trials.

 Evidence: Many large case series and observational studies of high quality.

 *Quality of evidence: **high**.*

2. Capnography is more accurate than other clinical methods in establishing the correct placement of endotracheal tubes but it is still not 100% specific and sensitive in establishing the diagnosis of correct or incorrect tube placement.

 Evidence: Randomised and blinded clinical trials and many large case series and observational studies of high quality.

 *Quality of evidence: **high***

3. Capnography accuracy can be increased by staff being familiar with the equipment and by the additional use of bronchoscopy in selected cases.

 Evidence: General observation that staff familiarity with equipment is likely to reduce errors in using equipment.

 *Quality of evidence: **Moderate***

4. Tube placement may be more difficult to confirm in the critically ill than in patients undergoing routine anaesthesia, therefore capnography should be more useful in the diagnosis of correct tube placement during intensive care than during anaesthetic practice, particularly as intensive care staff without specific anaesthetic training may be asked to make difficult judgements about the position of endotracheal tubes.

 Evidence: Many large case series and observational studies of high quality.

 *Quality of evidence: **High***

5. The use of capnography in critical care reduces the burden of harm associated with airway incidents.

 Evidence: Indirect evidence quoted above, small scale observational studies in emergency medicine. Lack of additional evidence is unlikely to ever be available due to methodological problems reviewed in the previous section.

 *Quality of evidence: **Low***

Recommendations

1. Capnography should be used for all critically ill patients during the procedures of tracheostomy or endotracheal intubation when performed in the intensive care unit.

Grade of recommendation: **Strong**

Based on:

A moderate level of evidence.

Advantages and disadvantages: Capnography reduces the risk of death and major disability as a result of airway misadventure. Capnography clearly does not remove the risk and, if incorrectly used, may contribute to the risk. The risk is relatively small for each patient but the negative outcomes would be catastrophic for the patient and relatives. For staff, there are additional major advantages in reducing the potential for a major complication associated with an intervention rather than an underlying disease process.
Values and preferences: The lack of other major or minor side effects of the intervention makes it likely that patients would express a strong preference for the intervention.
Economic evaluation: There has been no economic evaluation of the introduction of capnography.

2. Capnography should be used in all critically ill patients during mechanical ventilation in the ICU.

Grade of recommendation: We are unable to make a recommendation.

Based on:

We have not made a recommendation due to the lack of direct evidence that continuous capnography reduced the chances of catastrophic harm occurring due to an airway misadventure during routine mechanical ventilation. This clearly indicates an area for further study.

3. Capnography should be used in all critically ill patients who require mechanical ventilation during inter-hospital or intra-hospital transfer.

Grade of recommendation: **Strong**

Based on:

The level of recommendation has been upgraded to strong based on the increased chances of airway misadventure during transfer and the difficulties associated with the diagnosis of tube misplacement in difficult clinical environments.

Additional Uses of Capnography in Critical Care

The following recommendations concerning additional uses of capnography are based on strong evidence; however the nature of the recommendations does not make them suitable for the other aspects of the GRADE classification.

1. Use of the Capnograph waveform.

The Capnograph waveform is frequently abnormal in patients with bronchospasm and other conditions causing heterogeneous V/Q ratios and time constants. The review of the capnograph waveform may help in diagnosis and establishing response to treatment in patients with bronchospasm and other conditions [66, 67].

2. Use of the End Tidal - Arterial CO_2 Difference (ET Art CO_2 diff).

The physiological principles of the End Tidal - Arterial CO_2 Difference are very well described [68]. This difference can be used to calculate physiological dead space if the total CO_2 production is known. This requires integration of expired CO_2 concentration with the expiratory flow rate (known as Volume Capnography). There are many papers describing the use of this technology in monitoring patients with adult respiratory distress syndrome [69] [70], monitoring response to PEEP [71] and the diagnosis of pulmonary embolus [72] [73] as well as monitoring response to treatment in pulmonary embolus [74]. The topic of additional uses for capnography in the monitoring of CO_2 kinetics has been well reviewed [75].

3. The Use of Capnography as a substitute for estimation of arterial PCO_2.

End Tidal CO_2 ($_{ET}CO_2$) is determined by arterial CO_2, but also by many other factors, including physiological dead space, these other factors may alter independently of arterial CO_2. There are many publications showing that, for this reason, $_{ET}CO_2$ cannot be used as a substitute for arterial PCO_2 measurement [76, 77]. Continuous monitoring of $_{ET}CO_2$, with the measurement of arterial CO_2 when the $_{ET}CO_2$ changes significantly and at additional planned intervals, would seem most likely to offer tight control of arterial CO_2 until newer technologies become available.

