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Original Article

Modelling Airway Management using System Reliability Assessment Tools

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ABSTRACT

Airway management can be considered as a complex engineering process which includes a series of sequential or simultaneous actions (e.g., tasks or decisions) using different resources i.e., time, people, equipment and medications. We explored the decision-making and actions during the process of routine airway management. To elicit an understanding of cognitive strategies applied and influences on strategy selection using the Critical Decision Method. The task steps involved in action and decision making during the induction of routine airway process in both routine and complicated cases were identified using hierarchical task analysis. The systematic human error reduction and prediction approach was then used to examine the task steps at the lowest level of hierarchical task analysis in more detail. There were differences in airway practice and preparation between participants. The decisions were primarily made by the lead consultant anaesthetist, with the trainees and Operating Department Practitioners (anaesthetic nurse) supporting these decisions. Much of the team communication used code language, which appeared to be well understood by the team members and did not obviously impede performance in the context of routine airway management. Most of the experienced lead consultant anaesthetists rely on their past experience of "work-as-done" during the airway process. The results from this study illustrated that human factors and non-technical skills are important for airway management and for ensuring safe, high-quality intraoperative care. Further research is needed to determine how these skills work in conjunction and how they impact anaesthetic performance.

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INTRODUCTION

Safe and reliable airway management remains one of the most crucial responsibilities in anaesthesia, critical care and emergency medicine. Despite its importance, the UK National Audit Project 4 (NAP4) [1] reported that the process of airway management is neither 'completely safe' nor 'reliable'. This applied to both routine and non-routine settings. 'Minor

Process errors' were very common, such as failing to intubate first time or failing to use the intended tube. 'Catastrophic failures' as described in NAP4 [1], although rare, can result in serious outcomes e.g., brain damage, death and high cost [2,3].

Various conceptual frameworks can be used to describe airway management. Human factors / ergonomics describes non-technical skills (NTS) such as communication, situation awareness, teamwork, and decision-making that are needed to facilitate safe and effective task performance [1]. In Klemola and colleagues [4] description of uncertainty and unpredictability of anaesthesia; success at tracheal intubation is viewed as related not to uncertainty, but to the skill of the practitioner. An additional factor is the mismatch between the facets of human work [5], airway management in the real-world may not be the same as that taught, or even described by those involved.

Airway management is a complex engineering process which includes a series of actions (e.g., tasks or decisions) that might occur sequentially or simultaneously utilising different resources such as time, people, equipment and medications. Based on clinical experience, and data such as NAP4, we know that there may be some unpredictability and occasional catastrophic failures. Despite the inherent risks, there is a limited number of studies available on actions and decision-making as it relates to airway management in the clinical environment for a long-time engineer have had mechanisms and techniques [6] that enable them to analyse complex processes. These tools may allow systematic analysis of the airway management process if supported by robust, clinically credible data. The aim of this study was to explore the actions and decision-making during the process of airway management in routine care, to develop a model of routine airway management and decision-making using system reliability assessment tools.

METHODS

Study design and setting

This was a single centre qualitative study, using observation methods (video and audio recordings). Ethical approval was given by the London –Surrey Borders Research Ethics Committee (14/LO/1239, 26 January 2016). We sent each participant (anaesthetist and patient) a letter of invitation, an information sheet and consent to sign prior to participation. After participants had given consent, anaesthetists were asked to identify cases where they expected routine, uncomplicated airway management.

Video and audio recording

Video and audio recordings were made from the entry of the patient into the anaesthetic room until the airway was secured. Recordings were started and monitored by technical assistants outside the anaesthetic rooms, such that only clinical personnel were visible to the patient. Camera positions are depicted in Appendix 1. All the anonymised recordings were synchronized into a single file with Multiview, permitting simultaneous viewing of the three feeds (StudioCode Software). There were three periods per recording: 1) patient preparation and application of monitoring, 2) induction of general anaesthesia, and 3) airway management. Analysis of the recordings was an iterative process involving the following steps. A) A trained researcher reviewed all video footage and deconstructed airway management into basic steps. B) Using this basic framework, the original primary anaesthetist reviewed the recording with the researcher. The aim of this review was to describe the actions, and inactions (visible on the recording), the cues to decision making (sometimes visible, but only definable by the anaesthetist), and the thought process involved in decision points (not visible on recordings). C) Categorisation of the types and purpose of verbal communication between the lead anaesthetist, patient and operating department practitioner (ODP). D) Quantitative assessment of durations of airway management events.

