Comprehensive Cardiac Surgical Training: Individual to Team-Based Training

by

Abigail White

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Department of Surgery
University of Alberta

ABSTRACT

Simulation-based training is widely adopted amongst surgical specialties that have a minimally invasive approach such as laparoscopic surgery and predominantly open surgical specialties such as cardiac surgery remain in an apprenticeship model. The growing complexity of cases, scrutinized outcomes and increased focused on patient safety has changed the training environment. As a result, there is a growing body of evidence that suggests surgical trainees are ill prepared for independent practice by graduation.

Every educator knows the importance of simulation-based training, but because of small sample sizes, poor compliance with training programs and limited time and resources, simulation is not widely adopted amongst Canadian cardiac surgery programs. Based on an initial needs assessment we identified a desire amongst Canadian programs to use more simulation both in the context of training technical skills and nontechnical skills. The overarching purpose of this thesis research was to clarify the barriers to achieve independent practice and provide an example of a holistic approach to training, focusing on both technical and nontechnical elements of a surgeons.

To achieve the general research goals, we conducted semi-structured interviews of program directors in Canada (n = 9) and cardiac surgery trainees (n = 7). We used both a content and thematic analysis and identified that while the goal of surgical training should be an autonomous surgeon, we are producing competent, not autonomous surgeons. A recurring theme was the importance of nontechnical skills for an early

career surgeon but due to the constraints of present-day training, we do not effectively teach or assess those skills.

Identified in the needs assessment was the desire for more opportunities for home practice, specifically for coronary artery bypass and aortic valve replacement. To facilitate simulation-based training for technical skills, we developed a portable, adjustable, patient specific task trainer based off intraoperative patient measurements. We used a combination of 3D printing and silicone casting to replicate an aortic root and distal coronary artery. We evaluated the model for its educational value and functional task alignment using a group of novices (n = 5), intermediates (n = 4), and experts (n = 4). Applying Messick's framework of validity, we provided initial sources of evidence towards content, response process, internal structure, and relation to other variables. We identified that there was high functional task alignment, and high educational utility of our model.

To further delineate the educational value, we conducted a learning curve study with four junior cardiac surgery trainees. Using BORIS (Behavioral Observation Research Interactive Software), a video analysis program, we conducted both a subjective and objective assessment of their performance while completing a distal coronary anastomosis and an aortic valve replacement. We found that there was a statistical improvement in their performance using the subjective assessment, but on the objective assessment, their performance did not reach statistical significance for both the coronary model and aortic valve model.

The results from the needs assessment identified a need for non-technical skills training. Every surgeon knows, effective teamwork is critical to the success of an

operation. As mentioned previously, there is little focus on multidisciplinary team training in cardiac surgery. Using an immersive simulated operating room environment, we evaluated team communication using crisis scenarios. Video analysis was used to identify communication patterns and quality of communication. Each scenario consisted of a trigger where the task complexity increased. We evaluated communication pre and post trigger. We found that communication patterns differed amongst surgical team members and that communication pattern differed pre- and post-trigger. Surgical trainees were less likely to give a demand post trigger and were more likely to provide explanation and goal-sharing with team members. This is likely because of knowledge gaps and decreased confidence post-trigger. Identifying these knowledge gaps in a safe, simulated environment can help prepare trainees for the operating room. We also evaluated performance of the trainees using the NOTSS scale (nontechnical skills of a surgeon) and found that over the course of the simulation sessions, nontechnical skills improved. The thesis concludes with a summary of findings, explores the limitations of the work, and provides plans for the creation of a comprehensive training program nationally.

PREFACE

This thesis is an original work by Abigail White. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name “Patient Specific Simulators”, Study ID: Pro00103682, Date: September 4, 2020. Project Name “Cardiac Surgery Simulation Curriculum”, Study ID: Pro00102227, Date: July 21, 2020. Project Name: Autonomy in Cardiac Surgery”, Study ID: Pro00124265, Date: October 11, 2022, and Project Name “Cardiac surgical skills training: practice and cognitive improvement, Date: July 12, 2021.”

A version of chapter four was accepted for publication in the *Canadian Journal of Cardiology.* A. White, G. Singh, MC. Moon, B. Zheng, and SR Turner. Current status of simulation use in Canadian Cardiac Surgery Training Programs. I was responsible for design of survey data, data collection, composition, and revisions of the manuscripts. Co-authors reviewed surveys and were supervisory authors who assisted with revision of the manuscript.

A version of chapter five was accepted for publication in the *Annals of Thoracic Surgery.* A. White, D. O’Brien, G. Singh, B. Zheng, MC. Moon, SR. Turner. Characterizing the level of autonomy in Canadian Cardiac Surgery Residents. I was responsible for design of survey data, data collection, composition, and revisions of the manuscripts. Co-authors reviewed surveys and were supervisory authors who assisted with revision of the manuscript.

A version of chapter seven was accepted for publication in *Simulation in Healthcare.* A. White, SR. Turner, MC. Moon, B. Zheng. Assessment of a novel, adjustable task trainer for cardiac surgical skills. I was responsible for design of simulator, data collection, composition, and revisions of the manuscripts. MC. Moon provided input on the design of the simulator and remaining authors were supervisory authors who assisted with data analysis and revisions of the manuscript.

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LIST OF ABBREVIATIONS

3D	3-Dimensional
AVR	Aortic valve replacement
BID	Briefing, Intraoperative, Debriefing
BORIS	Behavioral Observation Interactive Software
CABG	Coronary artery bypass graft
CAM	Cognitive Apprenticeship Model
CBD	Competence-By-Design
CBME	Competency based medical education
CPB	Cardiopulmonary bypass
CT	Computed tomography
EPA	Entrustable professional activity
ETO	Educational Time-Out
GRS	Global rating scale
I6	Integrated-6
LAD	Left anterior descending
LoE	Level of evidence
LoR	Level of recommendation
MCS	Mechanical circulatory support
MVR	Mitral valve replacement
NOTSS	Nontechnical skills of a surgeon
OM	Obtuse marginal
OSATS	Objective structured assessment of technical skill
PDA	Posterior descending artery
PGY	Post graduate year
RCPSC	Royal College of Physicians and Surgeons of Canada
SMRI	Surgical Medical Research Institute
TPU	Thermoplastic polyurethane

CHAPTER ONE: INTRODUCTION

Chapter one provides the context and background for this thesis research. My personal thoughts on cardiac surgery training will be presented first, followed by an overview of cardiac surgery training in Canada, research objectives and thesis organization.

My personal thoughts

Many surgical specialties are moving away from the apprenticeship model of training and incorporating simulation into their training. As a cardiac surgery resident, I can say that our very open surgical specialty has remained in the apprenticeship model of training where formal simulation sessions occur on an infrequent basis. Cardiac surgery is a highly evidence based surgical specialty and there is a lack of evidence in the literature that says that simulation leads to better patient outcomes but there is an extensive amount of evidence that says simulation enhances performance. The lack of direct patient benefit, I believe contributes to the poor uptake of regular simulation practice within cardiac surgery programs. If we parallel our world to a professional athlete, everyone will agree that practice improves performance, but practice doesn't necessarily win games. No one would ever tell a professional team or athlete that they shouldn't practice because there's no direct causal relationship between practicing and winning. Practice has been identified as an essential component of expert performance, so why in surgery, is practice outside of the operating room not more routine (Ericsson, 2003)?

When I first started training, I was surprised by the lack of team-based training. If I can parallel our world again to professional sports, while there is a role for individual practice, to win a game requires the coordination and cooperation of the entire team working together. It begs the question of why in surgery do we only practice as individual practitioners when the successful operation is dependent on the coordination and cooperation of the entire team? As a trainee, going to the operating room is of course more exciting than practicing, but our patients deserve better than being our practice models. Surgical specialties are often compared to other high-risk industry such as aviation, but one of the major differences is that an error in aviation often also leads to the death of the pilot. An error in surgery, leads to the death of a patient but the surgeon walks away and for a lack of a better term, “harm free.” I often wonder if the risk ratio was the same for the surgeon and the patient, would we place more emphasize on preoperative practice. While my PhD focuses entirely on the use of simulation for the trainee, I believe that simulation is also for practicing surgeons. The true definition of an expert is an individual who constantly looks to improve (Ericsson, 2003), and my hope through my thesis and general sense of passion for simulation is that I can spark change in how we train not just surgeons of tomorrow but surgeons of today.

Cardiac surgery training pathways

Within North America there are different training pathways to become a board-certified cardiac surgeon. In Canada there is only one training pathway but in the United States there are three different paths you can take following completion of medical school to become a cardiac surgeon. In Canada, you complete six years of cardiac surgery training (Integrated 6-year (I6) program) directly following medical school. Historically, surgeons were trained as cardiothoracic and vascular surgeons in Canada, but now the Royal College of Physicians and Surgeons of Canada (RCPSC) recognize cardiac surgery, thoracic surgery, and vascular surgery as their own unique specialties (Bernard & Goldman, 2005). Vascular surgery and thoracic surgery became their own fellowships in 1986 and 1989 respectively, and in the 1990s the I6 training program was born and candidates from that point onward were only certified in cardiac surgery (Noly et al., 2017).

In the United States there are three different training pathways, (1) the traditional 5+2-3, (2) fast track (4+3) and (3) the integrated (I6) (Noly et al., 2017) . In the both the 5+2-3 years and fast track training pathways, the trainees complete general surgery training, before they complete a 2-3-year fellowship in thoracic surgery. In the past decade, the United States adopted a 6-year training program in cardiothoracic surgery directly from medical school (Noly et al., 2017), very similar to the Canadian system. It is because training pathways were shortened that prompted a shift from the apprenticeship model to a hybrid model incorporating simulation.

Traditionally in Canada to receive a certification in cardiac surgery one must meet all the objectives outlined in the speciality training requirements document by the Royal College of Physicians and Surgeons of Canada. This involves successful completion of the Royal College Surgical Foundations curriculum and exam, successful completion of specialty training requirements, successful completion of the certification examination and successful completion of a scholarly project (Royal College of Physicians and Surgeons of Canada, 2013). The specialty training requirements are a series of competencies and objectives that are expected to be met on various rotations completed during residency. Trainees are given a formative and a summative evaluation at the completion of a rotation, but there is no official documentation of what the trainee has done intraoperatively. Today, as part of the global initiative for *competency-based medical education* (CBME), the Royal College of Physicians and Surgeons of Canada (RCPSC) has recently transitioned to Competence-By-Design (CBD).

CBD aims to equip surgical trainees with specific competencies, allowing for the objective documentation of requisite surgical procedures and their component steps through discrete learning objectives called Entrustable Professional Activities (EPAs) (*Entrustable Professional Activities for Cardiac Surgery,* 2021). EPAs are scored on a Likert scale of 1-5, with 1 being the lowest score and 5 being the goal at the end of residency. (Table 1.1)

EPA	Definition
1	I had to do it
2	I had to talk them through
3	I had to prompt them from time to time
4	I needed to be there in the room just in case
5	I did not need to be there

Table 1.1: EPA definitions as defined by the Royal College of Physicians and Surgeons of Canada.

The objective of CBD is to ensure that the physicians graduating today are graduating with the competencies that were previously laid out in the traditional training model. Dr. Erin Wright, a member of the Royal College Specialty Committee claims that what trainees are expected to learn and know now is much more than traditionally expected (Wright, 2020). The new CBD curriculum breaks down the specialty training requirements in cardiac surgery and requires that trainees are observed performing a pre-specified number of repetitions and more importantly that the trainee is competent in the task.

Transition to Practice EPAs

The *transition to practice* year (TTP) is the final stage of training and is meant to be completed after the successful completion of the RCPSC cardiac surgery exam. This thesis will refer to two specific EPAs as they are related to both chapter five and six. TTP EPA #3 is *performing the breadth of core Cardiac Surgery procedures as the primary surgeon*.

EPA	Listed Procedures
#3 Performing the breadth of **core** Cardiac Surgery procedures as the primary surgeon	Coronary artery bypass grafting (CABG), aortic valve replacement (AVR), mitral valve replacement (MVR), mitral annuloplasty, resection of atrial myxoma, ascending aorta surgery, simple redo sternotomy, chest re-opening (post-op bleed or tamponade) and sternal re-wiring
#4 is Performing **advanced** cardiac surgery procedures with an experienced assistant	Aortic dissection, Bentall, emergency CABG, reoperations, simple mitral valve repair and a transcatheter valve replacement

Table 1.2: Listed procedures for the transition to practice year EPA #3 and #4.

There are subtle differences between the two EPAs as it pertains to complexity of procedure. In EPA #4, it specifies that the trainee is expected to do the procedure with an experienced assistant and minor prompting is permitted. Most surgical specialties would assume that the experienced assistant is in fact the surgeon.

Gaps in our Knowledge

There is a growing body of evidence that surgical trainees are currently graduating ill prepared for independent practice. Surgical training within cardiac surgery remains in an apprenticeship model of training and there exists a gap in the optimal approach to provide comprehensive training to cardiac surgery trainees from both an individual and team performance level.

How will this study aim to fill those gaps?

The overarching objective of this thesis was to provide a comprehensive approach to cardiac surgical training, starting with a needs assessment on the current state of training. Both quantitative (survey) and qualitative (interview) methodology were used to conduct the needs assessment. The results of the needs assessment dictated the need for simulation-based training focusing on both technical skills and non-technical skills of a surgeon. Two different simulation models were designed, tested, and implemented into practice to provide examples on how to conduct simulation-based training. A diagram of the overall structure of the thesis can be found in Figure 1.1.

