# THE COMPLEX EXPERIENCE OF SURGEON STRESS

# IN THE OPERATING ROOM

by

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Natashia Martina Seemann Masters of Science Institute of Medical Sciences University of Toronto 2016

## ABSTRACT

**Background**: Surgery is a demanding career; however, research examining acute surgeon stress is lacking.

**Objectives**: The aim of this study was to capture and explore surgeon stress in the operating room (OR) using a multifaceted methodology.

**Methods**: This exploratory pilot study collected surgeon's stress data from four facets: physiologic, cognitive, affective and sociocultural. Physiologic data included ECG and cortisol. Affective, cognitive and sociocultural data were captured through inventories, interviews, and observer notes. Data triangulation was used for analysis, focusing on moments of perceived and physiologic stress.

**Results**: A methodology to capture surgeon stress in the OR was refined. Heart rate and heart variability proved the most reliable, sensitive and specific physiologic stress data, but conveyed limited information without perceived stress data. The relationship between perceived and physiologic stress is complex and perceived stress can be present without physiologic stress and vice versa.

**Conclusions**: A multifaceted methodology is necessary to understand the complex surgeon stress experience.

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Dr. Mutabdzic assisted in brainstorming ideas for the project, and helped with data analysis and editing.

Ms. Gimon assisted in the literature review portion of this project. She also assisted in data collection and analysis.

Mr. Kyle Tsang assited in the data analysis of this project, specifically with respect to the software analysis of the physiologic data.

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## LIST OF ABBREVIATIONS

- ACTH- adrenocorticotropic hormone
- BP- blood pressure
- BPM- beats per minute
- ECG- electrocardiogram
- EDA- electrodermal activity
- GSR- galvanic skin response
- HF- high frequency
- HR- heart rate
- HPA- hypothalamic-pituitary axis
- HRV- heart rate variability
- LF- low frequency
- OR- operating room
- PANAS- Positive and Negative Affect Schedule
- POMS- Profile of Mood States
- RR- respiratory rate
- RSA- respiratory sinus arrhythmia
- sAA- salivary alpha amylase
- SNS- sympathetic nervous system
- STAI- State-Trait-Anxiety-Inventory
- VAS- Visual Analogue Scale

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#### **INTRODUCTION & OBJECTIVES**

Although chronic stress and burnout have been extensively studied in medicine [1-5], acute stress remains a relatively recent area of research [6]. The implications of acute stress on a physician's performance during a critical task, and subsequent patient outcomes, are important to understand as demonstrated by Leblanc et al.'s review [6] of the effects of acute stress on performance. Simulation studies have demonstrated that acute stress can affect not only technical skills [7-13], but also non-technical skills such as communication, teamwork and diagnostic decision-making [14-16].

The most widely accepted definition of acute stress states that it is an individual's response to a "high demand, high threat situation" [17]. The phenomenon of acute stress is a discrete event that takes place over minutes or hours. An acutely stressful event has an identifiable stressor that meets one or more of the following criteria: the situation must be interpreted as either novel or unpredictable, or the individual must feel a lack of control over the situation [18]. The study of stress in surgeons may be especially important due to the high demands and threats they are exposed to in the operating room (OR), and yet little research has been done in this area and only in recent years.

Over the last decade, many similarities have been drawn between the aviation industry and the OR. Two of the most notable are the introduction of an aviation-type black box used in the OR's [19] and the OR checklist which was originally adopted from from aviation [20]. This association is not surprising given the similarities between the two fields: both rely on experts having excellent technical and non-technical skills, human lives depend on both and both need to be able to deal with high acuity emergency situations that depend on their ability to manage stress well. While the aviation industry has put considerable effort into the study of acute stress in the cockpit, the study of acute stress in the OR is a relatively recent endeavor. Upon initial review of the literature, it became evident that the majority of studies that looked at stress in surgeons, had either focused on aspects of chronic stress, such as burnout, or had been carried out in a simulation setting. The few studies that had aimed to look at acute stress in the naturalistic OR environment, had often done so by looking at a single physiologic variable and correlating this with an outcome of interest such as error. The review of the literature demonstrated that stress is much more complex than simply physiology – it is a phenomenon that includes emotion, cognition and the complex interplay of environment and culture. Therefore, the primary aim of this study was to explore the experience of acute stress in surgeons more completely, collecting data from four components of the stress experience: physiology, cognition, emotion and culture.

In order to accomplish this, a multifaceted case study methodology was created, which aimed to capture differing aspects of the stress experience. This was an exploratory pilot study as no other research groups have attempted to capture stress as a complex phenomenon in this setting previously. The goal was to capture a wide variety of data with the aim of being able to determine which data points are most useful in the study of stress in the OR, and to determine their feasibility in this setting. The objective was to refine a succinct methodology to be used in future studies of stress in the OR.

A secondary objective of the pilot study was to explore the relationship between perceived and physiologic stress by surgeons in the OR. Several previous studies have attempted to correlate perceived and physiologic stress [21, 22], but the results have been confusing as the two generally do not correlate. In fact, a review by Campbell and Ehlert demonstrated that the majority of studies looking at the interaction between physiologic and subjective stress response failed to show a consistent relationship [23]. While studying and understanding both the subjective stress experience, and the physiologic stress experience are important, correlation is likely not the appropriate method for examining this relationship. Furthermore, a physiologic variable alone provides very little context as to why and how the surgeon is experiencing stress. Therefore, in this study we used data triangulation, a method that combines data from different methodologies (quantitative and qualitative) in the study of the same phenomenon. It should be emphasized that the goal of this pilot study was not to test a hypothesis, but rather to generate hypotheses for future studies to examine.

Therefore, the objectives of this exploratory pilot study were to:

- Refine a methodology for the study of stress as experienced by surgeons in the OR.
- Examine the relationship between perceived and physiologic stress as experienced by surgeons in the OR.

This thesis is presented in a paper-style in accordance with the Institute of Medical Sciences graduate program. The first paper is a review of the study of acute stress in the health professions. The second paper is a presentation of the methodology used in this exploratory pilot study, and recommendations of use of this methodology for future studies. The third paper is a presentation of the results of the study highlighting the complexity of surgeon stress and the relationship between physiologic and perceived stress.

#### **CHAPTER ONE: STRESS AS STUDIED IN THE HEALTH PROFESSIONS**

#### Introduction to Review

The review paper presented here is the result of a literature review undertaken as the introductory phase of this project. At the time this literature review was initially performed, the research team was in the introductory phases of designing this study and looked to previous work in the field for evidence on how best to capture and measure acute stress. It became evident that there was a paucity of data looking at the phenomenon of stress as a whole – including not only physiologic data, but also the cognitive, affective and sociocultural perspectives. Often studies used only one measure of stress (ie. heart rate) and attempted to draw conclusions about how this would effect performance.

The aim of this specific study was to explore the experience of acute stress by surgeons in the OR, but it was felt that the broader research community would benefit from a review examining how acute stress has been measured in the health professions. Therefore this literature review was extended to capture studies outside the realm of surgery, and even medicine. This provided a wealth of valuable studies not available through the strictly surgical literature.

The aim of this review paper was to present the methods through which acute stress have been measured in the health professions, the strengths and weaknesses of each measure on its own, and recommend a multifaceted methodology for future studies. This review paper has been submitted as a Research in Medical Education (RIME) Review Paper. If accepted, it will be presented at the Association of American Medical Colleges (AAMC)'s Learn Serve Lead Conference and then published in Academic Medicine.

# Capturing the Complexity of Acute Stress in the Health Professions: A Review of Methods for Measuring Stress and Suggestions for Moving Forward

Natashia M. Seemann, Tamara I. Gimon, Dorotea Mutabdzic, Vicki R. LeBlanc, Carol-anne E. Moulton

# **Abstract**

*Objectives:* Understanding acute stress in healthcare professionals has important implications for the wellness of providers and potentially, patient outcomes. Previous studies of stress in healthcare have often explored one dimension of the stress phenomenon in isolation or in a simulated setting. This review seeks to summarize the current landscape and propose a multidimensional methodology for capturing and studying the complexity of acute stress in healthcare professionals.

*Method:* A scoping review of the literature was performed to identify studies from MEDLINE, EMBASE and PsychINFO up to and including 2015. Identified studies were categorized by methodology used to measure acute stress. The differing methods used were then critically analyzed to identify strengths and limitations.

*Results:* The major methodological approaches to studying stress that were identified were physiologic, cognitive, affective and sociocultural. Measures of physiologic variables attributed to the stress response were most commonly collected in the literature. While sensitive, many physiologic measures lacked specificity and context. Self-reported inventory scales were commonly used in cognitive and affective based methodologies, but were not always directly measuring stress and are subject to limitations due to recall bias and misattribution. Sociocultural investigations have been limited, but provide important insight into previously underexplored aspects of the acute stress experience.

*Conclusions:* The current literature introduces several techniques for studying acute stress in health professionals. Each approach individually lacks specificity and is limited in providing context. A methodological approach focused on triangulating all components is needed to gain better understanding of the causes, experiences and effects of acute stress in the health professions.

#### **Introduction**

The concept of stress is complex and universally important, evident by the diversity in data collection methods used to measure stress across a multitude of disciplines. Understanding stress and its effects has been a pursuit of physiologists, psychologists, sociologists and anthropologists, each viewing stress with unique perspectives. The term stress was first coined in the 1930's by Dr. Hans Selye, an endocrinologist who viewed stress as a negative generalized response to physical stimuli[24]. He described the role of the Hypothalamic-Pituitary Axis (HPA) in the stress response and thus provided a method for identifying and quantifying stress in participants by measuring stress hormones[25]. Shortly thereafter, other researchers postulated and demonstrated that psychological stimuli [18]. It became evident that stress contained a major psychological component and was more than just a physiologic response to physical stimuli. As such, researchers recognized that other methods for identifying and measuring stress were needed – measures that were able to capture the cognitive, emotional and sociocultural components of stress.

Cognitive psychologists theorized that stress is a highly individualized phenomenon. They demonstrated that the perception of stress is dependent on an individual's unique analysis of a situation; whether they have the resources available to meet a demand, and whether the demand threatens a personal goal[26]. This is known as the "appraisal theory", and is a leading model of stress in cognitive psychology. Other fields of psychology studied

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stress as an affective phenomenon. Inventories, such as the State-Trait-Anxiety-Inventory[27], have been developed to identify and study stress as an emotional response to stimuli. Sociologists and anthropologists have theorized that individuals are embedded in a rich sociocultural environment, which affects not only the way they experience stress, but also how they manifest stress[28]. Within this perspective, the individual's experience of stress does not occur in isolation and the sociocultural context must be taken into account as an important moderator.

Stress is a frequently used term in our society but has various meanings depending on the context. Although it can be difficult, it is important to distinguish between acute and chronic stress. The classical definition of acute stress states that it is an individual's response to a "high demand, high threat situation" [17]. However, this classical definition was formed in a physiologic perspective. As the study of stress evolved from other approaches such as the cognitive, affective, and sociocultural ones, new definitions of acute stress arose. Therefore, acute physiologic stress is described as a discrete event that takes place over minutes or hours. An acutely stressful event has an identifiable stressor that meets one or more of the following criteria: the situation must be interpreted as either novel or unpredictable, or the individual must feel a lack of control over the situation [18]. In acute physiologic stress there is one exposure to the stressor, a stress response occurs, and the body returns to homeostasis once the stressor has been removed [29]. This normal physiologic response is designed to help the body deal with a stressful stimulus [24]. Over time, discrete acute stress events can become chronic stress. Chronic stress is defined as repeated exposure to a specific stressor over time, with a blunted response and a delay or failure to return to physiologic homeostasis[29]. While the acute stress response can be productive, chronic stress is pathologic and can lead to longterm psychological and physical health issues[30].

In the health professions literature, chronic stress has been extensively studied and has shown to be strongly linked to burnout[1-5]. Although acute stress has been extensively studied in other high-risk professions, such as the military and aviation fields, it remains a

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relatively recent area of research in the health professions[6]. The implications of acute stress on a healthcare provider's performance during a critical task, and subsequent patient outcomes, are also important to understand as demonstrated by LeBlanc et al.'s review[6] on the effects of acute stress on performance. Simulation studies have demonstrated that acute stress can affect not only a healthcare professional's technical skills[7-13], but also non-technical skills such as communication, teamwork and diagnostic decision-making[14-16]. In order to examine the effect of acute stress on the healthcare provider, the researcher must be able to accurately identify the presence of acute stress as well as link this acute stress episode to both the stressor and the outcome of study (ie. physician wellness, team interactions, patient outcomes, etc).

While each approach to studying acute stress has revealed important insights, no individual approach has led to a comprehensive understanding of this complex human experience. Within the study of human behavior, there has been an evolution of understanding from early Cartesian dualism viewing the mind and body as completely separate entities to a more physiologic approach attempting to reduce all behavior to its neurobiological elements to ultimately recognize that there can be multiple interacting levels of explanation of human behaviour[31]. Similarly, research on acute stress has shown that physiology can affect cognition and that emotion and social context can affect physiology[6, 32, 33] suggesting that the different approaches to studying stress may interact. Whereas traditionally, researchers perhaps tended to dismiss aspects of stress that did not fit within their narrow definitions as simply not representing true stress, a more modern perspective is one where acute stress can be seen as having physiologic, cognitive, affective, and sociocultural components all contributing to a broader acute stress experience.

This review seeks to examine existing approaches to studying acute stress in the health professions and to highlight the need for a more comprehensive methodology for future research in real-world healthcare environments. Such a multi-perspective methodology will guide efforts geared towards understanding a healthcare professional's wellness as well as its implications for patient care and outcomes.

# Methodology

A scoping review of the literature was performed in order to map the existing literature in the study of stress in the health care professions – in particular to understand the volume, nature and characteristics of the subject up until now [34]. This type of review was used rather than a traditional systematic review as it is generally more appropriate when a topic is of complex or heterogeneous nature [35]. This took place in an iterative fashion – first databases MEDLINE, EMBASE and PsychINFO were reviewed for relevant studies. From these, further collection of studies took place from bibliographies of studies, key journals, conferences and presentations of yet unpublished work. The aim of this scoping review was to provide a landscape of how stress in the health professions has been studied thus far, and identify research gaps for future studies.

#### The Study of Acute Stress in the Health Professions

#### Stress as a Physiologic Phenomenon

An acutely stressful event manifests physiologically through the activation of the Sympathetic Nervous System (SNS) and the Hypothalamic-Pituitary-Axis (HPA)[36]. The hypothalamus responds to a stressful stimulus by secreting corticotropin-releasing hormone, which in turn stimulates the pituitary gland to secrete adrenocorticotropic hormone (ACTH). ACTH acts on the adrenal glands to produce two main classes of hormones: glucocorticoids (i.e. cortisol) as well as catecholamines (i.e. epinephrine and norepinephrine). The catecholamine surge is then responsible for the activation of the SNS during a stressful event. This creates the "fight or flight" response with associated increases in heart and respiratory rates[37]. While the SNS response is quick and transient, the HPA response has a slower onset and can be more chronic[38]. As a stress hormone, cortisol acts primarily to increase blood sugar through promotion of gluconeogenesis. This in turn prepares the body to meet the demands of the stressor through provision of energy. In the brain, corticosteroids act on structures involved with cognition, specifically learning and memory: the amygdala, hippocampus and prefrontal cortex[39, 40]. Based on both the SNS and HPA physiologic responses, researchers have been able to use measurable biologic parameters as markers of increased stress in participants.

The great majority of researchers studying stress in the health professions have done so by measuring its physiologic manifestations and effects. These studies have used various permutations of physiologic measures linked to the stress response to measure acute stress and the outcomes related to it. Due to the relative ease of collection, heart rate (HR) and blood pressure (BP) have been the most commonly used physiologic measures in the reviewed literature. One or both have been used as markers of the stress response in studies of orthopedic surgeons[41], surgical trainees[42, 43], neurosurgeons[44], nurses[45], and anesthesiologists[22]. In addition, sweat gland activity is increased as part of the sympathetic activation associated with the stress response; the galvanic skin response (GSR) has been validated as a correlate of sweat-gland activity[46]. The GSR has also been used in several studies as a measure of acute stress, including surgeons performing tasks on laparoscopic simulators[47], physicians in simulated 'breaking bad news' scenarios[48], and members of a healthcare team involved in simulated airway emergencies[22].

The existing literature demonstrates a trend towards linking stressful events with measureable physiologic changes, and subsequently associates these changes with poorer performance. However, identifying and quantifying acute stress by physiologic parameters alone is subject to several confounders. The primary issue with using HR, BP or GSR as measures of acute stress is that elevations in these measures demonstrate physiologic arousal but do not necessarily represent physiologic stress. In other words, although these measures are sensitive, they are not specific to the physiologic stress responses[49]. The SNS activation can occur for reasons other than stress such as exercise, excitement and pain[50]. For example, a code-blue team leader's HR may be elevated due to arousal in an intense situation. However, if they feel equipped to deal with the task at hand, the HR elevation may not be reflecting acute

stress, but rather, challenge. Likewise, an emergency physician's GSR may be elevated simply due to the high heat required in a trauma resuscitation room.

Several studies have used heart rate variability (HRV), a more specific measure of stress than HR alone[51]. HRV is the variation in the time interval between heartbeats, and several different methods for detecting and calculating HRV exist[52]. While HR *increases* under conditions of stress, HRV *decreases* as a result of increased sympathetic signaling and decreased parasympathetic vagal modulation[53]. Czyzewska et al. studied HRV as a surrogate of the surgeon's mental load[54]. Bohm et al. compared the HRV of surgeons during laparoscopic and open procedures as a measure of stress in the varying cases[55]. Demirtas et al. demonstrated that plastic surgeons had decreased HRV on operating days compared to nonoperating days[56]. Kuhn et al. measured HRV of cardiac surgeons and their trainees while performing surgery and found the attending surgeons had lower HRV than the residents, particularly when they were supervising the residents performing critical steps of the surgery[57]. A study of physicians breaking bad news to their patients demonstrated increased HR and decreased HRV during the task[58]. HRV has also been used to evaluate the stress response in several studies of physicians working overnight shifts[59, 60].

In recent years, the measure of salivary alpha-amylase (sAA) has been proposed as a useful marker of SNS activity[61]. sAA reflects serum catecholamine levels, yet being salivary, is much easier to collect than serum and is therefore considered a useful marker for the stress response[61]. It has only recently been used in a limited number of healthcare studies, including one examining acute stress in shift-working healthcare professionals[62], and one in emergency room physicians and paramedics during a high-fidelity simulation[63].

