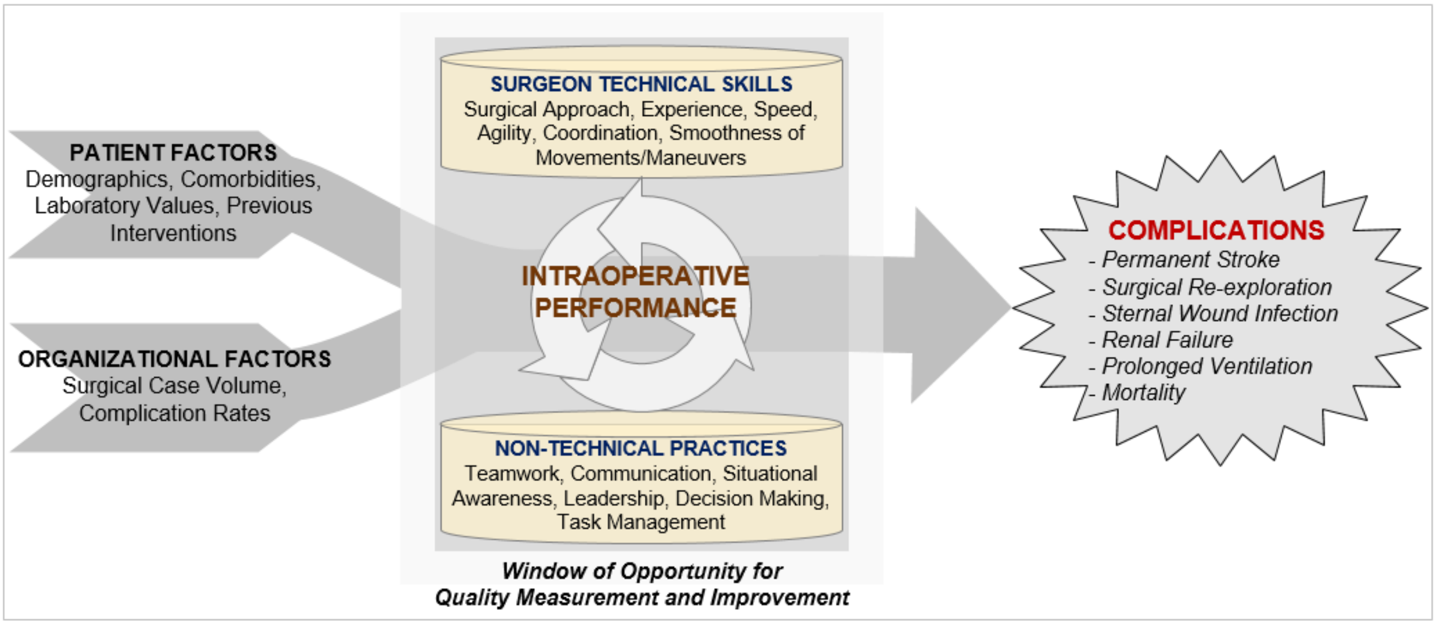
PCRC Proposal Cover Sheet

Title of Study or Project:	Novel Assessments of Technical and Non-Technical Cardiac Surgery Quality
Primary Institution:	Michigan Medicine
Principal Investigators:	Donald Likosky (UMI Cardiac Surgery) Francis Pagani (UMI Cardiac Surgery) Steven Yule (B&W Surgery / Medical Simulation)
Co-Investigators:	**B&W Emergency Med**: Roger Dias **UMI: Anesthesiology (**Michael Mathis, Matthew Caldwell); **Biostatistics** (Min Zhang); **Electrical Engineering and Computer Science (**Jason Corso); **Qualitative Methodology (**Sara Krein, Milisa Manojlovich)
Type of Study	Prospective, Observational Cohort Study
IRB Number/Status:	HUM00138871, 12/14/2017 (Non-regulated)
Hypotheses:	**H1:** Peer ratings of surgical technical skills are associated with differences in provider complication rates, after adjusting for established risk factors. **H2:** Peer ratings of non-technical practices are associated with provider complication rates, after adjusting for established risk factors.
Number of Patients/Participants:	A subset (n=6) of low and high-performance outlier MPOG hospitals (standardized major morbidity/mortality ratio that are significantly greater or lower than one) will be selected for participation. We will digitally record 506 surgeries from a total of 36 surgeons (6 surgeons per center), with each surgeon contributing at least 10 recorded surgery. We will look back 2 years for each surgeon's clinical outcomes: ~7,200 operations from 36 surgeons at six hospitals.
Power Analysis:	Our analysis will be based on outcomes for ~7,200 operations from 36 surgeons at six hospitals, and major morbidity or mortality rates from our preliminary data. **Aim 1**: For a two-sided test, alpha 0.05, we estimate having 98% power in detecting an odds ratio of 0.85 per one unit increase in a surgeon's technical skill on the rate of complications. At the probability scale, this assumes an effect size corresponds to, for example, a reduction of major complication rate from 20% to 17% per one unit increase in a surgeon's technical skill. **Aim 2:** As surgeon's non-technical practices are considered a surgeon-level variable, there will be sufficient power in detecting the same effect sizes as reported in the Aim 1. There will be about 85% power in detecting an odds ratio of 0.88 on major complications per 1 unit increase in non-technical practices (anesthesiologists, perfusionists and team) summarized as hospital-level variables.
Proposed statistical test/analysis:	**Aim 1**: Generalized linear mixed effect models with a logit link will be used to associate a surgeon's technical skills with STS' composite outcome, adjusting for patient risk factors (e.g., demographic and clinical factors), number of years since surgical fellowship training, year of surgery and surgery type by including them as fixed effects in the models. **Aim 2**: Generalized linear mixed effect models with a logit link will be used to associate peer-rater assessments of non-technical practices (surgeon, anesthesiologist, perfusionist) with STS' composite major morbidity and mortality. We will also explore whether non-technical practices modify the relationship between a surgeon's technical skills and our composite endpoint by including interaction terms of non-technical practices and technical skills. **Aim 3**: We will assess our video understanding's ability to correctly identify and track features within our testing dataset.
Resources (Brief summary of resources for data collection, personnel, financial):	NIH funds (19th percentile on first submission; resubmission 3/2019) to cover: - Investigator and analyst effort - Digital recordings of cardiac surgical operations across 6 medical centers - Integration of MPOG, STS, and video datasets - Peer-rater assessments of technical skills and non-technical practices - Semi-structured Interviews at a subset of centers - Computer-assisted assessments using a video understanding platform

Introduction

The epidemiology of cardiac surgery: Nearly 300,000 cardiac surgical procedures are performed annually in the U.S., accounting for more than $12 billion in direct 30-day payments[1,2]. Despite technological improvements and dramatic mortality reductions over the last several decades, major complications remain common (12-35%) and vary by hospital. Development of these complications increase a patient's risk of mortality 4.7-fold, prolong (>14 day) length of stay 7.0-fold, and are associated with more than $50K in additional healthcare expenditures[1,3–5]. While understudied, intraoperative performance (including the surgeon's technical skills and team-based non-technical practices) is likely a significant potentially modifiable determinant of surgical complications, **Figure 1**.