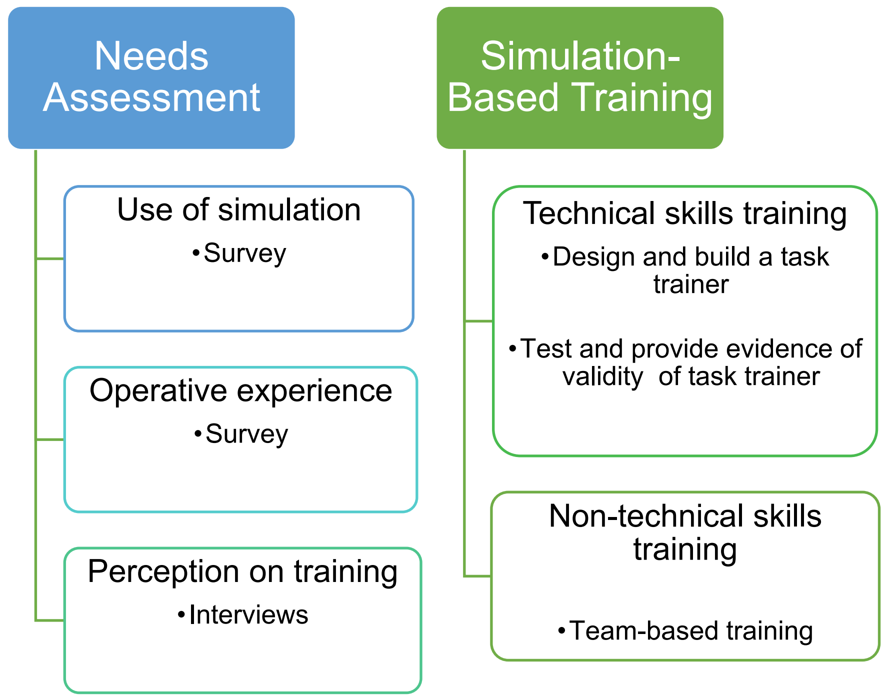


Figure 1.1: Overview of the objectives and key methodology used to achieve each objective.

Objective 1: To characterize the current state of simulation use and operative experience in Canadian cardiac surgery centers.

There is a paucity in the literature on Canadian use of simulation and operative experience of surgical trainees. Through the conduction of two nationwide surveys, staff surgeons and trainees will be asked about the current use of simulation at their centers and trainees will be asked about their operative experience to characterize the current state of training.

Objective 2: Using a qualitative analysis, explore the attitudes and perspective of cardiac surgery trainees and faculty on competency and autonomy.

We aim to characterize and explore whether there is a discrepancy amongst trainees and faculty surgeons regarding their attitudes towards training to help us identify challenges, barriers, and areas of improvement. To achieve this objective, semistructured interviews will be conducted with program directors and cardiac surgery residents from each cardiac surgery program in Canada.

Objective 3: To develop a task trainer with functional task alignment for coronary artery bypass and aortic valve replacement using intraoperative patient measurements.

As a result of the needs assessment, CABG and AVR were identified as desirable procedures for home practice. Measurements will be taken in the operating room to reflect the intraoperative constraints of the mediastinum when performing a CABG and AVR. 3D printing will be used to build the aortic root and coronary anatomy to develop a realistic model and then based on the intraoperative measurements a mediastinum will be created to represent different exposures of the aortic valve and coronary arteries.

Objective 4: To provide initial sources of validity evidence for the novel task trainer and evaluate its educational utility.

Before the introduction of any educational tool, it should undergo a rigorous process of validation. Messick's framework of validity will be applied, followed by a learning curve study.

Objective 5: To design and implement a team-based training model to train nontechnical skills in cardiac surgery.

Residency training focuses predominantly on technical skills training, but nontechnical skills (NOTSS) of a surgeon are essential for a successful patient outcome. Nontechnical skills are under trained and under assessed during cardiac surgery residency training. To provide a comprehensive approach to training, a fully immersive simulation environment will be created to allow for team-based training.

CHAPTER TWO: HISTORY OF SIMULATION, A LITERATURE REVIEW

History of simulation in medicine

Simulation is a tool that has existed in medicine for centuries with benchtop models, animals, and human cadaver models (Badash et al., 2016). The original purpose of simulation included learning human anatomy, studying disease pathology and experimentation to practice procedures. Advancing simulator technology in healthcare only started to gain way since the 1950s, when an anesthesiologist developed a mannikin to teach airway and resuscitative skills called “Resusci Anne” (Okuda et al., 2009). Overtime the mannikin has evolved to a fully functioning computer-controlled patient capable of replicating the human response to physiological and pharmacological interactions, which have only continued to improve (Okuda et al., 2009).

Simulation is an educational adjunct; it is not a replacement for real-world experiences. The goal of simulation is to replicate patient care scenarios in a realistic environment to allow for repeated practice, assessment, and feedback (Okuda et al., 2009). Gaba (2004) stated “simulation is a technique – not a technology – to replace or amplify real experiences that evoke or replicate substantial aspects of the real world in a fully interactive manner”. His focus was to emphasize the use of simulation to enhance patient’s safety, not just at an individual trainee’s level but at a systems-based level (Gaba, 2004).

A meta-analysis of over 600 studies and over 35000 trainees, including randomized studies demonstrated that compared to no intervention, technology-enhanced simulation consistently demonstrated improvements in knowledge outcomes, skills and behaviors and more moderate effects for patient-related outcomes (Cook et al., 2011). Only 4% of the included studies failed to demonstrate a benefit. There was a wide range of participants including medical students, residents, nurses, dentists, veterinarians etc. as well as a wide range of clinical topics from minimally invasive surgery, endoscopic procedures to full resuscitation/trauma training (Cook et al., 2011). Providing sufficient evidence and support that simulation-based training is beneficial.

Okuda et al. (2009) emphasized 10 features of simulations that contribute to effective learning: 1) repetitive practice, 2) integrated into a curriculum, 3) ability to alter degree of difficulty, 4) ability to capture clinical variation, 5) ability to practice in a controlled environment, 6) individualized, active learning, 7) adaptability to multiple learning strategies, 8) tangible/measurable outcomes, 9) use of intra-experience feedback and 10) validity of simulation as an approximation of clinical practice (Okuda et al., 2009). Many of these features are currently lacking in cardiac surgery simulation and will be explored further in this thesis.

In summary there is a general agreement that simulation as a learning tool/educational adjunct is of benefit to health care professionals. It allows the learner to practice patient care at their own pace away from the bedside. The question remains about why there is not a widespread adoption of simulation use in surgical specialties such as cardiac surgery.

History of simulation in surgery

Compared to medicine, simulation within surgical specialties has been less widely adopted until the last decade (Raemer, 2009). Traditionally surgical residents have been trained under the “apprenticeship” model whereby trainees learned by spending hours in the operating room observing preceptors and performing certain tasks of the operation on real patients (Baker et al., 2012). Since the early 2000's there has been a shift in how surgical residents are trained with a hybrid approach incorporating simulation (Raemer, 2009). This shift in training has occurred in direct response to current challenges such as resident hour restrictions, increase in focus on patient safety, growing complexity of cases and surgical innovation (Badash et al., 2016; Baker et al., 2012; Feins et al., 2017a; Raemer, 2009). As mentioned previously there is a concern that with the addition of shorter training programs in the United States, there will be younger, less-experienced learners entering the cardiothoracic program leading to fewer skills being mastered by graduation (Baker et al., 2012).

Skill Transferability

There is an inherent assumption that simulation-based training lends to transferable skills to the operating room, yet few studies have been able to demonstrate a correlation between simulation performance and surgical performance. A systematic review of all-comer surgical simulation compared to no simulation-based training by Sutherland et al. in 2006 identified 30 randomized control trials with over 700 participants. Their review focused on whether surgical simulation was effective at improving performance by looking at construct validity, which is that the simulator measures the skill it is designed to measure and the ultimate validation that simulation-based training has a positive influence on patient outcomes (Sutherland et al., 2006). The results of their review failed to demonstrate that simulation was better than traditional forms of surgical training, arguments being low-powered studies with small sample sizes and a failure to use validated simulator systems. None of the studies identified in their systematic review involved cardiac surgery (Sutherland et al., 2006). In

2008 a systematic review by Sturm et al. was conducted looking specifically at skill transfer to the operating room. They identified 10 randomized control trials and looked at overall performance, performance time, ability to complete procedure, senior supervising surgeon takeover, performance error, flow of procedure, time and motion, staff productivity, patient discomfort, and confidence of learner post simulation-based training as their outcomes (Sturm et al., 2008). Procedures included in the study were endoscopy, sigmoidoscopy, colonoscopy and laparoscopic procedures like an appendectomy and cholecystectomy (Sturm et al., 2008). Their results were more favorable compared to the results from Sutherland et a. (2006), in that learner who received simulation-based training before undergoing patient-based assessment performed better than learners who had not received the training. This improvement was not seen over all measured performance parameters, but the studies may have been underpowered with < 20 participants in each study (Sturm et al., 2008).

Over the years research around surgical simulation-based training has become more robust and Dawe et al. (2014) published a systematic review that strengthened the evidence for simulation-based training in surgery (Dawe et al., 2014). Their systematic review consisted of a total of 34 studies, 27 randomized trials and 7 non-randomized studies. Majority of the studies focused on laparoscopic procedures, including the following specialties: general surgery, obstetrics and gynecology, otolaryngology, and urology. Other procedures investigated including arthroscopy, open abdominal fascial closure, cardiac catheterization, femoral artery angioplasty and cataract surgery (Dawe et al., 2014). Outcome measures included overall performance based on global rating scales for the individual specialty, performance time, success rate (defined as percentage of participants able to complete the patient-based assessment, the number of participants able to complete the case independently without assistance from the supervising surgeon), performance errors, and patient discomfort. The overall conclusion of their review supported simulation-based training over no training. Only 5 out of the identified studies demonstrated no better performance over their peers who had not received any simulation-based training (Dawe et al., 2014). The heterogeneity seen in the review allowed the authors to evaluate a more general concept of skill transfer across a variety of settings and using a variety of different assessment tools (Dawe et al., 2014). However, key elements involved in the ability to assess skill transfer successfully involves the simulator design and functionality, the way the simulators are used, prelearning, learning style, feedback, and opportunities for reinforcement of learning (Dawe et al., 2014). Caution must be used when evaluating the results of such a review because of the variation in how simulation-based training was used. Specifically, variation seen amongst studies in the duration and intensity of simulation-based training (Dawe et al., 2014). An important concept in simulation research is having a very clear predefined set of educational objectives and measure of proficiency. Simulation alone does not guarantee learning to occur.

There is certainly a growing body of literature to support the use of simulation-training in surgery. Over the years better design and better understanding of how to use the tools for effective learning continue to develop. This body of literature does not exist within the realm of cardiac surgery possibly because the nature of operations does not allow for cost-effective, easily reproducible simulation-based training. There is also a paucity in Canadian literature surrounding the use of surgical simulation within Canadian training programs.

Simulation within Cardiac Surgery

Now that we've looked at simulation use within medicine and surgery, let us look more closely at simulation use within cardiac surgery. We will take a closer look at the use of simulation in the context of cardiopulmonary bypass, aortic valve replacement and coronary artery bypass grafting, as they are more relevant for the remainder of the thesis.

Cardiac Surgery Simulation Curriculum

Baker et al. (2012) applied the steps of formal curriculum development to implement a comprehensive cardiac surgery training program. They started with a needs assessment and then the top identified skills were organized into 12 monthly modules. Broad educational objectives and specific measurable objectives were created for each module identified (Baker et al., 2012). The modules were (1) anastomosis, (2) basic skills, (3) aortic valve, (4) mitral valve replacement and surgical management of atrial fibrillation, (5) Mitral valve repair and tricuspid valve repair, (6) aortic dissection, (7) minimally invasive valve surgery, (8) aortic root replacement, (9) valve sparing root, (10) endoscopic vein harvest, (11) left ventricular assist device insertion, and (12) cardiopulmonary bypass (Baker et al., 2012). Many of the simulators used were from the Chamberlain group but a combination of inanimate, animate, and cadaveric models was used. Although the experiences were overwhelmingly positive from the trainees based on a resident satisfaction survey the biggest critique would be a lack of specific assessment tools of learner performance. The trainees were evaluated on a perceived competency scale rather than an objective structured assessment (Baker et al., 2012).

A very key group in the promotion and development of a cardiac surgery simulation curriculum is a consortium of six hospitals in the United States (Massachusetts General Hospital, University of North Carolina Chapel Hill, Johns Hopkins, University of Rochester, Stanford University, Vanderbilt University and University of Washington). This group put together a 7-week syllabus focusing on component task training of cardiopulmonary bypass, coronary artery bypass grafting and aortic valve replacement (Feins et al., 2017). As the trainee developed competency, they were advanced to the next step. The final step was conduction of cardiopulmonary bypass, completion of coronary artery bypass grafting and an aortic valve replacement. Building on the competencies achieved by the trainees, they then completed simulation-based training for three adverse intraoperative events; massive air embolism, acute intraoperative aortic dissection, and sudden deterioration in cardiac function (Feins et al., 2017). The strength of their curriculum is for each task they developed a corresponding objective structured assessments of technical skills (OSATS) tool for trainee assessment (Feins et al., 2017).They were able to demonstrate a clear relationship between repetition of a task and improvement in performance. A limitation of their study was it was only designed to look at a level two on Kirkpatrick's model. The next step would be to see if their formal simulation curriculum leads to transferability of skill in the operating room and/or impacts patient outcomes (Kirkpatrick level three and four).

The papers by Baker et al. (2012) and Feins et al. (2017) were highlighted in this thesis as they are two groups that attempted to formalize simulation as part of a cardiac surgery curriculum. It is unclear in the literature whether either of their curriculums have been maintained at their respective programs or adopted by other programs.

Use of Simulation in Common Cardiac Surgical Procedures

As stated previously, we will focus more on simulation as it relates to cardiopulmonary bypass, coronary artery bypass grafting (CABG) and aortic valve replacement (AVR) as they are relevant to this thesis work.