4. The use of Capnography in patients with raised intracranial pressure.

Intracranial pressure may be exquisitely sensitive to changes in arterial CO_2 and the Brain Trauma Foundation guidelines now recommend the avoidance of hypocarbia in patients with brain injury [78]. AAGBI guidelines for the transfer of patients with head injury have also recommended the use of capnography during patient transfer [10].
The use of $_{ET}CO_2$ without arterial CO_2 monitoring will clearly produce poor arterial CO_2 control and would not be acceptable in the management of raised intracranial pressure. Alteration in $_{ET}CO_2$ should however, give an early warning of changing CO_2 levels before the routine estimation of arterial CO_2 and falling $_{ET}CO_2$ should also trigger estimation of arterial CO_2 levels. The use of $_{ET}CO_2$ in conjunction with arterial CO_2 measurement should therefore produce better control of arterial CO_2 than would be expected with the use of arterial measures alone. Clearly any delay in the identification of an airway incident in a patient with brain injury would be catastrophic.

The common association of head injury with neck and facial injury may also make airway incidents more common and difficult to recognise in patients after head injury, although we were unable to find studies that had reviewed this problem.

We were also unable to find articles associating the use of Capnography with outcome after head injury, or indeed with an improvement or lack of improvement in CO_2 control. This lack of evidence should be expected as there is little published evidence that even confirms any benefit to the routine measurement of intracranial pressure (ICP) monitoring after head injury [79]. Even without this evidence of benefit for ICP measurement, units that have introduced protocols of care of patients with head injuries involving the measurement of ICP have seen dramatic improvements to outcome [80]

5. Capnography after placement of nasogastric tubes

A capnograph trace can be obtained from a nasogastric (NG) tube placed inadvertently in the bronchial tree. This confirmation may be useful in the following circumstances:-

a. If a nasogastric tube is thought to have been misplaced in the bronchial tree, then obtaining a respiratory waveform would allow the nasogastric tube to be removed without having to use a chest x-ray to confirm this incorrect placement [81].

b. When advanced to the distal respiratory tree a nasogastric tube can transverse lung tissue and enter the plural space so causing a pneumothorax [82] [83]. NPSA guidance on Nasogastric tube placement [84] does nothing to prevent this possibility. Unfortunately this complication can occur in patients after lung transplantation or in other situations where a pneumothorax would be particularly undesirable. If a capnograph trace is obtained when the nasogastric tube has been advanced to about 25cm in an adult, then intrabronchial placement can be confirmed before the possibility of a pneumothorax would arise [85].

Capnography may therefore serve as an additional screening tool to confirm endobronchial nasogastric tube placement so reducing the requirement for chest radiology. It also reduces the chances of pneumothorax associated with nasogastric tube misplacement.

6. Capnography to assist bronchoscopy during percutaneous tracheostomy.

Percutaneous tracheostomy may rarely result in significant patient harm and death. One reason for this is that the cannula and needle initially used to cannulate the trachea may be misplaced outside the trachea. This can happen if the needle and cannula transect the trachea either entering anteriorly and leaving posteriorly or by cannulation of the trachea with the needle entering and leaving to one side of the midline. A capnograph trace can be used to confirm the cannula sits within the trachea by connecting the sampling port of a side- stream capnograph to the leur lock connection of the cannula and then observing the CO_2 waveform [86]. This has the advantage of avoiding potential damage to a bronchoscope by the cannulating needle and reducing the time that the endotracheal tube is partially obstructed by a broncho-

the endotracheal tube is partially obstructed by a broncho-scope.

The one study [86] that we were able to identify describing this technique was not powered to demonstrate the safety of the technique and there are many reasons why the cannula and puncture site should be viewed directly during percutaneous tracheostomy.

We would strongly recommend that capnography be used during all percutaneous tracheostomy procedures. If the sample line is attached to the cannulating needle to confirm tracheal cannulation this should protect the bronchoscope from needle damage. However, if this technique is used the cannula placement and presence of the guide-wire in the trachea must be then confirmed using direct visual inspection.