Figure 1. Conceptual Model



The Role of Technical Skills on Surgical Outcomes: Investigators have evaluated the association between technical skills and surgical outcomes[6]. Technical skills may be defined as "psychomotor action or related mental faculty acquired through practice and learning pertaining to a particular craft or profession[7]." Technical proficiency is thought to be achieved through didactic learning and operative exposure. To address deficiencies in this apprenticeship model, simulation (e.g., bench models[6,8,9]) has emerged as an effective mechanism for enhancing the learner's technical competency[6,10]. While established taxonomies exist to objectively assess a surgeon's technical skills (i.e., Objective Structured Assessment of Technical Skill, OSATS[11] – **Table 1**), they are often applied within simulated scenarios that may not mimic live patient situations. In one exception ten clinician experts used a modified OSATS assessment tool to rate a single 25-50-minute video segment of a laparoscopic operation from each of 20 surgeons. Ratings, linked to data from the last two years of each surgeon's experience, were inversely associated with a surgeon's clinical outcomes. Unlike bariatric surgery that principally involves ligating and removing structures, cardiac surgery involves a unique set of technical skills (e.g., creating/remodeling anatomical structures), while using high-powered magnification. Patients are also often purposefully exposed to periods of myocardial ischemia (i.e., aortic cross clamping), which requires the surgeon to conduct the operation efficiently to prevent ischemia-induced end organ injury.

The Role of Non-Technical Practices on Surgical Outcomes: Non-technical practices are both individual and team-based; defined as "the cognitive, social, and personal resource skills that complement technical skills, and contribute to safe and efficient task performance[12]." Most research to date has: (i) focused on developing robust taxonomies of behavior – **Table 2**; (ii) addressed causes of operative error; and (iii) been conducted in controlled non-operative experiments (e.g., simulation), although one study has shown training in non-technical practices to be associated with a drop in operative mortality[13]. The term 'non-technical practices' is broadly applicable, with key features and assessment tools customized to the operative role of individual team members and tied to their professional background. Cognitive practices include situation awareness[14], the process of developing and maintaining a dynamic awareness of the operative situation based on gathering and interpreting data from the operative environment. This domain is essential for effective decision-making[15]: skills for diagnosing a given situation inform a judgment about appropriate actions. For example, analyses of bile duct injuries during cholecystectomy reveal that 97% of avoidable complications result from failings in cognitive practices rather than technical skills[16]. Successful surgery also depends on social practices that allow multiple individuals with task interdependencies and shared goals to communicate and work effectively as a team[17]. Unfortunately, dysfunctional team dynamics, ineffective communication, and ambiguous leadership[18] account for a significant proportion of surgical morbidity and mortality[19](Fann et al. 2013). Furthermore, 82% of all closed malpractice claims are also attributed to system factors[20] that include those representing the operating room, where frequent and often unstructured clinical handoffs (involving the professional responsibility of patient care from one individual to another) may adversely impact patient safety[21–23]. Personal resource practices are required to mitigate the many interruptions and distractions (e.g., door movement, alarms, pagers, extraneous conversations, music) that pervade the operative environment and shift attention (including vital working memory resources) away from primary tasks. These disruptions can result in cognitive overload, acute stress, dysfunctional team dynamics and amplify variability in technical skills (e.g., through inefficient motion; inappropriate tissue handling; tremor), increasing the likelihood for error and operative complications[24,25]).

Table 1. Modified Objective Structured Assessment of Technical Skill (OSATS)

Domains	Description	Illustrative Surgical Tasks
Respect for Tissue	Gentle tissue handling that does not result in tissue injury	Passing a needle through a coronary artery without tearing of the tissue
Time and Motion	Economy of motion, maximum efficiency	Efficiency of suturing proximal anastomoses or new valve into native tissue.
Instrument Handling	Fluid use of instruments absent awkwardness	Fluidity of motion between scrub nurse and surgeon (and back)
Flow of Operation	Smooth transitions from one part of the operation to another	Smooth transitions from between cannulation (venous and aortic) phase to anastomosis phase.

Table 2. Taxonomies for Non-Technical Practices

Behavior Domains	Behavioral Elements from Non-Technical Assessment Taxonomies		
	Non-Technical Skills for Surgeons (NOTSS)	Anesthesiologists' Non-Technical Skills (ANTS)	Perfusionist Non-Technical Skills (PINTS)
Situation Awareness	• Gathering information • Understanding information • Projecting & anticipating	• Gathering information • Recognizing and understanding • Anticipating	• Monitors the circulatory and respiratory functions of the patient
Decision Making	• Considering options • Selecting & communicating option • Implementing & reviewing decisions	• Identifying options • Balancing risks & selecting options • Re-evaluating	• Initiates improved processes of care
Communication & Teamwork	• Exchanging information • Establishing a shared understanding • Coordinating team activities	• Coordinating activities with team • Exchanging information • Using authority and assertiveness • Assessing capabilities • Supporting others	• Uses closed loop communication to confirm ACT
Leadership/ Task Management	• Setting & maintaining standards • Supporting others • Coping with pressure • Preventing flow disruptions	• Planning & preparing • Prioritizing • Providing & maintaining standards • Identifying & utilizing resources	• Follows published protocols and guidelines in administration of heparin

A number of investigations have explored the relationship between technical skills and non-technical practices in surgery with inconsistent results[26–31]. Focusing only within professional silos rather than at team-level has been a limitation. While not yet examined, the interaction of team-based non-technical practices on the relationship between technical skills and outcomes is critical to advance understanding of the skills and practices that could improve cardiac surgical quality.

Computer Assisted Assessments: High-dimensional computer-based assessments of digital recordings are utilized inside and outside of healthcare to recognize and track human activity (computer vision). This field may offer unparalleled capabilities for conducting objective peer rater assessments by automatically identifying and tracking human activity in vivo equivalently to expert human raters.

Role of Video Understanding for Assessing Surgical Technical Skills and Non-Technical Practices Computer vision focuses on training computers to derive meaning and understanding from still images. Video understanding, a specialty within computer vision, focuses on identifying and tracking objects over time from video and training mathematical models and computers to understand the meaning within moving images.

Surgical Technical Skills**:** Assessment of a surgeon's technical skills is traditionally performed throughout surgical training by mentored observation in real or simulated situations. Alternative methods (e.g., video understanding) have evolved that may address some of the limitations (e.g., human rater bias, poor scalability) in these traditional approaches. Video understanding algorithms have been applied in a number of fields, including industrial robotics, autonomous vehicles, security surveillance and more recently healthcare (e.g., virtual colonoscopies, image acquisition, surgical decision-making). While there has been limited application within the surgical setting, a recent report documented 92.8% accuracy in computer vision's correct identification of steps utilized for sleeve gastrectomy[32]. Within a benchtop setting, investigators have applied computer vision to distinguish surgical skill (assessed through tracking of novice and experienced surgeon hand movements[33,34]) via videotaping and OSATS rating assessments. Azari et al. compared expert surgeon's rating assessments to computer-based assessments of technical skills (tying and suturing), as defined by fluidity of motion, tissue handling and motion economy[35]. Computer-based assessments had less variance compared to expert raters. In addition, Dr. Corso investigated the feasibility of computer-based methods for technical assessment of skill (e.g., suturing and knot tying) by ten surgeons of varying experience with robotic-assisted surgery[36]. Dr. Corso acquired 99 unique videos with 22,467 total frames, and developed a state-of-the-art deep learning-based surgical tool tracking system for this setting. The quantitative assessment against gold standard tool tracks found a 90.7% mean average precision over all test videos across all surgeon skill levels. Given these promising results, video understanding may provide a platform for objectively identifying surgical technical skills.