The review with the anaesthetists used the Critical Decision Method (CDM) [7,8]. CDM is a type of cognitive task analysis. Researchers use CDM to explain the mental processes used to implement a task, and consists of knowledge derivation, data analysis and knowledge demonstration [7]. Its purpose is to analyse information-processing, decisions and approaches underlying observable behaviour. Task analysis was performed using Hierarchical Task Analysis (HTA) [9]. HTA creates a hierarchy of goals, sub-goals, and operations that (in theory) describe how a task is performed [8]. The top level of the HTA was defined a priori as the maintenance and securing of the airway in the anaesthetised patient. The task analysis covered the period from patient preparation and application of monitoring to the point of confirmation of correct tracheal tube or supraglottic airway devices position. Each goal, task and sub-task was represented by using a flow chart diagram (Figure 1). The Systematic Human Error Reduction and Prediction Approach (SHERPA) [6] was then used to examine the task steps at the lowest level of the HTA in more detail.

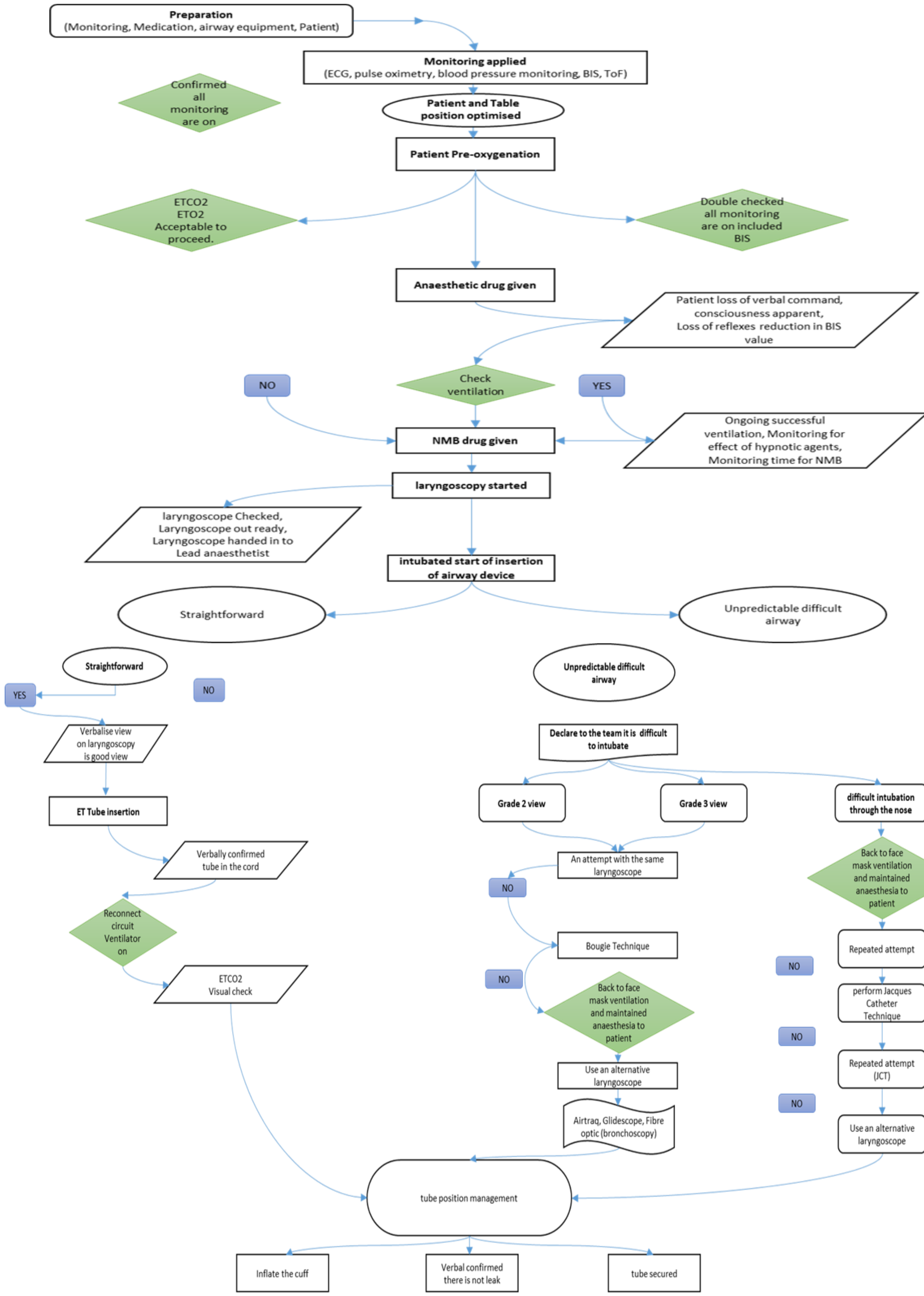

Figure 1. Process of Airway Management

RESULTS

In total twenty observations were completed. We excluded one recording due to technical problems. Three main themes and ten sub-themes were developed (Figure 2).

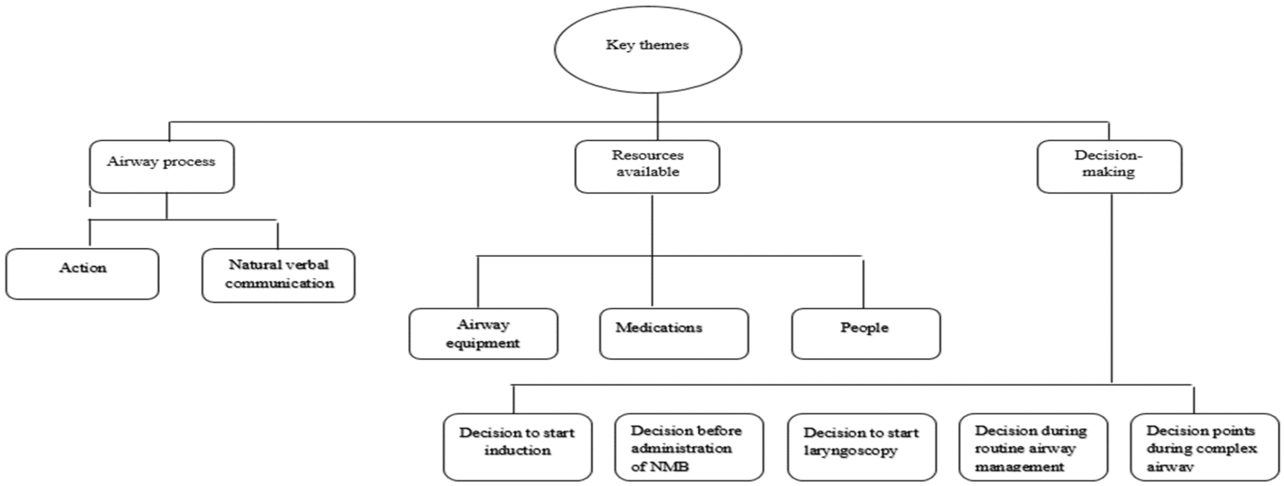

Figure 2: Identified themes

This theme broadly encompasses the order of actions and verbal communication during the process of airway management.

Actions

A) Preparation of patient position and application of monitoring

In all the video recordings, all anaesthetists preferred to have the patient's head close to the top edge of the trolley in the sniffing position. The reasons given were to avoid stretching by the anaesthetist, providing better pharyngeal airway patency and less force for laryngoscopy. There was variation between and within anaesthetists as to the sequencing of positioning and monitoring, partly explained by between-patient differences. There was complete consensus between participants that the order in which physiological monitoring was placed was immaterial, as long as it was connected correctly and working.

B) Patient monitoring

Patient monitoring in all cases included standard Association of Anaesthetists of Great Britain & Ireland (AAGBI) monitoring, and in 50% of cases processed EEG (BIS™), and neuromuscular blockade monitoring (train-of-four (TOF)) were also used. Feedback from the anaesthetists involved suggested that TOF monitoring was more likely to be used prior to intubation with certain neurosurgical pathologies.

C) Administration of induction agent

The choice of induction agent was determined by the clinical condition of the patient. The typical sequence was an opioid followed by propofol as an intravenous bolus or target controlled infusion (TCI). The most striking result to emerge from the data was the different practices of the anaesthetists when giving neuromuscular blocking drugs (NMB). Manual ventilation of the lungs by the anaesthetist following induction was performed in some but not all cases.

