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Continuous ST segment monitoring in the operating room

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CONTINUOUS ST SEGMENT MONITORING IN THE OPERATING ROOM

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Abstract

As anesthesia providers, the early detection and treatment of myocardial ischemia is crucial in reducing the patients postoperative mortality related to cardiac complications. Heart disease continues to be the leading cause of death in the United States. Delivering anesthesia to patients in the operating room with increased risk factors for cardiovascular disease requires increased vigilance, an advanced knowledge of the disease process and the monitoring tools available to the anesthetist for the earliest detection of myocardial ischemia. The ECG monitor has been used for decades in the operating room to monitor the heart rate of patients, but by assessing the ST segment of the ECG we can more specifically monitor the heart for ischemia. The purpose of this Independent Project is to provide a thorough and comprehensive review of the latest literature related to the use of continuous ST segment monitoring in the operating room. An expansive literature review was completed through the University of North Dakota's Harley E. French Library of Health Sciences. The literature provided current information on how ECG patch placement and lead selection can impact the accuracy and sensitivity of early ST segment changes. It also provided valuable information about the relationship between tachycardia and ST segment changes and how the duration of ST segment changes can impact the postoperative complication of myocardial infarction. The ability of the anesthetist to accurately utilize the features of continuous ST segment monitoring can be an invaluable tool in the prevention of postoperative complications.

Keywords: ECG, ST segment monitoring, myocardial ischemia, heart disease, anesthetic management

Continuous ST segment monitoring in the Operating Room

Background

Coronary artery disease remains the leading cause of death among both men and women in the United States (Porth & Matfin, 2009). Patients who carry multiple risk factors for coronary artery disease (CAD) can suffer from myocardial ischemia anytime when coronary oxygen demand exceeds supply. Risk factors for CAD include: race, male gender, age greater than 65y/o, hyperlipidemia, hypertension, cigarette smoking, diabetes mellitus, obesity and family history of premature development of CAD (Hines & Marschall, 2008). Traditionally practitioners have relied on patients to express symptoms of myocardial ischemia, such as chest pain, as the first warning sign. Identifying perioperative myocardial ischemia can be difficult because the anesthetized or sedated patient may not be able to express symptoms. Cardiac complications are the most common cause of post-operative morbidity and mortality, with the 30-day mortality rate exceeding 2% in moderate to high risk non-cardiac surgery (Landesberg et al., 2009).

There are multiple monitoring devices that can be used in the operating room to detect myocardial ischemia including transesophageal echocardiography, pulmonary capillary wedge pressures and electrocardiography (ECG). ECG is the most inexpensive, noninvasive and technically simple to operate. ECG has been routinely used in the operating room for decades, and is a standard of care for monitoring all patients receiving anesthesia (Nagelhout & Plaus, 2014). The ECG displays a continual tracing of the electrical activity of the heart from patches strategically placed on the chest. The ST segment of the ECG can be diagnostic for myocardial ischemia or infarction if there is elevation or depression from the patient's baseline (Shanewise, 2006). Visual detection of ST segment changes has not been shown to be reliable, and thus one of the advancements in ECG monitoring is the ability of the monitor software to set a baseline when the patient is initially connected and automatically, in real time, track the ST segment for changes (Shanewise, 2006). Alarms can be set to notify the anesthetist if changes exceed a predetermined elevation or depression. Proper use of this technology can be a very important monitoring strategy for early detection of intraoperative myocardial ischemia for patients that have increased risk factors for CAD or are undergoing a high risk surgery (Shanewise, 2006).

Case Report

The case being reviewed involved a 69 year old female with a history of renal cell carcinoma presenting for a right open, radical nephrectomy for a urinary fistula after partial nephrectomy. The patient's height was 4'10 and weight was 76kg. She was categorized as an ASA 3 and had allergies to Keflex, Morphine, Bactrim and Sulfa. Past medical history included asthma, hypertension, dyslipidemia, diabetes type 2, atrial fibrillation with prior partial nephrectomy, and chronic pain. Surgical history included a cholecystectomy, lumpectomy, lithotripsy, cystoscopy, shoulder/knee and hip surgery. The patient reported no personal or family history of anesthetic complications. Current medication regimen included Norvasc, baby Aspirin, Lisinopril, Amoxicillin, Xanax, Flexeril, Levothyroxine, Glucophage, and Zocor. A thorough preoperative examination included vital signs which were as follows: blood pressure 134/73, heart rate 90, respiratory rate 16, oxygen saturation 95% and a temperature of 97.9. Laboratory data included a complete blood cell count noting a hemoglobin of 11.5 g/dl, hematocrit 35.4 g/dl, and platelet count of 419 per mm^3. A complete metabolic panel was within normal limits and an elevated hemoglobin A1C of 6.1. No coagulation studies were completed. A pre-operative ECG was completed and demonstrated normal sinus rhythm with no ST segment abnormalities and an echocardiogram showed an ejection fraction of 65%, mild (grade 1) diastolic failure, mild LV hypertrophy, no wall motion abnormalities or valvular issues were noted. She was referred pre-operatively for a cardiology consultation and clearance for surgery. Her consultation note addressed the fact that the patient's METs was less than 4 with fatigue being her predominant symptom and she was classified as an intermediate cardiovascular risk due to her multiple risk factors and the proposed surgery. No further pre-operative studies were recommended. The patient was not able to be started on a beta blocker because of prior bradycardia. She was cleared for surgery.

