August 2020

Illuminating the Naturalistic Decision-Making Processes of Anesthesia Providers to Inform Medication Error-Reducing Interventions

Joshua Michael Biro
Clemson University, jbiro@clemson.edu

ILLUMINATING THE NATURALISTIC DECISION-MAKING PROCESSES OF ANESTHESIA PROVIDERS TO INFORM MEDICATION ERROR-REDUCING INTERVENTIONS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Industrial Engineering

---

by
Joshua Michael Biro
August 2020

Accepted by:
Dr. David M. Neyens, Committee Chair
Dr. Kapil Chalil Madathil
Dr. Mary Elizabeth Kurz

ABSTRACT

Medication errors in anesthesia are prevalent and efforts to address medication errors bring with them new potential avenues of failure, especially when the work system and 'work as done' are not considered in the design of the intervention. I employed two methodologies in interviews of anesthesia providers to help further understand the context of anesthesia 'work as done' to inform the design of future medication error-reducing interventions. Results of the first interview methodology, the critical decision method, revealed a diverse array of challenging scenarios in which 'work as done' often deviates from 'work as imagined.' Results of the second interview methodology, vignette-based interviews, revealed how the decision-making processes of anesthesia providers may vary even when managing an identical case. These interviews provide context to the otherwise nebulous 'variability' of anesthesia provider 'work as done.' This context highlights the potential unforeseen dangers that may occur with the addition of future interventions and suggests avenues in which future interventions may fit better into the workflow of the anesthesia provider with design considerations. Future design efforts should focus on supporting the resilience of anesthesia providers: the information seeking and problem anticipation which are used to safely manage the uncertainty and complexity of their work. Future work should assess how 'work as done' may vary in different hospitals, and additionally focus on how 'work as done' influences the process of medication administration.

DEDICATION

This thesis is dedicated to my mother and father, Susan and John Biro. I would not be the person I am today without their love, kindness, and support.

ACKNOWLEDGMENTS

First and foremost, I would like to acknowledge my advisor, Dr. Dave Neyens, for his guidance, expertise, and kindness that he has provided throughout my tenure as a graduate student at Clemson University. I would like to thank my committee members Dr. Kapil Chalil Madathil and Dr. Mary Elizabeth Kurz for the wisdom that they have provided me both inside and outside of the classroom. I would like to acknowledge my fellow members of the Ergonomics and Applied Statistics Lab: Katie Jurewicz, Rong Yin, Courtney Linder, and Maya Rucks for creating a learning environment from which we can all learn from each other. I would like to acknowledge everyone on the Patient Safety Learning Lab team from which this project was born: Dr. Catherine Tobin, Dr. Candace Jaruzel, Dr. Ken Catchpole, and Dr. Myrtede Alfred from the Medical University of South Carolina; Dr. Jake Abernathy, Dr. Sarah Coppola, and Dr. Ayse Gurses from Johns Hopkins University; and Dr. David Neyens and Dr. Anjali Joseph from Clemson University.

This project was funded under grant number HS026625- 01 from the Agency for Healthcare Research and Quality (AHRQ), U.S. Department of Health and Human Services (HHS). The authors are solely responsible for this document's contents, findings, and conclusions, which do not necessarily represent the views of AHRQ. Readers should not interpret any statement in this report as an official position of AHRQ or of HHS. None of the authors has any affiliation or financial involvement that conflicts with the material presented in this report.

TABLE OF CONTENTS

Page

TITLE PAGE i

ABSTRACT ii

DEDICATION iii

ACKNOWLEDGMENTS iv

LIST OF TABLES vii

CHAPTER

I. INTRODUCTION 1

Efforts to Reduce Medication Errors in Anesthesia 2
Decision Making in Anesthesia 6
'Work as Imagined' and 'Work as Done' 9

II. METHODS 12

The Critical Decision Method 12
Vignettes 13
Procedure 14

III. RESULTS AND DISCUSSION OF CDM INTERVIEWS 18

Seeking Information from the Patient 19
Seeking Information from Technology 21
Seeking Information from Colleagues 22
What Informs Information Seeking and Synthesis 23

IV. RESULTS AND DISCUSSION OF VIGNETTE-BASED INTERVIEWS 25

Variability in Seeking Information to Inform Anticipated Problems 26

Table of Contents (Continued)

Page

Variability in both Information Seeking and Taking Preparatory Actions in Response to Anticipated Problems 34

V. DISCUSSION AND CONCLUSION 44

Understanding Anesthesia Provider 'Work as Done' 44
Design Recommendations and Perspectives 45
Limitations and Future Work 47
Conclusion 49

APPENDICES 51

A: CDM and Vignette Interview Scripts 52

REFERENCES 57

LIST OF TABLES

Table		Page
1	Quotes from participants' responses for managing the patient's pain in various ways	36
2	Preparatory actions mentioned by each participant in response to prompt 5	40
3	Order of information seeking sources sought in response to prompt 5	43

CHAPTER ONE

INTRODUCTION

Anesthesiology and its practitioners are responsible for numerous aspects of patient care, including: prevention and relief of pain before, during, and after procedures; the evaluation and maintenance of normal physiological function; and, above all else, assuring the safety of the patient (Miller & Pardo, 2011). Given the complex and individualized nature of anesthesiology care, the occurrence of errors is all but inevitable. This inevitability has led to a partnership between anesthesia providers and industrial and systems engineers, all sharing the common goal of increasing the safety of the anesthesia system. Engineers have been researching the identification and reduction of anesthesia medication errors since the early 1980s. Craig and Wilson (1981) originally examined a broad scope of problems, referring to these incidents as "anaesthetic misadventures" and found that human error was most frequently a contributing factor. There have been many studies examining a range of anesthesia errors using a varying vocabulary: intraoperative problems (Fasting & Gisvold, 2000), anesthetic incidents (James, 2003), severe critical events (Engelhardt et al., 2019), medication errors (Glavin, 2010), and adverse drug events (Wittich, Burkle, & Lanier, 2014). Regardless of their nomenclature, one fact remains clear in the plethora of research: medication errors and error-related scenarios are still a problem today, just as they were a problem 40 years ago. Current estimates on the prevalence of medication errors range from 1 in 450 medication administrations (Yamamoto, Ishikawa, & Makita, 2008) to as many as 1 in 20 medication administrations (Nanji, Patel, Shaikh, Seger, & Bates, 2016). This alarmingly high statistic is perhaps

offset by the fact that the majority of medication errors that are reported lead to little or no harm, though the potentiality of harm due to medication errors is unceasing and can be lethal (Ajmal, 2011). Examples of common medication errors include wrong dose, wrong drug (often due to accidental substitution via syringe swap), omission (missed dose), and repetition (extra dose) (Webster, Merry, Larsson, McGrath, & Weller, 2001). Research suggests that these errors result from a variety of causes including: (i) organizational barriers, such as anesthesia providers working alone; (ii) cultural barriers, such as demotivating incident reporting systems (Eichhorn, 2010), and (iii) physical barriers, such as look-alike drugs (i.e., different drugs stored in similar ampoules or vials), sound-alike drugs (e.g., oxycodone and oxycontin), and abrupt changes in drug concentration from suppliers (Ismail & Taqi, 2013).

Efforts to Reduce Medication Errors in Anesthesia

Given the research focused on identifying and addressing medication errors in anesthesia, it remains surprisingly unclear why little has actually been done that improves this system (Grigg & Roesler, 2018). Concurrent expert commentary has resulted in numerous recommendations regarding how to reduce the prevalence and danger of medication errors and error-related events in anesthesia. Of 35 different recommendations found, the three most academically supported are: have an incident or error reporting system; label every medication with drug name, date, and concentration; and read and verify every vial, ampoule, and syringe label before administration (Wahr et al., 2017). Wahr et al. (2017) applied a framework developed by Kitson, Harvey, and McCormack (1998) to suggest three pillars that prevent the implementation and

adherence of expert recommendations: (i) a lack of proper research on intraoperative medication strategies; (ii) a lack of literature on how safety culture impacts implementation of medication strategies; and (iii) a lack of supporting tools necessary to motivate a drive for change.

Further investigation into research efforts proposing and assessing interventions to reduce medication errors reveals why these efforts have not led to substantial change: they lack proper consideration of the actual 'work as done' healthcare system. In practice, the myopic application of these interventions results in a lack of compliance, which can lead to greater danger. For example, Merry et al. (2011) performed one of the few randomized controlled trials assessing SAFERSleep, a multimodal system which incorporated many suggested improvements including: customized drug trays and drug trolley doors, pre-filled syringes, large legible color-coded labels, a barcode reader to provide verification of selected drugs immediately before administration, automatic compilation of an anesthetic record, and a warning system if an antibiotic has not been administered within 15 minutes of the start of anesthesia. The SAFERSleep system resulted in a significantly lower overall mean rate of drug errors (9.1% vs 11.6%), however most of these were drug recording errors, not drug administration errors (which are the direct source of danger). Drug administration errors alone were not significantly reduced. This may be due to a lack of compliance (i.e., anesthesia providers not using the SAFERSleep system despite its availability). Although compliance was found to be negatively correlated with error rate, anesthetists were fully compliant with all principles of the SAFERSleep system in only 18% of cases. It has been argued that a user's lack of

compliance with a system is not necessarily a reflection of the user, but instead a reflection of poor design of the system. Efforts to mandate compliance in these interventions (e.g., a mandatory bar code scanner developed by Khan et al. (2016) in which the drugs can only be administered after being scanned) may seem like a viable solution in theory; however, experts warn that such interventions could be dangerous to implement in practice. In a reply to Khan et al. (2016), Webster and Merry (2017) argue that implementing new technologies can introduce new potential modes of failure (e.g., software bugs, battery failure) and that so called "forcing functions" can often result in workarounds which can increase the risk of harm to patients.