To measure the HPA-axis of the stress response, salivary cortisol has been shown to be a sensitive and specific measure of stress[33] and is by far the most commonly used measure of stress in the psychology literature. Salivary cortisol was used as the primary measure of physiologic stress in neonatal and pediatric critical care nurses and physicians in a study by Fischer et al.[64]. Engelmann et al. used salivary cortisol as the main measure of acute stress in

a study implementing a noise reduction program in pediatric operating rooms[65]. It has also been used as the primary measure of physiologic stress in emergency medicine and general surgery residents[66], paramedics[8] and child protection workers[67] by LeBlanc's group.

Salivary cortisol can, however, be difficult to use in practice, particularly in real-world settings. The cortisol peak in response to a stressor occurs 20-40 minutes following the onset of the stressor[68] and typically returns to baseline one hour after stress cessation[69]. In a simulation setting, the onset of the stressor is controlled and predictable making the timing of the subsequent cortisol collection straightforward, but this is challenging in a naturalistic setting, and several stressors may present concurrently. The salivary cortisol level can also be affected by a number of factors that can be difficult to control in subjects such as exercise, caffeine consumption, and smoking. In addition, there is a normal diurnal variation of cortisol due to an individual's circadian rhythm[70]. Despite its limitations in certain applications, salivary cortisol remains the most commonly used specific measure of stress in the literature.

To further increase the likelihood of identifying acute stress, several studies have combined the collection of SNS and HPA markers. Rauchenzauner et al. performed 24-hour ECG and BP monitoring in combination with urine and serum samples for cortisol in physicians during on-call shifts and regular work-days[59]. In a study of pediatric critical care nurses, Looser et al. used salivary cortisol in addition to HR and HRV to measure acute stress and found that in times of 'high stress' there was a correlation between cortisol and HRV, but that in times of 'low stress' this correlation was lost suggesting that the HPA and SNS systems function independently[71]. A study by Goldstein et al. in female nurses measured 24-hour ambulatory BP and HR in addition to urine catecholamines and cortisol[45]. In a study by McGaw et al. BP, HR, sAA, and salivary cortisol were collected as measures of the acute stress response in 38 combat nurses encountering a crisis simulation scenario[72]. Interestingly, some studies have shown that serum epinephrine changes appear to be markers of psychological causes of acute stress events while serum norepinephrine more closely reflects physical stressors[73, 74]. While sAA and cortisol are well-accepted biomarkers of stress, there is a lack of correlation between the two[75], further supporting the complexity of the stress response. It is believed that the two physiologic systems (SNS and HPA) may respond differently to different kinds of stressors. For example, the HPA response appears to be more reactive to psychosocial stressors such as social evaluation and performance[76]. There is a suggestion that the ratio of sAA over cortisol may be a more sensitive measure of stress than either alone since it reflects both SNS and HPA activity[77]. These findings support not only the complexity of the stress response, but also the importance of a multifaceted approach to the study of acute stress given the multiple systems involved.

Interpretation of the studies using the physiologic stress response can be challenging for a number of reasons. Physiologic variables of the SNS, such as HR and BP, are not specific for stress and can be affected by multiple other factors such as the physician's fitness level and caffeine consumption[49]. Using HRV to study acute stress is more specific, although many calculations for HRV are available making comparison across studies difficult. Studies collecting surrogates of the HPA axis in addition to physiologic surrogates of SNS activation have attempted to increase the specificity of their methodology for acute stress, but these measures also have certain limitations. Serum and salivary cortisol levels and urinary catecholamines are constantly fluctuating, and capturing only one moment in time does not allow us to confidently draw conclusions about a person's level of stress at that exact moment. Furthermore, the HPA system shows rapid habituation, so repeated stressors show blunted cortisol responses over time when the subjective stress response remains increased[67].

These findings all support the notion that the 'acutely stressful event' is one that supersedes simple physiologic arousal; it is strongly influenced by an individual's interpretation of a situation[18]. While measures of the SNS and HPA stress response can be both specific and sensitive to acute stressors, the physiologic variables alone provide limited understanding of the cause and individual context of the acute stress response. Most importantly, if one cannot be sure acute stress is being accurately identified, it is impossible to draw conclusions about

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how that stress may be affecting the endpoint of interest – mental strain, technical skills, nontechnical skills and ultimately, patient outcomes.

#### Stress as a Cognitive Phenomenon

Stress is a highly individualized phenomenon because an individual's perception of stress is dependent on his or her unique analysis of the situation, the resources he or she has to meet the demand, and whether or not this demand threatens a valuable personal goal[26]. According to the appraisal theory, one of two types of psychological responses can manifest following this appraisal. When the resources are assessed as being sufficient to meet the demands, the situation is deemed a challenge and a positive psychological state of 'eustress' ensues. When the demands are assessed as outweighing the resources of the individual, the situation is assessed as a threat and a negative psychological state of 'distress' ensues. Therefore, an individual's cognitive appraisal is based on the perceived demands of the task and the perceived or actual resources of the individual in the stressful setting. For example, a surgeon may encounter an unexpected anatomic abnormality during a difficult operation, but if she perceives that her operative team is competent to help her manage this she may not cognitively appraise the situation as stressful. A stressful stimulus can also be interpreted differently by individuals based on a number of factors such as specific personality characteristics and distorted self-perception[78].

In order to measure the cognitive facet of stress, researchers within the health professions have used several different tools. Harvey et al. measured cognitive appraisal in residents before and after high- and low-stress trauma simulation scenarios[32] using a method described by Tomaka et al.[79]. The cognitive appraisal was measured as the subjective assessment of situational demands (*How demanding was the task you just completed?*) and available resources to deal with the demand (*How able were you to cope with this task?*). Another type of data collection method, qualitative interviews, allows researchers to gain a deeper understanding of a phenomenon and provide a useful way to study *how* healthcare workers think about acute stress and *why* they feel that way. A study by Shaw et al. used qualitative interviews to explore how physicians thought and felt about stress associated with 'breaking bad news' to patients[80]. This study demonstrated that complex factors such as patient characteristics and the culture of medicine affected the interpretation and experience of acute stress for physicians. Qualitative interviews allow researchers to gather more descriptive and detailed data regarding the cognitive appraisal of a stressful situation.

Measuring cognitive stress may not be as 'clean' or 'objective' as measuring physiologic stress, and is likely a reason why fewer attempts have been made in health professions research to measure cognitive stress. It may also be that because cognitive stress is considered 'subjective' it is less valued in the scientific community than 'objective' physiologic values and numbers. Even within the field, there is a lack of agreement of the best tool to measure cognitive stress. Furthermore, particularly in a naturalistic healthcare setting, participants are often asked to fill out an inventory after a stressful event has occurred. Therefore, their answers to inventory questions may be affected by their memory [81] as well as the outcome of the stressful event. For example, if the outcome of a code-blue resuscitation was that the patient had return of spontaneous circulation, the members of the code team may be elated with the success and thus have difficulty remembering how acutely stressed they felt during the resuscitation. There may also be an issue of 'impression management' [82] where health professionals may not admit to stress, or in other cases over represent their level of stress depending on the situation. Finally, while cognitive stress is studied in isolation, it is difficult to separate the causes and effects of cognitive stress from those produced by emotive or sociocultural conditions. For example, when asking a physician to weigh the resources they had to deal with a stressful patient encounter, their baseline emotion that day, the environmental setting, as well as the culture they are immersed in will likely affect their perceived resources.

#### Stress as an Affective Phenomenon

Stress itself can manifest as several different affective states. The most common is anxiety, but stress can also manifest as anger, irritation or fear[83]. Almost universally, stress is thought of as a negative emotion.

In the field of health-professional research, studies have used inventories designed to capture the subjective experience of stress. By far the most commonly used affective inventory to study stress in medicine has been the State-Trait-Anxiety-Inventory (STAI), which measures the individual's level of anxiety at a given moment in time[84]. This tool has been used in several studies with varying medical populations such as emergency medicine residents during in-training examinations[13], residents performing resuscitation[9] and trauma[12] simulations, paramedics during simulated critical events[11] and surgeons in the operating room[85]. These studies have demonstrated that the STAI is very sensitive at picking up an individual's anxiety level in the moment, and that perceived anxiety can have detrimental effects on performance in simulation scenarios.

Other tools have been used with far less frequency, but also provide a reliable assessment of mood in these populations. The Profile of Mood States (POMS) is used to assess a participant's affective state and contains a Tension-Anxiety subscale which has been used in healthcare studies to measure stress, such as one in palliative care nurses[86]. Another tool, the Positive and Negative Affect Schedule (PANAS) is comprised of two mood scales, one measuring positive affect and the other measuring negative affect; these two scales can be used in isolation[87]. The PANAS has been used to study stress in nursing and medical staff in a maternity setting related to miscarriage, stillbirth and neonatal loss[88]. One of the limitations of the PANAS is that it asks the participant to comment on physiological states of stress such as 'shaky' and 'sweaty' which leads to a more spurious interpretation of psychological stress[89]. The Visual Analogue Scale (VAS) can also be used as a measure of emotional stress. The participant is asked to indicate where they fit along a line whose limits are anchored by two items representing the extremes of an emotion[89]. For example, the participant may be given the introductory question 'How anxious do you feel right now?' followed by a line with limits of 'not anxious at all' and 'worst anxiety imaginable'. A benefit of this scale is the relatively quick administration and ease of use. Qualitative open-ended interviews would be a useful way to examine the emotional aspects of the stress experience. When participants have the opportunity to expand on their answers beyond 'yes/no' and 'on a scale of 1-5', they provide a richer account of the experience of the emotion and how they perceive to be affected by stress.

While each of the aforementioned inventories for measuring affective stress have been used effectively in many different settings, there remain limitations to all inventories. First of all, the inventories used to measure mood are created to measure mood 'in the moment', and in several healthcare settings, it may not be feasible to collect an inventory during the exact moment of stress. If there is a delay between the time of stress and time of inventory capture, there may be significant recall bias[89]. Furthermore, there is evidence to suggest that people can misattribute their feelings of stress to a particular source when that stress may actually be due to another source[90], making connecting a particular source of stress with an emotion difficult.

In addition to limitations of particular inventories or tools, there are also limitations of study subjects. There is emerging evidence that healthcare professionals may 'manage' their emotions through 'impression management' putting on a social performance that is acceptable in their specific setting[82]. Certain expressions of emotion might be considered professionally inappropriate in specific contexts, for example, if a nurse were to yell at a patient when he becomes frustrated with the patient's behaviour. This may also translate into limitations of the subjects when filling out inventories asking them to rate how they feel emotionally. For example, a paramedic may not indicate high levels of fear on an inventory since that may be an emotion viewed as weakness in his job. Sociologists view emotions as "social performances" in addition to the biologically or privately experienced phenomena[91]. These theories from differing disciplines provide important insight into how we can view the same phenomenon from several different perspectives.

While stress is considered an emotional state, the boundary between stress as 'emotion' and stress as 'cognition' is blurred. It has only been in recent years, in fact, that the health professions have even acknowledged emotion as a central tenant of their being and worthy of study[92-96]. This may stem from a cultural belief that emotions in healthcare providers, particularly traditionally negative ones such as stress, are perceived as dangerous, unpredictable and in need of managing[94]. Damasio et al. have studied emotion from a neuroscience perspective and have challenged the concept that emotions and cognitive functions are processed in separate parts of the brain [97]. They suggest that input from the subcortical emotional systems into the cognitive systems is stronger than input from the cognitive systems to the emotional ones. In fact, there is growing evidence that emotions have an important function to human cognitive processes [98], specifically in terms of memory and decision-making. The emotions experienced will fundamentally affect cognitive appraisal of stressful stimuli. If a surgeon is feeling particularly sullen about a recent complication, as an example, she may be less likely to take on a difficult case where there is a risk of similar complications. In parallel, one's cognitive appraisal of a stressful stimulus inherently affects the manifested emotion. If a paramedic arrives on the scene of an accident and appraises that he has the resources to deal with the demand, his level of anxiety will be reduced. Attempting to measure these constructs as separate entities may be simpler, but artificial in a naturalistic setting where the complex nature of stress cannot be separated. This further adds to an argument that stress is a complex phenomenon and in order to gain a more complete appreciation of the phenomenon, it should be studied as such.

#### Stress as a Sociocultural Phenomenon

Powerful and hierarchal cultures exist within the field of medicine, and healthcare professionals must navigate and work in these conditions on a daily basis[99, 100]. These cultures can affect what causes stress, how stress is experienced and how stress is manifested. An organizational culture that promotes innovation, for example, might accept a higher degree

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of risk than a culture that is more conservative. The culture that the health professional is situated within, therefore, might affect whether a particular outcome is perceived as stressful for that practitioner in that organization. An experience in one setting might be very different than an experience in another, which is why it is imperative to consider culture when studying acute stress. For example, Quality Assessment (formerly known as Morbidity and Mortality) Rounds take place weekly to review hospital complications and deaths with a view to learning from errors and improving patient care. If a physician practices in a particularly risk-averse culture, he or she may be reprimanded for experimenting with a new technique. On the other hand, if he or she practices in a culture where innovation is encouraged and rewarded, he or she may be praised for the same action. This sociocultural component of stress may or may not manifest as a physiologic stress response, or affect the individual's response on cognitive and affective inventories.

The study of culture has been much less robust than other components, but a few research teams have conducted ethnographic observations in order to capture the sociocultural component of the stress experience. This methodology has been used to understand which events and conflicts created stress in the operating room environment[85, 101]. Other research teams have used qualitative semi-structured interviews to understand the experience of stress. One group used qualitative interviews to explore surgeons' experiences and their mechanisms for coping with stress[102]. Another study used qualitative interviews to explore medical students' perception of stress and how gender may play into this experience[103]. However, to truly understand how the culture affects healthcare professional's experience with stress, formal ethnographic methods are required. To our knowledge, there are not yet any studies that have used ethnography as a method to investigate the sociocultural influence of acute stress in healthcare professionals.

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## Stress Studied as both a Physiologic and Perceived Phenomenon

Several research groups have begun to appreciate the importance of studying not only the physiologic, but also the perceived stress experience in healthcare professionals. These studies have attempted to understand the relationship between perceived and physiologic stress. Often, these studies have used correlation between two different dimensions of the stress experience, but the results have been confusing. For example, Phitayakorn et al. found no association between the STAI and physiologic measures of stress in a simulated environment[22]. In contrast, Arora et al. found strong correlations between STAI scores and physiologic measures during real-life surgeries[21]. Piquette et al. measured acute stress using the STAI, salivary cortisol and a cognitive appraisal questionnaire in medical trainees during simulated resuscitation episodes. They found statistically significant moderate correlations between the STAI and cognitive appraisal ratio but no correlation of salivary cortisol with either of the measures[9].

The vast majority of studies of multiple components of the stress system outside the field of health professions have failed to show a relationship between the subjective, SNS and HPA measures[23]. This highlights the complexity of the stress phenomenon and supports the theory that the relationship between each of the components and the resultant overall stress experience is complicated. Multifaceted studies within the health professions have provided important groundwork in highlighting the benefit and strength of approaching the study of stress more holistically. However, they have also demonstrated that each measure of stress – physiologic, cognitive, affective and sociocultural – captures different aspects of the stress experience, and can therefore not always be compared by a statistical correlation. Data triangulation - a technique that facilitates validation of data through cross verification from two or more sources may be a more appropriate way to analyze stress data. This method is particularly useful when combining several research methodologies to study the same phenomenon[104].

## Putting It All Together: Stress as a Complex Phenomenon

The inherent complexity of stress as a construct and the methodological limitations of capturing stress in the real world have restricted our ability to ask important questions about stress among the health professions. For example: How does stress affect the health care practitioner – not only in terms of their performance, but their own wellbeing? Can we train healthcare professionals to deal with stress in a better way? Will this improve patient outcomes? The great variation in the methodologies available to study each of the stress components sheds light on the complexity of the stress phenomenon. In order to capture a more adequate representation of the experience of stress, we suggest that studies should capture each facet of the stress experience: physiologic, cognitive, affective and sociocultural.





This more complete view of stress requires abandoning the notion that stress is a purely objective phenomenon that can only be captured and represented using numeric data. The cognitive and emotive representations of stress require an interrogation of the subjective, or perceived, experiences of stress. The cultural contribution to stress in any setting requires ethnographic data, with an analysis for how the culture contributes to the causes, experiences and expressions of the stress experience. The few studies that have captured more than one component have demonstrated that each measure of stress – physiologic, cognitive, affective and sociocultural – captures different aspects of the stress experience, and can therefore not always be compared by a statistical correlation. A different approach, such as data triangulation, may be better suited to the multifaceted approach to studying stress. A multifaceted methodology is therefore needed to investigate stress in complex, dynamic environments, such as healthcare settings. This approach to measuring stress may be better able to capture each component of the stress experience, which affects not only the overall experience of stress, but also each of the other components individually. As our understanding for how best to represent the complexity of stress improves, we can begin to answer more adequately challenging questions about stress in healthcare teams.

Case study is a research methodology that is particularly well suited to studies that requires holistic, in-depth investigation[105], such as the study of a complex phenomenon like stress. In experimental studies, data collection and analysis methods necessitate the loss of some contextual details, but case studies are designed to express such detail from the point-of-view of the participants by using multiple sources of data[106]. Case studies are defined as a disciplined (qualitative and quantitative) mode of inquiry, the aim of which is to understand and emphasize the complexity of that case[105]. They allow the investigation of complex unique phenomena where previous literature to guide the research is lacking[105, 106]. This is a research method that involves theoretical, methodological, data, and researcher triangulation to enhance rigor to gain a robust understanding of a phenomenon[105]. These four dimensions of triangulation serve to overcome the limitations of individual methods[107] and allow the

collection of different types of data to provide cross-data validity checks[105]. Case study methodology would be a novel and in-depth way to study acute stress in health professionals.

As illustrated, there are intrinsic weaknesses and biases in each of the individual methods of measuring stress, so a technique that combines multiple measures may help to overcome the weaknesses of any one measure alone. Case study and qualitative methods as well as the use of novel analyses like data triangulation, are needed in the study of stress in medicine in order to investigate aspects of the stress experience that have not yet been explored as a whole.