7. Use of the capnograph during the apnoea test to confirm brainstem death.

The Capnograph waveform can be used to detect signs of respiratory effort during the apnoea test to confirm brain stem death [87]. Systems that record the waveform can allow the flat waveform to be kept as part of the record of the test. The arterial - $_{ET}CO_2$ gradient may increase during the test so arterial PCO_2 must be estimated directly before and after the test.

8. Capnography as a guide to metabolic rate.

The most extreme derangements of increased metabolic rate should be open to diagnosis using time capnography, the classic example being malignant hyperpyrexia where a rising end tidal CO_2 concentration, with a constant or increasing minute volume is a vital early warning sign of the onset of the condition [88].

The integration of flow and expired CO_2 concentration allows calculation of total CO_2 production; this currently requires the use of a volume capnograph. This non-invasive technology has the potential to help in the diagnosis of infection, other systemic injury responses and other hypermetabolic states including thyro-toxicosis and phaeochromocytoma. It is unable to calculate true metabolic rate without a measure of oxygen consumption, as the respiratory quotation will vary between patients.

It is surprising that ventilators have not been designed with internal methods of estimating total CO_2 production by measuring CO_2 in the effluent gases from the expiratory circuit. This would remove the need for an extremely accurate pneumotachograph required for use in volume capnometry.

9. Capnography during spontaneous respiration.

The capnograph has been described as a respiratory monitor during monitored sedation during surgical procedures [89], [90] and in the assessment of sleep apnoea [91]. It may have a similar role in critical illness. Many critically ill patients are dependent on CPAP and this may be delivered using systems with little monitoring or alarms capable of detecting disconnection. In this situation capnography may have an important alarm function even if the high fresh gas flows mean that $_{ET}CO_2$ concentration will have little physiological significance.

Methods for Capnography

1. Side-stream and Mainstream Capnography

Capnography normally relies on the use of infra-red light that is shone through the gas sample. The vibrating molecules of CO_2 absorb specific wave lengths of infra-red light, the absorption being proportional to partial pressure of CO_2 in the gas sample.

During main stream capnography the light is shone through the gas in the patient circuit around the connection to the catheter mount. A transmitter and absorber are required within the patient circuit and a cuvette is also required.

In side-stream capnography a sample is drawn away from the main gas flow using a separate sample line to a unit that is normally housed in the main patient monitor.

The advantages and disadvantages of the two systems are set out below in Table B:

Table B: Advantages and disadvantages of mainstream and side-stream capnographs:

Mainstream capnography

Advantages:

1. Faster response time, intrinsically more accurate.

2. Will work during active humidification.

Disadvantages:

1. Does not allow analyses of anaesthetic vapours.

2. Uses an expensive probe which can be lost or broken and also requires a disposable or reusable curvette. This makes the device intrinsically more likely to be expensive.

3. Often requires calibration prior to use, this may be a cause of an absent capnography trace [49].

4. Additional weight on the ventilator circuit may increase the chance of disconnection; this may also be increased due to additional connections in the circuit (these may not be required for side stream capnographs if the sample line is connected to a Leur lock fitting on the HME filter).

5. Theoretical risks of earth connection near to the patient and risk of electrical injury.

Side-stream Capnography

Advantages:

1. Cheaper and more robust than mainstream capnography.

2. Will also measure anaesthetic gases. Although not normally an advantage in Intensive Care, this will be an advantage during anaesthesia, so increasing the demand for devices and reducing the cost.

3. Calibration can be carried out by the machine using room air and so does not require any input from staff.

Disadvantages:

1. May not work with active humidification due to rain out in connecting tubing.

2. Slower response time and intrinsically less accurate, the waveform may be prone to damping [92]. This effect will increase with the use of a heat and moisture exchanger proximally in the circuit [93].

3. Multiple sites for disconnection away from the circuit, which may increase the chances of an absent capnography trace being misinterpreted as an oesophageal intubation.

4. Use of Leurlock connections may allow incorrect connection to other devices or the connection of infusions into the airway. [94].

For many Intensive Care Units the cost of inline capnography may exclude its use except where active humidification is used, active humidification makes side-stream capnography much less effective due the effective of "rain out" in the sample line which would then obstruct the flow of gas through the sample line.