Non-Technical Practices: Non-technical practice assessments have predominantly occurred within simulated environments and relied on trained human observers, thereby limiting fidelity and ease of real-world deployment[37,38]. While potentially feasible, investigators have not evaluated whether video understanding could provide an objective, in vivo alternative for assessing non-technical practices. Video understanding may be used to assess features aligned with non-technical practices without relying on verbal communication (e.g., identifying the anesthesiologist's head movement and gaze fixation on monitoring equipment as a proxy for situation awareness; transferring of surgical instruments between team members as a proxy for decision making; converging upper body movements between perfusionist and surgeon as a proxy for teamwork, and gesturing, 'thumbs-up' hand actions as a proxy for leadership). Capture of regular door openings and foot traffic through the operating room may be indicative of surgical flow disruptions. Video understanding requires time-limited human observer involvement to develop algorithms after which the automated system may be deployed at scale.

Summary of Literature Underpinning the Proposed Studies: Major cardiac surgical complications are frequent and vary by hospital[1,39]. While peer rater assessments of technical skills are associated with risk-adjusted bariatric surgical outcomes, evaluation of a surgeon's technical skills or team's non-technical practices) within cardiac surgery are lacking[40]. Other sectors (e.g., public safety forensics) commonly employ computer-assisted assessments to address limitations in human behavior (e.g., lack of objectivity) and automate time-intensive human activities. To date, there has been limited application of these modalities within the healthcare sector to address threats of objectivity within existing assessment approaches. In addition, to our knowledge no previous studies have evaluated the relationship between computer-assisted assessments and surgical outcomes.

Impact: There is increasing demand from the public and payers for improving healthcare value, defined as quality divided by expenditures. Despite wide variability in cardiac surgical quality and robust clinical data from The Society of Thoracic Surgeons (STS) for risk adjustment and outcomes ascertainment, only 2% of hospital variability in some outcomes are explainable by currently recorded data elements[39].

This study, leveraging the infrastructure and track record of two established physician-led quality collaboratives, will advance our understanding of how peer rater assessments of surgical skills and non-technical practices contribute to major surgical complications. We will evaluate the feasibility of automating technical skills and non-technical practice assessments via a scalable video understanding platform. Our findings will serve as a first, foundational step aimed at minimizing postoperative complications through targeted intraoperative interventions.

Methods

Data Sources:

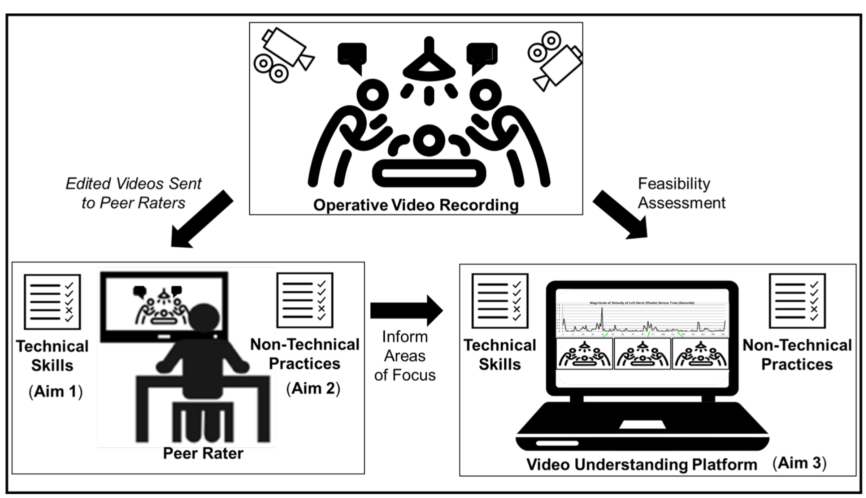
MPOG and Surgical Registry Data: Use of MPOG data has previously deemed to be "Not Regulated" by the IRB at the University of Michigan and each of the contributing member hospital's IRB. These data are integrated with surgical registry data (i.e., the Society of Thoracic Surgeons Adult Cardiac Database) for quality improvement and research. Patients are followed as part of participation in MPOG or Society of Thoracic Surgeons databases from the time of their index hospitalization until typically 30 days following discharge (up to one year).

Video Recording Data: The monitoring of cardiac surgical operations as outlined in this proposal has been deemed to be "Not Regulated" by the IRB at the University of Michigan (HUM00138871, 12/14/2017). The purpose of this component of our study is to ultimately optimize operative practices to minimize complications. Standard patient consent for cardiac surgical procedures permits videography. We will be video-recording while operating room personnel are working during surgical procedures. Other members of our investigative team, blinded to the hospital and operating room personnel, will review parts of the videos. Digital recordings will only occur during regularly scheduled surgical procedures. Operating room team member participation in our study will not constitute an element of the operating room personnel's job performance or evaluation, nor will it be part of their personnel record at their hospital.

Handling of missing data: The extent of missing data will be explored, including assessing to what extent missingness is informative. A number of approaches will be assessed to address missingness, including complete case analysis, mean/median substitution, and/or multiple imputation. The final decision regarding how to address missingness will be determined between the biostatistician and the rest of the investigative team.

Approach Summary:

Figure 2. Approach (Aims 1-3)



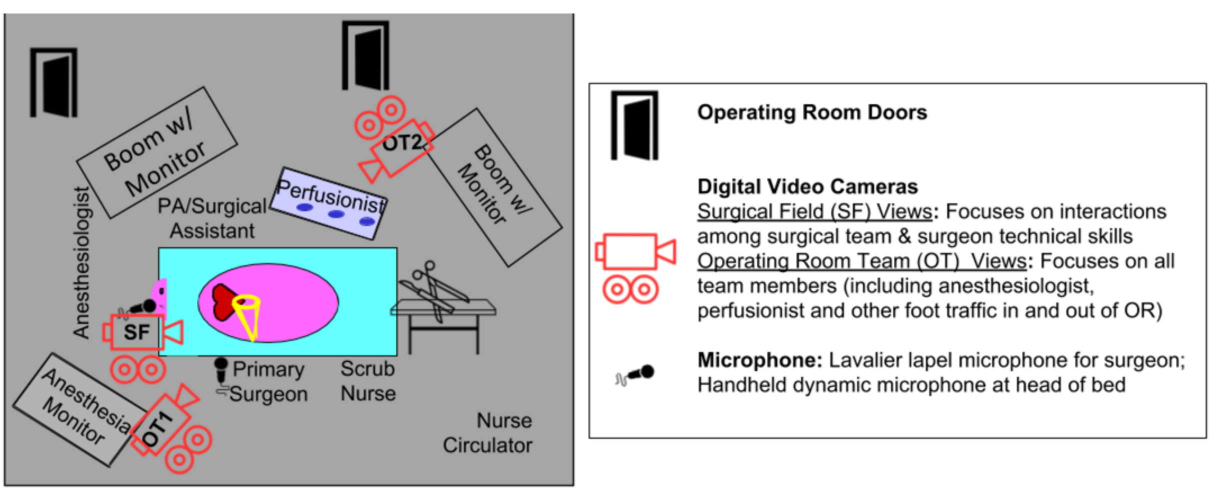
We propose undertaking a multi-center, national study nested within two physician-led quality improvement collaboratives to evaluate operative determinants of post-cardiac surgical complications, **Figure 2**. We will: (i) digitally record coronary artery bypass operations at six hospitals and use trained peer raters to assess a surgeon's technical skills and team-based non-technical practices using established taxonomies, (ii) associate these ratings with rates of major complications, and (iii) apply objective computer-assisted platforms to automate the identification and tracking of important technical and non-technical practices in recorded operations.