Cardiopulmonary Bypass Simulation

Conduct of cardiopulmonary bypass (CPB) is a fundamental skill of all cardiac surgeons. Not only does placing a patient on cardiopulmonary bypass involve a technical component, but it also more importantly involves the nontechnical skills of a surgeon. It involves the interaction between the (1) surgeon (2) anesthesiologist and (3) perfusionist.

One of the first CPB simulators was developed by Ramphal et al. (2005) and it is the most widely used CPB simulator by cardiac surgical programs. Not only does it allow for conduction of CPB, but it allows conduction of full cardiac operations using an explanted porcine heart connected to pressurized tubing. The Ramphal simulator is considered a “high-fidelity” simulator that exists within cardiac surgery (Ramphal et al., 2005). The simulator allows for trainees to respond to either pre-programmed or spontaneous changes in environment, like they would in the operating room. The barriers to its widespread adoption include cost, time and effort by the individuals involved in the simulation.

The “Orpheus” cardiopulmonary bypass simulation system by Morris et al. (2007) was developed for perfusionists. It is a primed circuit connected to an arterio-venous loop (Morris et al., 2007). It allows for manipulation of variables so that the trainee is required to trouble shoot. Hicks et al. (2011) used the Orpheus simulator at a cardiac surgery boot camp conducted in the United States. The trainees were assessed using an OSATS tool with overall pass/fail being assigned based on whether an error was a major deficiency (would result in a poor clinical outcome) or a minor deficiency (would not result in a serious morbidity) (Hicks et al., 2011). At the termination of the session trainees were all considered to have “demonstrated competence” but with room for improvement as very few performed all tasks correctly. The group concluded that technical skills and knowledge of CPB can be simulated but the need for assessment of nontechnical skills such as situational awareness, decision making, communication, teamwork, and leadership was lacking (Hicks et al., 2011).

In summary the Orpheus simulator and Ramphal simulator are the two most popular CPB simulators in Cardiac Surgery. They are both considered “high-fidelity” which means there is significant cost and time commitment devoted to their successful implementation. A major gap in CPB simulation is evaluating nontechnical skills of the trainee and team-based training.

Coronary Artery Bypass

Coronary artery bypass (CABG) is the most common operation performed by cardiac surgeons annually. It is therefore one of the most fundamental skills for a cardiac surgery trainee to develop. Many simulators exist from anastomotic task trainers to the conduction of an anastomosis on a beating heart using the Ramphal simulator

(Yanagawa et al., 2019). The essential component of coronary artery bypass is the ability of a trainee to perform an anastomosis. Fann et al. (2008), Fann et al. (2010), Spratt et al. (2019) are all examples of studies that used coronary simulators in the context of a home curriculum (Fann et al., 2008, 2010; Spratt et al., 2019). All these studies involve randomization of their participants to either receive a simulator for practice or not. Fann et al. (2008) was able to demonstrate that home practice with an anastomotic simulator decreased the time to complete an anastomosis on all-comer trainees. None of the studies identified transferability of skill or were designed to assess for transferability of skill to the operating room.

Aortic Valve Replacement

Aortic valve replacement (AVR) is the most common valve procedure conducted by cardiac surgeons annually. Like coronary artery bypass, performing an aortic valve replacement can be simulated by using task trainers such as a benchtop porcine model to conducting a full AVR using the Ramphal simulator (Baker et al., 2012; Feins et al., 2017; Ramphal et al., 2005). Said (2015) published an example of a very minimalistic, low structure fidelity aortic root simulator to focus on the very task of placing annular sutures, a fundamental component of aortic valve replacement (Said, 2015). This simulator has not been validated as an effective training tool but demonstrates a solution to barriers previously discussed which are cost and time associated with trying to conduct a high-structural fidelity simulation.

Russo et al. (2020) developed a very advanced three-dimensional simulation model for aortic valve and proximal aortic procedures by 3D printing. They recreated six different models of the aortic root and proximal aorta using known anatomical characteristics. The simulator was validated by a group of surgeons and unanimously was felt to be an adequate model (Russo et al., 2020). Further steps would be to evaluate the simulator as an effective training tool, by conducting a learning curve study.

Shortcomings

Coronary artery bypass simulators and aortic valve simulators are abundant. Many groups continue to look at CABG and AVR but fail to design studies that achieve higher than level 2 on Kirkpatrick's model. As stated previously the ability to conduct a coronary artery bypass and aortic valve replacement at the time of graduation are fundamental as they are the two most common cardiac surgical procedures performed per year. The question becomes what are the current simulators missing? Number 1: While a multitude of simulators exist, there are few that have undergone rigorous testing for validity (Trehan et al., 2014).

Number 2: Consideration should be given to the amount of simulation use, if simulation is infrequently, it may not be effective. The Ramphal simulator is a very resource intensive simulator, allowing trainees to practice full operations on cardiopulmonary bypass (Ramphal et al., 2005). The challenging aspect is availability and access for trainees. To run a Ramphal simulation takes a team, dedicated simulation facility and is expensive. Porcine heart models used for aortic valve replacement are also cumbersome for trainees as porcine hearts as well as training valves are not readily available for trainees. The coronary task trainers are very portable, very available, and relatively inexpensive but fail to provide functional task alignment. Misconceptions surrounding fidelity will be discussed in chapter three.

Loor et al. (2016) was one of the first groups to design a low structural fidelity but high functional fidelity simulator by attempting to mimic the obstacles (space constraints and depth) that are associated with operating in the exposed mediastinum. Their measurements came from preoperative computed tomography (CT) measurements (Loor et al., 2016). They built a model for cannulation, coronary anastomosis, aortic graft replacement and aortic valve replacement. Key measurements they took from the CT scans were distance from skin to vertebrae (depth), mid clavicular to mid clavicular (box width), skin to the aortic valve annulus (aortic valve depth) and skin to coronary artery (coronary depth) (Loor et al., 2016). What they did not consider is how the skin incision changes the operative environment and how all the materials to put a patient on cardiopulmonary bypass modifies the space available in the chest when conducting a coronary artery bypass and aortic valve replacement.

Number 3: A third consideration should be that the current task trainers that are readily available to use may not be appropriate for varying trainee level (Ryu et al., 2017). Ideal simulators should be adjustable or modifiable so that they allow the trainee to function at their skill level. A major limitation of the current simulators is the so-called “plateau-effect” or “ceiling effect” for trainees, which is the inability to advance their learning curve beyond basic technical skills (Ryu et al., 2017).

In summary, an ideal simulator should be available, adjustable, and patient specific to allow for distributed, deliberate practice of trainees. Patient specific simulators will be discussed next but could range from using intraoperative patient measurements that reflect the operative constraints to virtual reality simulators. Simulation-based training within cardiac surgery is still a relatively novel topic. The major challenges surrounding widespread adoption are cost and time commitment with little to no evidence to confirm that the skills learned in the simulated environment are transferrable to clinical practice.

Lessons Learned

Surgical simulation research has become more and more robust with some studies beginning to demonstrate transferability of skill to the operating room or in other words above a level two on Kirkpatrick's Model. This body of literature does not exist within cardiac surgery with majority of the research focusing on development of simulators rather than evaluation of the simulator as effective training tools. Simulation is most successful as a training tool when it is used with deliberate practice and distributed practice. Given the number of task trainers simulators that exist within cardiac surgery one likely does not need to continue reinventing the wheel but rather build on what is already available. Future research should be directed on enhancing the state of current simulators by creating adjustable simulators to compensate for the identified "ceiling effect" and patient specific simulators.

With technological advances, complex surgeries with unique, patient-specific anatomical variations and disease pathology can be replicated (Badash et al., 2016). Advances include 3D rapid prototyping, and patient-specific virtual reality (Badash et al., 2016; Ryu et al., 2017). A modifiable simulator capable of increasing complexity would eliminate costs of needing a different device for each level of training.

Anatomically accurate virtual reality simulations with patient-specific anatomy provide an opportunity for preoperative rehearsal (Badash et al., 2016). Such technology is already available for specific procedures in general surgery, urology, and plastic surgery (Endo et al., 2014; Eschweiler et al., 2016; Makiyama et al., 2015), and would be invaluable in congenital heart surgery, for complex adult cases, and in crisis management scenarios involving cardiopulmonary bypass. As case complexity in cardiac surgery increases, it is paramount that programs examine innovative tools, including simulation, to bridge operating room training gaps.

CHAPTER THREE SIMULATION-BASED TRAINING

Key Components of Simulation-Based Training

The previous chapter highlighted the history of simulation in both medicine and surgery and placed the foundation for why simulation is an essential educational adjunct in training today. The following chapter will explore the key features of simulation, beginning with a learning theory of why simulation works, a discussion of the cognitive apprenticeship model, followed by the concept of deliberate practice, misconceptions surrounding simulator fidelity, and commonly used performance parameters. The following features: (1) repeated practice for technical proficiency, (2) expert assistance and feedback, (3) learning within a professional context, and (4) simulation as an educational adjunct, were also highlighted previously as being important components of simulation-based learning (Kneebone, 2005).

Kolb Experiential Learning Cycle

The experiential learning cycle developed by Kolb is a constructivist theory that explains how simulation fits into learning. It is a 4-part learning process that occurs on a continuous cycle including: concrete experience, reflective observation, abstract conceptualization, and active experimentation (Kolb, 1984). Using simulation as an example, the new skill learnt in the simulation session would be considered a concrete experience for the trainee. The moderator would provide an assessment and feedback of the trainee allowing (reflective observation). The trainee should then consider how to improve their performance based on the reflective observation provided (abstract conceptualization). They will then actively experiment using the simulator during the simulation session on how they can apply the modifications, and the process repeats (Carter et al., 2005; Kolb, 1984).

Cognitive Apprenticeship Model

The apprenticeship model of training to this point has been discussed as being a suboptimal training method. Within the apprenticeship model, the trainees (apprentices) learn by observing experts who have mastered a particular task and by performing variations of the task adjusted to their level (Collins & Kapur, 2014; Lajoie, 2010). The apprenticeship model allows for an individual to learn a concrete skill within a specific context. The limitation of the apprenticeship model is that the cognitive skills behind the concrete activity are not observable. This led to the creation of the cognitive apprenticeship model (CAM), which is a framework that places emphasis on the process behind developing the skill, rather than a demonstration of the skill (Collins & Kapur, 2014; Lajoie, 2010). In the example of surgery, this would involve the surgeon providing an explanation and rationale for what they are doing while they are doing it.

There are six key instructional strategies involved in CAM and using surgery as an example, they will be explained (Collins & Kapur, 2014; Lajoie, 2010).

1. Modelling – surgeon demonstrates a task communicating their reasoning behind the task.
2. Coaching – surgeon observes the trainee performing the modelled task and provides feedback.
3. Scaffolding – surgeon gives the trainee tasks of increasing difficulty. The difficulty of the task is increased when less guidance (fading) must be given to the trainee.
4. Reflection – the trainee self-assesses their performance.

5. Articulation – the trainee verbalizes their reflections of their performance with the surgeon.
6. Exploration – the trainee is responsible for exploring beyond what was shown to them by the surgeon.

While CAM is certainly an improvement compared to the traditional apprenticeship model, it is not readily adopted in the operating room. Principles of CAM are certainly naturally present in simulation-based training.

Deliberate Practice

Anders Ericsson was a cognitive psychologist whose career explored the concept of *peak performance*. Ericsson (2013) states that "nobody becomes an outstanding professional without experience, but extensive experience does not invariably lead people to become experts." He introduced the concept of 10,000 hours of deliberate practice is required for any performer to achieve an elite status (Ericsson, 2003). The concept of *deliberate practice*, which is continued practice focused on a defined task with specific coaching and feedback on performance (Ericsson, 2003; Fann et al., 2010). Deliberate practice has 4 core components, (1) identification of a specific goal(s) for performance improvement, (2) intense focus, (3) immediate feedback by an expert and (4) increasing task complexity (Rowse & Dearani, 2019). Being able to adjust the simulation to trainees' level of experience is a very important component of simulation-based training and deliberate practice. For example, if the outcome is performance improvement on a simulator, then a trainee who already performs very highly in the pre-test may not perform better on the post-test after practicing on the simulator. This is referred to as a "plateau effect" (Fann et al., 2008; Rowse & Dearani, 2019). A *ceiling effect* is recognizing the limitation of the simulator itself to improve a trainee's performance. For example, a partial task trainer may be more appropriate for a junior trainee than a senior trainee who has already mastered the partial task trainer and is completing entire procedures intraoperatively (Fann et al., 2008; Rowse & Dearani, 2019).

Studies have also looked at what kind of "deliberate practice makes perfect?" (Rowse & Dearani, 2019). There are two different training strategies, "massed practice" and "distributed practice". Massed practice refers to practice that is delivered in continuous blocks of time with minimal or no break in between. For example, a surgical bootcamp would be classified as massed practice. Distributed practice refers to practice that is spread over periods of time with breaks in between. Within fields of psychology and athletics there is evidence that distributed practice is favored over massed practice in terms of motor skill acquisition and retention ((Donovan & Radosevich, 1999; Lee & Genovese, 1989; Moulton et al., 2006; Schmidt & Bjork, 1992). Moulton et al. (2006) compared distributed practice to massed practice on the ability of junior trainees to perform a microvascular anastomosis. Although both groups demonstrated improvement in microvascular anastomotic skill from pre-test to post-test, the individuals in the distributed practice performed significantly better on retention testing and specific outcomes measures such as number of hand movements, time, and global ratings (Moulton et al., 2006). This supports the concept that for simulation to be an effective learning tool it needs to become part of the surgical curriculum, so that it will occur more frequently.

In summary deliberate practice is a key and fundamental element of a successful simulation-based training program. Distributed practice and expert coaching are crucial and make universal implementation of a simulation-based training program more of a challenge as it is costly both monetarily and timely by those implementing the program(Rowse & Dearani, 2019) .