Although outside the scope of this review, we searched for meta-analyses and systematic reviews comparing active humidification with use of HME filters (Methods in appendix 1). A definitive Cochrane review is underway, but not yet available. Two meta-analyses show no benefit for either method of humidification [34] [95]; these reviews did not consider the effects of humidification on capnography. The additional costs of mainstream capnography would be considered as part of the cost benefit analysis of active or passive humidification.

2. Capnometry.

There are a number of disposable capnometers that use dye indicators. CO_2 will dissociate in solution and the acidity of dissolved CO_2 will change the colour of the indicator within the capnometer. The indicator produces a semi-quantative indication of CO_2 concentration. This technique has the following disadvantages; a) There is no display of the CO_2 waveform and b). It may be inaccurate at low CO_2 values, which may be found during cardiac arrest [44]. This means that the technique is not as intrinsically accurate for confirming tube placement, particularly in low cardiac output states, although the presence of a pulse greatly increases the accuracy of the device [44].

The major advantages of the technique are that it is simple to use and requires no complex equipment so that it may be particularly suitable after the patient has been transferred from ICU, or prior to admission, for example in the assessment for problems with long term tracheostomy tubes in ward areas. The simplicity of the device may also remove the potential for errors in setting up capnography equipment that could otherwise cause errors in the diagnosis of correct tracheal tube placement.

3. Factors to consider in the choice of capnographs:

Capnographs are respiratory gas monitors and should conform to international standards for this type of monitor. For the purchase of capnographs which are intrinsic to ICU monitoring systems, these factors include the clarity of the display, simplicity of setup, alarm functions, display and storage of data, accuracy of response time and the cost of any disposables required. For portable capnographs the strength of the product and its battery life will also be important.

What are the potential disadvantages of using Capnography?

1. Opportunity costs

Funds and training to develop capnography will divert activity from other areas of patient care. The estimated costs of introducing capnography across a healthcare system may be considerable [100]. We have not conducted a formal economic evaluation of the costs of introducing capnography into critical care; the costs would be highly dependant on the methods of airway humidification employed. We reviewed costs in a 17 bedded mixed general and neurosciences ICU with established capnography where a mixture of active and passive humidification is used. For 5788 patient days £9,500 were spent on disposables or replacement equipment for capnography during the financial year 2008/2009, most being spent on broken or lost cables. Future costs would also be dependant on the level of adoption of the technology, greater use reducing unit price; this means that an economic evaluation using current costs could significantly over estimate the true costs.

2. Incorrect use of equipment

Misinterpretation of the relationship between $_{ET}CO_2$ and arterial CO_2 could potentially leave patients hypercarbic [76-77]. Misassembly of equipment could result in the misdiagnosis of an endotracheal tube placement as an oesophageal tube placement [47-49].

3. Some small additional risks could be introduced.

The weight of an inline capnograph and the additional connections added to the circuit could increase the risk of circuit disconnection while the electrical equipment could present a risk of burn or electrical injury. The Leur-lock connections used in side-stream capnography present a risk of misconnection [94].

4. Other false positive and negative results

As set out in previous sections of this document; these are probably much less common in intensive care than in emergency medicine as emergency medicine patients are much more likely to be in cardiac arrest at the time of intubation.

Although the wide spread introduction of capnography into anaesthesia was associated with a reduction in airway associated mortality we cannot be sure this would be repeated in intensive care due to the differences in staff training and patient mix. Any potential risks associated with the introduction of capnography should be monitored using local incident reporting systems and by developing a national reporting system for patient safety incidents for critical care. This national system would establish how commonly airway incidents occur in UK critical care practice and how their frequency would be influenced by the adoption of routine capnography in critical care.

Acknowledgements:

Appendix 1: Search strategies

Journal list used to limit search:

Acta Anaesthesiologica Scandinavica; American Journal of Respiratory & Critical Care Medicine; Anaesthesia; Anaesthesia & Intensive Care; Anesthesia & Analgesia, Anesthesiology; British Journal of Anaesthesia; British Medical Journal; Canadian Journal of Anaesthesia; Chest; Critical Care (London); Critical Care Medicine; Intensive Care Medicine; JAMA; Journal of Critical Care; New England Journal of Medicine.