D) Intubation process

The intubation process was defined as starting once the anaesthetist managing the airway confirmed the patient was adequately anaesthetised and with adequate muscle relaxation (either through monitoring or clinical assessment, see below) and the assistant (ODP/anaesthetic nurse) handed them the laryngoscope. The process ended when the anaesthetist connected the ventilating circuit, turned the ventilator on and visually checked the capnograph trace. Then the tube was fixed in position.

The summary of duration of these sequences of actions can be found in Table 1. The section should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn. All figures and tables should be cited in the main text as Figure 1, Table 1, etc.

Table 1: Duration of actions order (minutes)

Process	Median (IQR)
Patient preparation and monitoring applied	3:41 minutes (2:02-7:50 m)
Administration of induction agent	1:01minutes (0:54-1:15 m)
Intubation process	1:39 minutes (1:12-2:40 m)
Cases when TIVA and BIS	4:33 minutes (2:13-8:17 m)
Cases without use BIS and TIVA, and uncomplicated cases	2:05 minutes (0:53-4:58 m)

TIVA, Total intravenous anaesthesia; BIS, Bispectral index. i.e. The process of patient preparation and applying physiological monitoring took up the largest proportion of time within the induction period compared with administration of induction agent and intubation process

Verbal communication during airway management
a) Patient communication

During the induction process, the direct conversation between the patients and the anaesthetist were predominantly task-related or reassurance. Other members of the team used these as cues for action.Task communication was mainly about patient preparation, positioning and explaining the medications given and their effect (Table 2). Early task communication frequently acted as prompts to the anaesthetic assistant that the process was about to start and the situation under control. Anaesthetists typically either provided direct reassurance or used distracting conversation (for instance talking about jobs or family) (Table 2), which was a useful indicator of loss of verbal communication and often acted as a trigger for administration of NMB.

Table 2. Indicative quotes concerning communication between the anaesthetist and the patient during airway process

Process	Task communication	Reassurance communication
Preparation/positioning	• What I need to do, laying you flatter and then double your pillow, to put you in better position. • We need to put in a cannula. • I will put extra monitoring across your chest. • We use brain monitoring as well to show us how sleep you are. • Give you fresh air to breath and then get you off to sleep.	• What I need to do, laying you flatter and then double your pillow, to put you in better position. • We use brain monitoring as well to show us how sleep you are.
Before induction	• I will get you off to sleep. • Here's some oxygen for you coming through this mask. • Keep your eyes open as much as you can please.	• Alright. • All is fine. • Well done you're doing really well. • Very good. • Going off to sleep.
NMBA	• This medicine will feel sore. • This is a strong painkiller. • Open your eyes for me? • Take deep breath for me. • A big breath in and out, please. • Can you take deep breath for me?	• How you doing dear? • You doing grand? • Doing well. • Are you warm enough? • That is great well done you're doing well. • You're doing great.
Laryngoscopy	No communication observed	No communication observed

NMBA, Neuromuscular blocking agent

Task communication was the most commonly observed mode of communication used by all participants, following by reassurance and communications addressing both needs (Figure 3).

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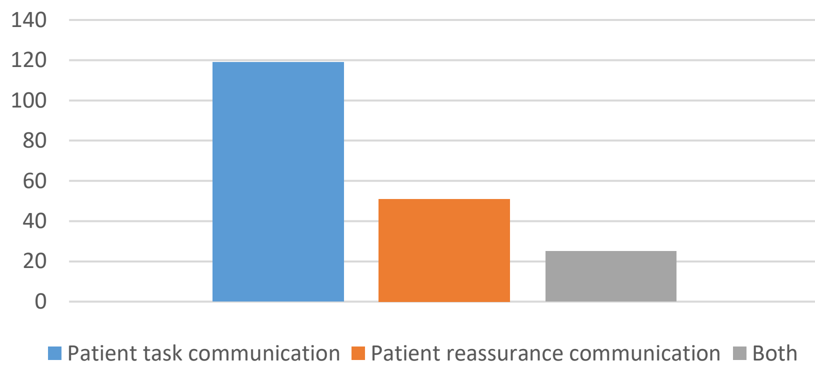

Figure 3. Frequency of communication to team via patient during the airway process

Four types of task communication between the team were found during the process of airway management. These included Closed-Specific (closed-loop communication), Open-Specific (non-specific language dependent on the context), Closed-General (double-checking) and Open-General (unclear language) (Table 3, Table 4).

