33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Challenges in Intraoperative Monitoring

Balachundar Subramaniam

Abstract
Predicting major adverse events following surgery remains a significant problem. Currently, the peri-operative period is too often considered a black box, with risk assessment and prediction largely based on static pre-surgical parameters. Here, we review the problem of intraoperative hypotension and outline some of the opportunities for improved monitoring during surgery

I. Introduction

Each year, 234 million major surgical procedures are performed worldwide. This is equivalent to one major surgery for every 25 human beings and is double the yearly number of childbirths[1]. Major morbidity occurs in 3-16% of all patient surgical procedures, with permanent disability or death rates estimated at 0.4-8%[2-3]. These high-risk surgeries include both cardiac and major non-cardiac surgery. Coronary bypass surgery is the most common open-heart surgery performed (about 300,000 patients/year in the US). Cardiovascular disease remains a leading cause of death worldwide, more so in United States due to increasing obesity and diabetes, resulting in substantial health expenditures- about $151.6 billion in 2007[4]. As the population ages and survives with co-morbid disease, more patients with increasing age, congestive heart failure, diabetes, pulmonary disease, and acute myocardial infarction present for complex cardiovascular surgery, with commensurate increase in the frequency of perioperative major adverse events (MAE). **MAEs have far-reaching consequences, importantly including an 1.4-8 fold increased risk of mortality [5] and vastly greater hospital costs[6]**. While overall mortality rates have gone down in cardiac surgery over the past two decades with improvements in surgical technique, monitoring, and perioperative processes[7], **significant morbidity remains for high-risk patients**. As this high-risk patient population increases, it is imperative to discriminate among them further to aid treatment triaging, prognostication, and targeted interventions. The current risk scoring systems define the characteristics of high-risk groups, but they have significant limitations in obtaining granularity *within* these large high-risk groupings to identify which of these septuagenarians, octogenarians, and patients with multiple comorbid conditions are more likely to experience MAE, and further in refining these risks in real-time as these patients' care progresses.

In this paper, we motivate the problem of high-risk surgical procedures and outline some of the monitoring challenges that should be addressed in the near future. In particular, we will use intraoperative hypotension as an example with which to anchor our discussion.

II. High-risk non-cardiac surgery

In a review from the UK hospitals, it was noted that only 13% of surgical admissions accounted for more than 80% of postoperative deaths [8]. Despite the identification of common risk factors such as increasing age, emergency surgery, increased comorbidities and the complexity of surgery, not all patients were admitted to the intensive care units. This could be due to lack of resources and simply reflect the increasingly common scenario of too many predicted high-risk patients by the standard risk scoring systems [9-12]. Interventional studies in the perioperative period, such as perioperative glycemic control[13], goal-directed fluid therapy[14] and neuraxial blockade[15-16], have produced conflicting results. These discrepancies can be explained in part by inappropriate risk stratification of patients at risk

This work was supported by the Department of Anesthesiology, Beth Israel Deaconess Medical Center, Boston, MA 02215.
B. Subramaniam MD MPH is with the Department of Anesthesia, Critical Care, and Pain Medicine, Beth Israel Deaconess Medical Center, and Harvard Medical School, Boston, MA 02115 (bsubrama@bidmc.harvard.edu).

for perioperative complications, in addition to other factors such as inappropriate interventional choice. To understand these issues, there is a need to identify risk factors for adverse outcomes, related to patient physiology and health care delivery processes.

In the structure/process/outcome model[17] of evaluating quality in health care, "structure" refers to how health care is organized, "process" is the method of delivery, and "outcome" is the state resulting from the health care processes. Despite the improvement in structure and process of the health care, there remains significant postoperative morbidity, and it remains a major challenge [18] to identify specific patients at higher risk of MAE. An enhanced risk prediction tool could help plan preoperative and postoperative triaging, informed consent and risk management, and intensity of intervention in targeted patients [18]. It is unlikely that a "one size fits all" risk predictor model approach would be able to accurately stratify patients at high-risk. **An accurate, dynamic risk stratification approach according to a patient's own baseline and evolving pathophysiological characteristics may lead to a better scoring system, and help perioperative caregivers to modify or abandon a planned surgical intervention if the risk is seen to outweigh the benefit [18].** Alternatively, patients at high-risk can be chosen for a targeted interventions with measures such as perioperative fluid optimization, beta blockade or a neuraxial blockade, and appropriate utilization of scare resources such as intensive care.