Simulator Fidelity

Another key concept to review around simulation is fidelity, which refers to the closeness of the model to reality (Munshi et al., 2015). Fidelity is often classified as high versus low fidelity, but this dichotomy of terms is oversimplified. Traditionally, “low fidelity” simulators allow for practice of individual skills and techniques, in other words they are component task trainers (Badash et al., 2016; Ribeiro et al., 2018). “High-fidelity” simulators are ones that integrate technical skills with hemodynamics, allow for crisis management, and team training and have the potential to replicate an entire surgery with a high degree of realism (Badash et al., 2016; Ribeiro et al., 2018). Both types of simulation have their role in training and neither fidelity has been shown to be superior to the other if the simulator is used within its scope (Dawe et al., 2014; Fann et al., 2012; Ribeiro et al., 2018). Low fidelity simulators are cheaper, less resource intensive and allow for quick, repetitive practice of a technical skill. High-fidelity simulators are very resource intensive, generally more expensive and are not easily reproducible unless an infrastructure exists within a program that supports simulation (Badash et al., 2016). High fidelity simulators are often confined to a small number of specialized centers, which as previously stated is costly but more importantly not available to all (Kneebone et al., 2010).

In this thesis, we move away from the dichotomous terms of high vs. low fidelity and focus on functional alignment. The misconception surrounding the term fidelity, which is that a higher fidelity model is superior to a lower fidelity model is often because individuals oversimplify fidelity as referring to the physical resemblance of the model. The more important question to ask is does the model allow for successful completion of the assigned objectives (Hamstra et al., 2014). Cook et al. (2013) conducted a review looking at technology-enhanced simulation in health professions education and attempted to classify simulation-based interventions as high or low fidelity. They found that there was a large amount of variation in how the same simulation technology was defined depending on what features of the simulator were emphasized by the authors (Cook et al., 2013). For example, mannikins used by anesthesia are more often considered high fidelity, versus surgeons view cadavers or animal models as having a higher fidelity than mannikins to simulate surgery (Cook et al., 2013; Hamstra et al., 2014). Hamstra et al. (2014)'s recommendation is to abandon the term fidelity altogether, and instead of using the term *structural fidelity*, refer to a simulators' physical resemblance and instead of the term *functional fidelity,* use functional task alignment.

A common misconception is that a simulators physical resemblance correlates with educational effectiveness but there is no evidence to support it (Beaubien & Baker, 2004; Grober et al., 2004; Hamstra et al., 2014a). As a result, an additional recommendation from Hamstra et al. (2014) is to focus on functional task alignment of the simulator and less on physical resemblance of the simulator. Functional task alignment focuses on the simulator's functional properties with the functional task requirements (Hamstra et al., 2014). For example, while using a synthetic task trainer, traditionally felt to be a low fidelity model, could have the functionality enhanced by having a surgical trainee wear surgical gloves and loupes.

Assessment and Feedback

Another very important aspect of simulation-based training that is often missing is assessment and feedback. There are a multitude of different performance measures such as performance time, performance error, global rating scales, procedure specific rating scales, and patient comfort. The operational definitions of outcomes are important for authors to define, and the same performance parameter may differ between studies. With respect to global ratings scales, the most validated tool within surgical simulation is modified versions of the *Objective Structured Assessment of Technical Skills* (OSATS) (Faulkner et al., 1996; Martin et al., 1997; Reznick et al., 1997; Vaidya et al., 2020). It was first used at the University of Toronto in the 1990s. It consists of two components: an operation-specific checklist and a global rating scale (Niitsu et al., 2013). The operation-specific checklist is tailored according to the procedure being assessed. For example, if assessing a coronary anastomosis, the scale would include an assessment of the arteriotomy, graft orientation, appropriate bites, appropriate spacing, use of instruments, needle angles, need transfer and suture management/tension (Feins et al., 2017). The components of the global rating scale can be applied to any procedure and include (1) respect for tissue, (2) time and motion, (3) instrument handling, (4) knowledge of instruments, (5) flow of operation, (6) use of assistants and (7) knowledge of specific procedure (Niitsu et al., 2013). For both the operative checklist and the global rating scale the learner is evaluated on a 5-point Likert scale. Criticisms of subjective assessment tools include rater variation and so when conducting simulation research, it is important to have very clear definitions of what constitutes a 1/5 versus 5/5 before an assessor participates, this is called rater training. This can often be accomplished by having the evaluators watch a video describing what would be considered a 5/5 (Niitsu et al., 2013). Vaidya et al. (2020) conducted a systematic review looking at the various technical skills assessment tools in surgery. They used the Modified Educational Oxford Centre for Evidence-Based Medicine *Level of Evidence* (LoE) and *Level of Recommendation* (LoR) classification system to rate each study (Vaidya et al., 2020). Level 1 is the highest recommendation and level 4 is the lowest. In their review the only tool with a level 1 recommendation was the OSATS tool.

The other component of assessment and feedback is the evaluation of the training session itself. Part of implementing a training program is assessing the impact and whether it is achieving their desired outcomes (Heydari et al., 2019). One method commonly used to evaluate training programs is *Kirkpatrick's model*. Kirkpatrick's model is a four-level pyramid that assesses the effectiveness of a training program; level one: response of the trainee to the training experience (satisfaction survey), two: the learner's learning outcomes and increases in knowledge, skill and attitude towards the attendance experiences (generally measured with a pretest and posttest assessment), three: students' change in behavior and improvement (did transferability of skill occur into the workplace) and four: results, the highest level of effective training (Bates, 2004; Heydari et al., 2019; La Duke, 2017). As mentioned previously, simulation-based training often demonstrates a level one and two with a growing body of evidence that for certain surgical specialties a level three on Kirkpatrick's model is achievable. Within the realm of cardiac surgery there is a paucity in the literature of any study demonstrating greater than a level two on Kirkpatrick's model.

In summary, the key to successful simulation training includes deliberate practice, that is performed in a distributed pattern. Fidelity of the simulator should be considered only after goals and objectives of that simulation session have been determined. The fidelity of the simulator is less important than the functionality of the simulator. OSATS is a very reliable and validated tool to assess trainees performance during a simulation session and Kirkpatrick's model focuses on the assessment of the simulation session itself.

Team-based training

Before we discuss principles around team-based training, we first need to define what a team is. A team as previously defined by Salas et al. (1992) is a "*distinguishable set of two or more people who interact, dynamically, interdependently, and adaptively toward a common and valued goal/objective/mission, who have been assigned specific roles or functions to perform, and who have a limited lifespan of membership"* (Salas et al., 1992)

Nontechnical skills of a surgeon (NOTSS) are cognitive and interpersonal skills of a surgeon (Flin et al., 2012; Vervoort & Hirji, 2020). Cognitive skills include situation awareness and decision making. Interpersonal skills include teamwork, communication, and leadership. The NOTSS rating scale is the most widely used tool for assessing nontechnical skills (Flin et al., 2007, 2012; Wood et al., 2017).

A common example of a complex team environment is the cockpit within aviation, with early evidence that team training enhances teamwork (Stout et al., 1997.) As in aviation, current approaches to teaching nontechnical skills includes simulation (fully immersive environment), role playing, didactic teaching, and courses on crisis resource management (Dedy et al., 2013; Hull & Sevdalis, 2015; Ounounou et al., 2019). Simulation-based training, such as a fully immersive environment receives the highest level of recommendation for training nontechnical skills (Ounounou et al., 2019). Team-based training involving a surgical team member should attempt to include a physical surgical task to help reduce the need to suspend disbelief and can help facilitate simulation buy-in for the surgical team member (Sparks et al., 2017).

CHAPTER FOUR: NEEDS ASSESSMENT OF CANADIAN CARDIAC SURGERY PROGRAMS

This chapter describes the needs assessment conducted via a survey to all Canadian cardiac surgery programs in Canada to determine a baseline on where we stand with simulation use.

Introduction:

The apprenticeship model of surgical education, relying solely on operating room training, may be insufficient to meet the contemporary needs of cardiac surgery learners, given the following challenges: (1) trainee duty hour restrictions; (2) more trainee time spent on non-operative tasks, such as ward duties and scholarly work; (3) greater time constraints on surgeons; (4) increased patient acuity/complexity; (5) increased scrutiny on patient outcomes; and, (6) increasing complexity of cases, including the need to develop new skills sets for minimally invasive cardiac surgery, transcatheter procedures, mechanical circulatory support (MCS), and aortic surgery (Yanagawa et al., 2019) .

Cardiac surgery is a highly technical surgical specialty, and the operating room is not always a suitable environment for trainees to practice. The stochastic nature of the apprenticeship model does not allow for deliberate practice and does not guarantee exposure to critical, rare scenarios. Given these challenges, educators have embraced simulation as an important adjunct for cardiac surgical trainees. This paradigm shift in North America gained purchase in the previous decade with the introduction of cardiac surgery bootcamps, which have evolved into fully developed simulation curricula (Feins et al., 2017; Raemer, 2009. Although limited, evidence suggests benefits of simulation in cardiac surgery training. A recent systematic review reported simulation is associated with improved learning outcomes, but translational evidence to the operating room is still lacking (Ribeiro et al., 2018).

There remains a paucity of literature on the Canadian experience with simulation. A needs assessment to understand the current uses and value of simulation-based training, and potential direction for future development of simulation curriculum within Canadian programs is required. The purpose of this study was two-fold: (1) to establish an understanding of the current use of simulation in Canadian cardiac surgery residency training programs; and (2) to examine the attitudes of Canadian educators and trainees toward simulation in cardiac surgery.

Methods:

Questionnaires were developed for cardiac surgery trainees and surgeons, consisting of 24 and 22 items respectively (questionnaire items can be found in appendix A of supplemental materials). Items were structured to examine the current use of simulation at each respective program, as well as attitudes towards the usefulness of simulation as an educational adjunct. Items were developed using a logical analysis approach by the authors with expertise in cardiac surgery and surgical education, using the RCPSC specialty training objectives in cardiac surgery as a guide (Royal College of Physicians and Surgeons of Canada, 2013). The initial questionnaire was distributed to two cardiac surgeons and one thoracic surgeon for review prior to administration, to ensure questions were relevant to address study objectives. Question format included: 1) yes/no; 2) multiple choice; 3) select all that apply; and 4) a series of questions on a Likert scale, from strongly disagree to strongly agree.

As part of the needs assessment, both trainees and surgeons were asked on a Likert scale (strongly agree to strongly disagree) to indicate their agreement with the following two statements, (1) This objective is an essential skill to master before completion of residency; and, (2) I believe trainees (or I) would benefit from having simulation-based training outside of the operating room for this particular objective. The objectives were taken from the Royal College of Physicians and Surgeons specialty training requirements for cardiac surgery (Royal College of Physicians and Surgeons of Canada, 2013).

All Canadian adult cardiac surgeons (n=91) and cardiac surgery trainees (n=93) at the 12 institutions in Canada with cardiac surgery residency programs were invited to participate. For institutions with multiple centers performing cardiac surgery, only those at the primary academic site were invited. Congenital surgeons were excluded. Questionnaires were administered electronically in 2020 using Survey Monkey. Four reminders were sent at biweekly intervals. Program directors from each institution were identified separately and received a unique invitation to the questionnaire in a separate e-mail to ensure representation from all academic institutions. Prior to closure of questionnaires, individual outreach was attempted to trainees, to gather representation from each program. Participation was voluntary and confidential. Descriptive statistics were used to summarize quantitative data. Ethical approval was obtained from the Research Ethics Board of University of Alberta.

Results:

Participants

There was a 41% (37/91) response rate from faculty surgeons, and a 36% (33/93) response rate from trainees. At least one faculty surgeon from each of the 12 academic institutions participated. All 12 residency program directors participated. Surgeon respondents were most frequently 10-20 years into practice (11, 30.7%), while 7 were fewer than 5 years (18.9%), 10 were 5-10 years (27.0%), and 9 were over 20 years into practice (24.3%). At least one trainee participated from 10 out of 12 residency programs (83.3%) and at least one from each year of training. The distribution of trainee responses are as follows: 8 (24.2%) were PGY-1; 4 (12.1%) were PGY-2; 6 (18.2%) were PGY-3; 7 (21.2%) were PGY-4; 3 (9.1%) were PGY-5; 1 (3.0%) PGY-6; and 4 (12.1%) were greater than PGY-6.

Simulation use

All programs used simulation for training to some degree. Only 4 (33.3%) programs used simulation for crisis management scenarios, such as a massive air embolism during cardiopulmonary bypass. All programs identified that their university had a dedicated simulation facility or location, but not necessarily specifically for cardiac surgery.

Most surgeons reported involvement with a simulation session either once a year (n = 20, 54.1%) or 3-4 times a year (n = 13, 35.1%). Similarly, 63.6% (n = 21) of trainees said they were involved in a simulation sessions 3-4 times annually (Figure 4.1).