Table 3. Communication between team during the airway process

Process	Closed-Specific	Open-Specific	Open-General	Closed-General
Before induction	• Is there a bougie? • Do we have Airtraq? • Do we have video laryngoscope? • Do we have a different size of LMA?		• Great, • Excellent, • Very good, • Ready? • Happy? • Ok.	• Let's go.
NMB	• Double checking *(i.e. Do we have orange Guedel*?)	• Well controlled. • Everything is fine. (*i.e. able to ventilate, ongoing successful mask ventilation, patient adequately a sleep, patient adequately paralysed*)	• Well done • All is fine. • Very good. • Ok that's better.	• You happy? • You ready? • You, Ok? • You alright?
Laryngoscopy	• Do we have a different size of LMA? • Is there a bougie? • Do we have Airtraq? • Do we have video laryngoscope?	• Nice view, • Grade 2 view, • Grade 3 view, • Difficult view, • Stiff neck, • View ok, • Good view	• Good, • That's good, • That's perfect, • Everything is fine, • Beautiful, • It is not easy, • Cool, • I am happy • I am alright • It is in cool • Well it is ok, • Looks good • Sounds good (*i.e. Verbal confirmed there is not leak, Visual check* $ETCO_2$).	• You happy? • You ready? • You, Ok?

LMA, Laryngeal mask airway.

Table 4: Response by anaesthetic assistant during the process of airway management

Anaesthetists	ODPs
• **Are you happy?**	• Yes, I am happy
• **You ready?**	• Yes, I am ready
• **You Ok?**	• Yeah, I am ok
• **You alright?**	• Yes
• **Do we have different sizes of LMA?**	• Yes, we have, all ready
• **Is there a bougie?**	• There is
• **Do we have Airtraq?**	• We got it
• **Do we have video laryngoscope?**	• It is here

LMA, Laryngeal mask airway.

The most frequently observed communication type between the anaesthetic team was open-general conversation, followed by open-specific, closed-general and closed-specific (Figure 4).

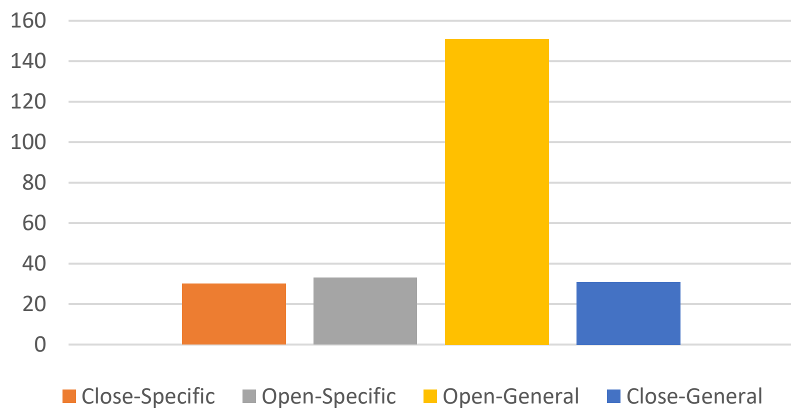

Figure 4: Type and frequency of communication between team during airway process

b) *Team communication*
Once the patient was anaesthetised, communication between the team was predominantly teaching and task communication, such as around airway device operation and drug effects.

Resources
a) Airway equipment
There was variation between the anaesthetists regarding airway equipment checking and equipment preparation. On reviewing the video observations, it became clear there was a discrepancy between what the individuals perceived they checked routinely and what actually happened. Participants were surprised that on some occasions they did not carry out the checks. They had presumed, when they asked the anaesthetic assistant about readiness for all airway equipment, this meant everything they would need was available and ready.

b) Medications
Medication preparation and administration of drugs was not specifically examined as a focus of this study.

c) *People*
In every case there was an additional trainee anaesthetist and anaesthetic assistant who performed a variety of tasks e.g., double-checking medications and airway equipment.
Patient positioning and airway equipment preparation of the observations are summarized in Appendix 2.