#### **Conclusions**

Unlike the pioneers of stress research, we have many ways to capture and describe the stress experience, and our understanding of stress as a complex phenomenon in these environments has matured. Previous studies of acute stress in the field of medicine have demonstrated that no one data point can capture the stress experience entirely and thus a multidimensional approach is required. Studying stress in this way will allow us to better understand the interactions between facets of stress and thus form a clearer picture of the whole stress experience. Most importantly, being able to capture, measure and understand acute stress in healthcare professionals will allow us to explore the implications of stress on healthcare providers' wellbeing as well as on patient outcomes.

# CHAPTER TWO: A NOVEL METHODOLOGY FOR STUDYING STRESS IN THE

# **OPERATING ROOM**

# **INTRODUCTION TO METHODOLOGY**

One of the aims of this exploratory pilot study was to refine a methodology for studying stress in the OR. The paper in this section presents the methodology used in this study, discusses the strengths and weaknesses of different aspects of the data collection process, and proposes a novel way of analyzing stress data from different facets of the stress experience. Finally, this paper presents the lessons learned throughout this pilot study, and recommends a refined methodology for studying acute stress in the OR for future studies.

This paper will be submitted to the American Journal of Surgery, Journal of Surgical Education or Surgery. A more detailed methodology with respect to the analysis using the BioPac software system is provided following the manuscript.

## Capturing Complexity: A New Methodology for Studying Stress in the Operating Room

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# Background

The operating room (OR) is a high stakes environment with a propensity to also be high stress for the surgeon. Despite the fact that acute stress has been extensively studied in other high stakes professions such as the military and aviation fields, it remains a relatively recent endeavor in surgery [6]. Recent studies have demonstrated that acute stress can affect not only a surgeon's technical skills [7-13], but also non-technical skills such as communication, teamwork and diagnostic decision-making [14-16]. These studies have demonstrated the need for a deeper understanding of the surgeon stress experience as it may have important implications for surgeons themselves, as well as the patients they treat.

To date, the study of stress in surgery has often been limited to studying only one facet of the stress experience [14, 108] or linking a single physiologic or subjective variable of stress with an outcome measure, such as technical performance [55]. This is likely an oversimplification of the multifaceted stress experience. Stress is an exceedingly complex phenomenon – it consists not only of a physiologic response, but also an affective component, a cognitive component and a sociocultural component. The physiologic component consists of two systems – the sympathetic nervous system (SNS), which creates the 'fight or flight' response, and the hypothalamic-pituitary axis (HPA) which secretes the 'stress hormone', cortisol [37]. The affective component deals with the individual's emotion surrounding the experience of stress. The most commonly manifested emotion of stress is anxiety, but it can also manifest as other emotions such as irritability or frustration [83]. The cognitive component deals with the individual's appraisal of a potentially stressful situation – whether they have the resources they need to meet a demand, and how much a demand threatens a personal goal [26]. The sociocultural component may be especially pertinent in the domain of surgery, where there remains a powerful hierarchy and a culture in which stress, uncertainty, and fear are viewed as weaknesses [100].

The purpose of this study is to refine a methodology for studying the complex phenomenon of surgeon stress in the naturalistic OR setting. Specifically, the aim is to identify appropriate data collection methods and data analysis strategies so that the complexity of the stress experience is more adequately represented in future studies.

#### Methods

This study was approved by the institution's Research Ethics Board. Participants in the study were staff surgeons from varying specialties (thoracic surgery, vascular surgery, hepatopancreaticobiliary surgery, general surgery) at one academic university hospital. Participation in this study was on a volunteer basis and surgeons consented to participate. Consent was also obtained from patients as this study took place in the naturalistic OR environment where surgeons were performing operations on real patients. Seven surgeons, with a range of experience level, were studied over 2-4 surgeries each. Eighteen cases were captured, including both elective and emergency cases. Baseline physiologic data was collected at the time of consent to the study, in the surgeon's office.

# Data Collection

Data were collected from four facets of the stress experience: physiology, affective, cognitive and sociocultural. Case study methodology was applied and each stressful event (identified by physiology or perception) was considered a unit of analysis [109]. The perception of stress was identified through the affective, cognitive and sociocultural data. Case study is an approach involving in-depth, detailed data collection from multiple sources [109] in order to explore and understand a specific issue or concern [110] – in our study, surgeon stress.

# Physiologic Data

Physiologic data from the SNS was collected using BioPac Canada Inc.'s equipment and software system. Electrocardiogram (ECG) data were collected, which allowed for the capture of heart rate (HR) and heart rate variability (HRV). Thoracic impedance (non-invasive impedance cardiography) was collected, providing an estimate of cardiac output [111]. Participants wore a respiratory belt that allowed for capture of respiratory rate (RR). In addition, the Galvanic Skin Response (GSR), which is a proxy for sweat-gland activity [46] was collected. The GSR is traditionally measured on a participant's hand, but this was not feasible in the OR setting due to the requirement for sterile technique and gloves. Therefore, the GSR sensors were placed on the surgeon's foot. To capture the HPA stress response, participants were asked to provide salivary cortisol samples before surgery, approximately 20-40 minutes post-stressful event (when peak cortisol levels are reached) [68] and post-surgery.


# Figure 2.1: Diagram of placement for BioPac physiologic monitoring equipment

# Affective Data

Anxiety, the primary affective state of stress, was assessed using the short-form State-Trait-Anxiety-Inventory (STAI) [84]. This scale was administered pre- and post-operatively and when feasible, intra-operatively post-stressful event. The STAI asks participants to rate on a scale of 1 (very much) to 4 (not at all) statements such as: *I am tense* and *I am relaxed*.

It was anticipated that surgeons in the OR may not feel comfortable publically verbalizing moments they perceived stress. In order to address this, a discreet foot pedal was placed by the surgeon's foot, which was linked to the BioPac physiologic monitoring system. The surgeon was instructed to push this pedal when they perceived stress at any time during the operation. When they did so, a flag was created in the software system aligned with the physiologic data. This enabled the surgeons to discreetly indicate to the research team their perceptions of stress. Affective data were also collected from the pre- and post-operative interviews, as well as detailed intra-operative observer notes.

## Cognitive Data

To assess the cognitive appraisal of stress in the OR, on-site pre- and post-operative interviews took place. Pre-operative interviews explored how the surgeons assessed stressors in the OR, what factors alleviated and aggravated stress, and whether there were any other anticipated factors that may affect their level of stress during that particular surgery. Postoperative interviews explored which parts of the surgery were perceived as stressful, as well as any alleviating and aggravating factors.

#### Appendix 2.1: On-site Pre- and Post-Operative Interview Templates

#### Pre-operative Interview Script

- 1. Which parts of the surgery do you anticipate may present challenges or require extra care?
- 2. Are there any other factors today that you feel may contribute to your level of stress?

#### Post-operative Interview Script

- Are there any factors that you feel may have affected your level of stress during the operation today?
- 2. Which parts of the surgery did you subjectively feel were stressful and why?
- 3. Your physiologic monitoring indicated increased arousal X times during the surgery. Can you tell me which X times you think this was?

### Sociocultural Data

Sociocultural data were captured through the pre- and post-operative interviews as well as by detailed intra-operative observer notes taken by an experienced researcher. Field notes captured observations of team interactions, both verbal and physical, silences and body language. Interviews and observations were used to explore how team composition, institutional regulations and the surgical culture affected the surgeon's experience of stress in the OR. Interviews were transcribed and coded for thematic analysis by the entire research team [112]. Deeper sociocultural data of the surgical culture collected through a formal ethnography was not performed as it was beyond the scope of this current study.

#### Study Protocol

*Pre-Operative:* Surgeon participants were connected with the wireless physiologic monitoring equipment. Salivary cortisol samples were collected from each surgeon for a pre-operative baseline immediately prior to starting the surgical case. A brief on-site pre-operative interview took place and surgeons completed the STAI. Surgeon participants were reminded to notify the research team, either verbally or by pushing the foot pedal, if they felt acute stress at any time during the operation.

*Intra-Operative:* The research team monitored the surgeon's physiology in real-time. An experienced observer recorded detailed, time-stamped notes describing what occurred in the OR. Observer notes included surgical events, OR team events, as well as interactions between members of the team. These notes were added to the BioPac software so they could be linked in time with the surgeon's physiologic data. The purpose for aligning these data was to triangulate the various data sets (for example, the physiologic stress data with the observer recorded sociocultural stress data). When a stressful event was identified, surgeons were asked to complete the STAI immediately following and provide a salivary cortisol sample 20-40 minutes post-stressful event when this was feasible and safe.

*Post-Operative:* Surgeon participants provided a salivary cortisol sample in the immediate post-operative period, while they unscrubbed from the case. The wireless physiologic monitoring equipment was removed. Following this, the on-site post-operative interview took place. Surgeons were asked to complete the post-operative STAI.



# Figure 2.2: Data collection in the operating room

a) Observer taking notes at the head of the operating table. b) Video recording of the operative field from an overhead camera. c) Video recording from a camera in the operative field. d) Real-time physiological data: 1-thoracic impedance, 2-GSR, 3-respiration belt, 4-HR, 5-ECG, 6-RR; \*indicates signal interference artifacts in ECG monitoring

#### Data Analysis

Three different types of data analysis were performed for the purposes of capturing the complexity of the stress experience: study of all physiologic variables across a case, data triangulation at perceived (i.e. cognitive, affective or sociocultural identified) stressful events and data triangulation at physiologic stressful events. As interview and observation data were collected using qualitative methodologies, the use of traditional statistical measures was insufficient to compare variables across all cases. Instead, data triangulation of all methods was used at each stressful event, either physiologic or perceived, with the stressful event acting as the unit of analysis. Data triangulation is a method of analysis that allows combination of data collected using different methodologies in the study of the same phenomenon [104]. There is evidence to suggest that traditional statistical methods for looking at perceived and physiologic stress data is fraught with difficulty and often inappropriate [23]. While some studies have found subjective and physiologic, and SNS and HPA measures correlate [21], the majority have not [22, 113]. Data triangulation at the point of the stressful moment, through combining data collection methods, allowed for the analysis of the experience of stress from different angles, providing a potentially more robust means for capturing stress in its complexity. For example, a surgeon identifies a perceived stressful event in the post-operative interview—"when the bile duct was ligated". Beginning with this perceived stressful event, the research team went back to the intra-operative observer notes to determine when during the case this occurred. Then data triangulation was performed: comparing the surgeon's physiology with the sociocultural, affective and cognitive data (i.e. foot pedal pushes, the surgeon's words and actions during this moment, interactions of the team members etc.) that were gathered at the corresponding time to the bile duct ligation.

### 1. Study of all physiologic variables across a surgical case.

All physiologic variables were plotted with the x-axis of time across an entire operative case. Because the physiologic variables were measured in different units, z-scores were calculated and used so that the physiologic measures could be compared. This part of the data analysis allowed for the understanding of how each of the physiologic measures responded throughout the duration of the surgical procedure, as well as in relationship to each other. Specifically, it allowed for the comparison of the physiologic parameters with perceived moments of stress as identified by the surgeon. This aspect of the analysis has allowed for recommendations about which physiologic variables are most useful for collection in future studies in this environment, by demonstrating which physiologic measures are most responsive to stress in the OR.

# Figure 2.3: Data from Step 1 Data Analysis: Z-scores of all physiologic parameters across a case



### 2. Data triangulation at perceived-stressful events.

Perceived-stressful events were defined as those moments identified by the surgeon as being stressful, through the affective and cognitive data. These moments were captured in three ways: from the surgeon verbally expressing stress during the stressful event, from the surgeon pressing the foot pedal during the stressful event, or from the surgeon during the postoperative interview. Using the detailed observer notes and video analysis, the research team was able to pinpoint the time period where this stressful event took place (i.e., *"when we ligated the common bile duct"*). As part of data triangulation, physiologic data for the surgeon was analyzed in detail for a five-minute window surrounding the identified event. This allowed for increased likelihood that the appropriate timing for the stressful event was captured. In particular, maximum HR, average HR, minimum HRV, average HRV and how these numbers compared to the surgeon's baseline data were isolated for comparison. This allowed the research team to explore the relationships between physiologic, affective, cognitive and sociocultural stress.

## 3. Data triangulation at physiologic-identified stressful events.

For each of the cases, the surgeon's baseline physiologic data was used to determine when there were significant changes from baseline. Flags were created in the physiologic data whenever the surgeon's HR was elevated at 140% of baseline HR, and when the HRV was less than 70% of baseline HRV [114]. These flags were marked as the physiologic-identified stressful events.

The detailed observer notes and interview data were then reviewed to determine what was occurring at the times of these physiologic-identified stressful events. This further allowed the research team to explore the relationship between the four facets of the stress experience.

#### **Results: Challenges and responses in the development of the PACS methodology:**

The study of surgeon stress is complex and multifaceted. In order to meaningfully address the complexity of factors involved in the study of surgeon stress, this study has developed the PACS (Physiologic Affective Cognitive and Sociocultural) methodology. The PACS methodology used in this exploratory pilot study proved acceptable to the surgeon participants and OR staff. The surgeons did not find the wireless physiologic monitoring equipment cumbersome, and felt that it did not affect their ability to operate. There was a mild Hawthorne effect initially, and most of the surgeon participants reported that they felt aware of the equipment and the research team's presence for the first few minutes of the operation, and in some cases throughout the entire first case. It was due to this phenomenon that the research team decided to follow fewer surgeons over more cases, so that the surgeon participants would become used to the presence of the research team and act in a more natural way.

Throughout the data collection process, several challenges were met and therefore changes were made to the study protocol. Given the dynamic nature and complexity of surgical cases (as compared to discrete events that are manipulated in a simulation setting), it became evident that it was at times difficult to link a surgeon-perceived stressful event back to the exact time in the physiologic monitoring data. At times, the surgeon-perceived stressful events were linked to a vague and potentially prolonged part of the surgery (ie. *"when I was mobilizing the liver"*). In cases like these, it was recognized that audio and video monitoring would be useful to link the physiologic data precisely in time with the surgeon's perceived stress. Therefore, collection of audio and visual data was added to the REB protocol as an amendment and collected for three cases as a proof of principle and to look at the feasibility of adding these data collection strategies in future studies.

In the naturalistic OR setting, there were several parts of the initial methodology that proved difficult to collect, or simply not feasible:

## Physiologic Stress

For the physiologic data, there were some measures that seemed to be greatly affected by noise or movement in the OR. When the ECG leads were fresh, there was excellent conductance with the gel-skin contact and clean ECG tracings were obtained. The same was not true for thoracic impedance, which was affected easily by movement of the surgeon, or by interference from the use of the electrocautery device during surgery.





While the signal using the foot as the location for the GSR sensors was adequate, it did not prove to be a sensitive or specific measure for stress in this setting. Many of the surgeon participants started the case off with a high GSR that slowly decreased throughout the case.

Figure 2.5: GSR Signal Throughout a Case



This may be due to autonomic activity and arousal early in the case, but may also be due to a surgeon's increased internal temperature upon arrival (ie. increased physical activity on the way to the OR), or perhaps due to the high temperatures in the OR during induction of anaesthesia. Furthermore, the GSR response did not appear to be as responsive to stressors throughout the surgery as other physiologic markers of stress. Phitayakorn et al. also found in their study using GSR as a physiologic measure of stress that the ankle location in scrubbed participants proved to be more variable and less sensitive than the traditional location on the hand [115].

To monitor the HPA response to stress, the initial protocol was to collect salivary cortisol samples 20-40 minutes post-stressful event to capture the peak cortisol response to a stressor. Unfortunately, in the OR setting, it was usually not feasible or safe to ask the surgeon to step away from the operating table in order to provide a salivary cortisol sample. Pre- and post-operative salivary cortisol samples for each case were collected, but in the absence of relation to a stressful event, the information provided was limited.

Table	2.1: S	alivary	cortisol
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		Pre-operative	Post-operative
	OR	Cortisol (nmol/L)	Cortisol (nmol/L)
Surgeon 1	1	2.7	1.9
	2	0.7	0.6
Surgeon 2	1	0.9	1.2
	2	0.5	1.1
	3	1.2	1.1
Surgeon 3	1	1.0	0.8
	2	0.6	<0.4
	3	3.3	1.0
	4	0.7	1.0
Surgeon 4	1	4.1	0.7
	2	2.7	0.6
Surgeon 5	1	<0.4	<0.4
	2	1.1	<0.4
Surgeon 6	1	2.7	1.9
	2	1.4	3.6
	3	1.9	0.5
Surgeon 8	1	Missing	<0.4
	2	<0.4	0.8

In terms of the physiologic data, HR proved to be the most sensitive physiologic marker of stress because ECG data was the most easily collected and interpreted. However, HR is a marker of physiologic arousal and is not specific for physiologic stress [49]. HRV proved to be the most specific physiologic measure of stress, again because ECG data was most easily captured and interpreted and because HRV is more specific to physiologic stress [51]. Cortisol is also a specific measure of stress [33], but given the limitations of collection timing in this study, was not a useful measure of physiologic stress.



## Figure 2.6: Clean ECG tracing

### Affective Stress

For the affective data, the STAI was used to assess the surgeon's level of anxiety. The pre-operative STAI provided a baseline of the surgeon's level of anxiety going into the case. This often acted as a prompt for them to discuss why their level of anxiety may be higher or lower in the pre-operative interview. The post-operative STAI provided an idea of the surgeon's

level of anxiety after completing the case. This was interesting to see, particularly with respect to comparison to the pre-operative STAI.

The intent of the initial protocol was to have the surgeons complete the STAI at the time of a stressful event because it is most sensitive for measuring anxiety in the moment. Unfortunately this proved to be non-feasible in most cases since asking the surgeon to step away from the operating table during these times of stress was not possible and would not be ethically sound in regard to patient safety. Requesting this information post hoc would be unreliable given issues of recall bias that may be altered depending on patient outcome. Although the pre- and post-operative STAI's provide information about anxiety during those moments, without being in relation to a stressful event, they provide limited information about the cases (stressful events) themselves. However, affective data was collected in real-time through the use of the foot-pedal and observer notes which commented on the surgeon's mood (ie. agitation, anger etc.)