When the patient entered the operating room, the standard monitors were placed including a 5-lead ECG. The patches were placed in the normal position on the chest, with the V lead (brown) placed in the V5 position (5^{th} intercostal space, half way between the midclavicular line and the mid axillary line). Continuous ST segment monitoring was initiated, a baseline J point was established for the 7 leads displayed and an ECG strip was printed prior to induction.

Her airway assessment included a Mallampati I, normal thyromental distance, normal inter-incisor distance and full range of motion of her neck. After pre-oxygenation, induction medications were given as follows: fentanyl 100mcg, propofol 150mg and rocuronium 50mg. The patient was intubated with a 7.0 ETT using a MAC 3 blade. Correct placement was confirmed with bilateral breath sounds and presence of an end tidal carbon dioxide wave form. The endotracheal tube was taped and secured while the patient was placed on volume control ventilation with a tidal volume of 550ml, rate of 12, positive end expiratory pressure of 5cm H2O with an inspiratory pressure ranging around 20cm H2O. Sevoflurane 2% was used as the inhalational anesthetic. An arterial line was started in the left radial artery with a good waveform and an additional 18G IV was started in the forearm.

Prior to incision the patient was given 1250mg of Vancomycin, 1 gram of Ofirmev and 100mcg of fentanyl. During the case the patient was given an additional 200mcg of fentanyl for analgesia and re-dosed three times with 10mg rocuronium to maintain 2/4 twitches. The case lasted three hours and was complicated by an increased blood loss to total 1100ml. The patient was given a total of 2500ml of lactated ringers and 500ml albumin. A hemoglobin was rechecked after the first 500mls of blood loss and resulted at 8.8 g/dl. The patient was cross matched for 2 units of RBCs and were administered prior to the end of the case. The patient's vital signs remained relatively stable throughout the case, only requiring 300mcg of phenylephrine to keep her BP within 20% of her normal. She remained sinus rhythm and her ST segments only deviated 0.1-0.3mm from the baseline throughout the case.

At the end of the procedure, muscle relaxants were reversed with 0.6mg glycopyrolate and 3mg neostigmine. Anti-emetics included Decadron 4mg and Zofran 4 mg. The patient was extubated awake without complications and placed on 4L O2 per nasal cannula. In the recovery room she denied any pain or nausea. The patient's hemoglobin the next day was 10.5 g/dl, she was discharged home 4 days later without complications.

Discussion

Coronary Heart Disease

Epidemiology

In 2010, the overall death rate attributed to cardiovascular disease had decreased by 31% compared to 2000 but the overall burden of disease has remained high. (American Heart Association). The total direct/indirect cost for care related to cardiovascular disease and stroke was estimated at $315.4 billion, compared to 201.5 billion for cancer care. It is the most expensive of all diagnostic groups (AHA, 2014). According to the American College of Cardiology and the American Heart Association (ACC/AHA) the prevalence of coronary artery disease increases with age. The population over the age of 65, is the fastest growing age group, and is estimated to grow 25-35% over the next 30 years (2007). "Thus, it is conceivable that the number of non-cardiac surgical procedures performed in older persons will increase from the current 6 million to nearly 12 million per year, and nearly one fourth of these—major intra-abdominal, thoracic, vascular, and orthopedic procedures—have been associated with significant perioperative cardiovascular morbidity and mortality" (ACC/AHA, 2007, p.162).

Risk Factors

There are numerous risk factors that contribute to the development of coronary artery disease including: male gender, increasing age, hyperlipidemia, hypertension, cigarette smoking, obesity, diabetes mellitus, sedentary lifestyle, family history and even psychological factors such as stress and having a type A personality (Hines & Marschall, 2008). As part of its 2020 Impact Goals, the American Heart Association is trending data on seven "health metrics" it believes are reflective of cardiovascular health. These metrics are smoking, body mass index, physical activity, healthy diet, total cholesterol, blood pressure and fasting plasma glucose (2014). Due to the broad range of risk factors that can contribute to coronary artery disease, there have been multiple risk calculators developed to try and assist the anesthetist in predicting pre-operative risk.

The 2014 ACC/AHA perioperative guidelines highlight estimating this risk based on a combination of both clinical risk factors and the surgical procedure being performed. For patients with risk factors for stable coronary artery disease, the ACC/AHA recommended the use of the

Revised Cardiac Risk Index (RCRI) or the National Surgical Quality Improvement Program (NSQIP) risk calculator (ACC/AHA, 2014). The NSQIP was developed by the American College of Surgeons and uses 20 patient predictors combined with the surgical procedure to predict the odds of a patient having 15 different adverse outcomes in the 30 days following surgery (UpToDate, 2016).

The RCRI is more specific to predicting cardiac complications including specifically myocardial infarction. The RCRI predicts this risk based on six factors: high risk surgery (intraperitoneal, intrathoracic, vascular or suprainguinal), history of ischemic heart disease, history of congestive heart failure, history of cerebral vascular accident, pre-operative treatment with insulin and pre-operative creatinine of >2mg/dl (UpToDate, 2016). Using the RCRI, the patient in this case study, would have received only one point (for high risk surgery) which translates to a 0.9% risk of a major cardiac event (UpToDate, 2016). According to the perioperative cardiac assessment algorithm, because this patient's risk was <1%, no further testing was needed. If her risk had been >1%, the next step would have taken into consideration her METs <4 (ACC/AHA, 2014). MET, or metabolic equivalent of the task, is an assessment of functional capacity or O2 consumption with activity. The ability to perform activities requiring 4 METs or more (such as climbing a flight of stairs or walking at >4mph) indicates good functional capacity. Perioperative cardiac risk can be increased with a METs <4 (Hines & Marschall, 2008). Like the patient in this case study, MET level can also be influenced by an underlying medical condition limiting their activity, so assessment of this can be inaccurate or nonspecific (similar to a patient with orthopedic problems).