Overall Strategy: We will use pre-established criteria for identifying hospitals for study participation from a pool of candidate MPOG hospitals. First, we will use each MPOG hospital's STS data to identify performance outliers based on a hospital's observed:expected rate of major morbidity/mortality over the prior two years. Given our interest in assessing differences in surgical technique, we will ensure adequate variability in participating surgeon performance within each candidate hospital based on STS data. Next, we will conduct a systematic review of the literature and review results from a recently conducted MPOG survey to identify important cardiac surgical technical practices and operative team-based non-technical practices that may be likely candidates for investigation through our surgical videos, including: (i) evidence of interdisciplinary training; (ii) access to a simulation center; and (iii) number of master TeamSTEPPS trainers. Together, these data will be used to select a subset (n=6) of low and high performance outlier hospitals for study participation.

Study Population: We will digitally video record adult, scheduled coronary artery bypass grafting operations using cardiopulmonary bypass performed by attending surgeons at six MPOG hospitals. We will only include operations performed by attending surgeons having operated at their videotaped hospital for at least two years.

Digital Recording: We will digitally record 506 operations across hospitals. We plan to pilot our protocol (e.g., setup of equipment, synchronization and recording from three cameras, documentation of operative phases through MPOG software, transfer of videos to Dr. Yule's laboratory, and video quality) at one hospital, refine our protocol, and initiate study activities at the other five hospitals, thereafter. Hospitals will send renderings of their preferred study operating rooms to our project's videographer, who will develop a video configuration protocol (**Figure 3**). The videographer will be available for consultation with each hospital's coordinator to ensure protocol standardization with Dr. Yule's laboratory certifying each hospital's digital recordings.

Figure 3. Schematic for Digital Recordings



Three additional camera angles were evaluated. Analyses found these views were often obstructed by clinical workflow and/or adversely impacted operative team's activities.

Per protocol, the study coordinator will work with participating cardiac surgeons and the anesthesiologist lead to identify candidate operations. The coordinator will randomly select, by week, different cardiac surgical operating rooms for video recording, and set up the video equipment prior to the patient entering the operating room. When possible, the study coordinator will digitally record two procedures (i.e., morning and afternoon cases) within a single day. Prior to the recording, the coordinator will synchronize the cameras with other operating room data sources (e.g., intraoperative MPOG record). As part of existing MPOG workflows, key transitions in phases of the patient's care are documented within the intraoperative record available through MPOG's software (e.g., patient room entry, preoperative brief, sternal incision, onset of bypass). Digital recording of the operation will begin when the patient arrives in the operating room (and therefore prior to the pre-induction verification) and end when the patient exits the operating room. The study coordinator will assign a unique study identifier, archive the digital recording and electronically transfer the video files from each camera to Dr. Yule's laboratory.

Dr. Yule's laboratory will: (i) conduct quality checks of all operative recording and will provide feedback to the study coordinator, thereafter. Digital records not meeting pre-specified quality standards (e.g., correct time synchronization across camera; capture of patient from entry to exit of operating room; capture of audio from surgeon and team members; receipt of MPOG time stamping) will not be analyzed; (ii) backup and create standardized edited video segments for peer raters containing only the critical portions of each operation (**Table 3**); (iii) transfer the video segments to the HIPAA-compliant web-based rating platform and (iv) assign peer raters to each video segment via the platform interface. Screening strategies will be applied to reduce the risk of raters reviewing individuals whom they may visually recognize. Twenty percent of video segments will be resubmitted to the same reviewer for test-retest reliability as well as to other reviewers for inter-rater reliability, with alpha set at 0.70 for concordance[41].

Table 3. Illustrative Operative Phases for Video Assessments

	Critical Portions of Operation	Rationale
Technical Skills Assessment	•Performance of distal arterial and venous anastomoses (exposure is completed → last suture is cut after tying) •Performance of proximal arterial anastomosis (Initial use of electrocautery to isolate area for anastomosis → last suture is cut after tying)	Video segment would contain technical skills (e.g., economy of motion: creation of anastomosis) that are critical for a successful operation.
Non-Technical Practices Assessment	•Pre-induction verification (prior to → end of discussions) •Pre-incision timeout (prior to → end of discussions) •Pre-bypass TEE assessment (surgeon request for TEE → completed discussion between surgeon and anesthesiologist) •Preparation and weaning from bypass (surgeon requests heart to be filled up → protamine finished)	Video segment would contain non-technical practices (e.g., decision-making and communication/teamwork: discussions during the verification and timeout as well as focusing on ensuring a safe weaning from cardiopulmonary bypass).

Peer Ratings: Peer raters will review and provide technical (Aim 1) and non-technical (Aim 2) assessments (total 5465) of segments of cardiac surgical operations. At least 3 surgeons will rate each surgeon's technical skills (modified OSATS including cardiac surgery-specific technical skills assessments) via a 5-point behaviorally anchored scale (**Table 1**) and non-technical practices (NOTSS[42]) for each video segment, while at least three anesthesiologists will rate the anesthesiologist's non-technical practices (ANTS[43]), and at least three perfusionists will rate the perfusionist's non-technical practices (PINTS). All non-technical taxonomies are validated and leverage a 4-point ordinal scale. Raters will answer questions concerning the audio and visual quality of the segments. We will employ a two-stage process for identifying candidate raters: (i) we will poll the MSTCVS-QC, MPOG and the Michigan Perfusion Society membership regarding potential raters working outside of Michigan or at hospitals not participating in MPOG; and (ii) if we are unable to secure a sufficient number, we will recruit raters from among members of the MSTCVS-QC, MPOG and the Michigan Perfusion Society. Segments (estimated 30-min in length) will capture each operation's critical phases (**Table 3**). Technical skills raters will be given one camera angle [Cam Surgical Field (SF)] of the operative field for their assessment. Given the inter-dependence of intraoperative team members, non-technical peer raters will be provided with the same operative field (Cam SF) and two other camera angles depicting the intraoperative team [Cam Operative Team (OT) #1 and #3] for their review. Raters will provide: (i) an assessment for each operative phase along with a short narrative description supporting their rating; and (ii) an overall assessment for each video segment. Raters will be given an Amazon coupon for completed reviews.

e-Learning Rater Training Module: We will develop a web-based training package for raters that will include: (i) foundational knowledge of the relevant tool; and (ii) video examples of correct identification, categorization and assessment. In the final assessment, raters will have to reach 0.80 consistency with gold standard ratings (provided by the investigative team) prior to participating in the rating study. Training materials will be adapted from those previously developed by PI Yule for the American College of Surgeons. Raters will undergo competency re-testing every three months by grading ten operative phases from standardized assessment videos[44]. We will set the bar at median 80% concordance with reference ratings for raters to continue conducting real operative video assessments[45]. Peer raters not meeting these criteria will receive automated feedback on outlier scores (relative to the reference ratings and peer raters), with the opportunity to regrade videos.