	OR	Pre-operative STAI	Post-operative STAI
Surgeon 1	1	9	14
	2	8	8
Surgeon 2	1	10	13
	2	10	9
	3	15	9
Surgeon 3	1	15	19
	2	11	12
	3	20	16
	4	20	19
Surgeon 4	1	11	10
	2	11	12
Surgeon 5	1	12	12
	2	10	8
Surgeon 6	1	8	12
	2	6	12
	3	15	6
Surgeon 8	1	14	12
	2	12	11

# Table 2.2: Short-form State Trait Anxiety Inventory (STAI) Scores

# Cognitive Stress

Onsite pre- and post-operative interviews allowed the research team to access the surgeon's cognitive appraisal of stress. The proximity of the post-operative interviews to the surgical case allowed for excellent recall of the intra-operative events and how they were

experienced by the surgeon. The interview transcripts were analyzed for emerging themes, common threads that were found throughout the interviews within the same surgeon, and across surgeons. The interviews began to explore the appraisal of the stress events, but were limited by the time available and focus of the surgeon participants. In-depth semi-structured qualitative post-operative interviews would have allowed for a more complete exploration of the cognitive appraisal of stress throughout the surgery and therefore will be recommended for future studies.

# Sociocultural Stress

Finally, in terms of the sociocultural data, a limited amount can be drawn from intraoperative observer notes and pre- and post-operative interviews but there were some interesting findings and trends. Several surgeons alluded to the difficult decision-making related to deciding whether or not to call a consultant surgeon for help. This is an interesting phenomenon that surgeons face and has been previously studied by other research groups [116, 117]. Another theme that arose was of the hierarchy in the OR, which was present within the surgical team (i.e. fellow, residents) and outside of the surgical team to the operative team as a whole (anaesthesia, nursing). Different surgeon participants navigated this hierarchy in different ways.

Given that this was a pilot study with a limited number of participants, it is difficult to form any concrete conclusions about sociocultural stress, however, one conclusion that can be drawn from this study is the importance of understanding the sociocultural component of stress in the complex OR environment. A formal ethnographic study of the culture in the surgical department and operating room teams would be required to fully appreciate the depth of the sociocultural component of the stress experience.

### Discussion

The PACS methodology is the first of its kind, attempting to draw upon four different aspects of the surgeon stress experience – physiologic, affective, cognitive, and sociocultural. Using this methodology places emphasis on both the perception of stress by the surgeon, as well as the physiologic stress response. Research involving health professionals has had a tendency to focus on either the physiologic or the perceived component of stress, but rarely both in the same study. Appreciating stress as a more complex phenomenon will allow researchers to gain a more in-depth understanding of the surgeon stress experience.

Despite the progress made in this exploratory pilot study, there remain important challenges in the study of stress within the surgical setting. Researchers have been limited in the exploration of one's perception of a phenomenon like stress by the participant's honesty, insight and understanding. The construct of stress is one that can mean different things to different people, and it is very complex, making it difficult to link a feeling of stress with a specific stressor [90]. There are many important—themselves multifaceted—variables to consider, such as the surgical culture and an individual surgeon's emotional state, which can make it difficult for the participant to tease apart and articulate their perception of stress. Furthermore, there may be hidden stressors that are not consciously accessible to the participant, or even the research team. For example, a surgeon may not be consciously aware that the presence of a new OR team member increases their stress level. In these cases, continuous monitoring of physiologic stress may help to identify times that the surgeon is feeling stress, without necessarily even being aware of this stress. There is evidence to suggest that people who experience physiologic stress without consciously being aware of it are at increased risk for cardiovascular and mental health issues [30]. Using the PACS methodology, researchers may identify such stressful events. Whereas a study exploring stress as a physiologic phenomena alone would indeed identify a moment of physiologic stress, there would be no way to meaningfully capture and compare whether the surgeon was cognitively aware of the stress in that moment.

Real-time physiologic monitoring allows the research team to further explore the moments that were physiologically stressful in the immediate post-operative period. In this study, heart rate was displayed in real-time, but the software system did not have the ability to calculate heart rate variability in real-time. Because heart rate variability is a more specific measure of stress, dips in this variable would also be useful to see in real-time and discuss with the surgeon in the immediate post-operative period. A software system that allows the input of each surgeon's baseline physiologic data pre-operatively, would provide the research team with the ability to see when the surgeon's heart rate and heart rate variability become significant throughout the case.

To truly understand a complex phenomenon like stress, studies in the naturalistic environment are vital, particularly when it comes to appreciating components such as the sociocultural effect. The naturalistic setting cannot be manipulated, and does not have discrete events that can be controlled and repeated in different subjects. This makes it exceedingly difficult to unquestionably associate any one outcome of interest with a specific stressor. It may be logical to assume that a surgeon with increased stress levels will perform more poorly, and certainly there are simulation studies which have demonstrated excessive stress can have a negative impact on technical performance [6, 7, 102], but with all the variables at play in a naturalistic setting, it is very difficult to link a stressor with a specific outcome such as technical performance. Until we can better understand how each of these factors affects the stress experience, we cannot accurately look at causation in the naturalistic OR environment.

With a refined methodology for studying stress in the OR, we may now start to test experimental hypotheses. Using the PACS framework, future studies will be able to answer questions such as 'Is there a pattern of surgeon stress responses?', 'What effect does surgeon stress response have on the surgeon's wellbeing? On the patient's wellbeing?' ' Are there certain surgeon stress responses that are healthier than others'? 'If so, can we teach surgeons healthy stress responses?'.

#### **Recommended PACS Methodology for Future Studies**

The pilot study undertaken for the validation and feasibility of the PACS methodology for studying surgeon stress in the OR has provided valuable insights for future studies. The following protocol is recommended for future studies:

#### Data Collection Methods:

*Physiologic data:* Wireless real-time ECG monitoring of the participants using the BioPac hardware and software. The ECG monitoring allows for collection and analyses of HR and HRV data. In addition, a system that allows for the input of the surgeon's baseline HR and HRV prior to the case as well as allow for real-time calculation of HRV is recommended. This would allow the research team to see physiologic identified stressful events in real-time.

*Affective data:* The short-form STAI is administered pre- and post-operatively in order to collect a validated measure of emotion in temporal proximity to the event of interest. The preoperative inventory allows for a baseline in the event that stressful events take place during the operation. Furthermore, the surgeon should be reminded to push the foot pedal anytime they 'feel' stressed throughout the case, which allows the research team to link perceived stress with physiology. Finally, emotional data should be collected during the debrief interview which will take place within one week of the operation. Allowing the surgeon participant some time between the operation, and the debrief interview will also allow for some personal reflection on the experience and may lead to richer data.

*Cognitive data:* Brief on-site pre- and post-operative interviews which will permit the research team to explore stressors, aggravating and alleviating factors, and also the collection of data in close temporal proximity to the event (operation). These should be followed by a more indepth semi-structured qualitative interview, the debrief interview, ideally within a week of the operation and after data analyses by the research team has taken place. The debrief interview will explore the cognitive, emotional and sociocultural aspects of stress in the OR.

*Sociocultural data:* In addition to detailed intra-operative notes from an observer experienced in surgery, it would be valuable to have a full-time anthropology-trained ethnographer to collect data on the sociocultural aspects of stress in the OR environment. The debrief interview may also explore aspects of the culture on the stress experience.

# Data Analysis:

The first recommendation is that data be analyzed as an ongoing process throughout data collection during the study. Performing data analysis in close temporal relationship to the data collection allows the research team and participants to more accurately recall events and details. It will also allow the research team to explore findings from the data analysis with the surgeon participant at the time of the debrief interview. This will gain a deeper understanding of the stress experience, and also allow for member-checking to ensure the research team is accurately interpreting the data [118].

The second recommendation in terms of data analysis is to further encourage the use of data triangulation as a method for analyzing data from multiple sources. This will allow for a richer understanding of the stress experience, and further validate the findings.

PRE - OP	O P E R A T I O N	POST - OP	PR								
STATE TRAIT ANXIETY INDEX	REAL TIME ECG	STATE TRAIT ANXIETY INDEX	NN EL	DEDDIEE							
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INTERVIEW	AUDIO & VIDEO RECORDING	INTERVIEW	ISIS NA								
INTERVIEW	OBSERVATION / NOTATION	INTERVIEW	RY								
	ETHNOGRAPHY										

#### Figure 2.7: Graphical Representation of Recommended PACS Methodology

## Conclusions

In conclusion, the PACS methodology allows for a more complete understanding of the complex phenomenon of surgeon stress in the operating room. It draws upon physiologic, cognitive, affective and sociocultural data and uses data triangulation as a method of analyzing data from varying sources. Furthermore, the recommended methodology is feasible for use in the busy OR environment and would be useful for studies in similar high-stakes environments such as the trauma bay, emergency department or intensive care unit. In future studies, using this methodology may allow researchers to begin to ask questions about how stress is affecting surgeons and looking at outcomes of interest such as the effect of stress on technical skills, non-technical skills and patient outcomes.

#### DETAILED METHODOLOGY FOR SOFTWARE ANALYSIS

The BioPac Canada's software system was relatively user-friendly in the data acquisition phase, but proved to be more challenging to use in the data analysis phase of this study. Therefore, a clinical engineer with expertise manipulating software systems and writing new software scripts was hired to assist in this phase of the study. The following is a detailed account of the analysis that was done using this software system so that it may be repeatable by future research teams. This aspect of the thesis is quite technical and may not be of interest to all readers.

#### Step 1: Structuring the Data

#### ECG Data

Biopac Systems Canada Inc. software contains built-in software scripts to perform common analyses of physiologic data. To calculate heart rate (HR), one of these software scripts was used on the electrocardiogram (ECG) data [ECG markings with BPM]. ECG complex markers were located and only QRS peak markers were displayed in order to reduce the amount of 'marker clutter' on the graph. This method performed better than an execution of the software functions [Find Rate] or [Find Cycle], which frequently identified incorrect waveforms. Following identification, the QRS markers were used to calculate HR and heart rate variability (HRV).

During the data analysis phase, there were events of interest (surgeon perceived stressful events) for which the timing demonstrated 'noisy' ECG data due to interference or a poor signal. In order to analyze the data during these events, QRS markers had to be manually added by finding the average point in time where a QRS peak was expected based on the preceding and following ECG data. However, there were areas of data in which the signal was

so poor that this was not technically possible and therefore analysis could not be performed on all surgeon perceived events as planned.





# Heart Rate Variability Data

There are several different methods of calculating HRV that exist and the method used in this study was Respiratory Sinus Arrhythmia (RSA). The RSA value (i.e. natural logarithm of the high frequency measure) was chosen because of its ability to connect the variation in HR that occurs during a breathing cycle. Furthermore, a software script for this method was built into the BioPac software and functioned well for the HRV calculation in this dataset. In order to calculate the HRV, the QRS marked ECG graph was used. The software script [RSA analysis for current file w/ presets selected and QRS detection] was applied to the area of interest. This script generated two figures. The first figure was a graph representing HR data, which was calculated from the frequency of QRS peaks per minute.





The second figure was a table of values that represent the HRV.

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5	30	60	3.996464	15.43008	23.3262	8 33.85176	0.39813	0.6018	7 0.661488	3.149580622			
6	60	90	26.14384	99.0424	129.7	3 13.55144	0.432929	0.56707	0.763448	4.865455368			
1	90	120	19.96432	81.5756	110.70	35.10264	0.42425	0.5757	0.736865	4.706878039			
0	120	150	12.57096	40.4/30	57.006	9.81212	0.449104	0.00004	0.815224	4.043170559			
10	150	210	5 74926	4.73040	10.9340	4 8.50404 9 7.41500	0.301986	0.69801	0.432637	2.391000059			
11	210	210	3 20422	20.01370	21.395	6 7.41596	0.490692	0.60162	0.903447	3.003194041			
12	240	240	0.356432	2 26954	10 5969	9 20.02496	0.308378	0.03102	0.4436/7	2 260559619			
12	240	300	6 4522	2.20504	52.28	6 26.02430	0.170392	0.02300	0.564455	3 956728649			
14	300	330	2 792936	13 76632	66 731	2 418.32	0 171015	0.82898	5 0.206295	4 20067261			
15	330	360	8.8318	35 03348	56 673	6 53 0064	0.382015	0.61798	5 0.618163	4.20007201			
16	360	390	13 69532	57 2732	95 122	8 16 27804	0.375818	0.62418	2 0.602096	4 555168688			
17	390	420	6.105	22,73348	27.8631	6 6.38056	0.449308	0.55069	2 0.815898	3.327305386			
18	420	450	2.737724	12.20736	21,4016	8 7.39404	0.363216	0.63678	4 0.570392	3.063469424			
19	450	480	55.168	206.9328	242,760	8 52.5204	0.460164	0.53983	0.852414	5,492076596			
20	480	510	50.5184	187.6704	219.563	2 20.11468	0.460842	0.53915	8 0.854745	5.391640118			
21	510	540	53.1736	200.2384	258.87	2 10.86772	0.436144	0.56385	6 0.773504	5.556333731			
22	540	570	94.7672	348.5972	340.85	2 38.4806	0.505617	0.49438	3 1.02272	5.831448365			
23	570	600	12.86936	47.52	52.987	2 10.12592	0.472802	0.52719	0.89682	3.970050375			
24	600	630	26.414	98.702	124.187	6 13.1034	0.442829	0.55717	1 0.794783	4.821793326			
25	630	660	1.802652	7.06424	9.6447	6 4.83592	0.422781	0.57721	9 0.732445	2.266414763			
26	660	690	16.02936	57.008	53.124	8 8.98956	0.517631	0.48236	9 1.0731	3.972643863			
27	690	720	23.98332	94.5608	115.238	8 9.02584	0.450719	0.54928	0.820563	4.747006497			
28	720	750	14.78228	55.2244	65.993	2 6.661	0.45558	0.5444	2 0.836816	4.189551706			
29	750	780	8.49664	31.88312	39.7204	4 4.97452	0.445273	0.55472	0.802688	3.681865917			
30	780	810	76.4004	286.0764	359.57	2 16.73228	0.443084	0.55691	6 0.795603	5.884914435			
31	810	840	5.61164	20.95876	27.5419	2 3.274424	0.432133	0.56786	7 0.760976	3.315709208			
32	840	870	7.8912	30.89024	46.036	8 30.16256	0.401553	0.59844	7 0.670992	3.829441077			
33	870	900	4.58956	19.34508	40.120	4 20.5908	0.325315	0.67468	5 0.482174	3.691884933			
34	900	930	6.9094	27.87124	46.44	4 30.5418	0.375041	0.62495	9 0.600105	3.838247286			
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# Figure 2.10: Table of HRV values generating using the RSA Analysis

An "epoch" width is a distinctive period of time used to reduce large data files into manageable sizes. An "epoch" width of 30 seconds was used to calculate the HRV. Certain features including very low frequency (VLF), low frequency (LF), and high frequency (HF) could be extracted for each epoch. A table of values corresponding to these frequency-domain measures used in HRV analysis was then generated (see Figure 3). Frequency domain methods count the number of normal R-R intervals that match their respective band. R-R intervals represent the HR tracing between two QRS peaks. For the purposes of this analysis, the HF band (0.15-0.40Hz) was used as the HRV indicator due to its relation with RSA.

### Sweat Gland Activity Data

Electrodermal activity (EDA) was used as an indicator of the galvanic skin response (GSR) of the surgeon. No scripts were needed in order to clean or prepare this data set.



#### Figure 2.11: GSR data over a single surgical case

# Respiratory Rate Data

Respiratory rate (RR) was used as an indicator of the breathing rate of the surgeon. No scripts were necessary to clean or prepare this data set.

# Figure 2.12: Respiratory rate data over a single surgical case



Using these four sets of values (HR, HRV, EDA and RR) different methods of data analysis were applied.

# Step 2: Analyzing the Data

# 1. Analyzing All Variables Across a Case

In general, there were three types of data sets from the operative cases in this study:

- Physiologic data sets where the entire surgery required minor or no manual manipulation of QRS markers.
- Physiologic data sets where some distinct areas in the surgery required minor or no manual manipulation of QRS markers.
- Physiologic data sets where the entire surgery required significant manipulation of QRS markers to generate meaningful data.

Unfortunately, during the data analysis phase, it was discovered that during the data acquisition phase there was an issue with the ECG leads. This led to a significant impairment of our ability to analyze the HRV data from several participants from which data had already been collected. The leads had dried out without the research team's awareness, which in turn lead to poor conductance signal from the skin. This unfortunately rendered the ECG waveforms in these cases unreliable for HRV analysis. Therefore, this third type of data set was unsalvageable and we were unable to perform full analysis on this data.

The first type of data set allowed us to perform "whole analysis" of the entire case. In this whole analysis, each of the physiologic variables was examined across a case and with respect to each other. The four physiologic variables used (HR, HRV, RR, GSR) are measured in different units and thus the next step in analysis involved normalizing the data. To normalize the raw data, a z-score technique was used. To calculate the z-score of each data point, the data point was subtracted with the average value over the case and divided by the standard deviation. This statistical measurement allowed for the determination of whether or not a particular value is typical versus atypical for a dataset. This also allowed for the determination of whether a certain value type (i.e. HRV) was a significant outlier or indicator of stress. However, on initial z-score analysis, due to the constant fluctuation of the four values, it was difficult to notice any meaningful trends. Therefore, a new table of values was created (see Figure 6) in which each data point was averaged among itself, the previous value, and the next value. This smoothing technique made it easier to notice trends across the case.