Myocardial Ischemia

Myocardial ischemia can happen anytime that myocardial oxygen demand exceeds coronary artery blood flow or oxygen supply (Morgan & Mikhail, 2013). This can be caused by atherosclerosis of the coronary arteries, thrombosis, severe hypertension or hypotension, tachycardia, hypoxemia, anemia or severe valvular disease (Morgan & Mikhail, 2013). Atherosclerosis is the most common cause of ischemia and is now being recognized as an inflammatory disease (Hines & Marschall, 2008). The multiple risk factors as stated above lead to the development of atherosclerotic plaque, which is made up of inflammatory cells. These plaques can be vulnerable to rupture due to their lipid core and thin fibrous caps (Hines & Marschall, 2008). When they rupture a cascade of events including platelet aggregation, activation and vasoconstriction can lead to complete coronary obstruction and thus myocardial infarction (Hines & Marschall, 2008). In the operating room, myocardial ischemia could be due to either an inflammatory response or a neuroendocrine stress response (Hines & Marschall, 2008). Surgery itself can create a pro-thrombotic environment, leading to decreased oxygen delivery similar to the plaque rupture described above. Catecholamine release can lead to tachycardia and hypertension that can both increase the propensity for plaque rupture but also increase the oxygen demand in a patient with an already compromised myocardial supply (Hines & Marschall, 2008).

Signs & Symptoms

The most common symptom of myocardial ischemia is angina. When the myocardium is ischemic it releases adenosine and bradykinin which stimulates the receptors of the thoracic sympathetic and somatic nerve fibers in the spinal cord that result in angina (Hines & Marschall, 2008). Angina can also radiate to the left arm, shoulder, neck or jaw. Other symptoms can include shortness of breath, epigastric pain, nausea or diaphoresis. In some patients, especially with a history of diabetes, there can be no symptoms at all (Hines & Marschall, 2008). Having the patient anesthetized in the operating room, complicates the early diagnosis of myocardial ischemia because they are unable to verbalize their symptoms. Some secondary signs that may be noticeable with perioperative monitoring include slow atrioventricular nodal conduction and hypotension due to decreased contractility (Hines & Marschall, 2008). Unfortunately, these are very non-specific signs, which can also be contributed to the anesthetics themselves. Tachycardia has been found to precede myocardial ischemia in many cases, due to the increased oxygen demand, and thus its presence can be a sign to the anesthetist to watch for ischemic changes on the ECG (Landesberg, 1993; Landesberg, 2001).

Cardiac Monitoring

Transesophageal Echocardiography (TEE)

Echocardiography can be used to identify myocardial ischemia through the detection and localization of regional wall motion abnormalities (RWMA) (Nagelhout & Plaus, 2014). When a segment of the myocardium is experiencing a perfusion deficit, that segment has less thickening and motion towards the center of the ventricle than normal, which is called hypokinesis (Shanewise, 2006). This can happen within one minute of a perfusion deficit, thus making it a more sensitive monitor than ST segment changes (Shanewise, 2006). RWMA can be caused by other factors than ischemia, including conduction abnormalities, sudden changes in preload or afterload and severe dysfunction of the right ventricle (Nagelhout & Plaus, 2014). Although it is more sensitive than ECG, there are several limitations to its use. These include its cost effectiveness in non-cardiac operations, it requires the anesthetist to have specific training in its use for proficiency, it is not practical for use in a continuous fashion like ECG, it can only visualize a small portion of the ventricle in a single view thus possibly missing ischemia in a non-visualized area and its use is limited to the period of time while intubated thus missing the critical time for ischemia during induction and emergence (Shanewise, 2006)(ACC/AHA, 2007). The 2014 ACC/AHA perioperative guidelines state, “the routine use of intraoperative echocardiogram during non-cardiac surgery to screen for cardiac abnormalities or to monitor for myocardial ischemia is not recommended in patients without risk factors or procedural risk for significant hemodynamic, pulmonary or neurological compromise”.

Pulmonary Capillary Wedge Pressures (PCWP)

Pulmonary artery catheterization can be used to monitor for intra-operative myocardial ischemia by measuring trends of the pulmonary artery wedge pressures (Nagelhout & Plaus, 2014). If the left ventricle function was to become impaired, there could be an increase in left ventricular end diastolic pressures (LVEDP), as indirectly measured by the pulmonary artery wedge pressure (Nagelhout & Plaus, 2014). Because LVEDP is only indirectly measured, other factors can falsely influence its trend including: mitral stenosis, COPD, increased pulmonary vascular resistance, and location of the catheter in the lung (Shanewise, 2006). Thus studies have concluded that PCWP does not have good sensitivity or specificity for detecting myocardial ischemia (Shanewise, 2006). It is also an invasive procedure that can have serious complications and requires the anesthetist to have knowledge and experience in interpreting its results (Nagelhout & Plaus, 2014). The 2014 ACC/AHA guidelines state that the use of pulmonary artery catheters may aid in the hemodynamic management of an already critically ill patient undergoing surgery but that its routine use, even with patients with elevated risk, is not recommended.