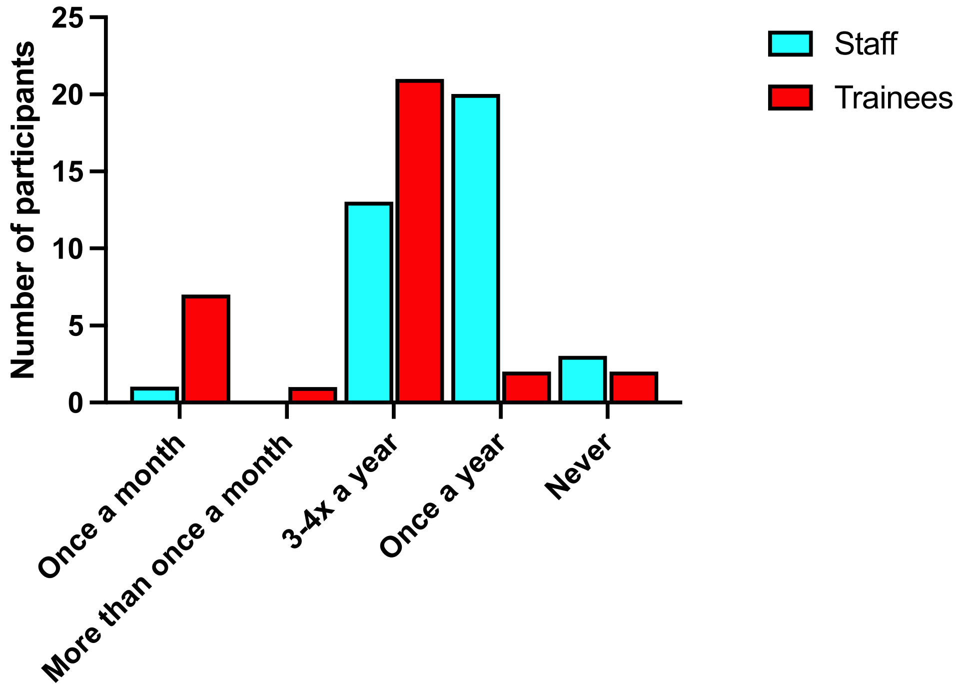


Figure 4.1 Frequency of simulation involvement for both trainees and staff.

Proctoring with porcine heart models was reported by 94.6% (n = 35) of the faculty surgeons. The second most common simulation strategy were anastomotic task trainers reported by 73.0% (n = 27). When faculty surgeons reported on their exposure during their residencies to simulation, their experience was stand-alone porcine heart models (n = 22, 61.1%), followed by anastomotic task trainers (n = 16, 44.4%). Similarly, 26 (92.9%) of current trainees used porcine heart models in a wet lab, and 22 (78.6%) received a simulation session with an anastomotic task trainer, in keeping with faculty responses (Figure 4.2).

In terms of individual trainees' experience with the simulation sessions, 68.8% (n = 22) indicated that the simulation started with a didactic session and 71.9% (n = 23) had specific stated learning objectives. 59.4% (n = 19) of the trainees were evaluated by a cardiac surgeon following the session. Of note, no institution reported including all three components: didactic teaching, learning objectives, and evaluation.

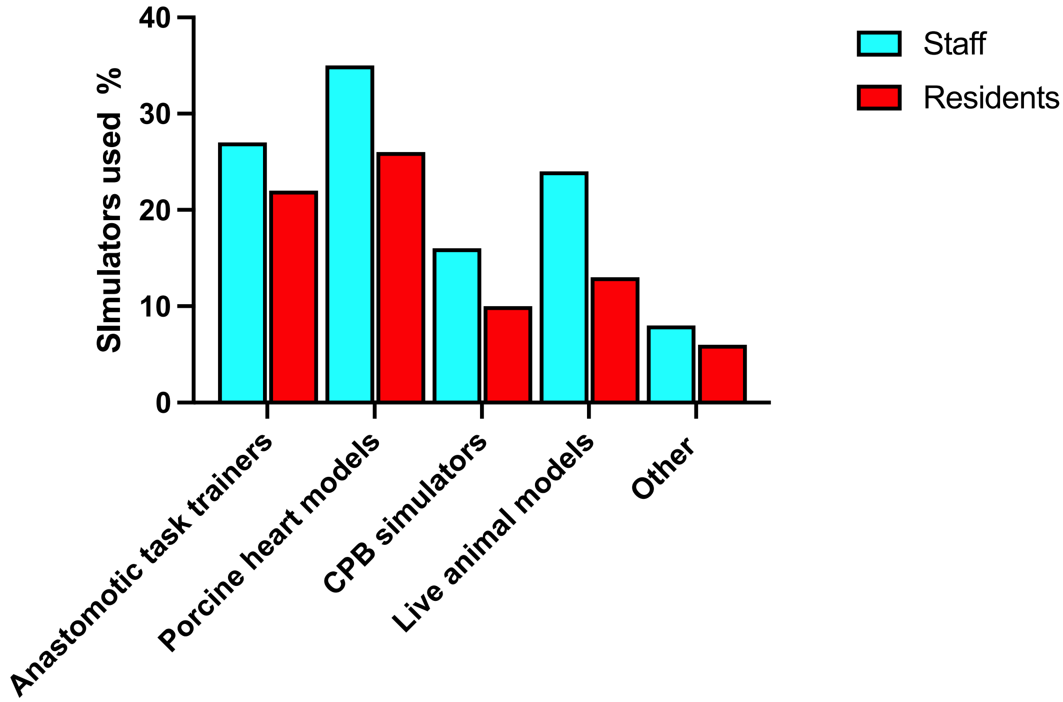


Figure 4.2 Type of simulation models currently being used in Canadian cardiac surgery training.

Informal simulation use

Nineteen (51.4%) surgeon respondents indicated they had never practiced at home with a simulator as trainees. There was a variable distribution of trainee responses, as 30.3% (n = 10) of trainees stated they never practiced at home with a simulator. Only seven (21.2%) trainees practiced at home once a week. A follow-up question on home practice was whether the trainee was more likely to practice if they were given specific "homework", 78.8% (26) of them answered yes.

Views regarding simulation

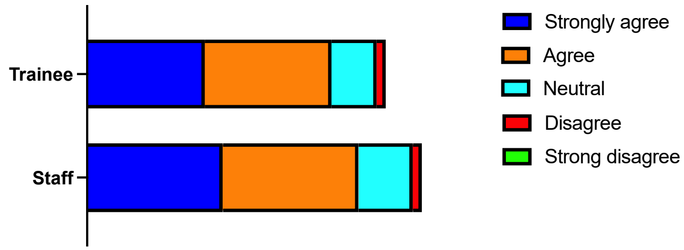
Trainees

Trainees were asked whether simulations sessions at the cardiac surgery bootcamp were useful (only applicable to bootcamp attendees). No respondents disagreed, and 45.5% (n = 15) strongly agreed. Trainees believed increased simulation of common (84.8%, n = 28) and uncommon (94.0%, n = 31) cardiac surgical procedures, and crisis management scenarios (93.7%, n = 30) would be beneficial (Figure 4.3). Overall, 81.8% (n = 27) of trainees indicated a desire for expanded simulation-based training at their center (Figure 3.3). Importantly, 90.9% (n = 30) of trainees believed operating room confidence would improve if able to practice the requisite skills beforehand.

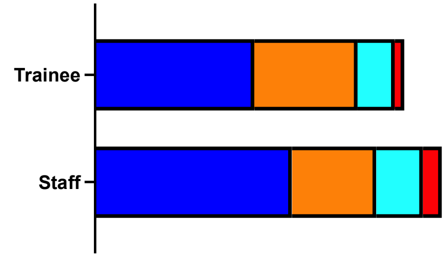
Surgeons

Most cardiac surgeons felt trainees could benefit from increased simulation exposure to common cardiac surgical procedures (81.1%, n = 30), uncommon procedures (83.8%, n = 31), and crisis management scenarios (89.2%, n = 33) (Figure 4.3). 81.0% (n = 30) of surgeons indicated a preference to increase simulation at their local institution (Figure 4). Interestingly, two-thirds of surgeons indicated they would benefit from incorporating simulation-based training into their individual practice.

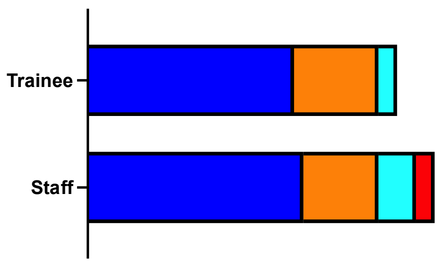
Twenty-nine (78.3%) surgeons felt more comfortable permitting a trainee to operate on patients following simulation-based training beforehand. Twenty (54.0%) surgeons identified a difference in trainee skill following a simulation session. Twenty-three (62.2%) surgeons reported a change in trainee confidence or demeanor in the operating room following simulation-based training.



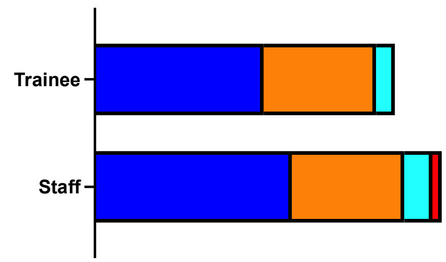
a) Simulation is something I would like to see more of at my own institution



b) Trainees would benefit from more simulation of common cardiac surgical procedures



c) Trainees would benefit from more simulation of uncommon cardiac surgical procedures



d) Trainees would benefit from more simulation of crisis management scenarios

Figure 4.3a-d): Perception on the benefit of simulation-based training according to trainee and staff

Open response items

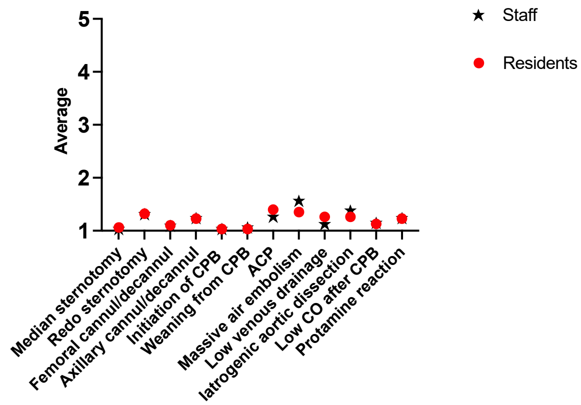
Trainees and faculty surgeons were asked to provide any additional comments or feedback on simulation-based training. Positive and negative comments from faculty surgeons and trainees can be found in Table 4.1. There were no negative comments regarding simulation-based training from trainees.

Positive comments from faculty surgeons	**Positive comments from residents**
"It is the future"	"It should happen every week, mandatory"
"It should become mandatory for residents; we need much more of it"	"These tools/simulators are out there, but in my experience, they are severely underused. I think all programs could benefit from more thoughtful use of simulation especially in the junior years"
"With increasing scrutiny on outcomes in cardiac surgery, with increased administrative scrutiny of OR time (i.e. cost), and increased case complexity, simulation before OR is essential"	"Helpful specifically at early stages of training"
"We are way behind as a specialty in developing simulation-based training, this should be mandated as being necessary prior to allowing residents to practice on living humans"	
Negative comments from faculty surgeons	
"Helpful for junior residents, but less so for seniors"	
"Not a substitute for reality"	
"Simulation lab can't compensate for the time waste outside the cardiac OR"	

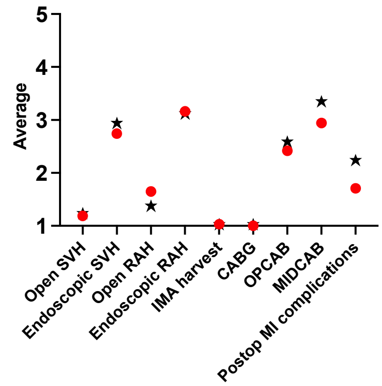
Table 4.1: Example positive and negative comments from survey respondents regarding the views on simulation

Royal College essential skills

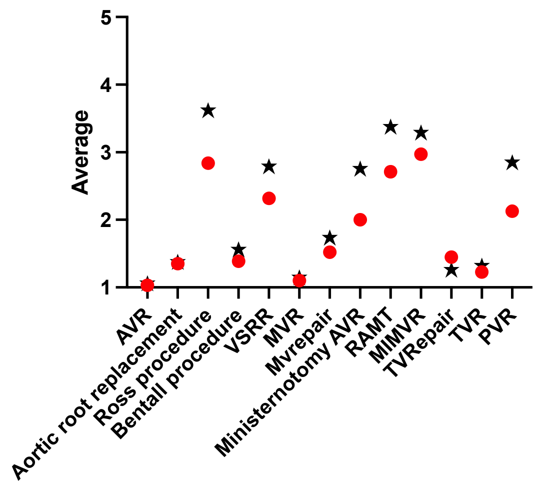
Question one examined which objectives from the Royal College of Physicians and Surgeons of Canada Objectives for Training in Cardiac Surgery were essential skills to master prior to residency completion (Royal College of Physicians and Surgeons of Canada, 2013). Trainees and faculty surgeons strongly agreed that coronary artery bypass surgery (97.1%, n = 33 faculty surgeons) and 100% (n = 31 trainees), along with aortic valve replacement (AVR) [94.1% (faculty surgeons) and 96.8% (trainees)] were identified as the most important skills (Figure 4.5). Trainees felt the following procedures were more important to master before completion of residency compared to faculty: valve sparing root, mini-sternotomy AVR, aortic cases, and left ventricular assist device (VAD), and biventricular assist device insertion. Average score on the Likert scale for all responses are detailed in Figure 4.5.



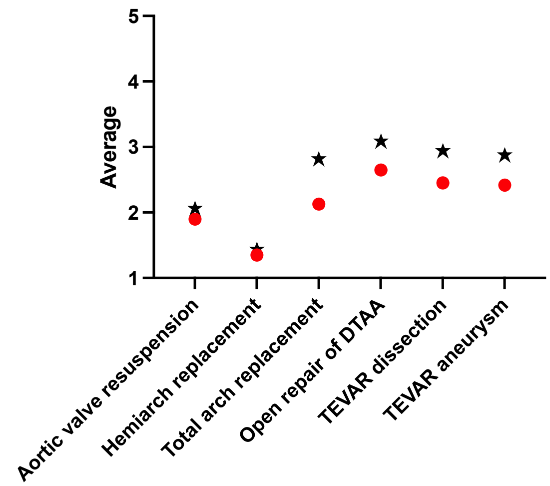
a) Fundamental skills and CPB crisis management



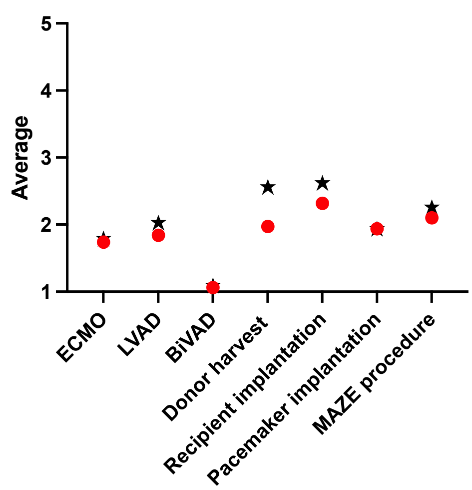
b) Ischemic heart disease



c) Valvular heart disease



d) Aortic disease



e) Heart failure and eletrophysiology

4.5: Faculty and trainee responses to the following statement: "This objective is an essential skill to master before completion of residency." Shown are average scores on the Likert scale. 1 = strongly agree, 5 = strongly disagree.