# Figure 2.13: Raw data, z-score and smoothed z-score for analysis of physiologic variables over a surgical case

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7	0	60	0.58212	4.11131	94.8267	7.63403	6.84984	5.7248		4:37 PM	-0.558	0.01788	3.40206	-2.82784		4:37 PN	1 -0.021	-0.2558	2.77434	-1.8666	7	
8	60	120	4.42724	4.84537	92.2876	6.11255	5.79178	10.5564		4:38 PM	0.5164	-0.52949	2.14662	-0.9055		4:38 PN	0.46311	-0.1179	2.602505	-0.9594	3	
10	120	240	10.1408	3.5/25/	95.4763	6.04118	5,71301	14.9811		4:39 PM	-1.347	0.15/91	2.25884	1 6832		4:39 PN	1 -0.75815	0.450891	2.153223	0.04420	2	
11	240	300	1.36695	4 14041	100 463	5 82881	4 75417	13 6413		4:40 PM	-0.516	1 23292	0.91542	0.32184		4:40 PM	0 92221	0.329699	1.525229	0.555552	9	
12	300	360	2.12805	3.94141	93,7897	4.23979	5.3362	11.3892		4:42 PM	-0.807	-0.20567	1.60604	-0.57417		4:42 PN	1 -0.43782	-0.16274	0.73229	0.23246	6	
13	360	420	6.85601	4.49925	87.7139	5.58048	3.70911	15.2194		4:43 PM	0.0096	-1.51548	-0.3246	0.94972		4:43 PN	1 -0.07473	-1.00491	0.802969	0.38036	8	
14	420	480	1.58951	4.88428	88.7432	6.32615	4.93287	14.7565		4:44 PM	0.5734	-1.29359	1.12746	0.76555		4:44 PN	0.523186	-1.44614	0.400463	0.5114	3	
15	480	540	5.67164	5.16641	87.6495	5.32643	4.31854	12.3774		4:45 PM	0.9865	-1.52936	0.39853	-0.18098		4:45 PN	0.923265	-1.22201	0.543252	-0.1300	8	
16	540	600	8.66938	5.31892	90.8329	8.83998	4.07013	10.3823		4:46 PM	1.2099	-0.84309	0.10377	-0.9748		4:46 PN	0.519326	-1.03012	0.311399	-0.1306	5	
17	600	660	6.33387	4.0567	91.4136	4.38546	4.34667	14.7521		4:47 PM	-0.638	-0.71791	0.4319	0.76382		4:47 PN	0.186735	-0.68752	0.239828	-0.144	ô	
18	550	720	5.27907	4.48501	92.4172	4.45028	4.13759	12.2723		4:48 PM	-0.011	-0.50156	0.18381	-0.22281		4:48 PN	1 -0.46783	-0.46941	0.174463	0.64856	5	
20	720	840	7 17186	5 12947	93.0002	6 39511	3 74763	12 2004		4:49 PM	-0.754	-0.10075	-0.09233	-0.25141		4:49 PN	0.055787	-0.4451	-0.06247	0.51015	2	
21	840	900	0.47318	3 99793	97 0402	6 30723	3 14832	15 1664		4:51 PM	-0 724	0.49506	-0.99001	0.92866		4:51 PN	-0.23413	0.089777	-0.37681	0.10353	5	
22	900	960	0.46373	3.87098	96.6886	10.8789	4.09939	11.9108		4:52 PM	-0.91	0.41925	0.13849	-0.36665		4:52 PN	1 -1.13677	0.358289	-0.30771	0.58977	8	
23	960	1020	0.43682	3.28018	95.4885	6.17988	3.92233	15.8668		4:53 PM	-1.775	0.16056	-0.07161	1.20731		4:53 PN	1 -1.36421	0.245768	-0.5501	0.48830	4	
24	1020	1080	0.82109	3.53197	95.4743	4.01931	2.53549	14.4013		4:54 PM	-1.407	0.15749	-1.71717	0.62425		4:54 PN	1 -1.31997	0.417731	-1.01943	1.09970	5	
25	1080	1140	6.74146	3.96161	99.0816	4.94553	2.91277	16.5209		4:55 PM	-0.778	0.93514	-1.26951	1.46755		4:55 PN	-0.99532	0.683945	-1.28343	1.09451	7	
26	1140	1200	6.47219	3.9453	99.1932	3.64415	3.25485	15.8277		4:56 PM	-0.802	0.9592	-0.86361	1.19175		4:56 PN	-0.49931	0.784531	-0.83959	0.77730	5	
27	1200	1260	0.3838	4.54818	96.8741	8.10467	3.65766	12.0095		4:57 PM	0.0813	0.45925	-0.38564	-0.32739		4:57 PN	1 -0.59657	0.8/311/	-0.58639	0.2639	5	
20	1200	1320	0.38573	3.76235	99 5909	5 14685	3.00293	12.0002		4:50 PM	-1.069	1.2009	-0.50992	0.17027		4:50 PN	-1.05708	0.901089	-0.52146	-0.0765	4	
30	1380	1440	2.73911	3.77303	96.605	4,78079	3.83273	14,7766		5:00 PM	-1.054	0.40123	-0.17792	0.77354		5:00 PN	-1.02157	0.815721	-0.1145	0.69070	7	
31	1440	1500	3.14724	3.83509	99.3872	3.29372	4.40679	15.6682		5:01 PM	-0.963	1.00102	0.50324	1.12831		5:01 PN	1 -0.90108	0.845824	0.210877	0.80975	7	
32	1500	1560	0.33501	4.02384	100.01	7.83912	4.24167	14.158		5:02 PM	-0.687	1.13522	0.30732	0.52742		5:02 PN	-0.52026	1.143276	0.366433	0.64147	9	
33	1560	1620	6.94958	4.55325	100.744	6.94146	4.22602	13.5077		5:03 PM	0.0887	1.29359	0.28875	0.26871		5:03 PN	-0.60192	1.473712	-0.00656	-0.1885	5	٣
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7	0	60	0.58212	4.11131	94.8267	7.63403	6.84984	5.7248		4:37 PM	-0.558	0.01788	3,40206	-2.82784		4:37 PM	-0.021	-0.2558	2.77434	-1.8666	7	
8	60	120	4.42724	4.84537	92.2876	6.11255	5.79178	10.5564		4:38 PM	0.5164	-0.52949	2.14662	-0.9055		4:38 PM	-0.46311	-0.1179	2.602505	-0.9594	8	
9	120	180	10.1408	3.57257	95.4763	4.4342	5.88636	14.9811		4:39 PM	-1.347	0.15791	2.25884	0.85492		4:39 PM	-0.75815	-0.13658	2.153223	0.54420	7	
10	180	240	0.46769	3.50685	94.5668	6.04118	5.71391	17.0629		4:40 PM	-1.444	-0.03816	2.05422	1.6832		4:40 PM	-1.10224	0.450891	1.742826	0.95332	2	
11	240	300	1.36695	4.14041	100.463	5.82881	4.75417	13.6413		4:41 PM	-0.516	1.23292	0.91542	0.32184		4:41 PM	-0.92221	0.329699	1.525229	0.47695	9	
12	300	360	2.12805	3.94141	93.7897	4.23979	5.3362	11.3892		4:42 PM	-0.807	-0.20567	1.60604	-0.57417		4:42 PM	-0.43782	-0.16274	0.73229	0.23246	ő	
14	420	420	1 58951	4.49920	88 7432	6 32615	4 93287	14 7565		4:43 PM	0.0096	-1.01040	1 12746	0.94972		4:43 PM	0.523186	-1.44614	0.802969	0.36036	3	
15	420	540	5.67164	5.16641	87.6495	5.32643	4.31854	12.3774		4:45 PM	0.9865	-1.52936	0.39853	-0.18098		4:45 PM	0.923265	-1.22201	0.543252	-0.1300	8	
16	540	600	8.66938	5.31892	90.8329	8.83998	4.07013	10.3823		4:46 PM	1.2099	-0.84309	0.10377	-0.9748		4:46 PM	0.519326	-1.03012	0.311399	-0.1306	5	
17	600	660	6.33387	4.0567	91.4136	4.38546	4.34667	14.7521		4:47 PM	-0.638	-0.71791	0.4319	0.76382		4:47 PM	0.186735	-0.68752	0.239828	-0.144	6	
18	660	720	5.27907	4.48501	92.4172	4.45028	4.13759	12.2723		4:48 PM	-0.011	-0.50156	0.18381	-0.22281		4:48 PM	-0.46783	-0.46941	0.174463	0.64856	8	
19	720	780	3.01605	3.97787	93.8682	4.92214	3.90486	16.3629		4:49 PM	-0.754	-0.18875	-0.09233	1.40469		4:49 PM	0.055787	-0.4451	-0.06247	0.31015	8	
20	780	840	7.17186	5.12947	91.7519	6.39511	3.74763	12.2004		4:50 PM	0.9324	-0.64498	-0.2789	-0.25141		4:50 PM	-0.18196	-0.11289	-0.45374	0.69398	2	
21	840	900	0.47318	3.99793	97.0402	6.30723	3.14832	15.1664		4:51 PM	-0.724	0.49506	-0.99001	0.92866		4:51 PM	-0.23413	0.089777	-0.37681	0.10353	5	
23	960	1020	0.46575	3 28018	95 4885	6 17988	3 92233	15 8668		4:52 PM	-1 775	0.41925	-0.07161	1 20731		4:52 PM	-1.36421	0.356269	-0.5501	0.38977	4	
24	1020	1080	0.82109	3.53197	95.4743	4.01931	2.53549	14.4013		4:54 PM	-1.407	0.15749	-1.71717	0.62425		4:54 PM	-1.31997	0.417731	-1.01943	1.09970	5	
25	1080	1140	6.74146	3.96161	99.0816	4.94553	2.91277	16.5209		4:55 PM	-0.778	0.93514	-1.26951	1.46755		4:55 PM	-0.99532	0.683945	-1.28343	1.09451	7	
26	1140	1200	6.47219	3.9453	99.1932	3.64415	3.25485	15.8277		4:56 PM	-0.802	0.9592	-0.86361	1.19175		4:56 PM	-0.49931	0.784531	-0.83959	0.77730	5	
27	1200	1260	0.3838	4.54818	96.8741	8.10467	3.65766	12.0095		4:57 PM	0.0813	0.45925	-0.38564	-0.32739		4:57 PM	-0.59657	0.873117	-0.58639	0.2639	6	
28	1260	1320	3.10095	3.76235	100.314	3.77301	3.55293	12.6502		4:58 PM	-1.069	1.2009	-0.50992	-0.07248		4:58 PM	-0.67873	0.901689	-0.52146	-0.0765	3	
29	1320	1380	0.38573	3.77698	99.5908	5.14685	3.41901	13.2603		4:59 PM	-1.048	1.04491	-0.66883	0.17027		4:59 PM	-1.05708	0.882349	-0.45222	0.29044	4	
30	1380	1440	2.73911	3.77303	96.605	4.78079	3.83273	14.7766		5:00 PM	-1.054	1.00102	-0.17792	1 12921		5:00 PM	-1.02157	0.815721	-0.1145	0.69070	7	
32	1500	1560	0.33501	4 02384	100.01	7 83912	4 24167	14 158		5:02 PM	-0.687	1 13522	0.30732	0.52742		5:02 PM	-0.52026	1 143276	0.366433	0.64147	9	
33	1560	1620	6.94958	4.55325	100.744	6.94146	4.22602	13.5077		5:03 PM	0.0887	1.29359	0.28875	0.26871		5:03 PM	-0.60192	1.473712	-0.00656	-0.1885	5	v
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60	120	4.42724	4.84537	92.2876	6.11255	5.79178	10.5564		4:38 PM	0.5164	-0.52949	2.14662	-0.9055		4:38 PM	-0.46311	-0.1179	2.602505	-0.95948		
120	180	10.1408	3.57257	95.4763	4.4342	5.88636	14.9811		4:39 PM	-1.347	0.15791	2.25884	0.85492		4:39 PM	-0.75815	-0.13658	2.153223	0.544207		
180	240	0.46769	3.50685	94.5668	6.04118	5.71391	17.0629		4:40 PM	-1.444	-0.03816	2.05422	1.6832		4:40 PM	-1.10224	0.450891	1.742826	0.953322		
240	300	1.36695	4.14041	100.463	5.82881	4.75417	13.6413		4:41 PM	-0.516	1.23292	0.91542	0.32184		4:41 PM	-0.92221	0.329699	1.525229	0.476959		
360	420	6 85601	4 49925	87 7139	4.23979	3 70911	15 2194		4:42 PM	-0.807	-0.20567	-0.3246	-0.57417		4:42 PM	-0.43782	-0.16274	0.73229	0.232466		
420	480	1.58951	4.88428	88.7432	6.32615	4.93287	14.7565		4:44 PM	0.5734	-1.29359	1.12746	0.76555		4:44 PM	0.523186	-1.44614	0.400463	0.51143		
480	540	5.67164	5.16641	87.6495	5.32643	4.31854	12.3774		4:45 PM	0.9865	-1.52936	0.39853	-0.18098		4:45 PM	0.923265	-1.22201	0.543252	-0.13008		
540	600	8.66938	5.31892	90.8329	8.83998	4.07013	10.3823		4:46 PM	1.2099	-0.84309	0.10377	-0.9748		4:46 PM	0.519326	-1.03012	0.311399	-0.13065		
600	660	6.33387	4.0567	91.4136	4.38546	4.34667	14.7521		4:47 PM	-0.638	-0.71791	0.4319	0.76382		4:47 PM	0.186735	-0.68752	0.239828	-0.1446	<u> </u>	
720	720	3.01605	3 97787	92.4172	4.45028	3 90486	16.3629		4:40 PM	-0.754	-0.50156	-0.09233	1 40469		4:40 PM	-0.46783	-0.46941	-0.06247	0.848568		
780	840	7.17186	5.12947	91.7519	6.39511	3.74763	12.2004		4:50 PM	0.9324	-0.64498	-0.2789	-0.25141		4:50 PM	-0.18196	-0.11289	-0.45374	0.693982		
840	900	0.47318	3.99793	97.0402	6.30723	3.14832	15.1664		4:51 PM	-0.724	0.49506	-0.99001	0.92866		4:51 PM	-0.23413	0.089777	-0.37681	0.103535		
900	960	0.46373	3.87098	96.6886	10.8789	4.09939	11.9108		4:52 PM	-0.91	0.41925	0.13849	-0.36665		4:52 PM	-1.13677	0.358289	-0.30771	0.589776	L	
960	1020	0.43682	3.28018	95.4885	6.17988	3.92233	15.8668		4:53 PM	-1.775	0.16056	-0.07161	1.20731		4:53 PM	-1.36421	0.245768	-0.5501	0.488304	<u> </u>	
1020	1140	6.74146	3.96161	99.0816	4.94553	2.91277	16.5209		4:55 PM	-0.778	0.93514	-1.26951	1.46755		4:55 PM	-0.99532	0.683945	-1.28343	1.094517		
1140	1200	6.47219	3.9453	99.1932	3.64415	3.25485	15.8277		4:56 PM	-0.802	0.9592	-0.86361	1.19175		4:56 PM	-0.49931	0.784531	-0.83959	0.777305		
1200	1260	0.3838	4.54818	96.8741	8.10467	3.65766	12.0095		4:57 PM	0.0813	0.45925	-0.38564	-0.32739		4:57 PM	-0.59657	0.873117	-0.58639	0.26396		
1260	1320	3.10095	3.76235	100.314	3.77301	3.55293	12.6502		4:58 PM	-1.069	1.2009	-0.50992	-0.07248		4:58 PM	-0.67873	0.901689	-0.52146	-0.07653	L	
1320	1380	2 73911	3.77598	99.5908	0.14685	3,41901	13.2603		4:59 PM	-1.048	1.04491	-0.66883	0.17027		4:59 PM	-1.05708	0.882349	-0.45222	0.290444		
1440	1500	3.14724	3.83509	99.3872	3.29372	4.40679	15.6682		5:01 PM	-0.963	1.00102	0.50324	1.12831		5:01 PM	-0.90108	0.845824	0.210877	0.809757	-	
1500	1560	0.33501	4.02384	100.01	7.83912	4.24167	14.158		5:02 PM	-0.687	1.13522	0.30732	0.52742		5:02 PM	-0.52026	1.143276	0.366433	0.641479		
1560	1620	6.94958	4.55325	100.744	6.94146	4.22602	13.5077		5:03 PM	0.0887	1.29359	0.28875	0.26871		5:03 PM	-0.60192	1.473712	-0.00656	-0.18855		

c)

Legend: a) Raw physiologic data, b) physiologic data after z-score calculation and c) physiologic data after z-score calculation smoothed by three

These values allowed for the creation of a graph depicting the four physiologic variables across a case, with time as the x-axis.







#### 2. Analyzing Data Around Surgeon Perceived Stress Events

The second type of data set allowed us to perform "point analysis". Five-minute timeframes of similar analysis described above were performed around areas of perceived stressful events as identified by the surgeon during the case, using the foot pedal or in the post-operative interview. For example, if during the case the surgeon thought they may have accidentally ligated the wrong vessel, the observer notes would be used to identify the time during the surgery this occurred. Then, a five-minute window around that event was analyzed to determine if a particular physiologic indicator demonstrated a response that was considered a significant change from baseline. For the purposes of this study, a cutoff of HR>140% of baseline and HRV<85% of baseline was used [114].

#### 3. Analyzing Data for Physiologic Stress Events

As a resting baseline, each of the surgeons provided physiologic monitoring data that was collected in their office in a resting state. These baseline values were then compared with the whole data set available for that particular surgeon. Areas of interest where the HR was elevated at 140% of average baseline HR were identified. Additionally, areas of interest where the RSA level was less than 100%, 85% and 70% of baseline were identified. Finally, areas where 95% of the maximum HR achieved in the case were also recorded [114].

	Average Heart	Heart Rate	Average	RSV	RSV
	Rate	(140%)	RSV	(85%)	(70%)
Surgeon 2	68.9	96.5	4.36	3.706	3.05
Surgeon 3	76.3	106.8	4.81	4.0885	3.37
	Max Heart Rate	95% of Max			
Surgeon 3 OR 2	114.92	109.174			
Surgeon 3 OR 3	94.48	89.756			

 Table 2.3: Cutoff values used to determine physiologically significant events

# **CHAPTER THREE: THE COMPLEX PHENOMENON OF STRESS IN THE OPERATING ROOM**

#### INTRODUCTION TO RESULTS

Presented in this section are the results of the exploratory pilot study. There was a large amount of data collected for this study, but as we were specifically interested in the stress experience, data analysis primarily took place around the stressful events, which were considered the units of analysis in this case study methodology. These events were either surgeon-identified stressful events, or physiologic-identified stressful events.

The results paper focuses on three aspects of the data: the story of surgeon stress in the OR, the causes of stress in the OR and finally the relationship between physiologic and perceived stress. This paper will be submitted to a surgical journal such as the American Journal of Surgery.

The results paper is followed by the presentation of a complete data table presenting the large amount of data collected throughout this study.

# Exploration of The Relationship Between Perceived and Physiologic Stress by Surgeons in the Operating Room

Natashia M. Seemann, Vicki R. LeBlanc, Carol-anne E. Moulton

#### Background

Despite the recognition that stress is prevalent in the operating room (OR) [119], few studies have attempted to understand the experience of surgeon stress in the naturalistic environment. Studies in the simulation setting have demonstrated that acute stress can affect not only a surgeon's technical skills [66, 102, 108, 120, 121], but also their non-technical skills [7, 122] such as communication, teamwork and leadership. Studies performed in the naturalistic OR setting have often used a single variable to identify and quantify stress (ie. heart rate or an inventory) and correlated this with an outcome of interest, such as technical difficulty [54, 55]. However, stress as experienced by a surgeon in the operating room is a much more complex phenomenon, affected by physiologic, affective, cognitive and sociocultural variables that interact to create the individual surgeon's experience. Studying one facet of the stress response alone is likely insufficient to understand the complex interplay of various factors that contribute to the experience of stress in the OR. Stress is a very individualized experience that is influenced by each facet of the stress experience. The effects of stress on individual wellness and performance, is also highly variable [113].