In addition to the new failure modes inherent in new technologies, the reduced risk of error that they provide may only exist within a particular frame of reference in the anesthesia delivery process. An example of such a technology is prefilled syringes. Traditionally, anesthesia providers must self-fill syringes – they take an empty syringe, fill it using an ampoule containing the desired drug, and then label the syringe. Errors in the use of self-filled syringes include drawing up the wrong drug (potentially due to look-alike and sound-alike drugs), or drawing incorrect amounts or concentrations of a drug (potentially due to abrupt changes in drug concentration from suppliers) (Ismail & Taqi, 2013). Prefilled syringes are already filled and labelled, theoretically simplifying the medication delivery process and reducing the risk of error. In reality, this risk may instead be transferred either upstream or downstream in the totality of the anesthesia delivery process. While prefilled syringes may reduce the cognitive workload of anesthesia providers during medication preparation and administration, and additionally

reduce the number of potential system vulnerabilities compared with self-filled syringes, new risks arise and old risks still exist in prefilled syringes (Yang, Rivera, Fortier, & Abernathy, 2016). Prefilled syringes are still susceptible to errors resulting from look-alike labels, sound-alike names, and abrupt concentration changes similar to the ampoules used for self-filled syringes (Gage Parr, 2019). Additionally, there are additional tasks associated with prefilled syringes that need to be accounted for in the work system (e.g., the expiration date must be checked more frequently than conventional ampoules and there is additional packaging that must be unwrapped for each syringe). While the benefits of prefilled syringes might outweigh the potential additional risks, overlooking the new modes of failure they introduce may increase their risk of harm until the system adapts to the change.

Technology design in healthcare systems should consider the inherent interactions with the organizations, tasks, and persons of the environment, as well as the subsequent processes and outcomes that result (Holden et al., 2013). In working towards designing better systems we must better understand the user and how they interact with the system. In the scope of anesthesia, the users are anesthesia providers: attending anesthesiologists, resident anesthesiologists, and certified registered nurse anesthetists (CRNAs). Interventions to reduce medication errors must be designed with an understanding of what decisions anesthesia providers need to make, the information used to make those decisions, and how those decisions are made. By examining what we know about decision making in anesthesia, we may be able to illuminate how new potential interventions will interact with and fit within the anesthesia process.

Decision Making in Anesthesia

Anesthesia is complex and requires numerous types of decisions to be made to ensure patient safety (Manser & Wehner, 2002). The complex environment anesthesia providers work in requires them to make decisions in the face of time constraints and unexpected changes, making their decision-making likely naturalistic (Phipps & Parker, 2014) and generally in line with the Recognition-Primed Decision (RPD) model (Raphaela Schnittker, Marshall, Horberry, Young, & Lintern, 2017). The RPD model asserts that, when faced with time-pressure and unclear situations, experts do not employ prescriptive decision-making strategies consisting of concurrent consideration of several options in search for an optimal course of action (Klein, 1993). Instead, they take a more linear approach, using their experience to mentally simulate a single course of action, generated from their recognition and subsequent assessment of the situation. This single course of action, if determined to work via mental simulation, will be implemented prior to considering other options, and will continue to be implemented until new information results in a reassessment of the situation.

Efforts to understand how anesthesia providers employ this naturalistic decision-making (NDM) process have been undertaken all over the world. Cuvelier and Falzon (2011) conducted interviews in a pediatric anesthesiology service in a French hospital in an effort to describe the variability anesthesiologists deal with and the strategies used to avoid the negative consequences of this variability. They theorized that the performance of an anesthesiologist relies on their ability to define an "envelope of potential variability," a list of various events which are anticipated despite not yet occurring, and

for which a protocol can easily be applied. Within this envelope of potential variability are events that are often known complications for which an anesthesiologist has been taught to prepare for, such as facing a difficult airway. Danger occurs when circumstances breach this envelope and the situation that the anesthesiologist is facing was not envisaged prior to its occurrence. These events are often exceptionally rare or extremely complex, where no clear course of action is understood to improve the situation (Cuvelier & Falzon, 2011). Whether an event falls within the envelope of potential variability (and can subsequently be adapted to) depends on both the uncertainty of the event and the anesthesia providers' anticipation skill. Skilled anesthesia providers operate with a broader envelope of potential variability, and therefore are better at adapting to more uncertain events. Cuvelier and Falzon (2011) suggest that resilience can be enhanced by either (i) increasing the knowledge of rare events, making an event more knowable; (ii) increasing an anesthesia provider's ability to project themselves into future real conditions, increasing their anticipation skill; or (iii) increasing an anesthesia provider's ability to diagnose that a situation has left the envelope of potential variability, to mobilize additional resources. In the context of medication errors and interventions to reduce them, novel interventions may create new events that breach the envelope of potential variability, in effect creating new modes of failure.

Schnittker et al. (2017) conducted interviews in two public hospitals in Australia to explore the cognitive processes of anesthesia providers specifically with respect to airway management (a critical component of the anesthesia delivery process). They found that the recognition-primed decision (RPD) model may be lacking in its ability to model

airway management due to the teamwork component inherent to anesthesia resulting in some decision making processes that are not entirely sequential (as described in the RPD model) despite still using situation-action matching, suggesting that the RPD model be adapted for this domain. In an additional analysis of their interviews, Schnittker et al. (2018) identified enablers (factors that facilitated success) and barriers (factors that impeded success) to successful airway management. In total, five factors were identified. Three of the factors identified (equipment location and storage, teamwork and communication, and experience and learning) were both enablers and barriers, indicating that they may facilitate or impede success depending on the circumstance. The other two factors (time and resource limitations, insufficient back up planning and equipment preparation) were uniquely barriers, indicating that they only impede success. While these interviews and the subsequent themes developed are specific to airway management, they do help provide key information for how anesthesia providers make decisions, and their conclusions should be considered when considering medication errors and interventions.

Fioratou et al. (2016) performed interviews at four hospitals in Scotland to explore the role of distributed situation awareness (DSA) on the anesthetic management of challenging major obstetric hemorrhage cases. This work is unique in that it utilizes a DSA framework instead of a naturalistic-decision making (NDM) framework for exploring the decision-making process of anesthesia providers. However, situation awareness and NDM are naturally linked; situation awareness serves as a major input in the decision making process, and additionally may impact the types of processes used

(Endsley, 1997). They found that anesthetists use varying sources of information such as external artefacts (e.g., monitors, blood suction containers), and interactions with other people (e.g., obstetricians, patients, other anesthetists) for perceiving, understanding, and anticipating a situation in an operating room. Fioratou et al. (2016) highlight that anesthetists do not use conventional models of situation awareness, where awareness would reside solely in the head of the anesthetist, but rather a distributed understanding of awareness emerges from anesthetist's interactions with the system.

The prior research in anesthesia decision making mentioned above provide helpful context for potential medication error intervention design. However, they all studied different anesthesia systems and took different perspectives towards analyzing their data. We cannot assume that the decision-making strategies made by anesthesia providers in France, Australia, or Scotland represent the decision-making strategies of anesthesia providers in the United States. According to the SEIPS 2.0 model, the processes and outcomes in a work system result from an interaction between the organization, tasks, persons, and environment (Holden et al., 2013). Physical and social variations in anesthesia providers' environments around the world will result in varied decision-making processes. While prior research helps define a general scope of the anesthesia decision-making processes, it is vital to understand how the health care systems in the United States create a unique context for anesthesia providers.

'Work as Imagined' and 'Work as Done'

Previous efforts to reduce medication errors have theorized success in a 'work as imagined' system, where clinical decision making is a rigid process and safety naturally

follows the adherence of standard procedures (Catchpole & Alfred, 2018). The utilization and subsequent failures of this approach are apparent in Merry et al.'s (2011) study of the SAFERSleep system. There was a significant reduction in drug administration errors when, and only when, anesthesia providers were compliant with the prescriptive standardized procedures for utilizing the system. The SAFERSleep system failed to reduce drug administration errors not due to a technical failure, but rather a systematic oversight; the requirement to adhere to a standardized, rigid, and inflexible process did not fit into the work processes used by anesthesia providers, thus resulting in a lack of compliance. This lack of compliance reflects the failures of the 'work as imagined' perspective. Anesthesia providers are not machines who keep patients safe by following a specific procedure; the healthcare system is far too complex for simple application of standard procedures to result in patient safety. Thus future efforts to reduce medication errors must consider the true 'work as done' system, where decision making is naturalistic and safety results from variability and adaptability (Smith & Plunkett, 2019). In 'work as done,' anesthesia providers are only able to keep patients safe by continually adapting and adjusting to the everchanging system in which they work. This aspect of safety, the ability to succeed under both unexpected and expected conditions, has been termed resilience (Hollnagel, 2014). In order to design around the 'work as done' system, we must first further our understanding of it.

Prior research efforts, such as those discussed in the section above, have discussed the concept (and importance of) anesthesia provider 'work as done,' where anesthesia providers must cope with the variability and complexity of the healthcare domain. To

help inform design efforts that may reduce anesthesia medication errors and improve and maintain high quality of care, we need to provide further context to the otherwise nebulous ‘variability’ and ‘complexity’ that anesthesia providers manage. What makes the anesthesia work system complex? What decisions do anesthesia providers need to make? How do they make those decisions? What resources do they use to make those decisions? How does this all culminate in a resilient system? This thesis will describe interviews conducted with anesthesia providers in order to illuminate their naturalistic decision-making processes, furthering our understanding of the complexities in the ‘work as done’ anesthesia system. By developing a better picture of anesthesia ‘work as done,’ we hope to provide helpful context with which to help inform interventions to reduce anesthesia medication errors in the future.

CHAPTER TWO

METHODS

There are various approaches one can take to elicit the naturalistic decision making of an expert. To account for the wide range of plausible decisions that can be made by anesthesia providers, we used two unique approaches: Critical Decision Method (CDM) interviews, and vignettes-based interviews. By utilizing these two methods, we hope to create an understanding of both the range of different decisions anesthesia providers need to make, as well as the varying decision-making processes anesthesia providers take when faced with the same challenge.