Key words (Mesh terms or words in title or abstract):

Capnography terms:

Capnography.mp. or exp Capnography/ Capnometry.mp. Capnograph.mp. (used without limit to journal title but limited to humans)

Adverse/critical incident terms:

Complication.mp. or morbidity.mp. or exp Morbidity/ or adverse event.mp. or risk Management/ or critical incident.mp.or event.m_titl. events.m_titl. incident.m_titl.

or incidents.m_titl. Risk Management/ or critical incident.mp. quality.mp. or Quality Assurance, Health Care/ Equipment Safety/ or Safety Management/ or Risk Management/ or Medical Errors/ or Accident Prevention/ or patient safety.mp. or Safety/ complication.

Airway terms:

tracheostomy.mp. or exp Tracheostomy/ intubation.mp. or *Intubation/ or exp Intubation, Intratracheal/ extubation.mp. airway.mp. mechanical ventilation.mp

endotracheal.mp. endotracheal.m exp Respiration, Airway Obstruction/ or artifical airway.mp exp Intubation, Intratracheal/ or endotracheal tube.mp.

(Artificial/ Limited to journal list).

For primary anaesthetic journals limited to those associated with critical care- limiting terms to intensive care.mp. or exp Intensive Care Units/ or exp Intensive Care/ or exp Critical Care/.

Humidification terms:

humidification.m_titl. (heat and moisture).mp. [mp=titl, original title, abstract, name of substance word, subject heading word] humidifier.m_titl. And metaanalysis.m_titl or meta-analysis.m_titl.

Head injury terms:

Head injury.mp. or exp Craniocerebral Trauma/ and exp Carbon Dioxide/ or hypocarbia.mp. or Hypercapnia/ or hypercarbia.mp. and

Randomized Controlled Trials as Topic/ or randomised controlled trial.mp.

Additional searches:

Papers that were identified as being relevant were then added to the Science Citation Index to identify papers that citied or referenced the original paper and if these papers were relevant then these were also included in the review.

Evidence based reviews, Meta-analysis or guidelines:

The Cochrane review was searched to identify relevant controlled trails and guidelines and other meta-analysis previously recognised by the reviewers were also included.

Appendix 2: Evidence Tables

Table 1: Papers reviewing series of critical incidents reported form intensive care units. Papers reviewed to identify airway associated incidents and associated harm.

Page one	Reference number	First author	Year published	Country of origin	Single Hospital or Multicentre	Total Number of Incidents All types	Number of Airway Incidents (%total)	Sample size	Airway Incidents Associated major harm or death (% all incidents)
[T1.1]	[92]	Orgeas	2008	France	Multicentre	3611	275 (7%)[f]	11,006 admissions	No deaths
[T1.2]	[46]	Hubler	2008	Germany	Single	70	17 (21%)	1 ICU 18 months	Not identifiable
[T1.3]	[47]	Sinopoli	2007	USA	Multicentre	1353	95 (7%)	20 ICUs over 2 years	Not identifiable[c]
[T1.4]	[48]	Chacko	2007	India	Single	280	92(33%)	4750 ventilator days	4 deaths
[T1.5]	[T1.]	Schuerer	2006	USA	Single	258	Not identifiable	1 unit 21 months	Not identifiable
[T1.6]	[T1.]	Graf	2006	Germany	Single	50	Not identifiable	217 patients	Not identifiable
[T1.7]	[T1.]	Rothschild	2005	USA	Single	343	Not identifiable	1490 days	Not identifiable
[T1.8]	[T1.]	Nast	2005	USA	Single	157	Not identifiable	4783 days	Not identifiable
[T1.9]	[T1.]	Needham	2004	USA	Multicentre	841	78 (9%)	23 ICUs 1 year	1 death 41 harm
[T1.10]	[T1.]	Osmon	2004	USA	Single	728	Not identifiable	2598 Patient days	6 Life threatening