ST Segment

The ST segment of the ECG is measured from the J point (the point at which the QRS segment ends and the ST segment begins) and ends at the beginning of the T wave (Nagelhout & Plaus, 2014). This segment should be isoelectric (or flat) as it represents when ventricular cells are in the plateau phase after depolarization and there is no electrical conduction (Nagelhout & Plaus, 2014). Ischemic or damaged tissue causes the cells of the myocardium to react abnormally. An ST segment that is depressed is indicative of myocardial ischemia due to either increased oxygen demand or limited coronary blood flow (Hines & Marschall, 2008). If the ST segment is elevated, there is total occlusion of a coronary artery, leading to a myocardial infarction (Hine & Marschall, 2008). When calculating the ST segment for deviation, it is compared to the preceding PR segment as an isoelectric reference (Nagelhout & Plaus, 2014).

There are differing opinions on where the ST segment should start being assessed. Some literature/manufacturers measure the ST segment starting at the J point, and some start 60 or 80 milliseconds from the J point (Nagelhout & Plaus, 2014). This debate will not be reviewed in this discussion. When the ECG is first connected to the patient, a baseline of the ST segment is established per the manufacturer’s analysis algorithm or a baseline can be set manually by the anesthetist (Drew et al., 2004). From this point on, subsequent ST segments will be compared to this baseline and displayed on the monitor as a positive or negative numerical value. Alarm parameters are generally set to notify the anesthetist if the ST segment were to change 1 to 2mm above or below the baseline, as this is generally considered significant (Drew et al., 2004). Clinical implications of this include: discharging the previous patient from the monitor prior to re-establishing an ECG so that the previous patient's ST segment baseline is not used for comparison, changing the position of an ECG electrode after baseline is established can produce false alarms because of the change in deflection, and a change in body position can alter ST segments, mimicking ischemia. If possible obtain the baseline ECG in the side-lying surgical position prior to induction (AACN, 2016). Patients that have a previously documented left bundle branch block or have a ventricular paced rhythm are generally not candidates for continuous ST segment monitoring because the nature of their ST segment is already steeply sloped which leads to frequent false alarms (Drew et al., 2004).

Lead Placement

In the operating room, either a 3-lead or a 5-lead ECG is used for monitoring. For this discussion, we will focus on the 5-lead ECG, as there is increased sensitivity in the identification of myocardial ischemia when multiple leads are monitored (Nagelhout & Plaus, 2014). A 5-lead ECG, as the name indicates, involves five ECG electrodes. It allows the anesthetist to monitor seven "views" of the heart. Even though the monitor only displays a continuous ECG waveform for two leads, it is monitoring the ST segments of all seven "views" (Drew et al., 2004).

Limb lead placement and corresponding areas of surveillance

There are four limb electrodes-the white electrode is placed on the right side of the upper chest under the clavicle, the green electrode can be placed in any convenient location on the right side of the trunk, the black electrode is placed on the left side of the upper chest under the clavicle and the red is placed on the lower left side of the flank in the anterior axillary line (Nagelhout & Plaus, 2014). These four electrodes placed on the perimeter of the chest, allow for the monitoring of six limb leads- I, II, III, AVL, AVR and AVF (Drew et al., 2004). Leads I and

AVL monitor the lateral wall of the myocardium that corresponds with the circumflex distribution of coronary blood flow. Leads II, III and AVF monitor the inferior wall that corresponds with the right coronary artery. AVR is generally not used as a diagnostic lead (AACN, 2016).

Precordial lead placement and corresponding area of surveillance

The fifth electrode is placed in one of the six precordial positions, and its position determines the anatomical area of the heart being monitored (Drew et al., 2004). Correct placement of these precordial leads is important because inaccurate placement can change the deflection of the waveform and potentially delay the sensitivity of that lead in the detection of ST segment changes (Drew et al., 2004). For the patient that has pre- or intra-operative ST segment changes and is going to be monitored in the post-operative period for ischemia, marking the location of the electrodes with indelible ink to ensure replacement of the patches to the same location is imperative as relocating as little as 1 cm away from its original location can lead to waveform changes (AACN, 2016).

Placement of the electrode for lead V1 is in the fourth intercostal space, right of the sternal border. Lead V2 is placed in the fourth intercostal space, left of the sternal border. V1 and V2 are monitoring the septal wall and the distribution of the left anterior descending coronary artery. ST depression in V1-2 can also be a reciprocal change that reflects posterior infarction related to the right coronary artery or the circumflex. Lead V3 is placed equal distance between V2 and V4. Lead V4 is placed in the midclavicular line at the fifth intercostal space. Leads V3 and V4 monitor the anterior wall of the myocardium supplied by the left anterior descending artery. The V5 electrode is placed horizontal to V4 on the anterior axillary line, half way between V4 and V6. V6 is placed horizontal to V5 on the mid-axillary line. V5 and V6, along with leads I and AVL, monitor the lateral wall supplied by the circumflex artery (Nagelhout & Plaus, 2014; AACN, 2016).

Lead Selection

The choice of what ECG leads to monitor the patient during the perioperative period is based on their history and pre-operative 12-lead ECG. As previously discussed, the four limb leads will always allow for continuous ST segment monitoring of leads I, II, III, AVF, AVR and AVL (Drew et al., 2004). So the decision left to be made is, which precordial (or V lead) is going to show the earliest ST segment changes specific to this patient and their history. Improper selection of this V lead can lead to unrecognized myocardial ischemia or infarction (Nagelhout & Plaus, 2014). If the patient has a pre-operative 12-lead that has ST segment changes in a specific lead, known as the ST fingerprint, than that lead should be monitored throughout the case. An ST fingerprint is a pattern of ST segment elevation or depression that is unique to a specific patient (AACN, 2016). Also if the patient has known coronary artery disease in a specific vessel, or recent coronary intervention, the leads selected should correspond with that coronary artery distribution (AACN, 2016).