The Critical Decision Method

An approach commonly used to elicit the naturalistic decision-making process of anesthesia providers is the Critical Decision Method (CDM) (Cuvelier & Falzon, 2011; Fioratou et al., 2016; Raphaela Schnittker et al., 2017). The CDM is a cognitive task analysis method focused on eliciting information pertinent to the naturalistic decision-making process described in the Recognition-Primed Decision (RPD) model (Klein, 1993; Klein, Calderwood, & Macgregor, 1989). To elicit the situational recognition key to decision making prescribed in the RPD model, the CDM uses a retro-respective interview strategy where an expert (in this case an anesthesia provider) describes a challenging, nonroutine case from their past. Decision points of this case are identified and then cognitively probed to reveal the cues, knowledge, goals, and other pieces of information pertinent to assessing the described situation.

While the CDM is a highly touted method for eliciting naturalistic decision-making processes, the complexity of anesthesia and the extreme variety of situations that arise in its application makes it difficult to assess how different anesthesia providers may vary in their decision-making processes. Different anesthesia providers may have different approaches when confronted with the same problem; understanding these different approaches is necessary to sufficiently account for the variability present in this domain. In order to account for this variability, we used vignettes as an additional interview component.

Vignettes

A vignette is a "brief, carefully written description of a person or situation designed to simulate key features of a real world scenario" (Evans et al., 2015). These simulated real-world scenarios are then presented to participants in order to elicit a response that predicts or proxies their actual behavior given the circumstance of the vignette. Vignette studies are structured similarly to other experimental designs, consisting of varying independent variables that allow experimenters to assess their impact on a dependent variable of interest (e.g., how a patient's gender influences general practitioners' identification and management of depressive symptoms [Ross, Moffat, McConnachie, Gordon, & Wilson, 1999]). To the author's knowledge, vignettes have never been used to assess decision-making in the anesthesia domain, though they do have a history of being applied in healthcare, including understanding attitudes, perceptions, and beliefs in nursing (Hughes & Huby, 2002), international and intranational variation in quality of clinical care (Peabody & Liu, 2007), and conflicts of interest experienced by

general practitioners in the course of child protection work (Wainwright, Gallagher, Tompsett, & Atkins, 2010).

The vignette used in this thesis varies from conventional vignette studies as only one identical vignette is used for every participant. Our goal in using a vignette-based interview is to assess how anesthesia provider decision-making processes vary when faced with the same scenario, thus no experimental manipulation of variables is necessary. For assessing clinical practice, the advantages of vignette methodologies include their cheap cost, ethical convenience, reliability, and validity (Peabody, Luck, Glassman, Dresselhaus, & Lee, 2000). Criticisms of vignette methodologies include uncertainty regarding their structural validity, whether they appropriately simulate a real-world scenario, and the subsequent external validity and generalizability of vignette responses (Barter & Renold, 2000). While few studies have compared vignette responses to actual responses, research suggests that clinical vignettes, if properly designed with methodological care, do elicit externally valid and generalizable responses from clinicians (Bachmann et al., 2008; Evans et al., 2015). A comprehensive examination of the validity of vignettes methodologies for studying clinicians' decision making has been conducted by Evans et al. (2015).

Procedure

This work was done in conjunction with a larger project and was identified as a research activity involving human subject that met exemption criteria under 45 CFR 46 and 21 CFR 56 by the Medical University of South Carolina Institutional Review Board. Interviews were conducted at an academic hospital system in the southeastern United

States. Both attending anesthesiologists and certified registered nurse anesthetists (CRNAs) were interviewed in order to elicit information from the two types of anesthesia providers. Interviews took place in conference rooms and offices in the different hospitals within the large medical complex to reach anesthesia providers with varying responsibilities and experiences. Participants were recruited via email and word of mouth from the research team as well as other clinicians at the hospital (snowball sampling [Noy, 2008]).

Developing the Interview

Each interview was split into two parts: (1) a modified CDM interview and (2) a vignette-based interview. Part 1 employed an interview strategy adapted from the Critical Decision Method (CDM) (Klein et al., 1989). We adapted the process to shorten the time required and to focus on the most apparent decisions and actions the anesthesia provider made in lieu of completing a comprehensive timeline of the whole surgical case. Part 2 utilized a vignette which presents the participating anesthesia provider with a hypothetical case to manage. To elicit the decision-making processes of anesthesia providers in a both a standard and challenging case, the vignette describes a scenario where a case initially begins as expected, but a series of complications arise as it proceeds. Initially, multiple vignettes were developed and presented to an anesthesiologist on the research team. That anesthesiologist singled out one vignette and refined its content and language to present a plausible and structurally sound scenario. The structured interview strategy was piloted with two anesthesia providers in order to

identify any issues with the strategy or wording. The script for the interviews, including the vignette, is in the appendix.

Interview Process

Interviews started with part 1, the modified CDM interview. In part 1, the participating anesthesia provider was asked to describe a case that they found particularly challenging; a case where someone else might have made different decisions than they did; or a case that they might wish to have made a different decision in hindsight. Following the anesthesia provider's telling of the case, a team of three researchers identified and probed what appeared to be the predominant decision point in each case. Upon completion of probing, the interview then moved on to part 2, the vignette-based interview. In part 2, the participating anesthesia provider was asked to manage the case of a 13-year-old boy's laparoscopic appendectomy. Through a series of prompts, the vignette presents a case increasing in complexity and becoming more atypical. Each prompt revealed more information about the progress of the case, and after each prompt the research team asked the participating anesthesia provider what they would do at the current stage of the case. Probing questions followed the anesthesia provider's response.

Analysis Plan

Interviews were transcribed using an automated transcription service and then personally verified. Potential avenues for analyses of data retrieved using the CDM include the structured approach and the emergent themes approach (Wong, 2004). The structured approach uses an *a priori* framework of decision making in line with the Recognition-Primed Decision (RPD) model, while the emergent themes approach is

exploratory, using its own data to develop unanticipated concepts. As discussed above, despite the fact that anesthesia provider's decision making has been found to be recognition-primed, the RPD model may be insufficient when applied to the domain of anesthesia (Raphaela Schnittker et al., 2017), thus the emergent themes approach was the analysis strategy used for this data. The emergent themes approach does not use an *a priori* framework, instead, themes and their relationships are identified from the transcripts themselves (Wong, 2004). Initially, broad patterns are identified from the transcripts, which are then used to theorize new structures and themes. The transcripts are then indexed and structured to explore each theme. Finally, the structured data is synthesized to reveal meaningful conceptualizations.

Our probing questions asked in response to the vignette-based interview answers were grounded in the same fundamental ideology as the probing questions asked in response to the CDM interview answers: to elicit information pertinent to the decision-making process employed. Thus, we were able to analyze both part 1 and part 2 of the interviews using a similar emergent themes approach. However, the vignette-based interview responses provide us with the ability to more directly compare decision-making strategies due to the consistency in the specific case and situation. Thus, we expected that different themes will emerge in analysis of the vignette-based interview data.

CHAPTER THREE

RESULTS AND DISCUSSION OF CDM INTERVIEWS

In total, 18 anesthesia providers were interviewed (8 CRNAs, 10 Attendings). These 18 anesthesia providers will be referenced as P1-P18 throughout the rest of the paper. Due to time constraints, four (P11, P12, P14, and P15) of the 18 anesthesia providers were only able to participate in the vignette-based interview. In total, the interviews took an average of 21.1 minutes (SD=7.2 mins). The modified CDM portion of the interviews took an average of 10 minutes (SD=3.7 mins). The vignette portion of the interviews took an average of 13.3 minutes (SD=2.7 mins).

As mentioned earlier, not all of the participants were able to participate in both the modified CDM interview portion and the vignette-based interview portion due to workload and schedules. Therefore, 14 anesthesia providers completed the modified CDM interview portion (5 CRNAs, 9 Attendings). For each participant, aspects of what made each case challenging and the themes relevant to medication error design considerations were identified. A list of 14 potential emergent themes were first developed, and then through discussion were revised and combined to generate a final list of three emergent themes.

Analyzing the data revealed three overarching themes: (1) the cases which anesthesia providers find to be challenging from a decision-making perspective are those where the anesthesia provider has incomplete information which inhibits their ability to confidently choose between differential diagnoses, (2) decision-making begins with anesthesia providers seeking information from either the patient, technology, or

colleagues, and (3) attributes such as personal experiences, special expertise, and working domain influence how anesthesia providers perform information seeking tasks and synthesize the information they provide. These themes and the context within this data help create a more accurate view of 'work as done' and generate insights into what potential medication error reducing interventions should look to avoid and what they could possibly help facilitate.

Seeking Information from the Patient

The cases that anesthesia providers self-identified as challenging revolved around confronting a lack of information. This lack of information manifested in many forms throughout the anesthesia process. This lack of information can occur preoperatively, intraoperatively, and postoperative, and for different reasons.

P5 and P18 both described a case where they had to seek out information preoperatively in order to make a decision. P5 described a case where they had to provide anesthesia for an obese patient (with a BMI>99) and had to decide between whether to do a regional block or general anesthesia. P5 did not know whether the patient was going to be able to lie flat for the entirety of the case, which is required for a regional block (P5's preferred anesthetic method for this patient). P18 described a case where they had to provide anesthesia to a patient coming from an outside hospital which had not been able to intubate the patient. P18 had to decide whether to do an awake fiberoptic intubation, a mask ventilation, or a nasal fiberoptic intubation. P18's patient had several prior surgeries on the same anatomical structure and a limited paper chart that had *"20% of the required information that would have been helpful for [P18]."* P5 was able to get an answer to

their quandary by directly asking the patient how they slept at home and determined that a regional block would be possible. P18 also questioned their patient but was not able to get a direct answer to their question, instead having to build a collection of indirect evidence:

"I asked [the patient] 'Did you ever remember being awake while they did that [procedure]?' And [the patient] said, 'no,' [they] had no recollection of that. So that was kind of indirect evidence for me that other people have not had to do an awake fiberoptic intubation on [them]. So, I said, 'okay, well, if that concept seems foreign to you, then they didn't do that to you any other time.' So, to me, that is indirect evidence that someone else was able to bag mask ventilate [the patient] and I could feel comfortable [with the case plan]."