Linkage of Peer Rater Assessments with Complications: We will associate peer ratings from recorded operations with each surgeon's complication rate for the previous two years using each hospital's STS data for risk adjustment and outcomes ascertainment. Next, we will evaluate the feasibility of using a video understanding platform to automate the identification and tracking of important skills and practices (identified in Aims 1 and 2).

Evaluating the Feasibility of an Objective, Automated Surgical Assessment Platform: We will use 150 recorded operations to develop our video understanding algorithms. For this developmental stage, we will apply our algorithm to the entire recording of each video and conduct semi-structured interviews with operating room team members at two low and two high performing hospitals. During this phase of our analysis, we will iteratively improve our platform's ability to identify technical skills and non-technical practices by comparing what the video captures to what operating room team members describe during interviews. By asking interviewees to comment on the videos, we will also be able to understand why certain events occurred in the operating room. Finally, we will validate our algorithm's performance among the pre-defined 30-minute video segments.

<u>Aim 1</u>: Investigate the relationship between peer-rater assessments of a surgeon's technical skills and variability in risk-adjusted patient complications

Approach: We will conduct peer reviewer assessments of digitally recorded cardiac surgical operations to identify technical skills significantly associated with major operative complications. First, to identify key skill areas and important phases of the surgical operations, we will conduct a systematic literature review identifying evidence-based surgical techniques protective of operative complications. Second, we will leverage survey responses from surgeons (via the MSTCVS-QC) concerning the most critical segments of an operation where technical skills have the greatest potential to influence the complication rates. We will initially only focus on the phases noted by the majority of respondents to be the most critical. We will digitally record approximately 506 surgical operations at each of three low and three high performance outlier hospitals. We will use findings from a previously conducted MPOG provider and hospital practice survey for hospital selection.

Similar to Birkmeyer[40], each surgical operation will be divided into pre-specified phases (Table 3) containing the most critical portions of the operation. Uniquely, each selected phase initially will be identified electronically through MPOG's intraoperative electronic health record. Existing workflow includes documentation, concurrent with clinical care, of operative phases by the anesthesiologist, thereby not necessitating protocol-specific training. Our team will review the entire digital recording (from Cam #OT2) to: (i) fine-tune the MPOG timestamping of events to the exact second; and (ii) add timestamps for important clinical steps not captured through MPOG (e.g., start and end time for proximal anastomosis). Our goal will be to create edited video segments not lasting on average more than 30 minutes in duration. Subsequent to completing the "previewer" step, we will distribute these video segments for peer rating through our HIPAA-compliant rating platform that will provide surgeon raters with a view of the operative field (from Cam SF). Reminder notices will be sent to the raters until we receive at least three peer ratings per video. Surgeon raters will provide domain-specific and an overall summary judgement (using a modified-OSATS taxonomy). Twenty percent of segments will be submitted for additional review to test peer rater reliability. We will associate the average ratings with the adjusted risk of major morbidity and mortality over the prior two years of each surgeon's operative experience.

Exposure Variables: Our primary exposure will be the average summary peer rating of each surgeon's technical skill.

Outcomes: The primary outcome will a surgeon's STS' composite major morbidity or mortality (i.e., permanent stroke, surgical re-exploration, deep sternal wound infection, renal failure, prolonged ventilation, or operative mortality) rate. We will use STS data to adjust for covariates incorporated within the STS' risk prediction models[46,47]. Data from the MPOG survey will provide unique information (e.g., number of years since fellowship for each surgeon).

Analytic Plan: To identify performance outlier hospitals, we will calculate patient risk-adjusted rates of major morbidity/mortality using the indirect-standardization method (i.e., using the ratio of observed over expected rate based on the hospital's patients). Hospitals with a standardized major morbidity/mortality ratio that are significantly greater or lower than one are identified as hospitals with worse or better than average hospitals, respectively. A subset (n=6) of low and high performance outlier hospitals will be selected for participation. We will digitally record 506 surgeries from a total of 36 surgeons (6 surgeons per center), with each surgeon contributing at least 10 recorded surgery. By recording multiple surgeries for each surgeon and conducting multiple reviews for each recorded surgery, we are able to better assess a surgeon's skills as it considers both the variability across surgeries within a surgeon and the variability due to raters.

Regarding analyses concerning technical skills, we will first use linear mixed effect models to model ratings of surgical procedures where raters and surgeons are included as random effects. Based on the fit of the linear mixed effect models, we will quantify variation in peer-rater assessments of a surgeon's technical skills and use the intra-class correlation coefficient to measure inter-rater reliability. We will use predictions of each surgeon's technical skill (overall and each individual domain and element) from linear mixed effect models as summary measures of a surgeon's technical skills in subsequent analyses. Unlike crude sample averages, these predictions may account for differences in number of videotaped operations and in raters to reduce bias due to raters. Generalized linear mixed effect models with a logit link will then be used to associate a surgeon's technical skills with our composite outcome. We model surgeons and hospitals as random effects, accounting for the nesting structure of the data (i.e., patients nested within surgeons and hospitals). We will adjust for patient risk factors (e.g., demographic and clinical factors), number of years since surgical fellowship training, year of surgery and surgery type by including them as fixed effects in the models. The factors of interest are summary measures of a surgeon's technical skills, which are included as surgeon-level explanatory variables. We will consider the overall ratings of a surgeon's technical skill, averaged across three raters and each domain individually.

Power Analysis: We used simulations to evaluate statistical power for a two-sided test, alpha 0.05. Our analysis will be based on: (i) outcomes for ~7,200 operations from 36 surgeons at six hospitals, and major morbidity or mortality rates from our preliminary data. We estimate having about 98% power in detecting an odds ratio of 0.85 per one unit (standardized) increase in a surgeon's technical skill on the rate of complications. At the probability scale, this assumes an effect size corresponds to, for example, a reduction of major complication rate from 20% to 17% per one unit increase in a surgeon's technical skill. There would be about 95% power in detecting an odds ratio of 0.88 (reduction of major complication rate from 20% to 18%).

Expected Outcomes: We expect to identify: (i) variation in peer-rater assessments of technical skills; and (ii) technical skills associated with surgical complications for further evaluation in Aim 3.

<u>Aim 2:</u> Investigate the relationship between peer rater assessments of intraoperative team-based non-technical practices and variability in risk-adjusted patient complications.

Approach: Findings from our systematic review and provider survey will direct our analyses (e.g., important non-technical practices to study, phases of operation for peer rater assessments). Video segments will be reviewed by at least three peer raters using a web-based grading platform (showcasing all three camera angles). Surgeons will rate surgeons using NOTSS, anesthesiologists will rate anesthesiologists using ANTS, and perfusionists will rate perfusionists using PINTS. We will associate peer rater assessments of non-technical practices with the risk adjusted odds of postoperative major morbidity and mortality.

Exposure Variables: Our primary exposure will be the average summary peer rating of each provider's non-technical practices.

Outcomes: Similar to Aim 1, the primary outcome will be the rate of major morbidity or mortality, adjusting for covariates contained within the STS' published risk models[46,47].