Table 1 continued

Page 2	Reference number	First author	Year published	Country of origin	Single Hospital or Multicentre	Total Number of Incidents All types	Number of Airway Incidents (%total)	Sample size	Airway Incidents Associated major harm or death (% all incidents)
[T1.11]	[55]	Beckmann	2003	Australia	Single	211	25 (12%)	827 Patient days	Not identifiable
[T1.12]	[56]	Beydon	2001	France	Multicentre	1004	123 (33%)[e]	French ICUs 1 year	5 deaths
[T1.13]	[57]	Bracco	2001	Switzerland	Single	241	47 (20%)[d]	2801 Patient days	Not identifiable
[T1.14]	[58]	Flaatten	1999	Norway	Single	87	Not identifiable	1 ICU 13 months	Not identifiable
[T1.15]	[59]	Buckley	1997	China	Single	281	88 (31%)	3300 admissions	Not identifiable[b]
[T1.16]	[60]	Beckmann	1996	Australia	Multicentre	610	124 (20%)	7 units 10 months	Not identifiable
[T1.17]	[61]	Donchin	1995	Israel	Single	554	Not identifiable	4 months 1 ICU	Not identifiable
[T1.18]	[62]	Hart	1994	Australia	Single	390	Not identifiable	2153 admissions	Not identifiable
[T1.19]	[63]	Giraud	1993	France	Multicentre	316	Not identifiable	400 admissions	2 deaths
[T1.20]	[64]	Wright	1991	UK	Single	137	Not identifiable	1 ICU 1 year	Not identifiable
					Totals:	11522 Range per study 50-3611	964 in 8502 incidents Median16% Range: (7-33%)	Not quantifiable	11 deaths in 6780 incidents 94 harmed in 3138 incidents

Table 2: Papers reviewing airway incidents associated with unplanned removal of tubes:

Reference number	First author	Year Published	Country of origin	Single unit or Multi site	Total Number of Tube displacements	Patient intubated days	Displacements Per 1000 Intubated days	Number requiring Re-intubation (% of total extubations)	Number requiring Re-intubation with in one Hour (% of total extubations)	Associated major harm or death (% all extubations)
PAGE ONE Table 2										
[T2.1]	Curry	2008	USA	Single site	31	Not identifiable	Not identifiable	15 (49%)	7 (22%)	Not identifiable
[T2.2]	Chang	2008	Taiwan	Single site	126	Not identifiable	Not identifiable	68 (54%)	55 (44%)	Not identifiable
[T2.3]	Mion	2007	USA	Multicentre	181	18308	10/1000	89 (49%)	Not identifiable	6 (3%)
[T2.4]	Bouza	2007	Spain	Single site	34	3710	9/1000	14 (41%)	Not identifiable	0 deaths other harm not described
[T2.5]	Krinsley	2005	USA	Single site	100	Not identifiable	Not identifiable	44 (44%)	Not identifiable	0 deaths
[T2.6]	Moons	2004	Belgium	Multisite	26	3849	7/1000	15 (58%)	Not identifiable	0 deaths 1 aspiration
[T2.7]	Lorente	2004	Spain	Single site	48	6054	6/1000	Not identifiable	Not identifiable	Not identifiable
[T2.8]	Jaber	2003	France	Single site	9	687	13/1000	Not identifiable	Not identifiable	0 deaths other harm not described
[T2.9]	Auraint	2002	France	Multicentre	22	1361	16/1000	Not identifiable	Not identifiable	0 deaths other harm not described
[T2.10]	Kapadia	2001	India	Single site	11	6339	2/1000	Not identifiable	Not identifiable	0 (0%) deaths. 2 (20%) severe

Table 2 continued

Reference number	First author	Year Published	Country of origin	Single unit or Multi site	Total Number of Tube displacements	Patient intubated days	Displacements Per 1000 Intubated days	Number requiring Re-intubation (% of total extubations)	Number requiring Re-intubation with in one hour (% of total extubations)	Associated major harm or death (% all extubations)
PAGE TWO Table 2										
[T2.11]	Epstein	2000	USA	Single site	88	5500	16/1000	42 (56%)	31(%)	0 (0%)
[T2.12]	Carrion	2000	Spain	Single site	102	4680	21/1000	90 (88%)	Not identifiable	Not identifiable
[T2.13]	Frezza	2000	USA	Single site	162	Not identifiable	Not identifiable	42 (30%)	Not identifiable	0 Deaths
[T2.14]	Chevron	1998	France	Single site	66	Not identifiable	Not identifiable	23 (35%)	13 in 15 minutes	1 death / 1 bronchospasm
[T2.15]	Amato	1998	Brazil	Single site	24	Not identifiable	Not identifiable	Not identifiable	Not identifiable	3 deaths
[T2.16]	Boulain	1998	France	Multi centre	56	3312	16/1000	28/46 (61%)	19 in 2 hours	1 death
[T2.17]	Betbese	1998	Spain	Single site	59	Not identifiable	Not identifiable	27 (46%)	Not identifiable	0 (0%)
[T2.18]	Atkins	1997	USA	Single site	50	Not identifiable	Not identifiable	37 (74%)	23(46%)	1 (0.5%) Respiratory arrest
Totals					Total: 1195. Median per study 53 (Range 9-181)	Total days 153800 Median per study: 4265 days (Range 687-18308 days)	Median rate dis-placement Per 1000 days: 12 per 1000 days (Range: 2 to 21 per 1000 days)	Total: 534 in 1081displace-ments Median % replaced:48% (Range: 30% -88%)	Total: 148 in 417 displacements Median% replaced in 1 hour:35% (Range: 20%-46%)	12 deaths in 888 displacements Median per study: 0 (Range: 0 to 6 deaths.)