In the surgical setting, the great majority of studies have used physiology as a measure of stress in their participants [54, 55, 57, 60, 123, 124]. Few studies have examined the perception of stress [119, 125, 126] and even fewer have examined both the physiology and perception of stress [21, 22, 127]. These studies have frequently attempted to understand the relationship between physiologic and perceived stress using correlation, yielding confusing results as some have demonstrated strong correlation, and others have demonstrated no correlation. While it is important to study and understand both the subjective stress experience, and the physiologic stress experience, correlation is likely not the appropriate method for examining this relationship [23, 113]. Furthermore, a physiologic variable alone, provides very little context as to why and how the surgeon is experiencing stress.

The aim of this preliminary exploratory study was to use a multi-faceted methodology (previously described PACS methodology), to explore the complex experience of surgeon stress in the OR and generate hypotheses for future studies. A secondary aim was to use this methodology to explore the relationship between physiologic and perceived stress.

# Methodology

The institution's research ethics board approved this exploratory pilot study. Seven surgeons at a single academic university hospital were studied during 2-4 operations each. Participants ranged in age, surgical experience, gender and specialty including general, thoracic, breast, vascular, hepatopancreaticobiliary and endocrine surgery. Both elective and emergency operations were captured. Baseline physiologic data was collected from each of the surgeon participants at the time of consent to the study. A large amount of data was collected throughout each of the cases, and data analysis was focused on the stressful events - either identified by the surgeons themselves (perceived) or by physiology. Each stressful event, was considered a case.

Case study methodology was applied. This is a strategy of inquiry used to understand a specific issue [110], in this case, stress in the OR. Case study research involves the exploration of cases through detailed, in-depth data collection involving multiple sources of information [109], in this study, physiologic, affective, cognitive and sociocultural data. The full methodology used in this study is reported elsewhere [ref for methodology paper].

#### Perceived Stress Data

Perceived stress was captured in three ways. First, the surgeon was encouraged to verbally notify the research team at any point during the operation when they perceived stress.

However, understanding that the OR environment may not be conducive to this level of transparency, a foot pedal was placed by the surgeon's foot throughout the operation. This foot pedal was connected to the software system and therefore the research team was able to see a flag in line with the physiology, any time the foot pedal was pressed. The surgeons were instructed to tap the pedal when they perceived stress, so as to discreetly alert the research team of the stressful event. Third, on-site immediate pre- and post-operative interviews explored the surgeon's experience of stress. The pre-operative interview guided the research team to points during the operation where the surgeons' anticipated they might experience stress. The post-operative interview asked surgeons to identify which parts of the surgery they perceived as stressful, and this helped verify events that were identified pre-operatively or intra-operatively and allowed for the discussion of unanticipated stress events that arose. These perceived stressful events from the interviews were then linked back in time with the physiologic data through detailed observer notes that were taken throughout the operation.

#### Physiologic Stress Data

Physiologic stress was captured using ECG data for heart rate (HR) and heart rate variability (HRV). Previous research has indicated that although HR alone is sensitive for stress, it is not specific [49]. Elevations in HR can be caused by other phenomena such as excitement, arousal, and exercise [50]. HRV, a more specific measure of stress [51] is the variation in the time interval between heartbeats. Unlike HR, which increases with stress, HRV actually decreases with stress. Several different methods of detecting and calculating HRV exist [52]. In this study, we chose to use the Respiratory Sinus Arrhythmia (RSA) analysis, as it is a validated method for calculating HRV [128] and is a software script written into the BioPac software.

BioPac Canada's wireless physiologic monitoring equipment was used in conjunction with their software system, and this allowed the research team to view ECG data in real-time. HR could be viewed in real-time, but HRV data required analysis of the ECG data following the surgery. Surgeons wore the ECG electrodes on their chest, underneath their scrubs, attached to a small wireless monitoring device. Physiologic arousal was identified when the surgeon's

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HR was >140% of their baseline HR at any time during the operation. Physiologic stress was identified when the surgeon's HRV was <70% of the surgeon's baseline HRV at any time during the operation. Although a range of physiologic "cut-off" values have been used in various studies, previous research has demonstrated that performance can be affected when physiologic stress reaches these values from baseline and thus, there were the "cut-off "values used in our study [114].

## Data Analysis

Data triangulation was used as a method of analysis at each of the physiologic and perceived identified stressful events. This is a method of analysis that allows combination of data sets collected using different methodologies in the study of the same phenomenon, in this case, a stressful event [104]. Using data triangulation allowed for analysis of the experience of stress from different angles, providing a more robust means for capturing stress in its complexity. Furthermore, when using case study methodology, holistic analysis of the entire case takes place, permitting the researcher to focus on a few key issues or themes, not for generalizing beyond the case, but for understanding the complexity of the case [109]. This manner of analysis was especially useful in this study; as such a large amount of data was collected, this permitted the research team to focus on stressful events of interest and develop an understanding of stress in the OR. Case study research also allowed the research team to look for a correspondence between two or more categories in order to understand the relationship between these categories [109]. One of the aims of this study was to understand the relationship or correspondence between physiologic and perceived stress.

## **Results Part 1: Case Study Example**

In keeping with case study methodology, several cases (stressful events) will be described, followed by a presentation of the collective data and the correspondence between physiologic and perceived stress.

## Surgeon 3, Case 3

**Case Details**: This was an emergency case designated highest priority (A). It was booked as an exploratory laparotomy for ischemic bowel secondary to a superior mesenteric artery thrombus. This case was complicated by the fact that the patient had undergone a complex abdominal surgery a few months prior, by another surgeon in the same institution. In addition, this emergency case was bumping Surgeon 3's elective cases for the day.

In the pre-operative interview, the surgeon anticipated that the parts of the surgery that would be stressful were: "really just the status of the patient, how acutely unwell they are, the possibility that the patient may not survive the operation".

The surgeon also identified several other factors present that may affect his level of stress in the OR during this case.

"I was woken up at 2:45 this morning by a call from my resident...

dealing with an unstable patient in the ICU since then"

"I just got yelled at by one my [elective] patients because they are now on

hold and have to wait. I likely will have to cancel my second case."

# Intra-operative Observations (selected presented)

9:42: surgeon scrubs in

9:57: "Uh-oh... smells like dead bowel"

10:00: discussing case with vascular surgeon, determining whether there is enough healthy bowel to proceed with resection

10:08: asks fellow to call consultant general surgeon

10:21: surgeon frustrated that they still have not been able to reach consultant surgeon 10:27: surgeon discusses case with consultant surgeon and vascular surgeon, decision made to

move forward with removal of all the dead bowel and attempted re-vascularization

10:45: surgeon scrubs out and vascular surgery team takes over



Figure 3.1: Physiology of Surgeon 3 Case 3

In the post-operative interview, the surgeon identified that "the decision making" was the most stressful part of the operation: "Probably the most stressful part of the operation was not being able to get a hold of my colleague." Using the intra-operative observer notes, the research team was able to identify this time during the case occurred from approximately 10:08-10:27. This time period was associated with an increase in HR, and a decrease in HRV, but these were not the highest or lowest values attained during the case. The highest HR attained during the case (94 beats per minute) was when the surgeon was assessing the length of viable bowel. The lowest HRV attained during the case (4.74) was when the surgeon first identified a large volume of ischemic dead bowel.

## **Results Part 2: Stressful Events as Perceived by the Surgeon**

Across 18 operative cases, there were 32 perceived stressful events identified by the surgeons, via foot pedal, verbally, or in the post-operative interview. These events were categorized into a framework of stressors. Eleven of the perceived stressful events were anatomy/technical related, and six were related to intra-operative bleeding. Therefore just over 50% of the perceived stressful events were related to technical aspects of the operation. The other 50% were related to stressors in the wider operating room or in some cases outside of the OR altogether. Five were related to the OR-team, three were related to decision-making in the OR, two were moments of fear where the surgeon wondered "did we mess up?" (one during an intra-operative cholangiogram, the other when a surgeon misheard a resident), two were related to teaching (i.e. resident sewing vascular anastomosis), one was related to a patient factor, and two were related to issues outside the OR altogether (i.e. sick patient on the ward).

Another finding that developed from this framework was the inter-surgeon variability associated with the perception of stress. For example, one surgeon felt that emergency cases were far more stressful than elective cases: "You don't have a chance to plan for them. You never know what you're going to find and so you can't plan what you're going to do" [Surgeon 8]. While another surgeon felt that elective cases were far more stressful. This surgeon elaborated that in an elective case, the surgeon has a pre-existing relationship with the patient and there is an expectation that the surgeon's job is to make the patient better, whereas in an emergency case, there is not as much expectation: "If someone comes off the street like this, you don't feel nearly as responsible" [Surgeon 3].

This inter-surgeon variability was also seen in the perception of what factors caused or alleviated stress in the operating room. For example, some surgeons consistently iterated that the composition of their team (fellows, residents, nursing etc.) either increased or decreased stress, while there were other surgeons who did not bring this factor up at all.

## **Results Part 3: The Relationship Between Perceived and Physiologic Stress**

Of 32 surgeon perceived stressful events, full physiologic data could only be analyzed in 11 events. This was due to issues with conductance of the ECG electrodes, signal interference due to movement of the surgeon throughout the operation, and missing data due to faulty electrodes. Of the 11 perceived stressful events analyzed, four resulted in a significant change from baseline in both HR and HRV (true physiologic stress), four resulted in a significant change from baseline in HR but not HRV (likely physiologic arousal but not stress) and three resulted in no significant change from baseline in either HR or HRV.

In order to identify physiologic stress events, the entire operative ECG was scanned and flags were placed at any point that the HR>140% of baseline and HRV<70% of baseline. Four cases, comprising the data of two surgeons were of adequate data quality to be able to analyze in this way. There were 17 HR-identified stress/arousal events across four cases, and nine HRV-identified stress events across the four cases. For the purpose of this study, only the HRV-identified stress events were considered physiologic stress since this is a more specific measure of stress than HR alone.

Of the nine physiologic-identified stress events in two surgeons across four cases, four were associated with perceived stress as expressed by the surgeon. In the cases where physiologic and perceived stress were associated, one was due to bleeding, thought to be from the inferior vena cava, one with taking the gallbladder off the liver and trying to identify the cystic duct, one when the surgeon discovered a high volume of dead bowel upon exploratory laparotomy, and one when attempting to make a decision about whether or not to 'save' the patient.

The relationship between perceived and physiologic stress presented in four ways:

- (1) perceived stress with physiologic stress (HR + HRV)
- (2) perceived stress with physiologic arousal (HR only)
- (3) perceived stress without physiologic stress or arousal
- (4) physiologic stress without perceived stress

Example Perceived Stress + Physiologic Stress: Surgeon 2, OR 3 – Left lobectomy and

wedge resections of liver for metastatic colorectal cancer.

Surgeon pushed foot pedal at 11:55

Time	Observer Notes	HR	HRV
11:54:15	Surgeon scared for a moment that it might be	115	4.07
	bleeding from the vena cava		
11:55:15	Surgeon says "Okay, now you got me worried"	108	4.07
11:55:37	Surgeon pushes foot pedal	111	4.07
11:55:43	Nervous that it's bleeding from the cava	111	4.07
11:56:58	Surgeon says "In principle, don't need to see the	106	4.07
	cava in a left, but I usually like to"		
11:58:01	Surgeon says "It can't be the cava"	102	4.18
11:58:04	Surgeon says "It was just a large ligamentum	102	4.18
	venosum"		

**Example Perceived Stress Without Physiologic Stress**: Surgeon 4, OR 2 – Repair of popliteal artery anaeurysm.

When asked in the post-operative interview to identify which parts of the case were identified as stressful, the surgeon comments that he felt stressed when there was bleeding from the popliteal vein (associated in time with the observer notes approximately 10:52-10:57).

*Post-operative interview: "*there was a little bit of bleeding from the popliteal vein that I needed to control."

Time	Observer Notes	HR	HRV
10:51:12	They seem to be having trouble with the distal	74	4.91
	dissection		
10:52:22	Discussion among surgical team of what they are	71	4.92
	trying to do		
10:53:53	Surgeon says "May need 6-0 prolene". There is some	71	4.92
	major bleeding		
10:54:03	Surgeon trying to control bleeding	72	4.92
10:54:07	Surgeon asks for prolene	68	4.92
10:54:14	Surgeon is repairing hole in popliteal vein	70	4.92
10:54:40	Fellow tying suture down	70	4.92
10:55:12	Surgeon reloading needle for next bite	71	5.01
10:56:16	Still quite a lot of bleeding	72	5.01
10:56:41	Surgeon says "Venous bleeding is very hard to control	72	5.01
	because it's difficult to see where it's coming from		
10:57:05	Surgeon tells anaesthesia they have lost about a unit	74	5.01
	of blood		
10:57:22	Bleeding now under control	71	5.01

# Example Physiologic Stress Without Perceived Stress: Surgeon 3, OR 3 – Exploratory

laparotomy, lysis of adhesions and resection of ischemic bowel.

Between 10:03-10:08 it was identified during the data analysis phase, that the surgeon's HR was elevated >140% of baseline and HRV decreased <70% of baseline, although the surgeon did not identify this part of the case as stressful.

Time	Observer Notes	HR	HRV
10:02:25	Surgeon continuing to free small bowel adhesions	92	4.75
	in order to make full assessment of bowel. Lots of		
	adhesions		
10:05:26	Mild bleeding	92	4.81
10:07:25	Continuing to free adhesions	90	4.81
10:08:13	Fellow enters the OR and the surgeon asks him to	93	4.81
	call the surgeon who previously operating on this		
	patient		
10:08:57	Identifying dead bowel, assessing how much is	94	4.81
	healthy. Surgeon is muttering "this is dead, this is		
	dead"		

# Discussion

The findings in this pilot study have demonstrated that the phenomenon of stress in the operating room is complex. Each stressful event is a unique case of how surgeons experience stress in the OR. The study of multiples cases has allowed us to begin to understand that there are different perspectives and experiences of stress in surgeons. Each case is so unique, that it does not make sense to attempt to globalize the findings, or prescribe strict cutoffs for what represents surgeon stress and what does not. Rather, this

case study methodology has allowed us to form a deeper understanding of the surgeon stress experience, and how each facet of stress contributes to the overall experience. Using data triangulation in the analysis of the data, allowed for a richer understanding of each case. For example, in each surgeon identified stressful event, we were able to look at that moment when the surgeon's physiology was, what the observer notes picked up, how the surgeon was feeling based on their verbalizations, use of the foot pedal or what they relayed in the post-operative interview. Using data from each of these sources, this study was able to shed light on the complex stress experience.

Examination across all cases allowed for the development of a framework of the sources of stress perceived by surgeons in the OR. Interestingly, almost 50% of the stressors were not related to the operation itself. One of the factors cited was the operative team composition, which included the surgical fellows and residents, the anaesthesiologist and the nursing team. As a cited source of stress to the surgeon, this is especially pertinent given that most surgeons have very little control over the composition of their team. Another frequently mentioned stressor was time pressure and the risk of having subsequent cases cancelled as a result of being overtime on a case. It is concerning that a surgeon's performance in the current case may be affected by concern regarding other cases. These sources of stress have not been frequently mentioned in previous studies and should be explicitly explored in future studies [85, 101]. There may be environmental factors, such as deliberate team composition and policies regarding cancellation of cases, that may help to alleviate stress in surgeons and provide safer OR environments for patients.

Examination of the relationship between perceived and physiologic stress, has revealed that the two are not consistently associated and thus the measurement of both perceived and physiologic stress is vital in order to capture the complex experience. Furthermore, the perception and physiology of stress is variable from surgeon to surgeon, and each case is a unique stress experience. It is evident from these findings, that the study of surgeon stress in the OR would be limited by studying one variable alone. We know from previous work that excessive physiologic stress negatively affects a surgeon's technical performance [66, 102, 108, 120, 121], but we do not yet know how perceived stress affects surgeon performance. It is possible that perceived stress affects a surgeon in different ways than physiologic stress and that different combinations of two, may lead to different manifestations of stress.

In this study, the research team was able to see HR data in real-time. This was helpful as it cued the observer to when the surgeon may be experiencing stress. However, the equipment and software system in this study did not allow for real-time calculation and knowledge of the HRV data. As mentioned, HRV is more specific for physiologic stress and thus being able to see this data in real-time would have been extremely helpful to the research team. Having the data analyzed in real-time would have allowed us to further explore physiologic stress events in the post-operative interview.

Perceived stress, as one would expect, is an individual's interpretation that stress is present. Therefore, there can be significant variability from person to person in what is considered stress, what causes stress, and how this stress is experienced. It is possible that one surgeon's perception of stress in this study is very different than another's. Certainly this was the case in a previous study that examined different surgeon's perception of risk assessment in the OR [129]. This pilot study was exploratory in nature and thus the aim was not to be too prescriptive about a definition of perceived stress, in order to fully explore the range of the phenomenon. However, this may have lead to misinterpretations of what should be identified as perceived stress. While these are limitations of studying perceived stress in any setting, the OR environment may present unique challenges. When asked in the post-operative period to recall which parts of the operation were perceived as stressful, there is likely to be a significant recall bias. Several of the cases were over three hours long, which may make it difficult for the surgeon to remember exactly which parts of the case were stressful. While the surgeon was provided with the foot-pedal to indicate stress in the moment, the use of this foot pedal varied greatly from surgeon to surgeon, and it is likely that even in the surgeons who used the foot pedal, there were moments when they may have forgotten to push it while perceiving stress.

There were several events identified in this study in which the surgeon experienced physiologic stress, which was not perceived by them as stress. What is unknown through this pilot study is whether this represents a lack of awareness by the surgeon, or perhaps 'impression management'. Goffman described the theory of impression management in 1959 as a social interaction between two people where one is putting on a desired front to the other, for the purpose of managing the impression others have of them [130]. While this study did not aim to look specifically at impression management in surgeons, previous studies have demonstrated that this social behavior is prevalent in the surgical world [82]. The surgical culture has traditionally not been one where stress was openly acknowledged or accepted [100]. Even though the surgeons in this study seemed particularly forthcoming about their experience of stress, it may be that there are certain aspects of the case that are 'accepted' causes of stress (ie. technical challenges, bleeding) but other causes of stress that are not accepted and thus not discussed (ie. team factors, personal crises). If, however, this represents a lack of awareness of physiologic stress, there is evidence that this may be dangerous to the surgeon's health. Several studies have demonstrated that people who are unaware of their bodies physiologic stress response are at greater risk for cardiovascular events such as myocardial infarctions [131]. Finally, given the limitations of the study methodology, it may be that surgeons did not report these physiologic events as stressful simply because they were not able to recall them by the time the post-operative interview took place.