Question two looked at which objectives would be beneficial to rehearse, should a suitable simulator exist (Figure 4.6). Again, similar responses were noted from both faculty and trainees, with the largest discrepancy detected regarding surgical management of aortic disease. Trainees strongly agreed aortic valve resuspension, hemiarch replacement, and total arch replacement should be simulated. In contrast to question 1, responses tended to be "neutral" and "agree."

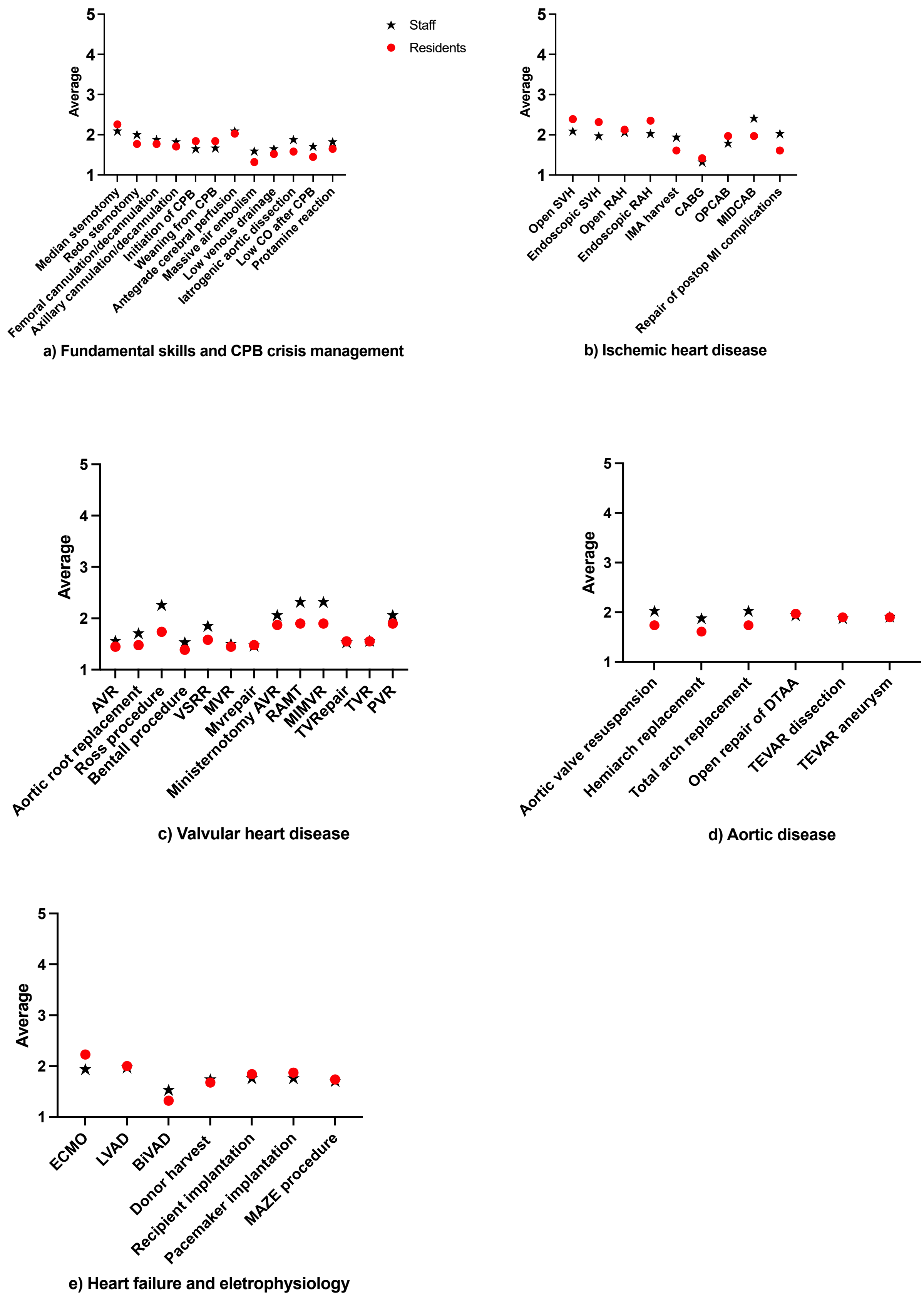

Staff
Residents
Average
Median sternotomy
Redo sternotomy
Femoral cannulation/decannulation
Axillary cannulation/decannulation
Initiation of CPB
Weaning from CPB
Antegrade cerebral perfusion
Massive air embolism
Low venous drainage
Iatrogenic aortic dissection
Low CO after CPB
Protamine reaction
a) Fundamental skills and CPB crisis management
Open SVH
Endoscopic SVH
Open RAH
Endoscopic RAH
IMA harvest
CABG
OPCAB
MIDCAB
Repair of postop MI complications
b) Ischemic heart disease
AVR
Aortic root replacement
Ross procedure
Bentall procedure
VSRR
MVR
Mvrepair
Ministernotomy AVR
RAMT
MIMVR
TVRepair
TVR
PVR
c) Valvular heart disease
Aortic valve resuspension
Hemiarch replacement
Total arch replacement
Open repair of DTAA
TEVAR dissection
TEVAR aneurysm
d) Aortic disease
ECMO
LVAD
BiVAD
Donor harvest
Recipient implantation
Pacemaker implantation
MAZE procedure
e) Heart failure and eletrophysiology

Figure 4.6 Faculty and trainee responses to the following statement: "I believe trainees (or I) would benefit from having simulation-based training outside of the operating room for this particular objective." Shown are average scores on the Likert scale. 1 = strongly agree, 5 = strongly disagree.

Open response items

Trainees were also surveyed regarding desired simulation for surgical procedures not currently being simulated. Respondents listed "crashing on bypass," "disasters," "bypass emergencies," "MIS, we have no MIS at our institution and get little exposure," and "transcatheter procedures" most commonly. Trainees were also asked to list surgical procedures they wished to practice at home. The most common responses were "coronary anastomoses" and "aortic valve replacement."

Discussion:

This study provides new insights into current simulation usage in Canadian cardiac surgery programs, as well as the attitudes of Canadian cardiac surgeons and trainees regarding the utility of simulation as an educational adjunct.

All programs identified simulation employed 3-4 times a year or less, and greater than 80% of trainees and surgeons indicated that they desired greater simulation at their institution. For simulation to be a successful educational tool, the following components are essential: (1) deliberate practice; (2) distributive practice; and (3) coaching by an experienced surgeon (Ericsson, 2003; Feins et al., 2017; Moulton et al., 2006; Raemer, 2009; Yanagawa et al., 2019).

Deliberate practice is the fundamental principal of simulation and has 4 components: (1) identification of a specific goal(s) for performance improvement; (2) intense focus; (3) immediate expert feedback; and (4) designed to challenge the individual with increasing task complexity (Ericsson, 2003).

This study highlights several deficits in cardiac surgery simulation in Canada, whereby these components are incompletely satisfied. Specifically, simulation tends be infrequent (3-4x a year), lacks appropriate structure, and insufficient evaluation by an expert following session completion. At the minimum, each simulation session should have either assigned pre-readings or a designed didactic session, specific objectives, and an evaluation with formal expert feedback (Feins et al., 2017).

While the introduction of the cardiac surgery bootcamp for Canadian trainee is a promising initiative, this survey identified that less than 50% of trainee respondents felt that the simulation sessions were useful. This may be due to the necessary mass practice bootcamp format of material delivered in continuous time blocks, with minimal or no break in between sessions (Moulton et al., 2006). In contrast, distributed practice is spread over periods of time, with breaks in between, and has been demonstrated as a superior learning method for motor skill acquisition and retention (Donovan & Radosevich, 1999; Lee & Genovese, 1989; Moulton et al., 2006).

View on simulation and essential skills

Survey results regarding the view of simulation as an educational adjunct were positive. This was demonstrated by majority of respondents indicating that the current generation of trainees would benefit from greater simulation of both common and uncommon cardiac surgical procedures, as well as crisis management scenarios. Cardiac surgical training in Canada has moved to competency-based learning, referred to as Competence-By-Design (CBD). The goal of CBD is for an increasingly objective approach to training, focused on completion of entrustable professional activities (EPAs) (*Entrustable Professional Activities for Cardiac Surgery*, 2021). An additional CBD component is the transition to practice year (TTP), whereby the trainee should be capable of functioning as a junior faculty surgeon. The two procedural EPAs for the TTP year in Canada are: 1) performing the breadth of core cardiac surgery procedures as the primary surgeon; and 2) performing advanced cardiac surgery procedures with an experienced assistant (*Entrustable Professional Activities for Cardiac Surgery*, 2021).

In 2016, a questionnaire was distributed to all cardiothoracic surgery trainees administered the in-service training examination in the United States, attempting to characterize the operative experience of cardiac surgery trainees (Shah et al., 2016) . By the final year of training, nearly 100% of trainees performed CABG and AVR, but very few performed advanced cardiac surgical operations such as aortic dissection repair, Bentall, or reoperations. These findings are consistent with the view on essential skills for cardiac surgery training identified in this study.

In the present study, advanced cardiac surgery procedures were identified by attending surgeons as less important to master during residency training. With the introduction of CBD, the view on essential skills in cardiac surgery will need to evolve. According to established EPAs and TTP, trainees should be performing advanced cardiac operations prior to completion of training.

Future direction

Addressing cardiac surgical training requirements is a specialty challenge that should be prioritized. This questionnaire identified that surgeons would feel more comfortable allowing trainees to operate with the knowledge that trainees had prior simulator practice. This is despite surgeons not reporting a visible benefit in their trainees' skill or confidence level in the operating room. This is likely due to the infrequent (3-4 times a year) and suboptimal use of simulation within cardiac surgery programs.

Since the introduction of simulation in surgical training, multiple studies have demonstrated that skill transfer occurs from the simulation lab to the operating room (Dawe et al., 2014). These studies have predominately been specialties with laparoscopic, endoscopic, and arthroscopic skills. As identified in this study, simulators currently used in Canada predominantly focus on a single task, such as anastomotic task trainers, or porcine heart models. This contrasts with the studies, where trainees conducted entire procedures or operations. Simulating an entire cardiac operation requires cardiopulmonary bypass or an immersive simulator environment, such as the Ramphal simulator (Ramphal et al., 2005). However, resource limitations make this challenging for all programs to provide. Operating room skill translation is more likely to occur if simulation is used more frequently and regularly.

Limitations

This study was limited by the response rate, as are all questionnaire-based studies. While surgeons and program directors from all Canadian training programs were represented, trainee responses were lacking from 2 out of 12 institutions. This may be due to the survey only distributed in a single language (English). The questionnaire was only distributed to academic centers as in Canada, community centers do not have trainees. While, non-academic centers may use simulation, the goal of this study was to identify simulation use in cardiac surgery residency programs. Congenital surgeons were also excluded as there are only 4 congenital programs in Canada and was felt to be beyond the scope of the present study. Additionally, the questionnaire did not address the barriers to simulation use in Canada or the operative experience of current trainees.

Conclusions:

The historical, exclusively apprentice model for cardiac surgery training must adapt and forge ahead. Within the Canadian context, this questionnaire has identified that simulation is valued and is broadly employed, with all institutions including simulation, to some extent. Most respondents indicated a desire for greater simulation at their center. This study identified that simulation in Canadian cardiac surgical programs is sub-optimally exploited as an educational tool. Areas for improvement identified included: designing a more structured approach with pre-readings, or didactic teaching; objectives development; and more regular evaluation. Simulation cannot, and should not, replace operative experience, but current demands on surgeons and trainees mandates broader and more effective application of simulation as an educational adjunct.

Our next step following the needs assessment regarding simulation-based training, was to survey Canadian cardiac surgery trainees on their operative experience to create an overall picture of cardiac surgical training today.

CHAPTER FIVE: CURRENT OPERATIVE EXPERIENCE OF CANADIAN CARDIAC SURGERY TRAINEES

This chapter explores the operative experience of Canadian cardiac surgery trainees. Previous literature from the United States would suggest that cardiac surgery trainees are not operating independently at the time of graduation for the breadth of cardiac surgery (Shah et al., 2016).

Introduction:

Cardiac surgery is a technically challenging surgical specialty, and the operating room does not always provide a suitable environment for trainees to acquire such skills (White et al., 2021). Over the past several years, major shifts in surgical education have brought into question whether surgical residency programs are truly producing competent and technically proficient surgeons (Mattar et al., 2013; Meyerson et al., 2017; Stephens et al., 2015). The following challenges limit the ability for the trainee to be autonomous in the operating room: (1) trainee duty hour restrictions; (2) greater time constraints on surgeons; (3) increased patient acuity/complexity; (4) increased scrutiny on patient outcomes; and (5) increasing complexity of cases (Mattar et al., 2013; Meyerson et al., 2017; White et al., 2021)

Surgical trainees are often not getting sufficient exposure to operating upon graduation (Meyerson et al., 2017; Shah et al., 2016.; Stephens et al., 2015). Previous Canadian literature reported many cardiac surgery trainees in their final year of training, believed they would not be ready to practice independently and 96% completed at least 1 year of additional training, which may have been at least in part due to apprehension of their surgical capabilities (Mewhort et al., 2017).