Analytic Plan: For Aim 2, we will use generalized linear mixed effect models with a logit link to associate peer-rater assessments of non-technical practices with STS' composite major morbidity and mortality. Models will be similar to those described in Aim 1, although will include average summary measures of surgeon's non-technical skill as surgeon-level explanatory variables, and hospital-level average summary measures of anesthesiologists and perfusionists. Both overall summary measures and individual scale domains will be considered. We will focus primarily on assessing the effects of surgeon, anesthesiologist and perfusionist non-technical practices, while adjusting for patient level risk factors and a surgeon's technical skills. In our secondary analysis, we will explore whether non-technical practices modify the relationship between a surgeon's technical skills and our composite endpoint by including interaction terms of non-technical practices and technical skills. We will also explore interactions of technical skills and non-technical practices with case complexities.

Power Analysis: The power analysis is based on 7,200 cases across 36 surgeons from six hospitals. As surgeon's non-technical practices are considered a surgeon-level variable, there will be sufficient power in detecting the same effect sizes as reported in the Aim 1. For example, there will be about 98% power in detecting an odds ratio of 0.85 for every 1 unit (standardized by standard deviation) increase in a surgeon's non-technical practices. There will be about 85% power in detecting an odds ratio of 0.88 on major complications per 1 unit increase in non-technical practices (anesthesiologists, perfusionists and team) that are summarized as hospital-level variables. There will be more than 90% power in detecting an odds ratio of 0.85.

Expected Outcomes: We expect to identify: (i) variation in peer-rater assessments of non-technical practice; (ii) whether non-technical practices modify the relationship between a surgeon's technical skills and complications; and (iii) significant non-technical practices for evaluation in Aim 3.

<u>Aim 3</u>: Explore the feasibility of using objective, data-driven computer-based assessments to automate the identification and tracking of significant, intraoperative determinants of risk-adjusted patient complications.

Approach: We will explore the feasibility of using a video understanding platform to identify important technical skills and non-technical practices in digitally recorded operations. To support developing the video understanding platform, we will conduct interviews and site visits at a subset of low and high performing hospitals to enhance understanding of a hospital's contextual features and important aspects of 'usual practice'.

Approach for Video Understanding: The video understanding approach will focus on two specific techniques (i.e., visual detection, visual tracking), which will be applied to significant surgeon technical skills and team-based non-technical practices (Aims 1 and 2). We will apply ambiguity reduction across the three time-synchronized video recordings to harmonize (rather than duplicate) features within and across video angles. We will use proven methods for video understanding (e.g., boosting[48] and deep learning[49]). We will use boosting for cases of limited data and deep learning for cases with ample data. We will learn detection models for surgical technical skills (e.g., surgeon's hands, instruments, instrument exchange including between scrub nurse-surgeon-scrub nurse), and non-technical practices (e.g., operative team member's head focused on the hemodynamic monitor) arising from Aims 1 and 2. We will learn these features using the following mutually exclusive datasets containing video segments: (i) a training dataset (used for training the video understanding algorithms); (ii) a computer vision validation dataset (used for measuring over-fitting, for example, of the video understanding algorithms); (iii) a computer vision testing dataset (used for computing the error statistics of the computer vision system to meet human feature annotation); and (iv) a study set (video segments for peer rater assessments).

Members of Dr. Corso's laboratory will observe the raw video from our training dataset to provide bounding-box annotations for each of these features in consultation with PI Pagani for contextual feedback. A certain detection model is initialized with a random set of parameters and then the training algorithm iteratively refines them based on the empirical performance of the model (ability to detect the phenomena bounding boxes automatically) based on the annotations in the training data. The validation set is used during this training process to protect against over-training and bias. Certain technical assessments will not only require detection in a video frame, but also the tracking of the detected object throughout the video frames ("visual tracking"). For example, to measure economy of motion during the surgery, we will detect the surgeon's hands at frame t, track the surgeon's hands at all future frames t+k, and then compute a trajectory of the centroid of the detected bounding boxes. Our team will use both classical physics-based tracking models such as Lucas-Kanade tracking[50] and modern deep-learning based methods[51]. We will compute a number of quantifiers on economy of motion (e.g., mean acceleration, variance of local change in the trajectory against a linear or smoothed trajectory).

Approach for Qualitative Interviews: Concurrent with developing and testing the video understanding platform, we will randomly select up to four hospitals (equal representation of low and high performance outlier hospitals) out of the total six participating in Aim 2 for more detailed investigation. We will conduct semi-structured interviews with interdisciplinary cardiac surgery operating room informants involved. To enhance our understanding of technical and non-technical operating room practices, we will collect data (through interviews with key informants) concurrent with conducting analyses. Using our conceptual model and insights from prior studies and Aims 1 and 2, we will develop a semi-structured interview guide to encourage new and/or unexpected ideas or concepts to surface. For each interview, the interviewer will play back video segments from an operation involving the interviewee and ask the interviewee to describe his/her role within that phase of care. The interviewer will ask questions that seek to better understand team member roles and influences on technical skills and non-technical practices. We expect the guide, which will be modified as new findings or themes emerge, will consist of seven to nine open-ended questions, with some probes. All interviewers will be trained in a three-day interviewer-training program at the University of Michigan Health Communications Laboratory.

Interviews will continue until reaching informational redundancy "saturation" at each hospital (saturation often occurs at 10-12 interviews or when sources have been exhausted). We will: (i) conduct 40-60 minute interviews in private rooms, (ii) digitally record and transcribe transcripts verbatim, (iii) compare 10% of transcripts against the recordings and correct transcripts as needed, and (iv) provide interviewees with a gift certificate.

Our thematic analysis will include both within and across case comparisons. We expect that: (i) in reviewing the videos, providers will complement peer rater assessments regarding how and why contextual factors influence performance (technical and non-technical); and (ii) interviewees will validate the video content to maximize our video understanding algorithm's fidelity. Thus, our interview findings will improve our interpretation of the video content to iteratively inform and enhance our video understanding platform training.

Exposure Variables: Our exposure variables will be the features derived from the video understanding platform (**Table 4**), which we will compare to a gold standard human identifying the same features.

Outcomes: Co-primary outcomes will be (i) peer rater assessments, and (ii) the rate of major morbidity or mortality (see D5.B.), adjusting for covariates contained within the STS' published risk models.

Analytic Plan: We will assess our video understanding's ability to correctly identify and track features within our testing dataset. Dr. Corso's laboratory team will observe the raw video in the testing set to provide bounding-box annotations for the features in study. These human annotated features will be compared to the automatically generated features from the video understanding system. We will compare the automatically generated features (from the video understanding system) to the human annotated features using standard metrics such as Intersection over Union[52] and DICE coefficient[53].