Decision-making

Decision-making was based on cues received from different parts of the anaesthetic environment, such as teamwork, monitoring, and patients.

a) Decision to start induction

There were six distinct cues identified in the period of time between making the decision to intubate and proceeding to administration of induction agents. The majority of cues were comparable across all lead anaesthetists except for two (checking of drugs and pre-oxygenation). All of the six cues influenced the anaesthetist's decision on when to commence administration of induction agent **(Appendix 3**).

b) ***Decision before administration of NMB***

A variety of observational and technical cues were used by lead anaesthetists to make the decision to give NMB either through monitoring and/or clinical assessment (Appendix 3).

Checking facemask ventilation before or after the NMB drug is given was a controversial topic among participants in the current study. Four out of six of the anaesthetists gave NMBs before checking whether the patient could be ventilated. The interview data showed that some of the anaesthetists were surprised with their working practice (i.e., they thought they had not checked the ventilation before giving NMB although they actually had).

c) Decision to start laryngoscopy

All interviewed anaesthetists reported that time was the major cue for the decision to start laryngoscopy. However, the observations showed that the real-world meaning of 'time' was not consistent.

d) Decisions during routine airway management

The most significant decisions during routine airway management were found to be analogous for all lead anaesthetists and their supporting teams. Decisions were based on cues observed during visualisation during laryngoscopy, tracheal confirmation and cuff management. Decision-making during routine intubation was found to be similar among all anaesthetists. The teamwork was based on verbal communication, body language cues and observation of patient physiological monitoring demonstrating situational awareness.

e) Decision points during complex airway management

In situations where difficult intubation was observed, the participants appeared to follow recommended guidelines. In addition, it was noted that there was effective teamwork and communication among the operating theatre team to achieve successful intubation. Furthermore, rapid plan changes were common in this scenario. Decision-making used during the airway process are included in Appendix 3

DISCUSSION

The purpose of this study was to describe systematically the process of airway management in routine airway management. Our study revealed distinct variations in the process. Some of these were relatively minor such as how patient monitoring was attached. Others, such as checking of airway equipment, may represent latent errors. Patient preparation took a significant proportion of the induction period, and this was more pronounced when TIVA and BIS were used.

Effective team communication was observed during the process of airway management, and the teams used check-back techniques and abbreviated communication. Most decisions were made by the lead consultant anaesthetist. Trainees and anaesthetic assistants engaged in specific behaviours in support of these decisions, but they were not primary decision makers. Instead, they contributed to the lead anaesthetists' decisions through situation monitoring.

Some decisions were based on novel approaches (e.g., fiberoptic bronchoscope or Airtraq™ optical laryngoscope), however all situations had been previously experienced by the lead consultant anaesthetists and their supporting team, thereby allowing for effective collaborative behaviour. In some cases, decisions could only be reached after considerable negotiation, and through different forms of support.

Human factors play a role in the interaction between individuals and their workplace settings. The data suggest that it is important for the anaesthetists and their supporting team to understand the real-time process of their work, instead of focusing on how they imagine the processes will occur.

NAP4 [1] highlighted the importance of human factors and training in achieving success in complex airway management. These results are consistent with the findings of other studies that have found that the complexity of patient care in an anaesthetic environment calls for anaesthetists to possess a range of skills and attributes such as communication, situation awareness, decision-making, and teamwork [10], which are collectively referred to as non-technical skills (NTS) [11] under the umbrella of human factors [10]. In this regard, an understanding of non-technical skills is necessary for safe and effective performance in the operating theatre environment during both routine and difficult airway management.

The literature on patient safety has broadly acknowledged the importance of teamwork for providing safe patient care [12]. We suggest that supporting team members play a crucial role in the process of airway management, particularly familiarity with the cues used by various team members.

Cues were rule-based and context-specific. In other words, cues were based on past successful experiences. Schnittker and colleagues [13] suggested cues provided by anaesthetic assistants or trainees are important for making key decisions during the airway management process. Furthermore, Klein and colleagues [14] argued cue analysis is important to produce actions, assess situations, and help make decisions in complex work environments.

In addition to cues, verbal communication is a hallmark of well-functioning teams and increases the speed and efficacy of task completion and is associated with better healthcare outcomes [15]. These results match those observed in an earlier study [16]. Task communication was also used by teams in the study. It can be conceptualized as “short-cuts” that communicate a lot of information but require members of the team to have a thorough understanding of each other and of the process. Closed-loop communication was used during routine and difficult procedures to confirm and certify information exchange [17]. These results corroborate the ideas of Smith et al, who suggested that experienced anaesthetists bring out these skills during teaching and training programmes [16].