In response to these and other criticisms of traditional surgical training, Canadian residency programs are currently transitioning to a Competence-By-Design (CBD) approach to training (Cardiac Surgery Specialty Committee, 2018). In the cardiac surgery CBD program, the Royal College of Physicians and Surgeons of Canada (RCPSC) defines 14 procedures the trainee is expected to perform at least once as the primary operator. Nine of these are considered core procedures, while five are considered advanced. As the transition to CBD is underway, it is critical to understand the current landscape of cardiac surgery trainees' operative experience, to identify existing challenges and areas for improvement. The aim of this study was two-fold: (1) to characterize the operative experience of Canadian cardiac surgery trainees and (2) to identify whether there is a gap between what skills trainees are expected to have by the end of residency training and what skills they are achieving.

Methods:

A 15-item questionnaire was developed for all Canadian cardiac surgery trainees (questionnaire items can be found in appendix B of supplemental materials). Items were structured to examine what aspects of the operation trainees were performing. Items were developed using a logical analysis approach by the authors with expertise in cardiac surgery and surgical education, using the RCPSC specialty training objectives in cardiac surgery as a guide. There are 14 procedures identified, 9 considered core skills and 5 considered advanced. Also included were 5 foundational cardiac surgical skills. Question format included: 1) yes/no; 2) multiple choice; 3) ranking; and 4) a modified Likert scale.

The Zwisch scale was used to delineate the progression to autonomy, which is a 4-level scale (Darosa et al., 2013; Meyerson et al., 2017). The first level (and the least autonomous) is “show and tell,” where the trainee assists the faculty surgeon throughout the entirety of the case (Darosa et al., 2013; Meyerson et al., 2017). At the second level, “active help,” the trainee performs steps of the operation, under direct supervision and guidance of faculty who assist to their full ability (Darosa et al., 2013; Meyerson et al., 2017). The third level, “passive help,” trainees perform the entirety of the case and controls the flow of the case, but faculty assists and when required aids in decision making (Darosa et al., 2013; Meyerson et al., 2017). At the final level, “supervision only,” the trainee is considered autonomous. The faculty surgeon is only there to observe and answer questions should they be asked.

All Canadian cardiac surgery trainees (n= 75) at the 12 academic institutions in Canada were invited to participate. Respondents were asked to identify their clinical post-graduate year (PGY), excluding dedicated academic time. Questionnaires were administered electronically in 2021 using Survey Monkey. The questionnaires were administered during the middle of the academic year. E-mail and social media were used to distribute the survey. Reminders were sent biweekly over a course of 4 months. Program directors from each institution were recruited to help encourage their trainees to participate. Prior to closure of the questionnaire, individual outreach was attempted to trainees writing their RCPSC exam in 2021, to gather representation of the graduating trainees. Participation was voluntary and confidential. Descriptive statistics were used to summarize quantitative data. Ethical approval was obtained from the Research Ethics Board of University of Alberta.

Results:

Participants

There was a 60% (45/75) response rate from trainees. There was representation from all Canadian residency programs, except one University. There was an equal representation of training levels, 13.3% (n=6) PGY-1, 17.8% (n=8) PGY-2, 13.3% (n=6), PGY-3, 24.4% (n=11) PGY-4, 13.3% (n=6) PGY-5, 13.3% (n=6) PGY-6 and 4.4% (n=2) higher than PGY-6. Of these, eight (17.8%) of the trainees were in their final year of residency. Identified by program, 31.1% (n=23) of participants were enrolled in a CBD program and the remainder of the respondents were in a traditional program.

Operative satisfaction

On average, trainees indicated that they were happy with their current operative experience (88.9%, n=40, Figure 5.1) but noted that operative experience varied significantly depending on the faculty surgeon they are working with that day (86.7%, n=39, Figure 5.1). Trainees were in the operating room 2-4 days/week while on cardiac surgery (60.0%, n=27). The trainee respondents indicated that there was usually only one trainee scrubbed into the case (73.3%, n=33), allowing trainees to be either primary assistant or primary operator for that case. A majority, but not all trainees indicated that by the end of residency they would be comfortable operating independently for the core breadth of cardiac surgery (n=35, 77.8%). Trainees were asked to rank reasons for doing a fellowship following residency (Table 5.1). The most common reason to do a fellowship was to learn advanced skills (n=29, 67.4%).

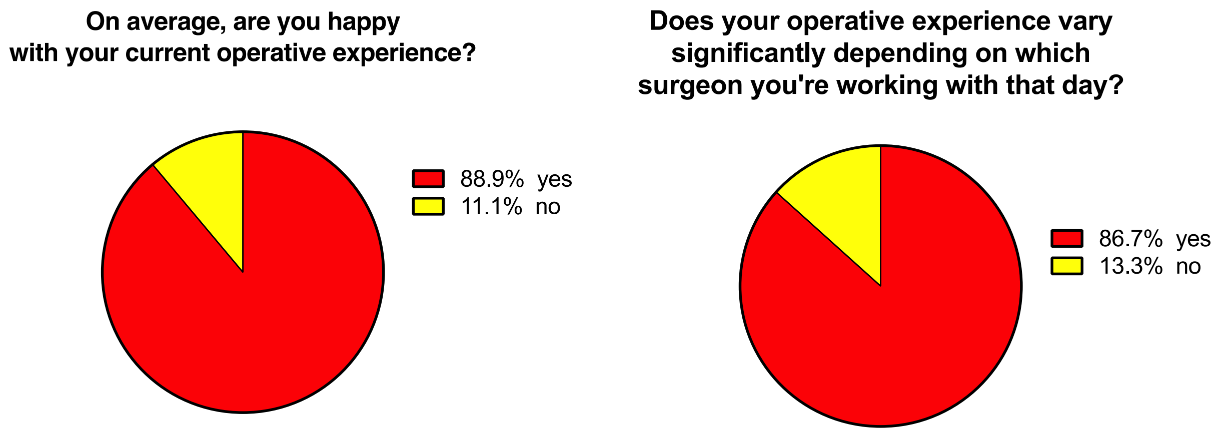


Figure 5. 1 Trainee responses regarding operative experience.

Reasons	1	2	3	4
To learn advanced skills	67.4% (29)	20.9% (9)	9.3% (4)	2.3% (1)
Will need more time to feel comfortable operating independently	13.6% (6)	27.3% (12)	31.8% (14)	27.3% (12)
To get a job at a specific centre	13.6% (6)	36.4% (16)	34.1% (15)	15.9% (7)
This is the way of our specialty	8.9% (4)	15.6% (7)	24.4% (11)	51.1% (23)

Table 5.1. Trainee rankings for entering a fellowship following completion of residency (1=most important, 4=least important).

Operative progression

When asked if the opportunities they received in the operating room aligned with the objectives of training to their level, 84.4% (n=38) of trainees said yes. Twenty-six trainees (57.8%) indicated that they were not able to progress in the operating room if the task was deemed beyond their level of training. Most trainees, 82.2% (n=37), indicated that the faculty surgeons allowed them to struggle/trouble shoot before taking over. Overall, 73.3% (n=33) of trainees indicated that they plan with their faculty prior to starting the case of what they, the trainee can be expected to do and what the faculty will do.

Trainees were asked to state where on the Zwisch scale they felt they were for the list of foundational, core and advanced RCPSC cardiac surgery procedural objectives. Figure 5.2 demonstrates where on the Zwisch scale the trainees currently were spending their time, regardless of operation, stratified by training level. In PGY-1 through 5, most time is spent in the show and tell phase. Overall, very little time is spent in the transitioning phases, active help, and passive help. Figure 5.3 is a breakdown of Figure 5.2 by PGY-level. Skills considered foundational or core cardiac surgical skills tended to be higher on the Zwisch scale, regardless of training level. The more senior the trainee is, the more autonomy they gain, except for advanced cardiac surgical skills. The shift towards supervision only for advanced skills occurs only in PGY-6.

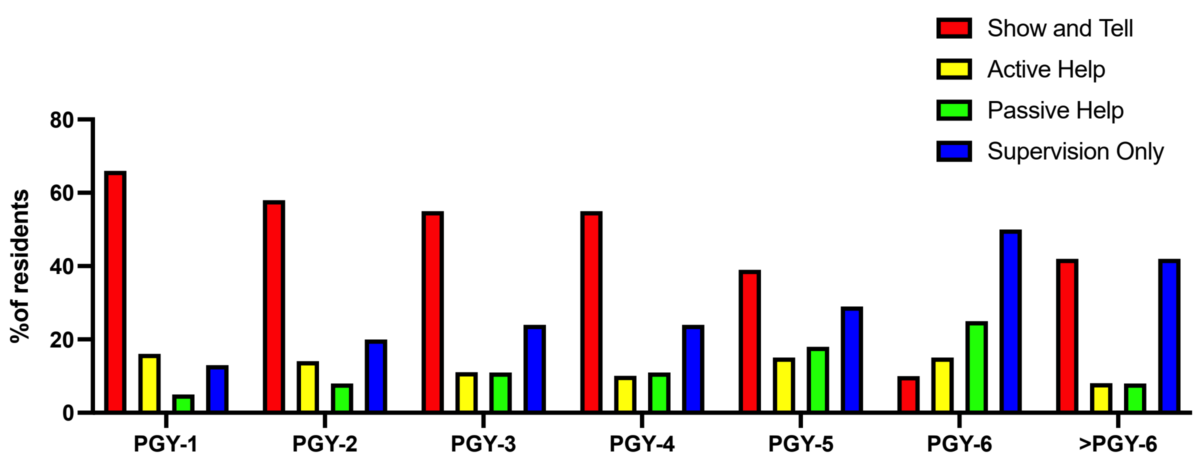


Figure 5.2: Percentage of trainees stratified by PGY-level in each phase on the Zwisch scale for the 18 listed procedures.

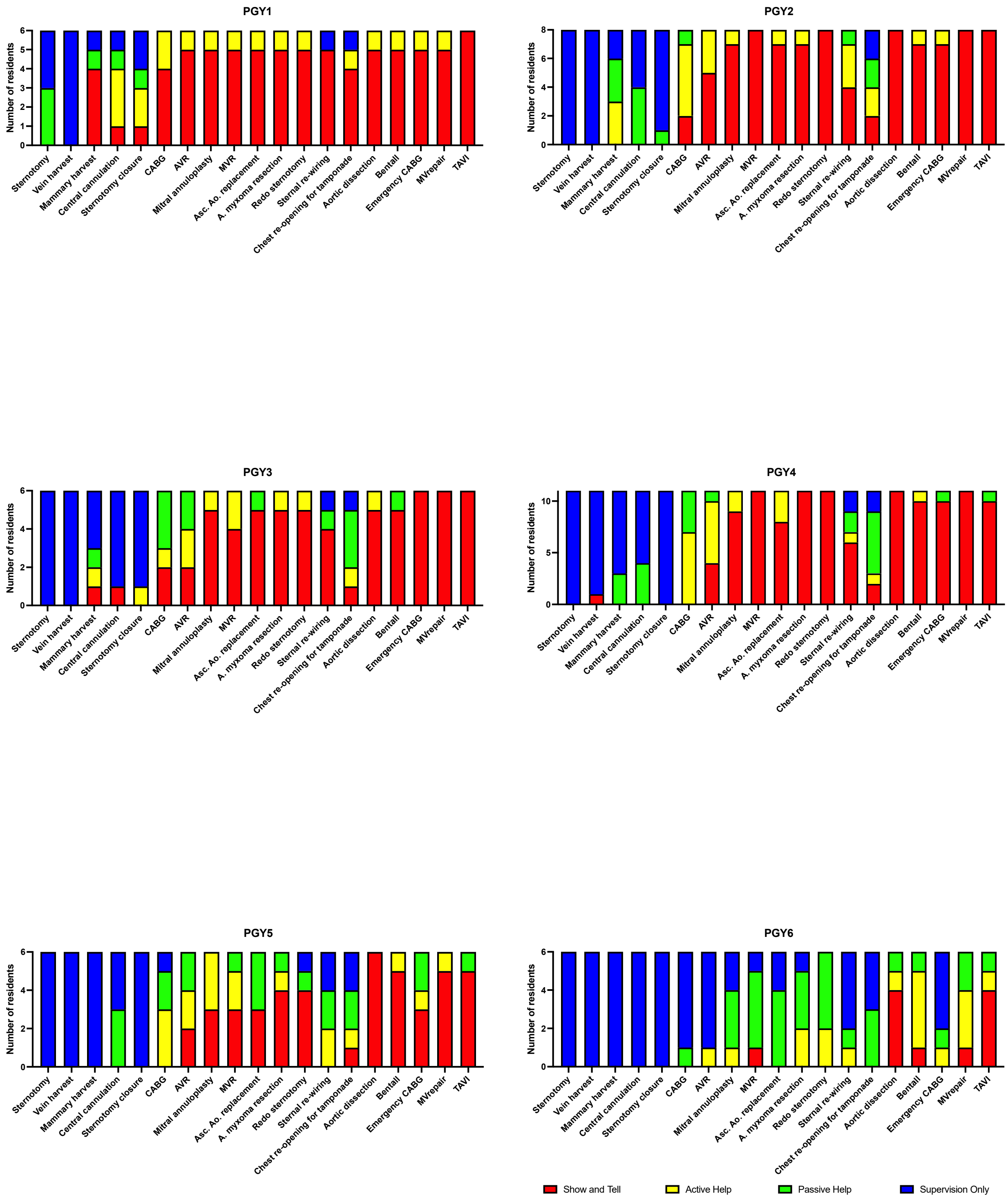


Figure 5.3: Currently, where are you on the Zwisch scale for the following procedures. Shown are the number of trainees stratified by PGY-level for each phase on the Zwisch scale.