The debate and change in practice comes in with patients that do not have documented coronary artery disease or a remarkable pre-operative 12-lead ECG. A systematic review of studies completed in the 1980-1990s and published in the Best Practice and Research of Clinical Anesthesiology, addressed the topic of monitoring for myocardial ischemia. This review was a synthesis of eighteen studies that addressed multiple topics related to perioperative ischemia and postoperative cardiac complications (Landesberg, 2005). One of the topics was continuous 12-lead ECG monitoring and lead sensitivity. At the time, and interestingly still used commonly today, lead II and V5 were primarily monitored in the OR and detected only 80% of significant ST changes (Landesberg, 2005). These studies were based on information gained from Holter monitoring in the outpatient setting to detect demand ischemia and they used absolute versus relative ST segment deviation (Landesberg, 2005). More recently, with the advancement of automated ST segment monitoring algorithms, studies have been completed during the intraoperative and postoperative periods using continuous 12-lead ECGs to determine the most sensitive leads for ischemia. In a landmark 2002 study, 185 patients undergoing vascular surgery were monitored in this fashion, with ischemia defined as ST segment deviation of 2mm in one lead or 1mm in two contiguous leads from the patient's preoperative baseline (Landesberg, Mosseri, Wolf, Vesselov, & Weissman, 2002). Post-operative infarction was defined by an elevation in troponin I levels. Of the 185 patients, 38 had transient ischemic events (ST depression) with 12 of those patients sustaining postoperative myocardial infarctions (Landesberg et al., 2002). It was found that lead V3 most frequently (86.6%) demonstrated ischemia and was the earliest to show changes, followed by V4 (78.9%) and V5 (65.8%). For the patients that suffered myocardial infarction, V4 was the most sensitive and the earliest in detecting ischemia (83.3%), followed by V3 and V5 (75% each) (Landesberg et al., 2002). The overall sensitivity in the detection of ischemia was 94.7% when either V3 or V4 was combined with the limb leads, compared to 76.3% when V5 was combined with the limb leads (Landesberg et al., 2002).

In 2005, a council of experts in Cardiology, Electrophysiology and Critical Care Nursing came to together to author the first formal standard for electrocardiographic monitoring in the hospital setting (Drew & Funk, 2006). From these practice standards the ACC/AHA derived guidelines for intraoperative ST segment monitoring in patient's undergoing non-cardiac surgery and recommend the use of V4 rather than V5 for the early detection of ischemia (2007). In 2008, the American Association of Critical Care Nurses published a practice-alert on ST-segment monitoring for all patients in the Intensive Care Unit at risk for demand ischemia (this included weaning from the ventilator). This practice-alert was based on a systematic review of literature on ST segment monitoring (Fox, Kirkendall & Craney, 2010).

As related to lead selection, leads V3 and III were found to be the most sensitive in detecting ischemia especially for patients with a cardiac history or numerous risk factors (Fox, Kirkendall & Craney, 2010). However the author stressed the importance of monitoring in a patient's "fingerprint" lead if they have had a previously documented ST segment change, as it will be the most sensitive lead in their case (Fox, Kirkendall & Craney, 2010). Of the limb leads, lead III has been found to be the most sensitive in detecting ischemia (Drew & Tisdale, 1993) (Flanders, 2007). As lead III is a limb lead that is continuously being monitored by the monitor's algorithm, this is not of as much importance as lead selection for chest leads. Lead II is more useful to have continually displayed for arrhythmia detection, especially atrial. The anesthetist needs to be aware of the numerical changes in lead III for ST segment deviation and have the appropriate alarms set (Flanders, 2007).

There are monitoring systems that can do continuous ST segment monitoring of all 12-leads from a five electrode ECG system. This is called a derived 12-lead or EASI. The five electrodes are placed in a specific configuration on the chest and allow for a more comprehensive assessment of the myocardium. Monitoring more than one V lead simultaneously, increases the sensitivity of ischemia detection from roughly 85% to 96% (Shanewise, 2006) (Landesberg, 2002). The use of this derived 12-lead also eliminates the need for the anesthetist to make a decision regarding the most appropriate chest lead. This type of monitoring is not equivalent to a 12-lead ECG but can closely correspond if used appropriately (AACN, 2016).

Perioperative myocardial infarction and ECG monitoring

As discussed earlier, perioperative myocardial infarction (PMI) can occur from either plaque rupture leading to acute coronary syndrome or from an imbalance in oxygen supply and demand (Landesberg et al, 2009). Studies from the 1990s and 2000s found common similarities among patients who suffered PMI. They found a strong association between long duration (>20 minutes) ST segment depression and progression to postoperative complications including myocardial infarction and death (Landesberg, 1993; Landesberg, 2001; Landesberg, 2009). In these studies, perioperative cardiac events were rarely (<2%) or never, preceded by ST segment elevation (Landesberg, 1993; Landesberg, 2001). The longer the duration of ST segment depression, the higher the postoperative trend of troponin levels (Landesberg, 2001). To note, these studies were completed on high risk patients undergoing vascular surgery. Another similarity in the studies was that each episode of ST segment depression was preceded by tachycardia from the patient's baseline (ranging from 90-120bpm). In the 2001 Landesberg study, patients were monitored using 12-lead ECG prior to induction through 72 hours post-operatively. According to this study, "twenty-six (68%) of all the longest ischemic events started during the period between 50 min before and 60 min after the end of surgery, during emergence from anesthesia (a time characterized by an increase in heart rate, blood pressure, sympathetic discharge and pro-coagulant activity). In eight (67%) of the patients with PMI, the longest ischemic episodes started within the same time period" (Landesberg, 2001, p.1842, 1843). None of the patients had significant ischemia (defined as less than 10minutes) during induction (Landesberg, 2001). Landesberg's prior study in 1993 highlighted a similar connection between ST depression and tachycardia, but this study found that the majority of "long duration" ST depression occurred in the postoperative period but shorter episodes were identified during high demand, low supply periods in the OR (intubation, emergence and extubation). Both studies noted that the ST depression was transient in all episodes, highlighting the importance of continuous ST segment monitoring (Landesberg, 1993; Landesberg, 2001).