In P5's and P18's cases, they were able to communicate with the patient directly to get an answer. This, however, is not always the case. Verbal communication between the anesthesia provider and the patient can be inhibited by language differences, as was the case in P1's patient who did not speak English and where the only translator they could get was over the phone, and in other cases simply because young pediatric patients may not yet have the ability to talk. Verbal communication is most often inhibited between patient and anesthesia provider because the patient is under anesthesia. In these cases, anesthesia providers still look to patients for answers, sometimes looking for blood loss or listening for breath sounds. These patient scans can be difficult in the actual 'work as done' world. P9 described having difficulties discerning the blood loss of a pediatric patient:

"[The patient] ended up losing a lot of blood and you couldn't really tell because [of] where they were. They were on top of a warming blanket which kind of cocoons them […] and blood loss was around towels".

P13 directly touched on the difficulties of listening to the patient:

"[In a training scenario] you'd be like 'well I'd listen for breath sounds'… but in real life, you listen for breath sounds and there's a lot going on in the OR, there's a lot of ambient noise. You listen and you're like 'sure sounds like we can hear breathe sounds from both sides.' So, the real-world context is often more difficult than the [training]."

Seeking Information from Technology

There were times when getting information from the patient alone was insufficient, obliging anesthesia providers to use the technology around them to collect more information. Anesthesia providers looked to monitors as an extension of the patient, listening and observing in pursuit of the information they need. Challenging cases arose from instances when monitors were not working, or the additional tests were not providing the anesthesia providers with information informative to their differential.

P1's case became exceedingly difficult after intubating when P1 discovered that there was no end-tidal CO_2 showing on the monitor. P1 began seeking potential diagnoses by seeking information from the patient. This included looking for chest rise, auscultating, and listening over the stomach. The information gained did not determine the appropriate diagnosis, so P1 then called on technology to help provide clarity; a video laryngoscope to check if the endotracheal tube was placed appropriately. This also did not lead to a clear diagnosis. Eventually P1 had to resort to the diagnosis highest on their

differential, which normalized the patient until extubation, at which point the patient was again not providing the proper benchmarks to indicate it was safe to extubate. Although the case ended safely, the stress of missing information still lingered:

"But still, in hindsight, I wonder, with that communication barrier and coming from a different country and exposures over there, what did we miss?"

P16 described a case where everything went uneventfully throughout the surgery, but the patient's health suddenly started declining in the Post Anesthesia Care Unit (PACU). The patient became hypotensive, so P16 went to their technological resources for information. Initial blood gas tests showed nothing concerning, but the eventual chest x-ray revealed a large tension capnothorax. P16 sought information from technology, and while it did provide some information to help guide the differential, it was far from giving them the solution they desired.

Seeking Information from Colleagues

When both technology and the patient were insufficient sources of information, anesthesia providers turned to their colleagues. In every case there was some indication that anesthesia providers sought information from surgeons, pharmacists, specialists, and/or other anesthesia providers. In the midst of a challenging case, P16 not only worked with the surgeon on the case but reached out to a colleague in the Intensive Care Unit to assist in examining the patient as well.

Some cases were difficult not because of missing information from a patient, but because of missing information from a surgeon, pharmacist, or other anesthesia provider. P2 had a specific specialization making their approach towards a case *"a little bit outside*

the box." In the case P2 described, the success of their unconventional approach relied heavily on their ability to communicate with the anesthesia team:

"A lot of my decision making revolves [around] knowing the patient, talking to the surgeon because I don't know what they're going to do exactly, it's not my field, and then talking to anybody else involved on the team."

In P8's response, they chose not to talk about a specific case, instead detailing many of the complications they find in robotic cases. Many of the complications that arise in robotic cases need to be addressed through communication with colleagues. Whether it be with other anesthesia providers:

"So part of the challenge is to get everybody on the same page of: 'where should these hemodynamics be running?'"

Or with surgeons:

[Regarding the positioning of the patient] "sometimes it comes down to talking with the surgeons …we kind of try to do everything we can [..to…] be able to let them do what they're doing, and then some of the decision is finally to come back and say 'look, you know, I've tried everything I could possibly think of doing here, you need to kind of work on your end a little bit to maybe give us a little bit of a break'"

What Informs Information Seeking and Synthesis

Across the interviews, often the example cases that the anesthesia providers described were complex due to a lack of information or barriers in acquiring information. This information was then sought out, usually utilizing a combination of the patient, technology, or colleagues. The interview data suggests that both how anesthesia

providers seek information and the decisions that anesthesia providers make once they find information depends on their specialties, the domains that they work in, and their personal experiences. P2's approach to their cases, described earlier, highlight how, by virtue of having a specialization, they have a different perspective than their colleagues*: "So the cardiac anesthesiologist and I were debating back and forth like what's really better for the patient?"* P6 discussed that their course of action was also likely different than what others would have chosen, not because of any specialization but because of their personal experience:

"So I think a lot of people may have chosen to use a video laryngoscope to intubate [the patient], but I chose a little more still-used-but-less-commonly-used technique of a fiberoptic intubation while the patient was still awake but sedated … and that would not have been an incorrect decision, but it was one with more limited secondary options. I may not have chosen the fiberoptic option if I was not very comfortable doing that option. Because these days… the video laryngoscope has cannibalized some of that experience [for others]."

Different domains also have different expectations that affect information seeking. When P13 was probed regarding whether their close work with the surgical team was unique, they responded:

"It's maybe a little bit of a broad generalization, but I would say cardiac anesthesia has a little bit more of that [communication with the surgical team]."

CHAPTER FOUR

RESULTS AND DISCUSSION OF VIGNETTE-BASED INTERVIEWS

All 18 participants took part in the vignette-based interview portion. Transcriptions of the interviews were imported into an open source qualitative analysis software package (Huang, 2016) for qualitative data analysis. Initial codes were created *a priori* based on expected decision-making strategies revealed in the literature as well as validating the vignette as a realistic scenario. Further codes were developed emergently from the content of the interviews, with a focus on revealing deviations between anesthesia provider decision making processes. An initial round of coding was performed, the methodology and results of which were discussed with all members of the research team in order to identify both potential oversights and new emergent themes, which were then incorporated into a second round of coding.

Analysis of the data reveals two primary strategies that anesthesia providers employ to manage the uncertainty/variability of a case: (1) Anesthesia providers seek information from sources that are likely to inform anticipated problems and (2) anesthesia providers seek to take preparatory actions in response to anticipated problems. While these strategies are consistent with prior literature, the responses to these vignettes reveal that there is variability in how different anesthesia providers employ these two strategies; there is variability in what information different anesthesia providers prioritize seeking and there is variability in what preparatory actions are performed. This variability has implications on how we think about interventions and suggest design guidelines that support a resilience engineering approach.

Variability in Seeking Information to Inform Anticipated Problems

The notion that anesthesia providers manage the uncertainty of a case by anticipating potential dangers, and the information seeking required to do so, has been discussed in the prior literature summarized in the introduction above. The participant's responses to each prompt support that this approach is an accurate view of 'work as done.' The variability in participant's responses; however, suggest that, despite similar applications of this approach, each participant has their own unique process for managing a case. We were able to identify this process and the variability in its execution throughout participants' management of the case: first, before the case begins; second, during standard maintenance; and third, as complication in the case arise.

Before the Case Begins

This approach is first revealed when participants were asked to provide their medication plan for the hypothetical patient presented in prompt 1. Sixteen participants described needing more information prior to coming up with a medication plan, as described by P3:

"For a 13-year-old appy [appy is shorthand for appendectomy], ***it would depend,*** *first of all, if they are showing signs of basically what we call ruptured appy or bad appy, where there is a lot of nausea, vomiting, possibly bowel obstruction, [perforated] bowel, things like that. If so, then they are an aspiration risk. If they're an aspiration risk, then you're looking at rapid sequence induction.*

While several participants also prioritized the patient's nausea and vomiting as their main concern, other participants prioritized different information, as evident in their

initial response to the prompt. P2 prioritized the expectations of the patient and parents: "*So again, this depends on my conversation with patient and parents, what their expectations are.*" P5 prioritized whether the patient had an IV in place: *"So this patient - it depends on whether this patient has an IV in place."* P15 alternatively prioritized the patient's demeanor: *"Well, that depends on the kid. If the kid seems to be really cool, 13 years old, I would probably not give Midazolam. If the kid is in severe distress, I would give some, depending on body size and how mature the kid appears to me."* Each participant described a unique and variable process for how they navigate their concerns while developing a medication plan for the patient. We continue to see variability in what concerns participants prioritize, and thus what information they seek, as they continue to manage the case.