Table 3: Papers reviewing other post procedure airway incidents (blocked tubes)

Reference number	First author	Year published	Country of origin	Single unit or Multi site	Intubated days	Total Number of Blocked tubes	Per 1000 Intubated days	Cardiac arrest or death (% all blocked tubes)
[T3.1]	Siempos	2007	Greece	Meta-analysis	22712	30	1/1,000	1 death
[T3.2]	Auriant	2002	France	Multicentre	1361	1	1/1,000	0
[T3.3]	Kapadia	2001	India	Single site Check for first study	6339	7	1/1,000	4 cardiac arrests
Totals					30412	38	1/1000	5

Table 4 : Incidents associated with endotracheal intubation:

Ref TABLE 4	Author	Year	Multicentre or Single	Country of Origin	Number of intubations in series	Number of Incidents	Incidents with harm
[T4.1]	Mort	2009	Single	USA	34	16	16
[T4.2]	Griesdale	2008	Single	Canada	136	63	34
[T4.3]	Wang	2008	Multicentre	International	3695	151	Not identifiable
[T4.4]	Schmidt	2008	Single	USA	322	37	13
[T4.5]	Vianello	2007	Single	Italy	46	3	0
[T4.6]	Frat	2007	Multicentre	France	206	19	Not identifiable
[T4.7]	Benedetto	2007	Single	USA	150	28	Not identifiable
[T4.8]	Jaber	2006	Multicentre	France	253	160	79
[T4.9]	Mort	2005	Single	USA	42	23	13
[T4.10]	Mort	2004	Single	USA	2833	1251	700
[T4.11]	Auriant	2001	Multicentre (2)	France	73	34	11
[T4.12]	Le Tacon	2000	Single	France	80	29	8
[T4.13]	Mort	1998	Single	USA	57	61	14
[T4.14]	Schwartz	1995	Single	USA	297	70	21
[T4.15]	Stauffer	1981	Multicentre	USA	226	19	17
				Total:	8,450.00	1,964.00	926.00

Table 4 continued

Table 4 Page 2

Ref	Author	Intubations n	Incidents n	Incidents (%)	Incidents with harm n	Incidents with harm %	Failed n	Failed %	Aspiration n	Aspiration %	Hypoxia n	Hypoxia %	Oesophageal Intubation n	Oesophageal Intubation %	Multiple attempts / difficult n	Multiple attempts / difficult %	Death n	Death %	CVS Compromise n	CVS Compromise %	Cardiac Arrest n	Cardiac Arrest %
[T4.1]	Mort	34	16	(47)	16	47	n/i	n/i	n/i	n/i	16	47	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i
[T4.2]	Griesdale	136	63	(46)	34	25	n/i	n/i	8	6	26	19	10	7	6	4	0	0	13	10	0	0
[T4.3]	Wang	3695	151	(4)	n/i	n/i	151	4	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i
[T4.4]	Schmidt	322	37	(11)	13	4	n/i	n/i	13	4	n/i	n/i	8	2	16	5	n/i	n/i	n/i	n/i	n/i	n/i
[T4.5]	Vianello	46	3	(7)	0	0	3	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[T4.6]	Frat	206	19	(9)	n/l	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i	19	9	n/i	n/i	n/i	n/i	n/i	n/i
[T4.7]	Benedetto	150	28	(19)	n/l	n/i	n/i	n/i	n/i	n/i	n/i	n/i	14	9	14	9	n/i	n/i	n/i	n/i	n/i	n/i
[T4.8]	Jaber	253	160	(63)	79	31	n/i	n/i	7	3	65	3	10	4	8	3	2	1	63	25	5	2
[T4.9]	Mort	42	23	(55)	13	31	0	0	n/r	n/i	13	0	5	12	5	12	n/r	n/i	n/r	n/i	n/r	n/i
[T4.10]	Mort	2833	1251	(44)	70	25	0	0	57	2	594	4	268	9	283	10	n/r	n/i	n/r	n/i	49	2
[T4.11]	Auriant	73	34	(47)	11	15	n/i	n/i	n/i	n/i	11	8	n/i	n/i	9	12	0	0	14	19	n/i	n/i
[T4.12]	Tacon	80	29	(36)	8	10	n/i	n/i	2	3	4	3	3	4	12	15	n/i	n/i	6	8	2	3
[T4.13]	Mort	57	61	(107)	14	25	2	4	0	0	12	0	9	16	14	25	1	2	22	39	1	2
[T4.14]	Schwartz	297	70	(24)	21	7	0	0	12	4	n/i	n/i	25	8	24	8	7	2	n/i	n/i	2	1
[T4.15]	Stauffer	226	19	(8)	17	8	n/i	n/i	17	8	n/i	n/i	2	1	n/i	n/i	n/i	n/i	n/i	n/i	n/i	n/i
	Total:	8450	1964		926		156		116		741		354		410		10		118		59	
	MEDIAN%	36%			20%		2%		3%		21%		7%		9%		0%		14%		2%	
	RANGE	7-107%			0-47%		0-7%		0-8%		0-47%		0-16%		0-25%		0-2%		0-25%		0-3%	
	Number of intuba-	8450			4399		6970		4250		3554		4442		4495		862		645		3702	