Although further studies are needed to identify if early detection would reduce the mortality associated with perioperative myocardial ischemia- a few highlights can be identified regarding intraoperative monitoring. The importance of preventing and having a low threshold for treatment of tachycardia is essential. As the episodes of ST depression were transient, choosing the most sensitive leads for its detection, will allow the anesthetist to identify that patient's specific fingerprint leads that show ischemia during periods of high demand and low supply. This early detection may allow the anesthetist to more aggressively reverse the cause of ischemia, limiting the time of ST depression and hopefully decreasing the incidence of post-operative myocardial complications. Identification of which leads the patient typically has been showing ST segment depression could also translate into consistency across the phases of care into the post-operative period in the early detection of myocardial ischemia.

Case Study Review

In retrospect, the case study discussed previously was a good example of a typical patient with increased risk factors for heart disease (age, hypertension, type 2 diabetes and hyperlipidemia) but based on cardiac preoperative evaluation was only deemed low to intermediate risk. Her preoperative ECG was noncontributory but her METs less than 4 due to fatigue was concerning. The ability to do continuous ST segment monitoring in the operating room was a valuable, simple and cost effective tool for this patient. Assuring that the ECG patches were placed in the appropriate positions for the most accurate data, establishing a baseline for the J point, identifying that the ST segment alarms were on and set to alarm with

1mm of elevation or depression were important steps in correctly monitoring for ST segment changes. Printing an ECG strip prior to induction is also a good practice for reference of the baseline throughout the case. The accuracy of these steps was confirmed by the literature reviewed in this Independent Project.

A highlighted area for improvement though was the selection of V5 for the chest lead. The evidence suggests that monitoring the patient in V5 is based on outdated literature and is not the most sensitive chest lead in the detection of ST segment changes. Since this patient did not have documented coronary artery disease, V4 would have been the more appropriate and sensitive chest lead for monitoring. Of the limb leads, lead III would show the earliest ST segment changes. It is still appropriate to display lead II, as the monitor will alarm automatically if there is deviation of 1mm in lead III without it being continuously displayed. The literature also highlighted the importance of accurate placement of ECG patches, especially the brown patch, as its placement is what directly dictates the chest lead being monitored, and thus the sensitivity to early ST segment changes. The patient did face a potential imbalance in her oxygen supply versus demand due to the increased blood loss but with timely replacement of her volume status with a combination of crystalloid, colloid and red blood cells her vital signs remained stable without any significant change in her ST segments from baseline. She also did not experience any episodes of tachycardia throughout the case, which the literature found to precede most incidence of ST segment depression. Again, the use of continuous ST segment monitoring was an appropriate and valuable tool in the assessment of intraoperative myocardial ischemia.

Conclusion

Although the incidence of intraoperative myocardial infarction is low, the mortality and costs associated with the adverse outcomes are high. As a large portion of our population ages, patients have more risk factors for heart disease and surgical options for treatment become more common, there is reason for the anesthetist to remain vigilant in the early recognition and possible reversal of myocardial ischemia during surgery. Changes in the ST segment of the ECG correlate with myocardial ischemia or infarction. Continuous ST segment monitoring on the ECG is a simple, cost effective and generally available tool for early recognition. Like most monitoring devices, it is essential that the anesthetist be knowledgeable in its use to provide the most accurate data. Evidence highlights the importance of accurate ECG patch placement, lead selection, establishment of baseline and setting appropriate audible alarms to ensure the earliest recognition of ST segment changes. Our anesthetic plan and early treatment during periods of imbalance in myocardial oxygen demand and supply was crucial in the avoidance of ischemia. The evidence provided in this Independent Project will educate anesthesia providers in the accurate use of continuous ST segment monitoring, thus providing their patients with the safest intraoperative experience.

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Continuous ST Segment Monitoring in the OR

Brett Cadwell, SRNA

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Introduction

- Coronary artery disease remains the leading cause of death for both men and women
  - The overall death rate has decreased 31% in the last 10 years, but the burden of the disease, esp. the cost of care, is the highest of all diagnostic groups at 315.4 billion dollars
- 1.4-3.9% of surgeries are complicated by a major perioperative cardiac event
- **Cardiac complications are the most common cause of post-operative morbidity and mortality**

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Myocardial Ischemia & Infarction

- Atherosclerosis of the coronary arteries is the most common cause of ischemia
- It is now being recognized as an *inflammatory disease*
- Imbalance between supply and demand can be caused by:
  - An underlying cardiac abnormality such as CHF or moderate to severe valvular disease
  - Catecholamine release during surgery can lead to tachycardia and hypertension which increases demand, along with increasing the propensity for plaque rupture
  - Tachycardia in the patient with stable coronary disease can decrease coronary blood flow because of shortened diastolic time

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General Risk Factors

- Male gender
- Age >65
- Hyperlipidemia
- Hypertension
- Cigarette smoking
- Obesity
- Diabetes
- Family history
- Sedentary lifestyle