During Standard Maintenance of the Case

In prompt 2, the participants were informed that the hypothetical case began uneventfully and is now in process. At this point in a case, anesthesia providers are generally in the process of performing "maintenance," a process of incorporating feedback from the monitors around them to successfully keep the patient asleep, paralyzed, and pain free. When asked what they would do at this point, almost every participant (16) describe a process of anticipating for things to wrong. Four participants, P1, P2, P8, and P13, explicitly describe looking and preparing for the worst possible events:

"In my head, I'm always thinking, even as an attending, okay, what's the worst thing that could happen? *What am I going to do if the endotracheal tube pops out? Or if*

he has bronchospasms? I always try to plan ahead of that and know where my plan ABC is for all these things. […] I try not to just think that every patient - "Oh, every 13-year-old boy is the same" - but there are certain things you want to watch out for. So are they going to need more drugs because they're a young patient? Are they going to react more to surgery? […] And then ***again, I try to think of worst case scenarios*** *like: What am I going to do if he has a bronchospasm? Do I have like my gas appropriately turned up? Do I have Precedex in case he wakes up uncontrollably later? So those would be things I think about." – P2*

Several other participants do not explicitly express preparing for "the worst thing that could happen," but instead discuss various potential problems they would look out for. For example, P14 describes being concerned about potential problems with the instruments: *"You said it's a well-placed* ***tube but it could get pushed down****. You know,* ***there's a lot of different things that can happen****. The cuff could be not inflated all the way and then the bellows on the ventilator would be dropping."* P3 describes anticipating that the patient could be in pain:

"So for the duration of the case, [an anesthesia provider] typically kind of weens down [their] vent settings throughout the case to see: one, are they going to be somebody that's kind of breathing on their own early? Which … ***could be an indication of pain under us, [the patient] not getting enough pain medication.*** *[…] The other thing [anesthesia provider's focus on] is getting the oxygen down, things of that nature to show that [the patient is] not at some increased requirement. So for example, if we're all*

breathing 21% and the kid can't breath 30% on a ventilator without desatting, ***that means something's going on with the kid****."*

The most commonly mentioned event indicative of participants anticipating potential danger is the special focus applied when insufflation occurs in the case, described by P13:

"I'm looking for abnormalities. I'm looking for things that are unexpected. ***With that particular case, also there's a crucial point when they insufflate the abdomen*** *...* ***that's a really critical point in the operation where you want to be vigilant about a sudden change****. And so those would be that would be times when I would be particular - not that I,* ***not that you're not alert all the time, but there are certain benchmarks during procedures where you want to pay particular attention and watch for certain known complications from that maneuver****."*

Even participants that curtly describe their process when asked what they would do at this point in the case, such as P5 – *"Really nothing, let the surgeon take the appendix out,"* and P10 – *"Maintain sounds good to me,"* further expand on their concern at the point of insufflation:

[In response to "What do you do now?"] "Really nothing, let the surgeon take the appendix out. And you know watch the watch the monitors, make sure you know ***they're going to be insufflating the abdomen*** *at this point if it's laparoscopic. […] So* ***anticipate what the surgical next surgical move i****s.* ***So it's going to be insufflation of the abdomen and with that can - comes up you know, some cardiac responses****." – P5*

*"**As they insufflate the abdomen there can be a vagal response, especially in that age, actually**. So that's just something that I look for as they're actually insufflating. […] And that's just something that you know, at that point in the surgery, I'm aware that can happen. […] **So that's kind of the next big portion of what I'm looking for**." – P10*

Again, each participant described a unique process of what concerns they are focused on while maintaining the patient, whether it be insufficient pain medications, dangers during insufflation, or, as P10 describes, having *"adequate muscle relaxant on board - it just it gives us peace of mind that they're not going to move with a big metal spike in their abdomen."* As complications in the case arise, we find variability in how the participating anesthesia providers seek information as they start to anticipate new potential problems.

As Complications in the Case Arise

As the hypothetical case progresses with prompt 3, participants are informed of arising complications. Participants are first informed that the case has been going on for 45 minutes (long for a laparoscopic appendectomy) and that there is frustration growing in the room, as can be seen on the surgeon's face. As expected, participants want to know more about the frustration as they start to anticipate potential problems, as described by P6:

*"**I would need to know the source of the frustration to know what I would do next**. It could be inner personal frustration. It could be equipment frustration. It could be frustration with the surgeon not being able to achieve his task. So I would really need to know that because the therapies for that are different."*

Participants already start to anticipate further complications and how they would be addressed, such as the patient not having enough muscle relaxant, mentioned by P17: *"And the other thing that I might double check, if they're really struggling,* ***is to make sure that the patient had enough muscle relaxation*** *cause when the surgeons are struggling sometimes it has to do with exposure which you can optimize by giving more muscle relaxant;"* the surgeon needing to open the patient, mentioned by P11: *"I mean,* ***if they open that's a different situation****, obviously, then probably I would need more pain medication, potentially a block at the end of the case;"* and bleeding being an issue, as described by P18:

"You know, and ***if I think that something is worrisome on their side of things, whether you know they're losing blood****, if it's something that's going awry that I might need to change what I'm doing to assist with. So if they're losing a lot of blood, I need to be on top of that and asking them 'well what's going on, are you losing a lot of blood?' And I have both [direct and] indirect ways of figuring that out. I hear the suction canister, I can see the suction canister. I know what type of surgery we're doing, and what's the risk of, you know, straightforward lap appendectomy, you're not gonna lose a lot of blood, so it's probably not going to be a big concern. But I would be able to kind of figure out indirectly, what's going on, or at least, you know, in that scenario."*

At this point in the case, the participants still describe using the same information sources they use for standard maintenance: *"Heart rate, vitals, again, oxygen saturation, make sure that patient's ventilated. Make sure that everything that I'm doing was within normal parameters" – P12*. We also see the inclusion of other potential information

sources in anticipation of potential problems, such as the suction canister mentioned by P18 above. The greatest source of variability between participants at this point in the case is whether they would choose to communicate with the surgeon as a source of information. Six participants said that they would reach out to the surgeon seemingly without hesitation:

"***So communication, again is key***. *I ask, 'Well, how can I help you? Is there something you're missing? Do you need him to be more relaxed? Are you planning on opening? Is there any change in the surgical plan?' So I kind of try to understand why they're getting frustrated." – P2.*

Six participants describe potentially reaching to the surgeon, depending on factors such as their personal relationship with the surgeon:

*"**That depends on my personal relationship with the surgeon to be honest**… So if that would be a tension between the surgeon and me, I would probably shut up and just watch it more closely, alerted. If the surgeon is kind of friendly and psychologically healthy person… I would go "What's wrong? … Can I help you with something?" I would address it that probably" – P15;*

Or their concern for the patient's safety:

*"So, you know, if it gets to the point where you feel like something's unsafe, then you might make the recommendation, 'hey, is there somebody else that could [take over the case]"… So that's one of those things, **you just kind of ride it out unless, unless you feel like it's becoming unsafe**" – P14.*

Six participants describe not being inclined to reach out to the surgeon at all: *"You know, that's certainly not in my scope of my practice to, to even comment on or to deal with. So I would probably not do anything.* ***This frustration is a surgical problem****" – P5.*

The distinction of whether the participant would or would not talk to the surgeon shows a clear deviation in the information seeking process. We know from prior studies that communicating with colleagues is a vital method of receiving cues (i.e., information seeking) that inform accurate recognition and assessment of the situation (Fioratou et al., 2016); however, here we see that anesthesia providers take different approaches to this information seeking. Some participants would reach out to the surgeon and get information directly, others may only reach out to the surgeon depending on their relationship or concern for the patient's safety, and others are not inclined to reach out to the surgeon at all, instead only getting information via listening to the surgeon or have otherwise determined that surgeon frustration is not pertinent to their responsibilities in the case. Anesthesia providers that are not communicating with the surgeon could be missing out on valuable information required to safely manage the case.

Participants' responses to prompts 1 through 3 highlight the process anesthesia providers use to manage uncertainty: anesthesia providers anticipate potential problems and seek information to assess whether these potential problems will come to fruition. In assessing the variability between anesthesia providers, we find that this process plays out differently for each anesthesia provider. Participants responses indicate a variability in what problems they anticipate and how they seek information to inform those problems.

As the hypothetical case progresses past prompt 3, the participants are informed that their anticipated problems have come to fruition – the surgeon needs to open the patient and the surgeon is confronting a problem with bleeding. At this stage in the case, the participant anesthesia providers are no longer just anticipating future problems; they are taking preparatory actions in response to the problems in front of them. In addition to the continued variability we see in information seeking and problem anticipation, we see variability in what preparatory actions participants describe taking.

Variability in both Information Seeking and Taking Preparatory Actions in Response to Anticipated Problems

Variability in Taking Preparatory Actions as the Case Changes to Open

In prompt 4 the participant is informed that the surgeon needs to open the patient. At this stage in the case, the anesthesia provider shifts from solely anticipating potential problems to addressing the problem confronting them. Every participant describes at least one action that they would take in response to the surgeon needing to open, with the two most common responses being (1) to manage the increase in pain expected by the increased incision size, mentioned by 14 participants, and (2) to reassess and potentially increase the paralytic to ensure the patient does not move as the surgeon gains access to the appendix, mentioned by 10 participants. While the need for these actions to be taken are expressed by most participants, how the participants would accomplish these tasks is variable from participant to participant. While not every participant who mentioned needing to manage the increase in pain described how they might do so, those that did described doing so in various ways. These ways include simply increasing the amount of

narcotics that were already being supplied to the patient, changing the narcotic, providing non-narcotic analgesics, and using regional techniques. Quotes from participants supporting each of these choices can be found in Table 1.