## Conclusions

This exploratory pilot study has allowed for a deeper understanding of the complex stress experience of surgeons in the OR. It has highlighted the inter-surgeon variability in the causes of stress, the experience of stress, and the manifestations of stress. It has also emphasized that the relationship between perceived and physiologic stress is complex, and it is important to consider the implications of perceived stress in future studies. Going forward we must continue to use a multi-faceted methodology, which includes both

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measures of physiologic and perceived stress, in order to investigate each surgeon as an individual. The continued use of analysis tools like data triangulation will allow for a more elaborate and holistic understanding of how surgeons experience stress in the OR. Understanding this phenomenon more completely will allow for the creation of individualized stress assessments, and the eventual creation of stress-training programs for surgeons.

Table 3.1: Full Data Exploratory	Pilot Study of Surgeon	Stress in the OR
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							Pre	-operative	Intra-o	perative			Post-	operative
OR	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights
Surg	geon 1								•					·
1	Open cholecystectomy + Seg 4B/5 resection	Elective	N	May 21 2014	2.7	9	87.5	Is this cancer or not? Decision on what surgery to do? Patient bleeding to death on ward. Meetings this morning so lots in my head. Too many people scrubbed	1. Coming through the cystic plate - 10:36-11:43	Unable to fully analyze	1.9	14	98.8	No specific parts identified as stressful, felt on edge throughout case due to monitoring, caffeine and morning meetings
2	Lap wedge resection liver (seg 5) + cholecystectomy	Elective	N	May 21 2014	0.7	8	97.3	Fact that it's lap instead of open, if you get into bleeding more difficult to stop	1. Coming through the liver - 14:00-14:35 (significant change from baseline in HR and HRV) 2. Coming across where the cystic plate joins the liver - 14:27-14:29 (significant HR but not HRV)	Unable to fully analyze	0.6	8	98.5	Coming through the liver because risk of bleeding
Surg	jeon 2											<u> </u>		
1	Whipple for obstructive mass	Elective	Y	June 16 2014	0.9	10	95.5	Taking the uncinate off the SMA and SMV may be more difficult. Meeting and scope booked concurrently.	1. "When we nailed the IPDA" - 11:57-12:01	None	1.2	13	92.4	A lot of stuff in my head, but didn't think it affected me. When we nailed the IPDA. I'm not that uptight about much anymore. I know I can fix it, or someone around here can fix it so it's not a big deal.
2	Whipple	Elective		June 25 2014	0.5	10	80.9	Arterial anatomy may be difficult. Taking the uncinate off the portal vein and SMA. Pancreatic anastomosis b/c this is a soft pancreas. On call. Too many patients to round on.	1. Taking the uncinate process off of the SMA and SMV because the cyst was stuck - 11:39 (not physiologically significant)	None	1.1	9	76.7	Taking the uncinate off the SMA and SMV because cyst was stuck

							Pre	operative	Intra-o	perative			Post-	operative
OF	R Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights
3	Left lobectomy + multiple wedge resections seg 5,6,7,8 for metastatic CRC	Elective	Ν	Aug 25 2014	1.2	15	89.7	A lot of mets so operating on both sides of the liver. Worrying about liver function post-op. I can't stand the resident	<ol> <li>Bleeding from the spleen (pedal pushed) - 10:31 (significant HR but not HRV)</li> <li>Bleeding, concern that it may from the vena cava (pedal pushed)- 11:55 (significant HR but not HRV)</li> <li>During the cholangiogram there was a moment when anatomy was unclear and they thought they may have injured a major bile duct - 12:54-12:59</li> </ol>	1. 11:54-11:55 - Surgeon scared for a moment that bleeding was from vena cava	1.1	9	84	Haven't done in a lobe in ages. Never seen that anatomical variant so worries him. Tough case, questioning decision to do it in the way they did. An intra-op cholangiogram was done and there was a moment when they thought they may have cut a bile duct they didn't want to. Discussed case with colleague surgeon before case and she said if you mess it up you can just recontruct it with a roux- en-y so was planning exit strategy in case that happened. The equipment kept busting, I hate that.
Sui	rgeon 3													
1	Right hepatectomy for metastatic rectal ca	Elective	N	Aug 11 2014	1	15	92.8	Mobilization of the liver because of prior liver surgery. Portal dissection due to previous PVE. First day back from vacation, 450 unanswered emails. Brand new fellow. Circulating nurse usually doesn't do general surgery.	<ol> <li>Fellow was tentative, resident very aggressive, difficult to balance - throughout the case</li> <li>Rotating nurse tripping on headlight - 12:28</li> <li>Anaesthesia fellow struggling to manage CVP - 12:02-12:27 (not significant)</li> <li>The portal dissection - 11:06-11:42 (significant both HR and HRV)</li> <li>Mobilization of the liver - 10:32-11:02 (significant both HR and HRV)</li> <li>Dividing the bile duct - 13:02-13:44?</li> </ol>	Unable to fully analyze	0.8	19	90	Fellow was too tentative, senior was too aggressive. Inexperiened scrub nurse. Nurse stepping on headlamp. Colleague called in, de-stressed the situation. Anaesthesia fellow inexperienced with controlling CVP. Portal dissection difficult. Defining anatomy stressful. Dividing the bile duct.

								Pre	-operative	Intra-o	operative			Post-	operative
c	DR (	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights
		Dpen :holecystectomy	Elective	Ν	Aug 11 2014	0.6	11	95.2	Failed chole from another surgeon, likely lots of inflammation, triangle of Calot will be difficult. End of the day so nurses whining about the case going so late. Still sort of coming down from my first case.	1. Taking down the gall bladder, figuring out where the cystic duct was - 17-02- 17:10 (significant both HR and HRV)	1. 16:39-16:42 - Discussion with team, nurse who was not pleased case went ahead so late, working on exposure, teaching residents 2. 16:58-17:08 - Trying to identify triangle of calot, annoyed about equipment they don't have, asks anaesthesia to suction NGT to deflate stomach and improve visualization of anatomy, difficult dissection of gallbladder, surgeon thinks about calling pathology but realizes they've all gone home, got into cyst by accident, bleeding, clipping, upset about senior's dissection, warns about danger of retrograde move, risk of getting into CBD, discussing options if can't identify anatomy, surgeon says "better to be safe and do a subtotal cholecystectomy" 3. 17:12-17:14 - specimen out, senior resident placing figure of 8 suture, adjusting thoracic impedance electrode on surgeon, removing drain, surgeon tells fellow and senior to dry up bleeding	<0.4	12	91	Pressure to get case done quickly

Emergency Video							Pre	operative	Intra-operative		Post-operative			
OR	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights
3	Exploratory laparotomy + lysis of adhesions + resection ischemic bowel (SMA thrombus)	Emergency	Ν	Nov 20 2014	3.3	20	68.5	Will be difficult to get into abdomen given complex abdominal wall hernia. How acutely unwell the patient is, the chance they may not survive the operation. Worry about what we're going to find. Woken up at 2:45am about unstable ICU patient, dealing with that since then. Elective case got cancelled, got yelled at by my patient when disclosed. Sleep deprivation. End of ACS week, tired, stressed, strung-out. De- stressors = good fellow, resident and anaesthetist	1. Decision making - 10:15- 10:31 (not physiologically significant)2. Not being able to get a hold of colleague for opinion on her patient - 10:14- 10:27 (not physiologically significant)	1. 9:58-9:59 - surgeon says "smells like dead bowel", "the rest of the bowel looks marginal"2. 10:03-10:05 - lysing adhesions, some mild bleeding3. 10:07-10:08 - contining to free adhesions, fellow comes in and surgeon asks fellow to call consultant surgeon who performed Whipple on this patient previously4. 10:17 - discussing whether or not to try "saving" the patient, recounting discussion with patient's wife	1	16	68.2	General condition of the patient, severity of the illness. Co-managing multiple sick patients. Fatigue. Burden of recent complications. Decision making of whether or not to resect bowel. Most stressful part was inability to get a hold of colleague to help with decision making.
4	Exploratory laparotomy + evacuation blood + revision stoma and feeding tube	Emergency	Ν	Nov 20 2014	0.7	20	72.3	Patient is heparinized, bleeding and very complex abdomen. 4th OR in short time period. Patient unstable, maxed on pressors. Guilt of this patient having a complication and rocky post-op course after elective surgery. Not sure how much more he can take.	1. "The situation" - fourth operation, elective patient with rock post-op course - throughout case 2. "Sense of dread" while opening, don't know what you're going to find - 13:11- 13:20	Unable to fully analyze	1	19	79.9	The patient's condition, the history, all the things leading up to this case. The fact that this was my elective patient, and feel responsible for the complications the patient has experienced
Sur	geon 4													

Emergency Video						Pre-operative			Intra-operative		Post-operative			
OR	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights
1	Fem-pop bypass with saphenous graft	Elective	N	Sep 2 2014	4.1	11	81.5	Assessing the saphenous vein as an acceptable conduit, no option to use prosthetics in this patient given baseline soft tissue infection. Time pressure to get case done by noon so second case is able to go forward. Anaesthesia decided to place epidural last minute and had difficulty so definitely will set back time, wasn't counting on that.	<ol> <li>Learning the patient was given therapeutic anticoagulation earlier than intended accidentally by anaesthesia team - 9:06</li> <li>Wathing resident sew vascular anastamosis (lack of control) - 10:35-10:53</li> <li>Watching fellow sew vascular anastamosis (lack of control) - 11:06-11:24</li> </ol>	Unable to full analyze	0.7	10	74.7	Patient was accidentally given full dose of therapeutic heparin by anaesthesia at the beginning of the case rather than when re- anastomosis occurred. Increased stress when fellow and resident are sewing anastomosis due to less control.
2	Repair popliteal artery aneurysm	Elective	N	Sep 24 2014	2.7	11	72.1	Ensuring good quality of the vein harvest and selecting proximal and distal areas for reapir. Only surgeon and medical student to start, no residents or fellows. Patient's case already delayed due to difficult airway.	1. Applying the locking hemoclip to the proximal popliteal artery - 11:30 2. Bleeding from the popliteal vein - 10:50-10:57 (not physiologically significant)	Unable to fully analyze	0.6	12	67.6	Stress related to whether or not second case would be allowed to go ahead. Aplying hemoclip to proximal popliteal artery. Bleeding from the popliteal vein. Family issues at home related to scheduling and commitments.
Sur	geon 5													
1	Laparotomy, reduction + repair diaphragmatic hernia	Emergency	N	Aug 27 2014	<0.4	12	86.4	Emergency, re-operative case. Already been operated on twice by another surgeon, now has complication. Had to cancel elective case and go tell patient cancelled.	None	Unable to fully analyze	<0.4	12	91.9	Unscheduled/emergency nature of the surgery. Time pressure because of another big case to do and already had to cancel a case.

							Pre-	operative	Intra-o	perative			Post-	operative
OR	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights
2 Sur	Clam-shell thoracotomy + resection thymoma + L pneumenectomy and pleural excision geon 6	Elective	N	Aug 27 2014	1.1	10	78.3	Concerned about the ability to get the tumour out because it was deemed resectable at another site. Tumour wrapped around the hilum of the lung, the heart and the aorta so will be a challenge to get out. Starting a big case at 3pm not ideal (earlier emergency cases bumped this). Going to end up with nursing and anaesthesia shift change in the middle of the case	1. Latter part of the surgery, last bit of trying to get the tumour out, had to make a new incision for better access - 18:42-19:12	Unable to fully analyze	<0.4	8	Unreadable	Latter part of the operation was very difficult, looked like tumour may not be resectable. Details of what surgeon was doing was less apparent to second anaesthesia team due to changeover, one point patient was moving and anaesthesia wanted to re- paralyze but since patient was getting pneumenectomy, shouldn't be paralyzed because can prevent them from being able to get off ventilator, therefore required more vigilance on part.
1	L hemi- thyroidectomy	Elective	Ν	Sep 17 2014	2.7	8	60.8	Thyroid actually located in superior mediastinum. Operating around recurrent laryngeal nerve always stressful.	<ol> <li>Trainee as scrub nurse - throughout the case</li> <li>Bleeding in the upper poles area - 9:00-9:03</li> <li>Recurrent laryngeal nerve was difficult to find - 9:08-9:15</li> <li>Senior resident not following instructions - 8:59- 9:18</li> </ol>	Unable to fully analyze	1.9	12	Unreadable	Trainee nurse slowed things down, frustration with not getting instruments quickly. Some bleeding in the upper poles and felt anxious at that part because had a bleed from superior thyroid artery week before which required emergency opening of incision so was remembering that. Recurrent laryngeal nerve was especially difficult to find given bleeding. Senior resident was not listening to instructions.

					Pre-operative				Intra-o	operative	Post-operative				
OR	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights	
2	R hemi- thyroidectomy	Elective	Ν	Sep 17 2014	1.4	6	Unreadable	Patient is diabetic and tissues will be more friable, more bleeding. When reviewing ultrasounds before the case, one said nodule was on R side, the other said on L side so had to confirm with radiology which side it was on and make sure.	1. Bleeding while mobilizing the lateral aspect of the thyroid - 11:44-11:53	Unable to fully analyze	3.6	12	Unreadable	Technically difficult because of thyroiditis, planes were off, more bleeding. No second assistant so scrub nurse had to come up and retract and thus instruments were not passed up in a timely fashion. Just as case was finishing, was told next elective case was on hold for emergency A case.	
3	Exploratory laparotomy + Graham patch repair	Emergency	Ν	Sep 17 2014	1.9	15	Unreadable	Uncertainly of doing emergency case like this, don't know what we will find. Elective case was cancelled.	None	Unable to fully analyze	0.5	6	Unreadable	Says he did not feel any stress, this was an easy case, surgery in the abdomen is much easier than in the neck.	
Sur	geon 8										•				
1	Exploratory laparotomy + washout for dehiscence	Emergency	γ	Sep 23 2014	Missing	14	Unreadable	This is the patient's third surgery in a month, on high dose steroids. Concern about adhesions and what the fascia is going to be like, will we be able to get it back together? Concern about injuring the bowel. A case in the middle of the day	1. The decision making - throughout 2. Misheard senior resident, thought he said "I just put a stich in the bowel" - 13:47	Unable to fully analyze	<0.4	12	Unreadable	Was an unusual clinical scenario that I had never deal with before and therefore working through what the best to do was. Very glad other surgeon was there to weigh in with opinion and reassure of decision making. One point where surgeon thought senior resident said he put stitch in the bowel, but just misheard.	

						Pre-operative				Intra-operative			Post-operative				
	OR	Case	Emergency / Elective	Video Capture	Date	Cortisol	STAI	Average HR	Interview Highlights	Perceived Stressful Events	Physiologic Stressful Events	Cortisol	STAI	Average HR	Interview Highlights		
	2	Laparoscopic appendectomy	Emergency	Y	Sep 23 2014	<0.4	12	66.4	Evening so don't have full complement of staff in the hospital in case things don't go as planned. Senior resident on call is quite junior. Have not evaluated the patient myself pre-operatively and arriving at a time when the patient is already anaesthetized.	1. Dissecting around base of appendix - 19:40	Unable to fully analyze	0.8	11	70	The initial dissection around the appendix was a bit stressful because the base and the cecum initially appeared involved, so were thinking about needing to do partial resection of cecum/using stapler. Resident was cautious which was good given abilities.		

#### **GENERAL DISCUSSION**

Many of the ideas that will be discussed in this section have been previously presented elsewhere in this thesis, specifically in the discussion sections of each of the papers presented. This section will serve to further elaborate on these points and allow for a deeper discussion of the four main components of the study of stress experienced by surgeons in the OR: the data collection process, the data analysis, understanding the data and implications of these findings.

# 1. Data Collection

## Importance of Studying Stress in a Naturalistic Environment:

The overarching purpose of this exploratory pilot study was to gain a deeper understanding of surgeon stress in the OR. In order to do this, the research team felt that studying this complex phenomenon in the naturalistic OR environment was vital to gain a more authentic experience, albeit more challenging methodologically. Simulation settings have undoubtedly led to important groundwork for studying stress in surgeons; these studies have paved the way in understanding how different measures of stress can be used to capture the stress experience. They have identified the implications of stress on a surgeon's technical [66, 102, 108, 120, 121] and non-technical performance [7, 122] and have suggested the need for the ongoing study and understanding of surgeon stress in the OR.

While simulation studies are excellent for experimental designs, there are limitations to studying a complex phenomenon like stress in this environment. First of all, despite the high-fidelity nature of simulations in the current research landscape, it is unlikely that the stress of a real patient's life can be replicated in that setting. The stress associated with simulations can be linked to performance and image rather than the stress associated with a patient's potential outcomes [132]. For example, there are excellent simulation models for replicating trauma scenarios. These scenarios take place in a lifelike trauma bay that contains all the equipment and medications usually found in this setting. A Sim-Man patient is able to interact with the team, display physical exam findings and undergo procedures or physical manipulations. These scenarios are dynamic and a facilitator has the ability to change outcomes such as the Sim-Man's vital signs, depending on the actions of the trauma team members. These scenarios are excellent for training and research purposes. High quality research has been done in these settings to understand the interactions of team members, communication, teamwork, and the impact of stress on these[32, 66, 133]. However, while students performing a trauma simulation may feel stress, this stress may not solely be due to the study participants being worried the 'trauma patient' will not survive the scenario. The stress may be related to the judgment of their performance by their peers and possibly mentors [134]. While these scenarios can replicate the stress of needing to act quickly and make decisions with little information, they may not replicate the stress of a patient's life depending on those decisions and actions. The emotions associated with this level of responsibility are important to understand. Previous work has demonstrated that these pressures can have significant effect on the healthcare provider's psychological wellbeing [129, 135, 136].

Furthermore, there are sociocultural aspects of the OR environment that likely cannot be captured in a simulation setting. There is a deeply ingrained culture within surgery that has traditionally favoured surgeon's acting as all-knowing and infallible [100]. This culture limits the ability of the surgeon to show 'weakness' by admitting to acute stress in the OR, or admitting that the situation they are dealing with has demands that outweigh the resources they have. In some real life cases it has been documented that this culture fostered an environment in which surgeons failed to call for help when it was needed, for fear of how it would be perceived by their colleagues and their intraoperative team [137]. There also exists within surgery, a powerful hierarchy whereby the staff surgeon is viewed as significantly more important than the fellow, the fellow more important than the senior resident, the senior resident more important than the junior resident, and the junior resident more important than the medical student. This hierarchy has been studied in other medical disciplines such as anaesthesia, and has demonstrated a reluctance to speak up by the junior members of the team, even when they believe the patient's life may be in danger [138].