Table 5 : Incidents associated with intra hospital transport:

Ref	Author	Year	Centre Country	Number of transfers	Extubation / displacement n (%)	Hypoxia n (%)	Ventilator problem n (%)	Need for intubation n (%)	Cardiac Arrest n (%)
[T5.1]	Papspon	2007	Single centre Australia	339	3 (0.8%)	14 (4.1%)	29 (8.6%)	4 (1.2%)	3 (0.9%)
[T5.2]	Lahner	2007	Single centre Austria	452	1 (0.2%)	n/i	1 (0.2%)	n/i	7 (1.5%)
[T5.3]	Damm	2004	Single centre France	123	0 (0%)	11 (8.9%)	26 (21%)	n/i	2 (1.6%)
[T5.4]	Beckman	2004	Multi centre Australia	176	3 (1.7%)	21 (11.9%)	4 (2.3%)	4 (2.3%)	6 (3.4%)
[T5.5]	Szem	1995	Single centre America	203	0 (0%)	4 (2.0%)	0 (0%)	0 (0%)	3 (1.5%)
[T5.6]	Hurst	1992	Single centre America	100	0 (0%)	2 (2%)	0 (0%)	0 (0%)	0 (0%)
			Totals	1393	7 in 1393	52 in 941	60 in 1393	8 in 818	21 in 1393
			% Range	100%	0.5% Range 0%-1.7%	6% Range 2%-12%	4% Range 0%-21%	1% Range 0%-2%	2% Range 0%-3%

Definitions used in intubation tables:

Incidents

All of the various papers use differing definitions of an incident with some including minor trauma etc. Clearly while these complications may be of importance they are less relevant to the value of capnography. For this reason the incident rate reported here is the sum of the incidents describing hypoxia, multiple attempts or difficult intubation, oesophageal intubation, cardiovascular instability, or death so that the incident rate and may differ from the total incident rate reported in the individual papers.

Incidents with harm

The sum of the number of reported incidents of hypoxia, aspiration, death and cardiac arrest..

Hypoxia

There were a number of different definitions used in the papers cited. A number of papers differentiated between hypoxia and severe hypoxia; where this was the case these two categories have been amalgamated.

Multiple attempts of difficult intubation

Most papers reported the number of patients requiring > 2 laryngoscopies. Other authors have reported either prolonged intubation time, or a composite of time / need for senior help / multiple attempts as being representative of difficulty. These various differing approaches have been amalgamated into one category to represent difficult intubation.

Cardiovascular Instability

Again there was a wide range of definitions in the different papers cited. Only hypotension or bradycardia (however defined in the original work) were included in this category.

Death

Deaths occurring either directly due to airway management or in the immediate post intubation period. Most studies did not explicitly state there were no such deaths.

References

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Table 5

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