Method of managing increase in pain	Example of supporting participant quotes
Applying more of the same narcotic	*"And then I would probably also give a little bit more analgesic, which would be Fentanyl cause it's more you know, the opening's more stimulating than the laparoscopic wounds that they've already made." – P17* *"So I probably preemptively give them probably some fentanyl prior to them opening." – P16*
Changing the narcotic	*"Maybe switching from something short acting Fentanyl to a Dilaudid which is longer acting which can carry the patient into the PACU" – P12* *"And so up until that point, probably would have been able to get away with the Fentanyl as the opioid, but in this case, I'd probably started thinking about more of a longer longer lasting opioid medication like Delaudid" – P13*
Providing non-narcotic analgesics	*"So there's some other medications we can give like precedex and ketamine to help with larger incisions." – P13* *"Probably going to go ahead and give more of a narcotic because it's going to be much more stimulating. I may give that precedex. That's that other medication we give to kind of decrease the amount of narcotic but it helps with pain." – P14* *"So I'm thinking about titrating, narcotics and appropriately or if I need to do other non-narcotic pain medication." – P18*
Using regional techniques	*"I would typically employ some kind of regional technique as long as it's fine from the surgeon's perspective" – P3* *"You could, again, if they're allowed to do some sort of a block or something afterwards, you can alert the pain team too as well." – P11* *"So if we convert from the laparoscopic procedure to an open procedure, you know, we can do nerve blocks to help out with that pain." – P18*

Table 1: Quotes from participants' responses for managing the patient's pain in various ways

Another point of variability in how the participants manage the case at this point arises in the whether or not the participant would take further preemptive actions to help manage the case, such as adding a second IV line. Participants 5, 8, and 10 all mention considering adding a second IV, and each come to a different conclusion. At this point in the case P5 would not add a second IV: *"it would not impact my management. I'm happy still with one IV it's only an appendectomy".* P8 describes potentially adding a second IV depending on the presence of other information: *"So I might not necessarily put an IV or [arterial] line in. But if all of the sudden I know they nicked something big and they're losing [blood], then that's going to be the next step of getting a second IV" – P8.* In contrast to participants 5 and 8, P10 describes how they would always add a second IV at this point in the case: *"I always will just kind of get under one of the arms and start a second IV. Just can't hurt. I mean, if you end up getting into a bloody situation, it's nice to have a second IV for giving blood. So I would start a second IV."*

Variability in Information Seeking as the Case Changes to Open

While the information that the surgeon is going to open the patient serves as a major cue in assessing the situation and implementing actions, it did not lead to a complete recognition of the situation; most (10) participants felt that they needed to know more about why the surgeon was opening in order to properly assess and act on the case, such as P8: *"It would depend on why do they think that we're opening? Is it just that it's just a bad appendix? And they're going to have to wash out? Or did they get into some bleeding and now we're having to worry about that?"*

We see different participants describe different approaches to seeking this information. Similar to prompt 3, there is still a separation between those who would and would not talk to the surgeon, however several participants who would not have talked to the surgeon earlier would do so here, such as P7 who at this point would "*communicate with the surgery team*." P9 describes how they would initially try to understand the surgeon's reasoning for opening through visual inspection and would only communicate with the surgeon if that did not answer their concern:

"If you can communicate with the surgeons, the big thing is like … what kind of problems are you having? … ***If I can tell what's going on based on looking I try not to interject, they're usually pretty good about like, [mentioning] if something's going wrong****. If it's because they can't get the damn thing in a bag … I don't ask them anything like I can see that they can't get it in the bag. But yeah, communication, I guess."*

Some participants, like P5, describe a view of the surgeon's process as separate from the anesthesia provider's process. While P5 does describe how they would have to manage the increased pain response and check on paralytics, their responsibility goes no further than patient safety and is not concerned with the surgeon's troubles:

*"Whether it's open or laparoscopic I still am responsible for patient hemodynamics and stability. So whether [the surgeon] is opening up or whether [the surgeon] is doing it laparoscopically****, my focus is on the patient. The surgical field is totally [the surgeon's]****."*

This view is contrary to other participants who describe taking a much more active role in communicating with the surgeon, like P2: *"And if he is going to open I'd*

talk about 'do you anticipate losing a lot of blood and like, what are the issues that you're running into? Do you need him to be more relaxed? How can I help you?' Essentially."

Variability in Taking Preparatory Actions as Bleeding Becomes a Problem

In Prompt 5 the participant is informed that the surgeon begins to mumble about some "damn bleeding," suggesting that there is a problem with patient blood loss. Again, participants take preparatory action in response to this information. Potential preparatory actions include starting a second IV line, an arterial (A) line, and/or an external jugular (EJ) line, supplementing fluids, sending off type and screen/cross labs, calling for extra blood, and asking for help from other colleagues. While most every participant mentions sending off labs, there is variability in which of the several other preparatory actions participants mention, as seen in Table 2.

Preparatory Actions Mentioned

P	Send off labs	Add a second IV	Start an A-Line	Start an EJ-Line	Supplement fluids	Call for blood	Ask for help
1	•					•	
2	•				•	•	
3	•		•				
4	•						
5		•					
6							
7	•	•					•
8	•	•	•		•		
9	•	•		•			•
10	•	•			•	•	
11	•						•
12	•						
13	•					•	•
14	•	•	•		•		•
15	•	•	•	•			•
16	•		•				
17	•						•
18	•	•			•		
#	16	8	5	2	5	4	7

Table 2: Preparatory actions mentioned by each participant in response to prompt 5

Variability in Information Seeking as Bleeding Becomes a Problem

Despite the many preparatory actions described, these are still only potential actions; whether these actions would be taken is dependent on further information seeking, as described by P2: *"But again, a lot of [these potential actions] relies on conversation with the surgeon, how [the patient's] presenting on the vital signs, ventilator, and otherwise."* All participants describe taking steps to learn more about the status of the bleeding, either by reaching out to the surgeon, assessing the blood loss from the field, and/or calculating the patient's allowable blood loss. Seven participants, like P16, begin this process by reaching out to the surgeon: *"I would speak up and say, 'Hey, we got a problem down there?' or 'Are we having some bleeding?'"* Eight other participants, like P6, would first assess blood loss from the field: *"Look at the field, see if I can see the bleeding. Listen, see if the sucker is very active. Then you look for the containers that the blood goes in where it's aspirated.… So you do your little blood assessment."* Two participants, P13 and P17, begin by calculating the allowable blood loss:

"So I'm going to run a quick calculation in my mind about how much blood loss will be allowable until we would potentially be needing like a transfusion. And so once, having done that calculation, that would sort of give me an idea of how much time I have" – P13.

Table 3 shows the different information sources mentioned by participants, and in what order those sources were mentioned. While these information sources are not mutually exclusive (two participants, P13 and P16, mentioned using all of these

information sources), the variability in what information sources are primarily used highlight the different approaches that anesthesia providers may take to assess a potentially dangerous emerging situation.

Information Seeking Sources

P	Talk to Surgeon	Look/listen for blood loss	Calculate allowable blood loss
1	**1**		
2	**1**	**2**	
3	**1**		
4		**1**	**2**
5	**1**		
6		**1**	
7		**1**	
8	**1**		
9	**1**	**2**	
10		**1**	
11		**1**	
12		**1**	
13	**3**	**2**	**1**
14		**1**	
15	**1**		
16	**1**	**3**	**2**
17	**2**		**1**
18	**2**	**1**	

Table 3: Order of information seeking sources sought in response to prompt 5. The number indicates whether the source was mentioned first, second, or third in the response.

CHAPTER FIVE

DISCUSSION AND CONCLUSION

Understanding Anesthesia Provider 'Work as Done'

These two-part interviews provide a functional context for understanding how anesthesia providers perform 'work as done.' The modified critical decision method interviews illuminated the complexity of the anesthesia domain: how variability and uncertainty make patient safety challenging. Complexity can arise from cases that require special anesthetic considerations such as robotic cases, cases with complications, or obese patients (that have mobility and dosage complications). In addition to navigating those complex cases, anesthesia providers also face unpredictable conditions; language barriers, erroneous monitors, and missing patient history are just a few of the additional challenges that anesthesia providers must manage. These challenges forced anesthesia providers to adapt; they asked creative questions and used the resources around them to find information pertinent to assuring the safest anesthesia experience they can provide.

The vignette-based interviews illuminated the strategies that anesthesia providers use to stay resilient, and the variability within those strategies. Anesthesia providers were constantly seeking information in anticipation of potential problems, looking for the worst-case scenario and preparing for it to come to fruition. These are the strategies that anesthesia providers employ to create a resilient system, one which "can adjust its functioning before, during, or following events and thereby sustain required operations under both expected and unexpected conditions (Fairbanks et al., 2014, p. 1). Inherent in

the operation of a resilient system is a variability that derives from the insufficience of protocols and the willingness to adjust required to sustain safety. For anesthesia providers, this variability means that information seeking, anticipating, and preparing is performed differently for each anesthesia provider. Thus, our understanding of anesthesia provider 'work as done' can be tied to our understanding of how anesthesia providers create a resilient system. These interviews highlight why former design efforts have failed. The complexity of the anesthesia work system requires that anesthesia providers constantly adjust and adapt to keep patients safe; prescriptive guidelines and protocols cannot account for this variability and thus anesthesia providers perform 'workarounds,' avoiding those interventions in order to continue their resilient management process.

Design Recommendations and Perspectives

Efforts to reduce medication errors or any harm in anesthesia should support, and avoid hindering, the resilience of anesthesia providers whenever possible. Anesthesia providers perform resilience by seeking out information in anticipation of things going wrong. Thus, design efforts should focus on supporting anesthesia providers in two ways: (1) supporting their ability to seek information and (2) supporting their ability to anticipate things that could go wrong.

The interviews highlight several potential avenues for supporting information seeking. P13's response to the modified critical decision method interview indicates that environmental factors can inhibit their ability to seek information, as ambient noise in the OR made it difficult for P13 to hear the patient's breathing. Designs efforts may want to incorporate the ability to isolate clean information, and conversely avoid introducing new

noise. In addition to helping anesthesia providers get clean information, design efforts should also consider the timeliness and availability of information. Anesthesia providers efforts to anticipate potential problems shows that timing of information is important, the sooner the anesthesia provider is made aware of pertinent information, the faster they can respond and act accordingly. Another design consideration identified in the vignette interview data analysis stems from the anesthesia provider's varying willingness to communicate with the surgeon. While efforts to mediate personal relationships may fall outside of an engineer's capabilities, there are other avenues to address the lack of information that may result in this circumstance. Smartly placed displays may be able to provide the anesthesia provider with the surgeon's perspective which could help the anesthesia provider anticipate surgical problems without the need for direct communication.

Additional considerations for supporting the resilience of anesthesia providers may stem from the anticipatory component for anesthesia maintenance. Anesthesia providers managed the hypothetical case by actively anticipating potential dangers. New design efforts must be careful not to introduce potential dangers unfamiliar to anesthesia providers, or it may inhibit their ability to anticipate and subsequently manage the new uncertainty introduced. Conversely, new design efforts could focus on increasing anesthesia provider's ability to anticipate potential dangers, a possible avenue of which could be encouraging anesthesia providers to share their resilient approaches/experiences with their colleagues.