Table 4. Illustrative Examples of Potentially Significant Intraoperative Skills and Practices and Associated Video Understanding Measures Across Surgical Phases

Significant Peer Rater Assessments Video Understanding Measures	Surgical Phase	Surgical Phase	Surgical Phase
Technical Skills			
Economy of Motion Mean velocity of suturing hand	Proximal Anastomosis	Suturing Valve into Native Tissue	
Non-Technical Practices			
Interpersonal Skills % of time task-critical team members are in the operating room	Pre-incision Timeout	Initiation of Bypass	Weaning from Bypass
Situation Awareness % of time each team member's visual field focuses on hemodynamic monitors	Weaning from Bypass		
Flow disruptions # of door openings/hour over the phase # of personnel, other than team members, entering and leaving the operating room	Patient in Operating Room until Pre-incision Timeout	Initiation of Bypass	Weaning from Bypass

We plan a two-phased analysis. First, we will measure agreement and associate each video understanding feature with each component of the technical and non-technical (assessments (specific to each surgical phase) using Pearson/Spearman correlation coefficients or Kendall's Tau, depending on measurement distribution. Second, we will identify the best combination of video understanding features that is most closely associated with each domain of the technical and non-technical scores (specific to each operative phase). To do so, we will use generalized linear regression models to model each domain and overall summary of the technical and non-technical scores as dependent variables and include all relevant features derived from the video understanding platform as independent variables. We will: (i) select features using variable selection and (ii) quantify the magnitude of information in peer-rating that can be identified by the computer using (generalized) R squares.

Expected Outcomes: We expect our video understanding platform will perform similarly to human raters in terms of identifying important surgical technical skills and team-based non-technical practices.

Areas for Discussion / Known Limitations

1) **Engagement of institutional stakeholders**: Critical to the success of this project, is having clarity among all intraoperative stakeholders regarding : (i) our team's ability to protect study data from legal discovery, impact of videography equipment on intraoperative standard workflow, and processing/storage of protected health information throughout the duration of the project. Through lessons learned from obtaining pilot data at Michigan Medicine, we plan to develop an in-depth FAQ document and project protocol handbook for participating institutions.

2) **Recruitment of Peer Reviewers:** Video reviews performed for this project will ultimately require review of cardiac surgery recordings, clipped to the segments deemed most representative of surgeon technical skills / operating room team non-technical practices, and most determinative of outcomes. Target length for videos will be 30-45 minutes. We are interested in developing a strategy for recruiting reviewers within MPOG, including a discussion of reviewer compensation.

Variables to be Collected

Single Measures

Variable Name	**Definition**	**Column or concept**	**Concept ID**	**Format**	**Notes**
MPOG_Patient_ID	MPOG Patient ID Number	MpogPatientId		Char	
MPOG_Case_ID	MPOG Case ID Number	MpogCaseId		Char	
DOS	Date of service				
Proc_Name	Actual Procedure description from AIMS text (scheduled description if actual unavailable)	MPOG Extraction Preferences: AIMS_Actual_Procedure_Text	18108	Character	Scheduled ID: 18107
Age	Patient age in years	Phenotype Age(Years)		Numeric	≥ 18 years of age
Gender	Patient Gender	Phenotype Sex		Male/Female	
BMI	Body Mass Index (WHO Classification)	Phenotype BMI		Numeric and categorical	
Height	Patient height in cm	Phenotype Height		Numeric (cm)	
Actual_BW	Actual body weight	Phenotype Weight		Numeric (kg)	
AsaClass_cleaned	ASA Class	Phenotype -- AsaClass_cleaned	70233	Numeric	
MPOG_Institution_ID	Insitution ID Number	Phenotype Institution		Character	
Anesthetist_First	Staff ID for Anesthetist present at 'Anesthesia Start'	MPOG Standardized Views : Case providers : Anesthetist_First			
Anesthetist_last	Staff ID for Anesthetist present at 'Anesthesia End'	MPOG Standardized Views : Case providers : Anesthetist_Last			

Anesthetist_Primary	Staff ID for Anesthetist with the most time signed into case	MPOG Standardized Views : Case providers : Anesthetist_Primary			
Attending_First	Staff ID for Attending present at 'Anesthesia Start'	MPOG Standardized Views : Case providers : Attending_First			
Attending_last	Staff ID for Attending present at 'Anesthesia End'	MPOG Standardized Views : Case providers : Anesthetist_Last			
Attending_Primary	Staff ID for Attending with the most time signed into case	MPOG Standardized Views : Case providers : Attending_Primary			
Emergent	Emergency surgery	Phenotype EmergencyStatus_YesNo		Yes / No	
Anesthesia_Start_DT	First date and time when anesthesia started for case	Phenotype AnesthesiaStart		Mo/Day/Year HH:MM	
Patient_In_Room_DT	First date/time when patient in room documented	Phenotype PatientInRoom		Mo/Day/Year HH:MM	
Pre_Induction_Verification_DT	First date/time when pre-induction verification performed	Compliance – Preinduction Verification	50301	Mo/Day/Year HH:MM	
Ventilator_Start_DT	First time when valid ventilator data recorded	MPOG : Physiologic Observations : End Tidal CO2, Peak Inspiratory Pressure, Tidal Volume Actual		Mo/Day/Year HH:MM	Valid ventilator data if meets all 3 criteria ≥ 3 continuous minutes: - ETCO2 ≥ 5 mmHg - Peak Inspiratory Pressure ≥ 5 cm

					H_2O - Tidal Volume Actual ≥ 100 ml Valid data: PIP between -40 and 100
Pre_Incision_Timeout_DT	First time when a pre-incision timeout recorded	Compliance – Preincision timeout	50198		
Induction_End_DT	Induction end time	Phenotype InductionEnd	50005	Mo/Day/Year HH:MM	
Surgical_Incision_DT	Surgical incision time	Phenotype SurgeryStart	50006	Mo/Day/Year HH:MM	
CPB_Start_First	First Cardiopulmonary Bypass Start Time	Phenotype Cardiopulmonary Bypass Start			
CPB_End_Last	Last Cardiopulmonary Bypass End Time	Phenotype Cardiopulmonary Bypass Ensd			
Surgical_Dressing_Complete_DT	End of surgical procedure	Phenotype SurgeryEnd	50007	Mo/Day/Year HH:MM	
Anesthesia_End_DT	Anesthesia end time	Phenotype AnesthesiaEnd	50009	Mo/Day/Year HH:MM	
Patient_Out_Of_Room_DT	Last date/time when patient transport from room documented for case	Phenotype PatientOutOfRoom		Mo/Day/Year HH:MM	
Ventilator_Start_ETCO2	ETCO2value at time when first ventilator data recorded	MPOG : Physiologic Observations : End Tidal CO2		Numeric	
Ventilator_End_DT	Last time when valid ventilator data recorded	MPOG : Physiologic Observations : End Tidal CO2,	3185	Mo/Day/Year HH:MM	Valid ventilator data if meets all 3 criteria ≥ 3 continuous minutes: - ETCO2 ≥ 5 mmHg

		Peak Inspiratory Pressure, Tidal Volume Actual			- Peak Inspiratory Pressure $\geq$ 5 cm H_2O - Tidal Volume Actual $\geq$ 100 ml Valid data: PIP between -40 and 100
Surgical_Duration	Minutes from procedure start to procedure end	Phenotype SurgeryDuration		Numeric	
Anesthesia_Duration	Minutes from anesthesia start to end	Phenotype --AnesthesiaDuration		Numeric	

Repeated Measures

Variable Name	Definition	Column or concept	Concept ID	Format	Notes
Anesthesia_Attending_ID					
Anesthesia_Attending_Sign_In	Sign-in time(s) for every anesthesia attending involved in case	Staffing Types – Anesthesia Attending	6000	Mo/Day/Year HH:MM	(May be 50168)
Anesthesia_Attending_Sign_Out	Sign-out time(s) for every anesthesia attending involved in case	Staffing Types – Anesthesia Attending	6000	Mo/Day/Year HH:MM	(May be 50167)