(2014 ACC/AHA)

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Specific Risk Factors

- **Revised Cardiac Risk Index (RCRI)**
  - Surgical procedure
  - History of ischemic heart disease
  - History of CHF
  - History of CVA
  - DM requiring insulin
  - Creatinine >2mg/dl
- **National Surgical Quality Improvement Program (NSQIP)**
  - 20 patient predictors combined with surgical procedure to give odds of 15 different adverse outcomes specific to that procedure

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Identifying Perioperative Myocardial Ischemia

- Difficult because patients are unable to express symptoms (which is usually the first sign)
- How else can we detect it? Are their warning signs while under anesthesia?
- Monitoring devices used for detection
  - Transesophageal echocardiography
  - Pulmonary capillary wedge pressures
  - Electrocardiography

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Transesophageal Echocardiography

- Detects and localizes regional wall motion abnormalities (RWMA)
- RWMA happen within one minute of perfusion deficit, thus most sensitive monitor for detection
- Limitations are: not cost effective for routine use, requires specialized training for proficiency, can only visualize a small area of myocardium at a time and use limited to time while intubated (possibly missing critical risk times for ischemia)
- Thus 2014 ACC/AHA guidelines do not recommend its routine use for non-cardiac surgery for ischemia monitoring

Pulmonary capillary wedge pressures

- Monitors for ischemia by measuring trends of the pulmonary artery wedge pressures that correlate with left ventricular function
- It is an indirect measurement thus can be falsely influenced by multiple factors: mitral stenosis, COPD, location of catheter etc
- Cons: Invasive procedure with potentially serious complications
- Poor sensitivity and specificity

Electrocardiography

- Changes in the ST segment can indicate ischemia or infarction
  - **ST depression** can indicate myocardial ischemia from either increased oxygen demand or limited coronary blood flow
  - **ST elevation** can indicate myocardial infarction from total occlusion of a coronary artery
- Advantages:
  - ECG is already a standard of care for the monitoring of patients under anesthesia
  - Cost effective
  - Noninvasive
  - Simple to operate
  - Monitors multiple "views" of the heart simultaneously and continuously,
  - Can be highly sensitive and specific for detection of ischemia or infarction

Case Information

- Surgical Procedure
  - Right open, radical nephrectomy for a urinary fistula after partial nephrectomy for renal cell carcinoma
- Age- 69 y/o
- Weight- 76kg
- Gender- female
- ASA- 3
- Allergies- Keflex, Morphine, Bactrim & Sulfa

Pre-operative Evaluation

- Medical History
  - Asthma, hypertension, dyslipidemia, diabetes type 2, atrial fibrillation with prior partial nephrectomy, chronic pain
- Surgical History
  - Cholecystectomy, lithotripsy, cystoscopy, shoulder/knee and hip arthroplasty
- Pre-op VS
  - BP 134/73, HR 90, RR 16, oxygen sat 95%
- Pre-op labs
  - Unremarkable (Hct 35.4 g/dl and Cr 0.9mg/dl)
- Airway assessment
  - Mallampati I, normal TMD, normal inter-incisor distance and full ROM in her neck

Cardiac Pre-operative Evaluation

- ECG
  - NSR, no ST abnormalities
- Echo
  - EF 65%, mild diastolic dysfunction, mild LV hypertrophy, no RWMA or valvular issues
- METs level
  - **< 4 with fatigue being her predominant symptom**
- Cardiology consultation classified her as an intermediate cardiovascular risk d/t the procedure itself and she was cleared for surgery.
- No beta blocker was ordered d/t history of bradycardia

Intra-operative Monitoring

- Connected to standard monitors
  - Including 5-lead ECG with V lead (brown) placed in the V5 position
  - ST segment monitoring was initiated, baseline established
  - Alarms set for 1mm deviation and ECG strip printed
- Arterial line placed in L) radial artery with a good waveform
- Additional 18G IV started in the forearm

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Anesthetic Course

- Induction
  - Fentanyl 100mcg
  - Propofol 150 mg
  - Rocuronium 50mg
- Technique
  - Intubated with 7.0 ETT
  - +BBS, +ETCO2
- Vent Settings
  - VCV w/ TV 550, rate 12, PEEP 5
- Maintenance
  - Sevoflurane 2%
  - Ofirmev 1gm pre-incision
  - Fentanyl 50-100mcg prn
  - Rocuronium 10mg prn
- Anti-emetics
  - Decadron 4mg
  - Zofran 4mg
- Reversal
  - Glycopyrolate 0.6mg
  - Neostigmine 3mg

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Intraoperative Issues

- Total Anesthesia Time
  - 3 hours
- Estimated Blood loss
  - 1100ml
- Volume replacement
  - Crystalloid 2500ml
  - Albumin 500ml
  - 2 units RBCs (mid-case Hgb 8.8g/dl)
- Surgical course
  - Required Phenylephrine 300mcg to maintain BP within 20% of baseline
  - UOP >1ml/kg/hr throughout case
  - **ST segments remained 0.1-0.3 mm from baseline**

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Post-operative Course

- Extubated awake in the OR, placed on 3L NC
- Pain level in PACU 1/10
- No PONV reported
- Admitted to general floor
  - Next day Hgb 10.5g/dl
  - Discharged on day 4 with no complications

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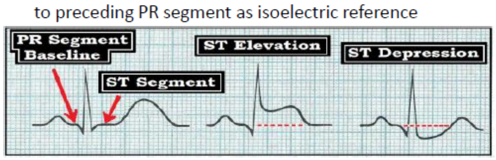
Continuous ST segment Monitoring