Importantly, there appears to be no clear ‘standard’ practice for patient and airway equipment preparation and handling, despite this being a fundamental component of safe airway practice [18, 19].

There was a discrepancy between what the anaesthetists perceived they checked routinely and what actually happened. This represents a mismatch between work-as-done and work-as-disclosed [5], and highlights an area for further education. Conversely, anaesthetic assistants always checked the availability of absolute resources needed (i.e., syringe to inflate cuff of airway device and tape/tie to secure airway device), which represented work-as-prescribed[5].

Our participants agreed that one of the main methods of assessing NMB was time (watching the clock) but our observations showed this is not happening in practice. This represents a discrepancy between ‘work-as-imagined’ and ‘work-as-done’ [5]. Other important assessment methods were clinical judgment and the use of devices such as train-of-four and depth of anaesthesia monitors. These discrepancies further highlight the need for more studies on actions and decision-making processes, and how to improve these.

CONCLUSION

This was a single-centre study and the participants were all aware of the recordings, which may limit its internal and external validity. However, all of the participants reported that their practice was consistent with their normal practice; review by the investigators (who have worked in numerous hospitals in the UK and Australia) confirmed that airway management was consistent with practice elsewhere. Even with detailed review of the video and audio feed it is not possible to re-imagine the internal thoughts and decision making of the individuals involved.

There were differences in airway practice and preparation between participants. The decisions were primarily made by the lead consultant anaesthetist, with the trainees and ODPs supporting these decisions. Much of the team communication used coded language, but the teams worked well together and this did not appear to cause any problems in the context of routine airway management. Most of the experienced lead consultant anaesthetists rely on their past experience of "work-as-done" during the airway process. These results may be useful to educators in airway management, and to those seeking to improve the reliability and safety of airway management in routine and non-routine settings.

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Conflicts of interest. None.

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نمذجة إدارة مجرى الهواء باستخدام أدوات تقييم موثوقية النظام

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المستخلص
يمكن اعتبار إدارة مجرى الهواء عملية هندسية معقدة تتضمن سلسلة من الإجراءات المتسلسلة أو المتزامنة (مثل المهام أو القرارات) باستخدام موارد مختلفة، أي الوقت والأشخاص والمعدات والأدوية. استكشفنا عملية اتخاذ القرار والإجراءات أثناء عملية إدارة مجرى الهواء الروتينية. لاستنباط فهم للإستراتيجيات المعرفية المطبقة وتأثيراتها على اختيار الإستراتيجية باستخدام طريقة القرار الحاسم. تم تحديد خطوات المهمة المشاركة في العمل واتخاذ القرار أثناء إدخال عملية مجرى الهواء الروتينية في كل من الحالات الروتينية والمعقدة باستخدام تحليل المهام الهرمي. ثم تم استخدام نهج تقليل الأخطاء البشرية والتنبؤ بها بشكل منهجي لفحص خطوات المهمة على أدنى مستوى من تحليل المهام الهرمي بمزيد من التفصيل. كانت هناك اختلافات في ممارسة مجرى الهواء والتحضير بين المشاركين. تم اتخاذ القرارات في المقام الأول من قبل استشاري التخدير الرئيسي، مع دعم المتدربين وممارسي قسم العمليات (ممرضة التخدير) لهذه القرارات. وقد استخدم الفريق في كثير من اتصالاته لغة مشفرة، والتي بدا أن أعضاء الفريق يفهمونها جيدًا ولم تعيق الأداء بشكل واضح في سياق إدارة مجرى الهواء الروتيني. ويعتمد معظم استشاريي التخدير ذوي الخبرة على خبرتهم السابقة في "العمل كما تم" أثناء عملية مجرى الهواء. وقد أوضحت نتائج هذه الدراسة أن العوامل البشرية والمهارات غير الفنية مهمة لإدارة مجرى الهواء وضمان رعاية آمنة وعالية الجودة أثناء الجراحة. وهناك حاجة إلى مزيد من البحث لتحديد كيفية عمل هذه المهارات معًا وكيف تؤثر على أداء التخدير.
الكلمات الرئيسية. إدارة مجرى الهواء، اتخاذ القرار، تحليل المهام، سلامة المريض.