Additional design considerations stem from cases that require special anesthetic considerations, such as robotic cases, cases with complications, or obese patients (that have mobility and dosage complications), which may extend the considerations required for effective information seeking and safe design. Involvement of other professionals such as perfusionists or multiple anesthesia providers may also require adaptation. Future interventions must consider the additional complexities inherent in these cases. Given the variability of anesthesia provider 'work as done,' both in the cases that an anesthesia provider is responsible for managing, and how anesthesia providers manage the same case, one set of recommendations or design is unlikely to fit all scenarios.

The complexity of the anesthesia work system and the variability between anesthesia providers identified in this work support the notion of a resilience engineering approach to designing an intervention in this field – an approach where the differences in how anesthesia providers manage a case are not inhibitive of the success of an intervention, where interventions are devoid of forcing functions, allowing anesthesia providers to continue using their own systems and strategies for success that they have personally developed over years of experience and training.

Limitations and Future Work

Anesthesia providers were interviewed during breaks in their day and thus we had a limited amount of time to interview them. As a result, we were not able to probe deeper into the rationale behind the many decisions that the participating anesthesia providers describe making throughout the interviews. These short interviews, in conjunction with the limited demographic information we could provide in order to keep anonymity, made

it difficult to assess why anesthesia providers described making one decision instead of another. Additionally, interviews were only conducted in one hospital. Systematic differences between hospitals may hinder the external validity of these results.

The vignette interviews presented the participants with a pediatric case, which gave pause to the decision making of four participants that describe being unfamiliar with pediatric work, such as P7: "*I mean, I don't do pedes here at this institution. So that for me is all you know, I probably wouldn't be doing that case."* However, two of those participants reaffirm that a 13-year-old is of similar stature to many adults and thus are unlikely to have any differences in their process, as mentioned by P12: *"We don't really do 13 year olds here anyways, but, at other facilities that I work we do and really, if he's healthy, we're not gonna take any different steps really."* The vignette-based interviews are vulnerable to the common methodological concerns for which vignettes have been criticized for, including their structural validity, whether they appropriately simulate a real-world scenario, and the subsequent external validity and generalizability of vignette responses (Barter & Renold, 2000). While tacit decisions were likely omitted in many of the participants' responses, the information that the participants did share is likely representative of their processes in a real-life scenario (Evans et al., 2015). Additionally, there were instances where participants mentioned that the vignette provides a realistic case that an anesthesia provider may encounter, such as how the surgeon mumbling about bleeding is an accurate portrayal of a possible surgeon, mentioned by P2: "*I do agree that a lot of surgeons will kind of mumble and not tell you anything."* P7 provided a

testimonial for the realism of the case as a whole: *"I mean, really cases could go just like that."*

Future work should further explore how anesthesia providers in other hospital systems may further increase the variability in the decision-making process identified in this work. Future work should also look at the medication administration process in particular, as the hypothetical case presented in our vignette did not explore the decision-making process associated with medication administrations, instead it only focused on medication determination and selection. Future work may also want to consider additional applications of the vignette methodology, as it may serve fruitful in assessing the 'work as done' anesthesia system and how new design efforts may interact with it.

Conclusion

Medication errors in anesthesia are prevalent and efforts to address medication errors bring with them new potential avenues of failure, especially when the work system and 'work as done' are not considered in the design of the intervention. We employed two methodologies in interviews of anesthesia providers to help understand the context of anesthesia 'work as done' to inform the design of future medication error-reducing interventions. Results of the first interview methodology, the critical decision method, revealed a diverse array of challenging scenarios in which 'work as done' often deviates from 'work as imagined.' The different challenging situations were diverse, making it difficult to generate emergent themes of similarities in how providers use information and make decisions. The secondary set of interviews were conducted using vignette-based interviews. Results of the vignette-based interviews revealed how the decision-making

processes of anesthesia providers may vary even when managing an identical case. These interviews highlight the potential unforeseen dangers that may occur with the addition of future interventions and also suggest avenues in which future interventions may fit better into the workflow of the anesthesia provider with design considerations. Future design efforts should focus on supporting the resilience of anesthesia providers: the information seeking and problem anticipation which are used to safely manage the uncertainty and complexity of their work. Future work should assess how ‘work as done’ may vary in different hospitals, and additionally focus on how ‘work as done’ influences the process of medication administration.

APPENDICES

Appendix A

CDM and Vignette Interview Scripts

Introduction: Hello, my name is Josh. I'm here to study how anesthesia providers like yourself make decisions. The interview will be split into two parts. For the first part, I'm going to ask you to detail a case you worked on that was particularly challenging. For the second part, I will describe a theoretical case to you and ask how you would manage the case. I am audio recording this interview so I do not have to take notes. This interview is anonymous, so please do not name specific individuals or use your name in your responses.

Part 1 – Personal Account

Obtain Unstructured Account: Onto part 1. Please think about a case that you had worked on that you found particularly challenging. A case where, in your opinion, someone else might have made different decisions than you made. Or a case that, given hindsight, you might wish to have made different decisions, such as choosing a different medication or dosage. Once you have a case in mind, please describe this case and what you did from start to finish.

(Participant response, take notes of key information)

Construct Incident Timeline: I am now going to repeat the case you shared based on my understanding. The purpose of this is to identify "decision points," basically the times where you made your decisions. Please correct any errors that you identify with my telling and fill in any gaps that you think I have missed.

(Construction of timeline)

(Decision points identified)

Decision Point Probing: Now I am going to ask you some questions about some of the decisions you made in the case you described. These questions are meant to illuminate your reasoning and decision-making process. These questions are in no way meant to be critical of the decisions you made.

Potential Probing Questions:

- What did the preoperative assessment indicate about the case?
- What information did you look for to guide that decision? Where did you look for that information? What information led you to make the decision that you made?
- Is there any other information which, if you had at the time, would have changed your decision?
- What barriers prevented you from making another decision (e.g. medication not already prepared). If these barriers did not exist, would you have made a different decision?
- If you had the same case today, is there anything you would have do differently?
- Is there anything else that you wish to say regarding this case?

Part 2 – Pediatric Vignette Response

Introduction: Onto part 2. I will now describe an anesthesia case which you will theoretically be participating in as your usual role as an anesthesia provider. I will then ask you what you would do to manage the case. Please answer as truthfully as possible. Again, this interview is anonymous, so please do not name specific individuals or use your name in your responses.

Prompt 1: You're approaching your third case of the day: an otherwise healthy 13-year-old boy is scheduled for a laparoscopic appendectomy. He is average height and weighs 45 kilograms. The case is occurring at your hospital and in the operating room that you have the most experience with. You walk into the room and start preparing for the case. You are standing next to the anesthesia machine at the head of the surgical table and you stop briefly to take in your surroundings.

Questions 1:

- Describe your environment. What do you see?
- What is your medication plan for the patient?
- What supplies and medications do you need?
- How do you check to make sure you have everything you need?

Prompt 2: The case for the 13-year-old boy's laparoscopic appendectomy begins. Induction occurs uneventfully. Surgical prep and incision also occur uneventfully. In place is a well-placed ETT and one well-functioning IV.

Questions 2:

- What do you do now?
    - What information are you using where do you get it?
    - What else are you thinking about and why?

Prompt 3: Though the case started uneventfully, it has now been 45 minutes. Frustration is growing in the room.

Questions 3:

- What do you do now?
    - What information are you using where do you get it?
    - What else are you thinking about and why?
- Do you have any reason to question or rethink your medication plan?
    - What information do you need to make this determination?

Prompt 4: The surgeon says "I have to open."

Questions 4:

- What do you do now?
    - What information are you using where do you get it?
    - What else are you thinking about and why?
- Do you have any reason to question or rethink your medication plan?
    - What info do you need to make this determination?

Prompt 5: It has now been five minutes since the patient was opened. The surgeon begins to mumble under their breath about some "damn bleeding." Your gut is telling you that something's not quite right.

Questions 5:

- What do you do now?
    - What information are you using where do you get it?
    - What else are you thinking about and why?
- Do you have any reason to question or rethink your medication plan?
    - What info do you need to make this determination?
- Do you have any final thoughts on the case?

REFERENCES

Ajmal, M. (2011). Accidental intrathecal injection of aminophylline in spinal anesthesia. *Anesthesiology*, *114*(4), 998–1000. https://doi.org/10.1097/ALN.0b013e31820d86a7

Bachmann, L. M., Mühleisen, A., Bock, A., Ter Riet, G., Held, U., & Kessels, A. G. H. (2008). Vignette studies of medical choice and judgement to study caregivers' medical decision behaviour: Systematic review. *BMC Medical Research Methodology*, *8*, 1–8. https://doi.org/10.1186/1471-2288-8-50

Barter, C., & Renold, E. (2000). I wanna tell you a story: Exploring the application of vignettes in qualitative researchwith children and young people. *International Journal of Social Research Methodology*, *3*(4), 307–323. https://doi.org/10.1080/13645570050178594

Catchpole, K., & Alfred, M. (2018). Industrial Conceptualization of Health Care Versus the Naturalistic Decision-Making Paradigm: Work as Imagined Versus Work as Done. *Journal of Cognitive Engineering and Decision Making*, *12*(3), 222–226. https://doi.org/10.1177/1555343418774661

Craig, J., & Wilson, M. E. (1981). A survey of anaesthetic misadventures. *Anaesthesia*, *36*(10), 933–936. https://doi.org/10.1111/j.1365-2044.1981.tb08650.x

Cuvelier, L., & Falzon, P. (2011). Coping with uncertainty. Resilient decisions in anaesthesia. *Resilience Engineering in Practice: A Guidebook*, (January 2011), 29–43. https://doi.org/10.1201/9781317065265-3

Eichhorn, J. H. (2010). APSF Hosts Medication Safety Conference. Consensus Group Defines Challenges and Opportunities for Improved Practice. *APSF Newsletter*, *25*(1), 1–20. Retrieved from http://www.apsf.org/newsletters/pdf/spring_2010.pdf%5Cnpapers2://publication/uuid/5BD6DDDE-F510-49B6-8BC3-4FE7353C0662

Endsley, M. R. (1997). The Role of Situation Awareness in Naturalistic Decision Making. In C. Zambock & G. Klein (Eds.), *Naturalistic Decision Making* (pp. 269–284). Mahway, NJ: Lawrence Erlbaum.