There are, however, inherent difficulties to studying a complex phenomenon such as stress in the naturalistic environment. The OR is an intricate environment where there are endless variables that can affect the outcomes of an operation, such as patient factors (medical comorbidities, severity of illness), OR-team factors (fellows, residents, nursing, anaesthesia), surgeon factors (experience level, fatigue, wellbeing), environmental factors (equipment, temperature), system factors (time pressures, hospital policies), and cultural factors (risk adversity, hierarchy). In an environment so complex, it is difficult to control or even account for all variables, which makes studying causation challenging. For example, it is plausible that a surgeon who experiences excessive stress in the OR, will likely be unable to perform at their best and this could lead to poorer patient outcomes, yet designing a study in a naturalistic environment to prove this would be difficult. To address important questions like these, we must continue to understand the experience of stress in the OR, and to develop a methodology that will enable us to examine the interactions between the cognitive, emotive, physiologic and sociocultural contributions to this phenomenon.

# Importance of a Multifaceted Approach

In this study, the results have demonstrated that perceived stressful events and physiologically identified stressful events were not always mutually inclusive, and both

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were also identified in isolation of the other. This emphasizes the importance of using a multifaceted methodology to study stress in the OR. If the research team were to use only one measure of stress, they would undoubtedly miss out on a deeper, more complete understanding of the stress experience. This sentiment has been echoed in other studies looking at stress in the OR. Phitayakorn et al. used both the STAI (subjective) and GSR (physiologic) to measure stress during an OR simulation. Although this study found that there were dynamic physiologic changes throughout the simulation, without a qualitative component to understand what was going on in that moment, the physiologic equipment may show a spike in heart rate and valley in heart rate variability during an aspect of the case. Then, the research team can say that the surgeon was physiologically stressed at this point, but without a qualitative component. The answers to these questions is what will help to understand the individual's stress experience and help surgeons learn healthy ways to deal with stress.

## **Baseline Physiology**

It is important to emphasize that in this study physiologic stress was qualified by a significant change from a participant's baseline, rather than a strict cut-off number which could be applied to all participants. This makes the data more reliable since there are significant differences in physiology from one individual to another, and many factors that play into that physiology such as fitness level and caffeine consumption [50].

In this study, a surgeon's 'baseline' physiology was collected at the time of consent to the study. This was most often done in the surgeon's office in a private and calm setting. We did not, however, control for the time of day that this baseline physiologic data was collected. Furthermore, we did not control or account for variables that could be contributory to physiology such as recent exercise or caffeine consumption. In future studies, it would be useful to collect surgeon baseline physiology in a more controlled manner, even though it may not be possible to account for all factors that may affect this baseline reading in the real-life setting. This would include collecting baseline physiologic data at the same time of day for each participant to account for diurnal fluctuations. There may also be workday stressors that would affect the surgeon, thus it would be useful to encourage relaxation of the surgeon before the baseline physiology is collected.

## Importance of Real-time Monitoring

This study has demonstrated the utility of real-time physiologic monitoring. When the research team is able to see the surgeon's physiology throughout the case, it can cue them to stress the surgeon might be experiencing and gives them the ability to further explore the moments that were physiologically stressful in the immediate postoperative period. In this study, the research team was able to see the heart rate in real time, but the software system used did not have the ability to calculate heart rate variability in real-time. In future studies, it would be useful to be able to input the surgeon's baseline physiology into the software system prior to the case, along with the thresholds for physiologic stress. This would allow the research team to see a threshold outside of which, the surgeon would be considered physiologically stressed. Then, in the immediate post-operative interview, the physiologic stressful events could be explored in close proximity to the event, allowing for a better memory of what occurred and how the surgeon was feeling at that time.

It may be even more difficult to capture real-time subjective monitoring of the stress experience in the OR. As described, the culture in surgery has not been one where openness is encouraged or where stress is accepted as commonplace. Therefore, strategies such as 'think-aloud' where the surgeon would be encouraged to talk through what they are thinking and feeling throughout the case would likely not be feasible. There is not currently a research method that allows researchers to be 'inside' the surgeon's brain, and information gathered in the OR is limited by what the surgeons are willing and able to tell us. In this study, the foot-pedal was introduced as a way for the surgeon to indicate perceived stress. While this proved useful, it likely was not comprehensive. It did not fully allow the exploration of the severity of stress the surgeons were feeling when they pushed the foot pedal, nor why they were feeling stressed in that moment. Surgeons were also not consistent with pushing the pedal for every perceived stressful moment. For example, some surgeons pushed the foot pedal regularly throughout the operative case and others never used the foot pedal but did report stressful events in the post-operative interview. These immediate post-operative and debrief interviews allowed the research team to explore perceived stress in more detail but were limited by what the surgeon was able to recall by that time. There may be issues not only with what they are able to recall, but there may also be subconscious minimizing of a stressful experience [139]. Furthermore, there may have been conscious minimizing of stressors due to impression management [82]. For example, a surgeon may have felt it was acceptable to tell the research team they were stressed in a moment of major bleeding, but may feel it is not acceptable to disclose they were stressed in a moment when they were thinking about a personal issue.

While these limitations do currently provide challenges to the study of stress in the OR, being aware of them will allow us to consider them in future study designs and invent new methodologies, which might help overcome these barriers.

# 2. Data Analysis

The results of this study have emphasized the complexity of the relationship between physiologic and perceived stress. Most studies examining this relationship have found that physiology and perception of stress do not correlate [22, 23, 113], and it is likely that correlation is not the appropriate method to analyze these kinds of data.

In this study, data triangulation was used as a method for analysis. Data triangulation is a social sciences methodology that facilitates validation of data through cross verification from two or more sources and may be a more appropriate way to analyze stress data. This method is particularly useful when combining several research methodologies to study the same phenomenon [104] and can be used with quantitative, qualitative and mixed-methods methodologies. In this pilot study, a large amount of quantitative physiologic and inventory data, as well as qualitative data through observer notes and interviews, was collected. Rather than present means, pre- and postoperative numbers (which standing alone provide little information), this method of analysis allows the research team to tell a story about surgeon stress in the operating room. This methodology appreciates the complexity of a phenomenon of stress, rather than trying to simplify it.

# 3. Understanding the Data

While the physiologic data was limited by the collection issues encountered, the results of this study demonstrate there is inter-surgeon variability in the causes, experience of, and manifestations of stress. This is true for stress as defined by both surgeon perception as well as surgeon physiology. This is perhaps not surprising when one considers the complexity of the stress experience. An individual's perception of stress depends on his or her assessment of the demand, the resources they feel they have to meet that demand, and whether or not that demand threatens a personal goal

[26]. Each of these is deeply affected by a person's previous experiences, their selfesteem and self-efficacy. For example, if a surgeon has had a recent complication performing a normally routine right-hemicolectomy for colon cancer, the next time she performs this operation her assessment of the demand of the operation may be different than it was prior to the complication.

Following the appraisal of the stressor, the body reacts with a physiologic response. This response is also highly variable from person to person and is affected by many variables such as cardiovascular health, physical fitness, and caffeine consumption [50]. A recent study by Phitayakorn et. al [115] recommended that, given the significant variability in individual's physiology, research groups should focus on individuals rather than groups when studying physiologic stress. Certainly the data in this study support this approach along with the importance of comparing each surgeon's physiology to their own baseline rather than using arbitrary cutoffs.

As the surgeon is experiencing stress, their personal feelings of stress may be different than how they manifest that stress. If the stress is severe enough, it will manifest itself in deterioration of a surgeon's technical and non-technical skills. This impairment may be due to physiologic symptoms such as tunnel vision or shaky hands. It can also lead to cognitive symptoms such as the inability to focus or think straight. There are emotional manifestations of stress, the most common of which is anxiety, but at times people manifest stress with anger, frustration or fear [83]. There is significant interplay with the environment and culture while negotiating how stress will be manifested. Certain manifestations of stress may not be appropriate in the OR setting [82]. For example, while leaving the room may be an appropriate option when experiencing a stressor at home, this is not an option for the surgeon in the OR.

Many parallels between this study and a recent study looking at risk assessment in surgeons can be drawn [129]. In this study, using a qualitative research design, the research team aimed to understand how individual surgeons negotiate risk, how they

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perceive it, and how they make decisions about accepting or rejecting risk. This aim is essentially examining the cognitive appraisal of a surgeon when weighing the demands and resources they have to deal with a specific operative case. In this study, the comfort zone was defined as a surgeon feeling competent and capable or managing the risk that was inherent to a particular case – essentially a cognitive appraisal. Similar to the findings in this study, where different surgeons had very different interpretations of the stress experience, the risk assessment study found that different surgeons had very different views of what was considered risky and not. This likely holds true in the interpretation of stress as well. For example, a breast surgeon who has a solely elective practice would likely find operating on a trauma patient very stressful. On the other hand, a trauma surgeon, who performs little to no elective cases, may find an axillary lymph node dissection in a young woman extremely stressful. This emphasizes the perspective that stress is not an objective phenomenon that can be understood in the same way from one individual to the next. Just as there is no 'objective' way to measure risk assessment, there is no 'objective' way to measure stress in a truly meaningful way.

Some research has suggested that inter-individual stress responsivity patterns may have their roots in critical development periods in early life. The adaptive calibration model (ACM) proposes four different patterns of physiologic stress responsivity, which are in turn associated with certain personal characteristics [140]. The first is a *sensitive stress response pattern*. This is characterized by moderate SNS responsivity, and a high HPA reactivity. In the sensitive pattern, the individual is believed to have high emotional stability, good inhibitory control and delay of gratification. The second is the *buffered stress response pattern*. This is characterized by moderate SNS and HPA activity. The individuals in this pattern are believed to be less responsive to stress, lower risk of anxiety and depression, less risk-prone and highly sensitive to social feedback. The third pattern is the *vigilant stress response pattern*. This pattern is characterized by high SNS and HPA responsivity. This profile is associated with heightened attention to threat and danger, and high trait anxiety. These individuals are also believed to have slower or absent habituation to repeated stressors. The authors also propose that there are gender differences in the vigilant patterns - the male vigilant exhibits a 'fight' pattern while the female vigilant exhibits a 'flight' pattern. Finally, the fourth pattern is the *unemotional stress response pattern*. This is characterized by blunted responsivity in both the SNS and HPA systems. It is believed that this is a male-biased pattern that correlates with low empathy, impulsivity and a tendency for anti-social behaviours.

This model needs to be further tested in a larger and more diverse population to see if these stress responsivity patterns are valid. In the context of this study, it would be interesting to see if these different stress responsivity patterns are seen in surgeons, and, if so, what is their significance? If these patterns are formed early in life, does this mean that they cannot be changed? Are there certain stress reactivity profiles that are more appropriate for professions like surgery? Are there certain stress reactivity profiles that would do very poorly in a profession like surgery? Or alternatively, can we help people learn about their stress reactivity profiles and manage them in adaptive ways? These are all important questions that must be studied in future projects.

## 4. Implications of These Findings

Previous research suggests that a certain amount of stress can actually be activating and improve performance, but at some point, when the demands of the situation outweigh the resources of the individual, stress starts to have a negative effect on performance [141]. In a surgeon's case, this means worse performance in surgery, which likely translates to worse outcomes for patients. Yet it is not only patients who suffer when a surgeon experiences too much stress, there is a significant burden on the individual surgeon and the rest of the operative team. There is certainly evidence to suggest that physiologic stress, specifically a decreased heart rate variability, is an independent risk factor for cardiovascular disease [131]. Decreased heart rate variability has also been associated with a greater incidence of psychiatric diseases such as depression and post-traumatic stress disorder [142]. However, there is evidence to suggest that biofeedback training to make people aware of their heart rate variability can actually improve heart rate variability and decrease the risk associated with physiologic stress [143]. Perhaps if we can better understand surgeon stress profiles, we can use strategies such as biofeedback to make them aware of their stress responses and thus learn how to modulate them. This may improve the health of surgeons, which may in turn improve the health of their patients.

## CONCLUSIONS

This study has allowed for the refinement of a methodology, which will allow for a more complete understanding of the complex phenomenon of stress in the operating room. This methodology draws upon data from four facets of the stress experience: physiologic, cognitive, affective and sociocultural. This multifaceted methodology then uses data triangulation, as a method of analyzing data from the varying sources and allowing for a topography of surgeon stress. Further progress building on this methodology is needed to enable us to make higher stakes claims about our understanding of surgeon stress in the naturalistic environment of the OR that might then be transferable to other similar environments.

This study has also highlighted the great inter-surgeon variability in the causes of stress, the experience of stress, and the manifestations of stress. This variability emphasizes the need to consider surgeons as individuals in future studies, with a view to understanding individual stress profiles. The findings have emphasized the complexity of the relationship between perceived and physiologic stress, indicating the need to capture data from both aspects in future studies. Using this refined multifaceted methodology in future studies will allow for the investigation of important questions about how stress affects surgeons, their operative teams, and patients.

# FUTURE DIRECTIONS

With the proposed refined methodology for studying stress in the OR, future studies stemming from this project will be able to begin to ask hypothesis-testing questions.

- 1. How does acute intra-operative stress affect a surgeon's health?
  - a. From this project, there is evidence that surgeons are indeed experiencing intra-operative stress. Furthermore, the refined methodology for studying stress in the OR has given us the tools to study this complex phenomenon. In order to study how intra-operative stress is affecting a surgeon's health, we can compare a surgeon's intraoperative level of stress with markers of cardiac health such as heart rate recovery, heart rate variability. We can also compare intra-operative stress with markers of mental health using scales for anxiety, depression and burnout.
- 2. How does acute intra-operative stress affect a surgeon's technical skills?
  - a. In order to answer this question, future studies can compare the intraoperative stress of a surgeon to measures of technical skills such as instrument path length. It can also compare the level of stress to operative outcomes such as patient complications and mortality.
- 3. How does acute intra-operative stress affect a surgeon's non-technical skills?
  - a. Non-technical skills are a vital component of being an excellent surgeon.
     These include skills such as leadership, communication and ability to
     work in a team. Each of these skills can be measured using different
     validated scales, and then compared to the intra-operative stress.

- 4. Are there strategies that can be used to help surgeons understand their stress experience in the OR? Do strategies such as biofeedback improve the stress experience for surgeons?
  - a. Empirical findings from this study suggested that surgeons appreciated learning about their patters of stress in the OR. Given that there were events that were physiologically stressful, but not necessarily perceived as stressful it may be that providing surgeons with information about what caused them stress can help them prepare for and manage these stressors. Strategies such as biofeedback, providing the surgeon's feedback on their physiology, may allow them to be more aware of their physiology.
- 5. Are there stress responsivity patterns of surgeons in the OR? Are these patterns consistent in the same surgeon across cases? If so, do these stress responsivity patterns have implications on the surgeon's own health, their technical or non-technical skills?
  - a. In this study, while limited by the small number of surgeons, there seemed to be different stress responsivity patterns. In future studies, it would be useful to know whether these patterns are consistent within the same surgeon across cases. For example, if one surgeon showed a low SNS and HPA stress response to stressors in an elective operation, would the same be true in an emergency operation. Furthermore, are the specific stress responsivity patterns that are better suited to the stress associated with operating. This could be studied by comparing different stress responsivity patterns to outcomes of interest previously discussed such as the surgeon's cardiovascular and mental health, the surgeon's technical and non-technical skills and finally patient outcomes.
- 6. What strategies can be used to help surgeons cope with stress in the OR? Can these strategies be taught and implemented into surgical education programs?

a. Despite the evidence to support that stress is common in surgery, there is little in the way of resources or programming to help surgeons deal with this stress. This study has taken the first step in understanding surgeon stress in the OR, and future studies can learn what strategies can be used to help surgeons cope with stress. For example, it seems as though the OR team composition plays significantly into the stress level of many surgeons. A future study could examine the relationships amongst this team, and determine whether or not more consistent or cohesive teams help to reduce surgeon stress. Or perhaps a future study will demonstrate the effectiveness of mental rehearsal in reducing surgeon stress in the OR. When we determine what strategies are useful in helping surgeons cope with stress, we will be able to develop educational programs to teach these strategies and incorporate them into surgical residency training programs.

This methodology will also allow us to further examine the relationship between perceived and physiologic stress in this unique setting.

- Are there specific stressors that are more likely to cause physiologic stress or perceived stress?
  - a. It has been hypothesized that different types of stressors are more likely to cause physiologic or perceived stress. For example, perhaps stressors related to time pressure are more likely to cause perceived stress while stressors related to team factors are more likely to cause physiologic stress. These relationships can be more completely examined in future studies.
  - b. It would also be interesting to know if there are certain types of stress that affect certain types of skills. For example, it may be that certain

skills are affected by physiologic stress and other skills are more greatly affected by perceived stress.

- 2. What are the effects of perceived stress on performance?
  - a. While there is evidence to support the effects of physiologic stress on performance, there is little research examining the effect that perceived stress has on performance. This is especially important to understand as we now understand that the stress is experience is much more complex than physiologic variables can demonstrate. Future studies can examine the relationship between perceived stress and performance.
## SIGNIFICANCE OF THIS PROJECT

This exploratory pilot study is the first to use a multifaceted methodology to study acute stress in a naturalistic high-stakes setting like the OR. By capturing a large amount of data, this research project has been able to distill a refined methodology for the ongoing study of acute stress in the OR, as well as other high-stakes environments such as the trauma bay, ICU or emergency room.

The findings in this study have demonstrated the complexity of the relationship between physiologic and perceived stress. The results have demonstrated that looking at a single variable to understand stress is incomplete, and misses out on the complexity of the stress experience. This emphasizes the need for the multifaceted methodology moving forward. We have also introduced a novel technique for analysis of data from each of the different facets of the stress experience: data triangulation within a casebased methodology. This method of analysis will allow for a richer understanding of the complex stress experience.

While this methodology has emphasized the importance of capturing both perceived and physiologic stress, further research is needed in order to understand what the significance of stress is on the surgeon themselves, their well-being, their technical and non-technical performance and indirectly the patient on which they are operating. This project has generated several hypotheses, which can be tested in future studies.

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