- ST segment is measured from J Point (end of QRS segment at isoelectric line) to the beginning of T wave
- When calculating for deviation, ST segment is compared to preceding PR segment as isoelectric reference



Source: ecginterpretation.com

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Continuous ST segment monitoring

- When 5-lead ECG is connected, the monitor's algorithm establishes a baseline
- At predetermined intervals, all subsequent ST segments are compared to this baseline and deviations are displayed as a positive or negative numerical value
- Alarm parameters are set to notify if ST segment changes > 1-2mm from that baseline
- **Visual detection of changes has been shown to NOT be reliable**
- Implications: Discharging previous patient from monitor, changing electrode placement after baseline has been established, change in body position can alter ST segments
- **Limitations: Previously documented left bundle branch block or ventricular paced rhythm are not candidates.**

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ECG Lead Placement

Limb leads= I,II,III, AVR, AVF, and AVL

- I and AVL monitor the lateral wall generally corresponding with circumflex distribution
- II, III and AVF monitor the inferior wall and correspond with right coronary artery perfusion
- AVR is generally not a diagnostic lead
- Limb leads are derived from the white, green, black and red electrodes placed on the perimeter of the chest
- Even though the monitor only displays one of these leads continuously, it is monitoring the ST segments of all 6 of these leads

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ECG Lead Placement

- **Precordial leads= V1-V6**
  - V1 and V2 monitor the septal wall and the distribution of the left anterior descending artery (LAD). Can also show reciprocal changes of the posterior wall
  - V3 and V4 monitor the anterior wall and the distribution of the LAD as well
  - V5 and V6 monitor the lateral wall and circumflex distribution
  - With a 5-lead ECG, only one precordial lead is continuously displayed and monitored for ST segment changes
  - Which precordial lead is monitored, is determined by where the anesthetist places the brown lead

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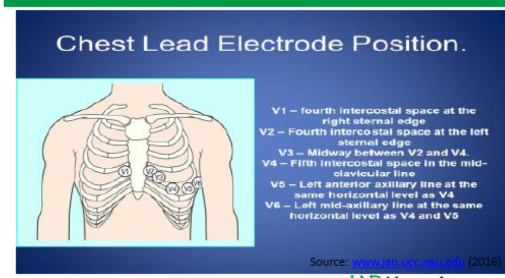
Chest Lead Placement



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Lead Selection

- Historically we have monitored in II and V5
  - Prior research was based on holter monitoring, not in the OR
  - ST segments were measured from the isoelectric line, not the patient's baseline
- New research used continuous 12-lead ECG monitoring prior to induction through the 3rd post-operative day and measured deviation (2mm in one lead or 1mm in two contiguous leads) from the patient's baseline

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Novel ECG Lead Selection

- Ideally, if the patient had a 12-lead which demonstrated changes in a specific lead or known CAD in a certain vessel, then that specific V lead known as a "fingerprint" should be monitored as it will be the most sensitive
- **V3 was found to be the most sensitive chest lead**, showing ST segment changes the earliest. Along with lead III
- **V4 was found to be the most specific.** V4 was the second most sensitive lead but it was better at detecting ST segment changes that would progress to myocardial infarction (defined by elevation in troponin)

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Recommendations

- ACC/AHA recommended intraoperative ST segment monitoring in lead V4 rather than lead V5 for patient's undergoing non-cardiac surgery
- AACN published practice-alert around the same time based on a systematic review of literature recommending:
  - Leads III and V3 be used for patients with a cardiac history as it will show changes the earliest
  - Stressed importance of monitoring in "fingerprint" lead if previously documented change in ST segments
- Some monitors have the technology to do derived 12-lead (or EASI) monitoring. This will monitor ST segments in all 12 leads removing need to make a selection

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Characteristics of Perioperative Myocardial Infarction (PMI)

- Almost always preceded by ST segment depression
  - Rarely preceded by ST elevation (leading to hypothesis of majority of PMI caused by imbalance of supply and demand, not plaque rupture)
- Strong association between duration of ST depression (>20 min or 60 min cumulative) and progression to myocardial infarction
  - The longer the duration of depression correlated with a higher trend in peak troponin levels
- **Each episode of depression was preceded by tachycardia**

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Characteristics of Perioperative Myocardial Infarction (PMI)

- Highest risk of significant ischemia (>10 min) is from emergence through post-op day 2
  - Majority of prolonged ischemia events started during emergence (d/t increased heart rate and blood pressure, sympathetic discharge and pro-coagulant activity)
  - May see brief episodes during high demand periods (intubation, tachycardia)
- > 50% of PMI are silent (no symptoms)

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Review of Case Study

- Continuous ST segment monitoring was a simple, cost effective and valuable tool for a patient with increased risk factors undergoing a high risk surgery
- Assuring **correct** ECG electrode placement for the most accurate data
- Establishing a ST segment baseline
- Setting the alarms at 1mm of deviation
- Printing a ECG strip prior to induction for reference were all good strategies for effective ST segment monitoring
- Areas of improvement include: monitoring in lead V4 (because the patient did not have **documented** CAD) instead of V5 for more sensitive detection of ST segment changes
- Patient did not experience any episodes of tachycardia but this literature review highlighted again the connection between this and myocardial ischemia

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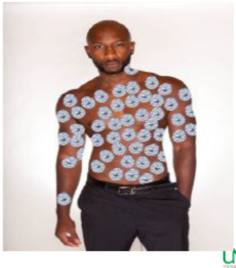
Thank You
Any Questions????



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