Engelhardt, T., Ayansina, D., Bell, G. T., Oshan, V., Rutherford, J. S., & Morton, N. S. (2019). Incidence of severe critical events in paediatric anaesthesia in the United Kingdom: secondary analysis of the anaesthesia practice in children observational trial (APRICOT study). *Anaesthesia*, *74*(3), 300–311. https://doi.org/10.1111/anae.14520

Evans, S. C., Roberts, M. C., Keeley, J. W., Blossom, J. B., Amaro, C. M., Garcia, A. M., … Reed, G. M. (2015). Vignette methodologies for studying clinicians' decision-making: Validity, utility, and application in ICD-11 field studies. *International Journal of Clinical and Health Psychology*, *15*(2), 160–170. https://doi.org/10.1016/j.ijchp.2014.12.001

Fairbanks, R. J., Wears, R. L., Woods, D. D., Hollnagel, E., Plsek, P., & Cook, R. I. (2014). Resilience and resilience engineering in health care. *Joint Commission Journal on Quality and Patient Safety*, *40*(8), 376–383.

https://doi.org/10.1016/S1553-7250(14)40049-7

Fasting, S., & Gisvold, S. E. (2000). Adverse drug errors in anesthesia, and the impact of coloured syringe labels. *Canadian Journal of Anesthesia*, *47*(11), 1060–1067. https://doi.org/10.1007/BF03027956

Fioratou, E., Chatzimichailidou, M. M., Grant, S., Glavin, R., Flin, R., & Trotter, C. (2016). Beyond monitors: distributed situation awareness in anaesthesia management. *Theoretical Issues in Ergonomics Science*, *17*(1), 104–124. https://doi.org/10.1080/1463922X.2015.1106620

Gage Parr, K. (2019). Medication Error Related to Look-Alike Prefilled Syringes. *APSF Newsletter*, (October), 51.

Glavin, R. J. (2010). Drug errors: Consequences, mechanisms, and avoidance. *British Journal of Anaesthesia*, *105*(1), 76–82. https://doi.org/10.1093/bja/aeq131

Grigg, E. B., & Roesler, A. (2018). Anesthesia Medication Handling Needs a New Vision. *Anesthesia and Analgesia*, *126*(1), 346–350. https://doi.org/10.1213/ANE.0000000000002521

Holden, R. J., Carayon, P., Gurses, A. P., Hoonakker, P., Hundt, A. S., Ozok, A. A., & Rivera-Rodriguez, A. J. (2013). SEIPS 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients. *Ergonomics*. Taylor & Francis. https://doi.org/10.1080/00140139.2013.838643

Hollnagel, E. (2014). *Safety-I and safety-II: The past and future of safety management*.

Safety-I and safety-II: The Past and Future of Safety Management (Vol. 0139). Ashgate Publishing, Ltd. https://doi.org/10.1080/00140139.2015.1093290

Huang, R. (2016). RQDA: R-based Qualitative Data Analysis. Retrieved from http://rqda.r-forge.r-project.org/

Hughes, R., & Huby, M. (2002). The application of vignettes in social and nursing research. *Journal of Advanced Nursing*, *37*(4), 382–386. https://doi.org/10.1046/j.1365-2648.2002.02100.x

Ismail, S., & Taqi, A. (2013). Medical errors related to look-alike and sound-alike drugs. *Anaesthesia, Pain and Intensive Care*, *17*(2), 117–122.

James, R. H. (2003). 1000 anaesthetic incidents: Experience to date. *Anaesthesia*, *58*(9), 856–863. https://doi.org/10.1046/j.1365-2044.2003.03334.x

Khan, S. A., Khan, S., & Kothandan, H. (2016). Simulator evaluation of a prototype device to reduce medication errors in anaesthesia. *Anaesthesia*, *71*(10), 1186–1190. https://doi.org/10.1111/anae.13600

Kitson, A., Harvey, G., & McCormack, B. (1998). Enabling the implementation of evidence based practice: a conceptual framework. *Quality and Safety in Health Care*, *7*(3), 149–158. https://doi.org/10.1136/qshc.7.3.149

Klein, G. a. (1993). *A recognition-primed decision (RPD) model of rapid decision making*. *Decision Making in Action: Models and Methods*. https://doi.org/10.1002/bdm.3960080307

Klein, G. a, Calderwood, R., & Macgregor, D. (1989). Critical Decision Method for Eliciting Knowledge. *Ieee Transactions On Systems Man And Cybernetics*, *19*(3), 462–472. Retrieved from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=31053

Manser, T., & Wehner, T. (2002). Analysing Action Sequences: Variations in Action Density in the Administration of Anaesthesia. *Cognition, Technology & Work*, *4*(2), 71–81. https://doi.org/10.1007/s101110200006

Merry, A. F., Webster, C. S., Hannam, J., Mitchell, S. J., Henderson, R., Reid, P., … Short, T. G. (2011). Multimodal system designed to reduce errors in recording and administration of drugs in anaesthesia: Prospective randomised clinical evaluation. *BMJ (Online)*, *343*(7826), 1–14. https://doi.org/10.1136/bmj.d5543

Miller, R. D., & Pardo, M. C. J. (2011). *Basics of Anesthesia* (6th ed.). Elsevier Health Sciences.

Nanji, K. C., Patel, A., Shaikh, S., Seger, D. L., & Bates, D. W. (2016). Evaluation of Perioperative Medication Errors and Adverse Drug Events. *Anesthesiology*, *124*(1), 25–34. https://doi.org/10.1097/ALN.0000000000000904

Noy, C. (2008). Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology*, *11*(4), 327–344. https://doi.org/10.1080/13645570701401305

Peabody, J. W., & Liu, A. (2007). A cross-national comparison of the quality of clinical

care using vignettes. *Health Policy and Planning*, *22*(5), 294–302. https://doi.org/10.1093/heapol/czm020

Peabody, J. W., Luck, J., Glassman, P., Dresselhaus, T. R., & Lee, M. (2000). Comparison of vignettes, standardized patients, and chart abstraction: A prospective validation study of 3 methods for measuring quality. *Journal of the American Medical Association*, *283*(13), 1715–1722. https://doi.org/10.1001/jama.283.13.1715

Phipps, D. L., & Parker, D. (2014). A naturalistic decision-making perspective on anaesthetists' rule-related behaviour. *Cognition, Technology and Work*, *16*(4), 519–529. https://doi.org/10.1007/s10111-014-0282-2

Ross, S., Moffat, K., McConnachie, A., Gordon, J., & Wilson, P. (1999). Sex and attitude: A randomized vignette study of the management of depression by general practitioners. *British Journal of General Practice*, *49*(438), 17–21.

Schnittker, R., Marshall, S., Horberry, T., & Young, K. L. (2018). Human factors enablers and barriers for successful airway management – an in-depth interview study. *Anaesthesia*, *73*(8), 980–989. https://doi.org/10.1111/anae.14302

Schnittker, Raphaela, Marshall, S., Horberry, T., Young, K., & Lintern, G. (2017). Exploring Decision Pathways in Challenging Airway Management Episodes. *Journal of Cognitive Engineering and Decision Making*, *11*(4), 353–370. https://doi.org/10.1177/1555343417716843

Smith, A. F., & Plunkett, E. (2019). People, systems and safety: resilience and excellence

in healthcare practice. *Anaesthesia*, *74*(4), 508–517. https://doi.org/10.1111/anae.14519

Wahr, J. A., Abernathy, J. H., Lazarra, E. H., Keebler, J. R., Wall, M. H., Lynch, I., … Cooper, R. L. (2017). Medication safety in the operating room: Literature and expert-based recommendations. *British Journal of Anaesthesia*, *118*(1), 32–43. https://doi.org/10.1093/bja/aew379

Wainwright, P., Gallagher, A., Tompsett, H., & Atkins, C. (2010). The use of vignettes within a Delphi exercise: A useful approach in empirical ethics? *Journal of Medical Ethics*, *36*(11), 656–660. https://doi.org/10.1136/jme.2010.036616

Webster, C. S., & Merry, A. F. (2017). Forcing functions and their consequences. *Anaesthesia*, *72*(2), 266–267. https://doi.org/10.1111/anae.13796

Webster, C. S., Merry, A. F., Larsson, L., McGrath, K. A., & Weller, J. (2001). The frequency and nature of drug administration error during anaesthesia. *Anaesthesia and Intensive Care*, *29*(5), 494–500. https://doi.org/10.1177/0310057X0102900508

Wittich, C. M., Burkle, C. M., & Lanier, W. L. (2014). Medication errors: An overview for clinicians. *Mayo Clinic Proceedings*, *89*(8), 1116–1125. https://doi.org/10.1016/j.mayocp.2014.05.007

Wong, B. L. W. W. (2004). Data Analysis for the Critical Decision Method. *The Handbook of Task Analysis for Humancomputer Interaction*, (April), 327–345.

Yamamoto, M., Ishikawa, S., & Makita, K. (2008). Medication errors in anesthesia: An

8-year retrospective analysis at an urban university hospital. *Journal of Anesthesia*, *22*(3), 248–252. https://doi.org/10.1007/s00540-008-0624-4

Yang, Y., Rivera, A. J., Fortier, C. R., & Abernathy, J. H. (2016). A Human Factors Engineering study of the Medication Delivery Process during an Anesthetic. *Anesthesiology*, *124*(4), 795–803.