III. Intraoperative hypotension

A. Definition of Intraoperative Hypotension

Even though current anesthetic practice is to keep the intraoperative systolic blood pressure within 20% of the baseline systolic blood pressure[19], this convention is not evidence based. Studies that have examined intraoperative "hemodynamic instability" have reportedwide variations in the incidence of "hypotension"ranging from 5% to 99% due to the lack of standard defintions [20-21](for example:<80, or 90 or 100 mm of systolic blood pressure; <10% or <20% or <40% from the baseline blood pressure). These issues might explain the conflicting results in studies associating Intraoperative hypotension with stroke[22-24]. Despite this variation in definition, intraoperative hypotension has been shown to be of significant concern in patients with MAE, such as myocardial infarction[25].

B. Studies Attempting to Correlate Intraoperative Hypotension with MAEs Using Linear Methods

Standard hemodynamic derangements, such as increased preoperative pulse pressure, intraoperative hypertension, hypotension, and tachycardia, have been retrospectively associated with MAE [45-48], but these associations have not been explored in a manner that would permit intervention. In a study that attempted to relate intraoperative hypotension to one-year postoperative mortality, varying definitions were applied for Cox regression analysis and regression tree analyses and there was no causal relation between intraoperative hypotension and mortality[26]. However, subsequent analyses revealed that in elderly patients, the mortality risk increases when the duration of intraoperative hypotension becomes sustained, and this duration depends on the hypotension threshold used in the study[26]. A Surgical "Apgar" Score[27] was recently derived incorporating the lowest heart rate, lowest blood pressure, and total blood loss in an attempt to predict MAE. Despite the suggestions that intraoperative hypotension is associated with MAE, using linear techniques and fixed thresholds to define hypotension did not lead to conclusive results and thus fails to provide clinical guidance for perioperative blood pressure management. These static approaches have not only failed to utilize the availability of beat-by-beat data but also the adaptive responses to varying intensity of surgical stimuli. Nonlinear dynamical models, however, can capture this complex adaptive responsiveness encoded in time varying hemodynamic parameters [28-29].

C. Intraoperative Hypotension is a Dynamic Phenomenon

From basic physiology, we understand that a wide range of blood pressures can provide sufficient perfusion because of cardiovascular regulation,but alsothat at some point decreased blood pressure and decreased flow will cause end organ ischemia. However, how much decrease for how long remain unknown. A clinically more relevant issue is, "what threshold and duration of intraoperative hypotension or hypertension would lead to MAE such as stroke"? Different MAE, such as myocardial infarction, stroke, or renal failure,may have different thresholds and duration in individual patients, further influenced by their age and comorbid conditions[30]. A decreased ischemic tolerance of the spinal cord to a lowering of perfusion pressure after clamping of noncritical segmental arteries was seen in pigs[30], suggesting that a patient with vascular disease may have different threshold for spinal cord ischemia compared to a healthy patient with intact collateral circulation. Patients with anemia could also have a different end organ ischemic threshold compared to a patient with normal hemoglobin levels. Patients with different comorbid conditions at varying points of a disease spectrum or a combination of diseases can have different hypotensive thresholds.Finally, simple anesthetic management principles can have a significant impact on perioperative mortality[31] and strongly suggest that intraoperative anesthetic management matters[32].**These issues strongly suggest that intraoperative hypotension is a dynamic phenomenon and not only varies from patient to patient but also *within* a patient undervarying conditions.**

D. Intraoperative Hypotension and Autoregulation

Blood flow is independent of blood pressure in the autoregulatory zone. However, in anesthetized patients, the elderly, and patients with comorbid conditions, the limits of the autoregulatory zone can vary significantly. For example patient temperature, such as during cardiac surgery, may influence autoregulation and adequacy of perfusion. Joshi et al. recently showed that patients undergoing cardiac surgery with hypothermic cardio-pulmonary bypass had abnormal cerebral blood flow autoregulation that worsened with rewarming, and the severity of this dysregulation correlated with postoperative stroke[33]. A dynamic,real-time index of integrated cardiovascular function, including reflex control mechanisms such as autoregulation, could potentially guide perioperative blood pressure management to reduce MAE.

IV. How to Improve Outcome

Interpretation of information from the intraoperative monitors with inbuilt cues can play a significant role in enhancing early detection and intervention to reduce injury from significant adverse events such as bronchospasm and pulmonary embolism. Including simple details such as age adjusted minimum alveolar concentration (MAC) of inhalation agents can reduce overdose of anesthetic agents to elderly and fragile patients. The final frontier is to give information about appropriate blood pressures for a given patients based on perfusion data such as cerebral oximeter will be extremely useful to reduce individual organ injury and morbidity.

Acknowledgment

The author would like to thank Profs. Ary Goldberger, MD and Brett Simon, MD, PhD for their contributions towards this manuscript.

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