Segmentation of Surgical Cases using MPOG Data

see “Segments for Case – Sheet1.pdf”

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Technical Video Segments

Segment	Segment Start - MPOG Phenotype - existing	Segment End - MPOG Phenotype - existing	Segment Start - MPOG Concept - existing	Segment End - MPOG Concept - Existing	Segment Start - MPOG Phenotype - proposed	Segment End - MPOG Phenotype - proposed	Segment Start - MPOG Concept - Proposed	Segment End - MPOG Concept - Proposed
Incision to Sternotomy	Video Assessment	Video Assessment	50006	Video Assessment	Video Assessment	30 minutes prior to cardiopulmonary bypass start (phenotype) OR 15 minutes prior to cardiopulmonary bypass - arterial cannula inserted note (concept ID 50421) OR 15 minutes prior to cardiopulmonary bypass - blood pressure lowered note (concept ID 50424) OR 15 minutes prior to first heparin dose (concept ID 10211) (whichever is earlier)	2 minutes prior to incision (MPOG Concept 50006)	Video Assessment
Sternotomy to exposure of the heart	Video Assessment	Video Assessment	Video Assessment	Video Assessment	"Incision to Sternotomy" Segment End	"Cannulation for CPB" Segment Start	Video Assessment	Video Assessment
Harvest of the LIMA	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Harvest of SVG	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Cannulation for CPB	Video Assessment	Video Assessment	Video Assessment	Video Assessment	2 minutes prior to cardiopulmonary bypass - arterial cannula inserted note (concept ID 50421), if not present then 2 minutes prior to cardiopulmonary bypass - blood pressure lowered note (concept ID 50424), if not present then 3 minutes prior to first heparin dose (concept ID 10211), if not present then 30 minutes prior to cardiopulmonary bypass start (phenotype)	Cardiopulmonary Bypass Start (phenotype)	Video Assessment	Video Assessment
Performance of distal arterial anastomosis	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Performance of distal vein anastomosis	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Performance of proximal arterial anastomosis (free radial or IMA graft)	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Performance of proximal vein graft anastomosis	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Return to CPB for surgical reintervention (if applicable)	Video Assessment	Video Assessment	Video Assessment	Video Assessment	SBP-DBP<20 (MPOG Concept: 3030) or HR <=5 (MPOG Concept: 3005) ---AND--- RR<=2 (MPOG Concept: 3580) or EtCO2<=5 (MPOG Concepts: 3235, 3236) ---AND--- previous ending of cardiopulmonary bypass (new phenotype: "First cardiopulmonary bypass end")	"Decannulation from CPB" segment start	Video Assessment	Video Assessment
De-cannulation from CPB	Video Assessment	Video Assessment	Video Assessment	Video Assessment	10 minutes prior to last cardiopulmonary bypass end (currently existing phenotype) OR 10 minutes prior to protamine administered (MPOG concept ID 10381) Whichever is earlier	"Sternal Closure" segment start	Video Assessment	Video Assessment
Sternal closure	Video Assessment	Video Assessment	Video Assessment	Video Assessment	60 Minutes prior to Procedure Finish (MPOG concept ID 50007)	"Wound Closure" segment start	Video Assessment	Video Assessment

Non-Technical Video Segments

Segment								
Pre-induction verification	Video Assessment	Video Assessment	50301	Video Assessment	Video Assessment	Video Assessment	2 minutes prior to Compliance - Preinduction verification to confirm patient, procedure, site, and equipment (MPOG Concept ID 50301)	2 minutes after Compliance - Preinduction verification to confirm patient, procedure, site, and equipment (MPOG Concept ID 50301)
Pre-incision timeout	Video Assessment	Video Assessment	Video Assessment	Video Assessment	2 minutes prior to Compliance - Preincision timeout to re-confirm patient, procedure, and site (MPOG Concept ID 50198); if not available then 10 minutes prior to Procedure Start (MPOG concept ID 50006)	2 minutes after Compliance - Preincision timeout to re-confirm patient, procedure, and site (MPOG Concept ID 50198); if not available then Procedure Start (MPOG Concept ID 50006)	Video Assessment	Video Assessment
Sternotomy to exposure of the heart	Video Assessment	Video Assessment	Video Assessment	Video Assessment	"Incision to Sternotomy" Segment End	"Cannulation for CPB" Segment Start	Video Assessment	Video Assessment
Pre-bypass TEE assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment
Harvesting of conduit for operation	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment	Video Assessment

Technical Video Segments

Segment	Segment Start - MPOG Phenotype - existing	Segment End - MPOG Phenotype - existing	Segment Start - MPOG Concept - existing	Segment End - MPOG Concept - Existing		Segment Start - MPOG Phenotype - proposed	Segment End - MPOG Phenotype - proposed	Segment Start - MPOG Concept - Proposed	Segment End - MPOG Concept - Proposed	
Preparation and initiation of CPB	Video Assessment	Video Assessment	Video Assessment	Video Assessment		2 minutes prior to cardiopulmonary bypass - arterial cannula inserted note (concept ID 50421), if not present then 2 minutes prior to cardiopulmonary bypass - blood pressure lowered note (concept ID 50424), if not present then 3 minutes prior to first heparin dose (concept ID 10211), if not present then 30 minutes prior to cardiopulmonary bypass start (phenotype)	Cardiopulmonary Bypass Start (phenotype)	Video Assessment	Video Assessment	
Preparation and initiation of cardioplegic arrest	Video Assessment	Video Assessment	50428	Video Assessment		Video Assessment	Video Assessment	Cardiopulmonary bypass - cardioplegia start (MPOG concept ID 50428)	10 Minutes after Cardiopulmonary bypass - cardioplegia start (MPOG concept ID 50428)	
Performance of distal anastomosis	Video Assessment	Video Assessment	Video Assessment	Video Assessment		Video Assessment	Video Assessment	Video Assessment	Video Assessment	
Performance of proximal anastomosis	Video Assessment	Video Assessment	Video Assessment	Video Assessment		Video Assessment	Video Assessment	Video Assessment	Video Assessment	
Separation from CPB	Video Assessment	Video Assessment	Video Assessment	Video Assessment		5 Minutes prior to "First cardiopulmonary bypass end" (new phenotype)	Protamine started (MPOG Concept ID 10381) OR 15 minutes after "First cardiopulmonary bypass end" Whichever is earlier	Video Assessment	Video Assessment	
Return to CPB for surgical reintervention (if applicable)	Video Assessment	Video Assessment	Video Assessment	Video Assessment		SBP-DBP<20 (MPOG Concept: 3030) or HR <=5 (MPOG Concept: 3005) ---AND--- RR<=2 (MPOG Concept: 3580) or EtCO2<=5 (MPOG Concepts: 3235, 3236) ---AND--- previous ending of cardiopulmonary bypass (new phenotype: "First cardiopulmonary bypass end")	"Decannulation from CPB" segment start	Video Assessment	Video Assessment	
Post-procedural debrief	Video Assessment	Video Assessment	Video Assessment	Video Assessment		Video Assessment	Video Assessment	Video Assessment	Video Assessment	
Wound closure	Video Assessment	Video Assessment	Video Assessment	50007		Video Assessment	Video Assessment	30 Minutes prior to Procedure Finish (MPOG concept ID 50007)	Procedure Finish (MPOG Concept ID 50007)	