Trainees were also asked at what PGY level they were first permitted to operate at Zwisch level 3 (passive help) or above for the same procedures (Figure 5.4). Interestingly, responses for skills considered core cardiac surgical skills were like advanced skills, in that the most selected option was *not applicable*.

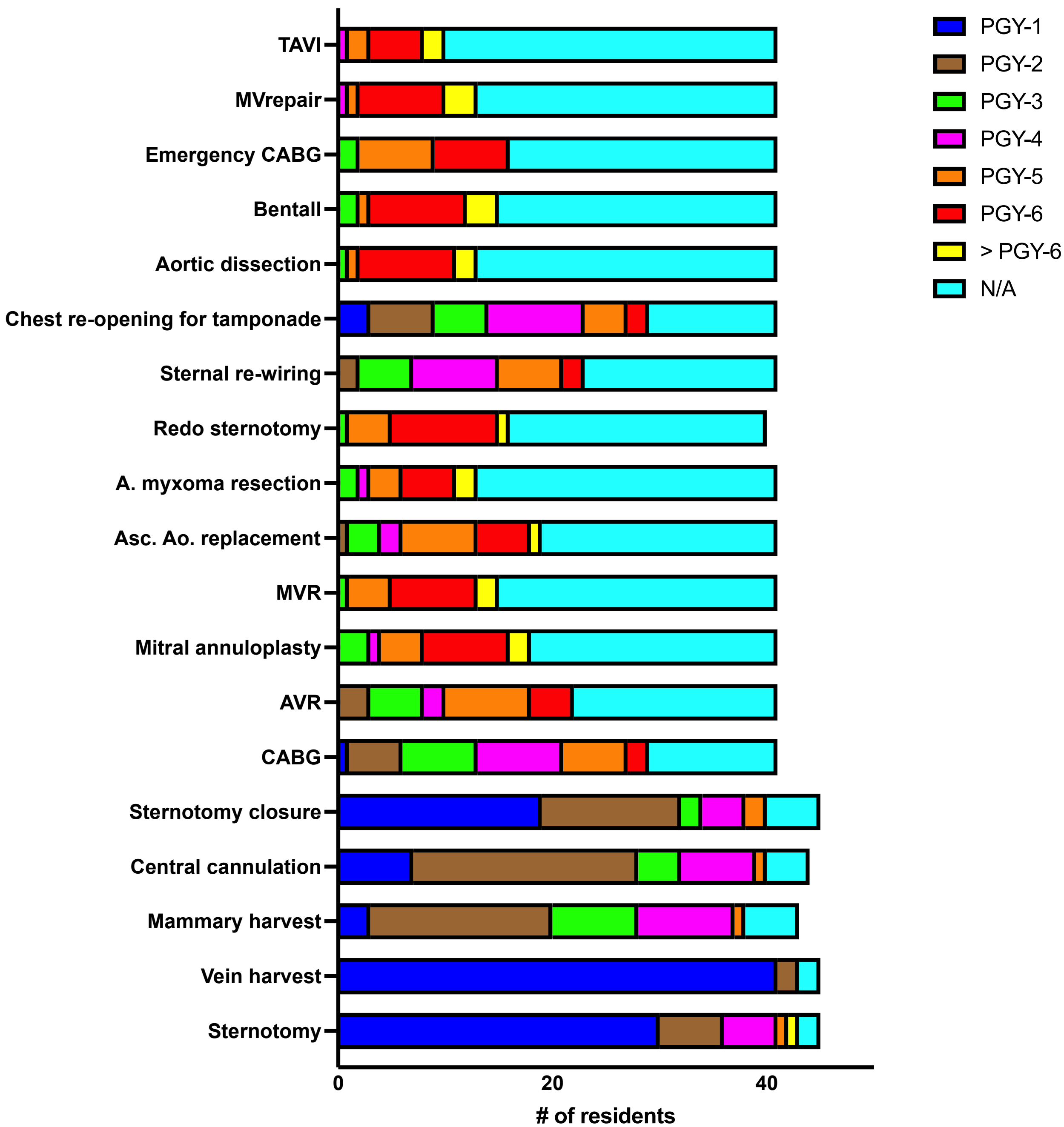


Figure 5.4: Trainees were asked: at what PGY level did you first get to operate at Zwisch scale 3 (passive help) or above for the following procedures? Responses are stratified by PGY-level.

Discussion:

Canadian cardiac surgery trainees have previously reported low levels of confidence in their ability to practice independently at the completion of their residency (Mewhort et al., 2017). This current survey sought to better characterize what aspects of the operation trainees are performing and at what level. There were two major findings: (1) an overall slow progression of skills, from PGY-1 to PGY-5, and (2) very little time is spent in the transitioning phases, *passive help,* and *active help*.

Operative satisfaction

The results of this questionnaire are improved compared to previously reported Canadian data in terms of satisfaction with the operative experience. Our results demonstrated a nearly 90% satisfaction rate, compared to a previously reported 70% in 2017 (Mewhort et al., 2017). In a previous survey, 57% of trainees in their final year did not feel as though they would be able to operate independently by the time of graduation. This is lower than the current survey results of 77.8%. Two possible explanations could include improvement in trainee training and/or perception of trainees has changed over the past 5 years. The high operative satisfaction rate found in this survey and perception of independence at graduation would suggest that there may be a discrepancy in how trainees are performing in the operating room and confidence level at achieving competence. Case volume alone does not establish competency (Safavi et al., 2012). Other factors such as: 1) specific rotations offered, 2) the balance between inpatient and outpatient experience, 3) the timing of rotation in junior versus senior years, and 4) the effects of other programmatic influences such as, subspecialty centralization will impact achieving competency (Safavi et al., 2012). Anecdotally, there are programs in Canada where while on rotation a trainee may only work with one or two surgeons for a rotation. Within that training model, it is possible that by completion of residency, a trainee may not have had enough exposure to certain cardiac procedures. With the introduction of CBD, it may be necessary to plan rotations that will provide the trainee the best opportunity to meet objectives.

An encouraging aspect of Canadian cardiac surgery programs identified in this survey is the amount of one-on-one exposure trainees have with faculty surgeons as well the time spent in the operating room while on cardiac surgery rotations. As expected, experience in the operating room is often largely surgeon dependent. Although not assessed in this survey, additional contribution to experience in the operating room would be trainee skill level.

Competency by design (CBD) is an approach to training that focuses on completing a specific set of milestones, in the format of entrustable professional activities (EPAs) (Cardiac Surgery Specialty Committee, 2018). CBD is intended to accommodate the varying abilities and rates of skill development of individual trainees, compared to the prior time-based program (Noly et al., 2017). The primary emphasis of CBD is competence acquisition (Noly et al., 2017). Trainees are expected to progress according to demonstrated competency, and objectives are not restricted by year of training level. Despite this, nearly 60% of trainees indicated that they were not being advanced regardless of achieved competencies (Noly et al., 2017).

Operative progression

The results of this survey are like the experience reported in the United States in that coronary artery bypass and aortic valve replacement are routinely performed at an independent level at graduation (Shah et al., 2016). In the prior Canadian time-based program, there was no pre-specified number of cases graduating trainees were expected to do as the primary surgeon. As indicated above, there are 14 procedures in CBD trainees are expected to perform at least once as the primary operator. An ideal training model would allow trainees to move in a natural progression from ‘show and tell’ into ‘supervision only’ in their final year of training. Except for CABG and AVR, majority of Canadian trainees remained in the *show and tell* phase for core and advanced procedures regardless of their PGY level. A possible explanation for why we do not see a natural progression of autonomy, is it is not clear when trainees should move between the levels on the Zwisch scale. EPAs are formative assessments of competence and are important in determining when a trainee should gain more autonomy. It may be useful to assign the core and advanced procedural EPAs to specific years to encourage progression.

When trainees were asked, *at what PGY level did you first get to operate at Zwisch scale 3 or 4 for the following procedures,* majority of respondents indicated ‘not applicable’ for core and advanced surgical skills. Cardiac surgery has evolved to include specialized programs requiring a specific skill set (heart failure, aortic surgery, minimally invasive surgery), and as a result additional 1- or 3-year fellowships effectively become a requirement to get a job in a cardiac surgery center in Canada (Noly et al., 2017). The perception that a procedure requires fellowship training is a possible explanation for why majority of the core and advanced surgical skills are considered above residency training. A study conducted in general surgery found that 80% of faculty members did not expect graduating trainees to be operating independently for complex operations (Wagner et al., 2018). The subspecialty areas in cardiac surgery may make up majority of a surgeon's practice; they may do few AVR and CABG a month. In a scenario, where a trainee is working with an aortic surgeon, theoretically the trainee could be more advanced on the Zwisch scale for aortic procedures than for CABG, although this will be dependent on individual trainee skill level. In this survey, trainees are achieving competency in CABG and AVR by time of graduation and not in these subspecialty areas. It raises the question of how to approach learning opportunities in complex operations or even what defines complexity?

Solutions

Within the current group of trainees, there are very few graduating/senior trainees who would be able to log completion of EPAs for the core and advanced cardiac surgical skills. The potential implication is that Canadian trainees are not graduating with full surgical competence. The EPAs within CBD help by specifying the requirement of performing at least one of all core and advanced cardiac surgical procedures with an experienced assistant (i.e., faculty surgeon). Allowing trainees to perform parts of complex or advanced procedures in preparation for being the primary surgeon in their final year may be a suitable solution. However, as noted in this survey, very little time is spent in the active and passive help phases.

Simulation could play an important role in preparing trainees for these complex cases prior to performing on real patients in the operating room. A review of existing literature on surgical training, skill acquisition and simulator-based training found that deliberate practice is the key to developing top-ranking experts in various fields (Yokoyama, 2019). There is a potential necessity here to enhance the current state of cardiac surgical simulators. Proving competency in a simulated, controllable environment may allow trainees to gain more autonomy in the operating room.

Limitations

Despite the anonymous nature of the survey there may have been some hesitance on the part of respondents to answer honestly about their operative experience. Trainee perception on their level of autonomy is an inherent limitation to our survey. Future study should involve an observational study of autonomy in the operating room to compare perception to reality. A unique situation that faced surgical trainees beginning in mid-late 2020 was the COVID-19 pandemic that caused operating theatres to reduce their case volumes. Reduced operative experience could certainly affect a trainee's progression to autonomy, with operative volumes returning to normal it may be worthwhile re-administering the survey to determine whether there was a difference. An additional, unavoidable limitation is the small sample size of Canadian cardiac surgery programs.

Conclusion:

Despite high levels of satisfaction among Canadian cardiac surgery trainees with their training, this study identified low amounts of autonomy amongst core and advanced cardiac procedures. Graduating trainees are not operating as the primary operator for procedures identified as requirements for training as per the Royal College of Physicians and Surgeons of Canada. Specific metrics on when it is appropriate to allow a trainee to progress on the Zwisch scale may be necessary.

CHAPTER SIX: ISSUES WITH CONTEMPORARY SURGICAL TRAINING

Chapter five explored the operative experience of Canadian cardiac surgery trainees and identified that there was a low level of autonomy for many core and advanced cardiac procedures. This chapter further explores the attitudes and perspectives of cardiac surgical training in Canada from the perspective of trainees and surgical program directors.

Introduction:

As part of the global initiative for competency-based medical education (CBME), the Royal College of Physicians and Surgeons of Canada (RCPSC) has recently transitioned to Competence-By-Design (CBD) residency training models. This has represented a significant shift in surgical education and training delivery. CBD aims to equip surgical trainees with specific competencies, allowing for the objective documentation of requisite surgical procedures and their component steps through discrete learning objectives called Entrustable Professional Activities (EPAs) (*Entrustable Professional Activities for Cardiac Surgery*, 2021). A trainee's development towards a competency, such as performing aortic valve replacements in the field of cardiac surgery, is tracked, and assessed through performance on EPAs.

All surgical specialties function in a team environment, but cardiac surgery is unique with the addition of a team-member, the perfusionist, who operates the cardiopulmonary bypass machine. Prior studies and chapter five have demonstrated a limited extent of trainee operating autonomy during routine and advanced cardiac surgeries (Shah et al., 2016; White et al., 2022) and several factors exist within contemporary surgical training that may be limiting resident autonomy in the operating room. These include duty hour restrictions, increased time spent on scholarly work and ward duties, greater patient acuity/case complexity, increasing scrutiny of operative outcomes, and a greater focus on operative efficiency and patient safety (Perone et al., 2017; White et al., 2022). Limitations inherent to current training models could also significantly contribute to diminished trainee operating autonomy.

While CBD training models aim to produce a competent surgeon, autonomy is not necessarily implicit to such training paradigms (White & Moran, 2023). Competence is developed by observing and assessing trainee performance on technical aspects of an operation under direct supervision, thus fulfilling the components of the EPAs. However, operating as the primary surgeon allows a trainee to engage in unique and critical decision-making opportunities, which represents an integral experience towards developing operative independence and autonomy (Hammond Mobilio et al., 2020; Sandhu et al., 2017) Ideally, as a resident develops more competencies, staff surgeons would deliberately and progressively seek to create an environment of increasing autonomy (Cassidy et al., 2021; Salim et al., 2020; Sandhu et al., 2017). However, data has shown that a significant proportion of graduating surgical residents' complete cases as assistants, with autonomy particularly limited in moderate to high complexity cases (Shah et al., 2016.; White, O'Brien, et al., 2022).

Recent evidence suggests a gap likely exists between the attainment of competencies as set out by the RCPSC and those required to enter independent practice. These transition to practice (TTP) EPAs are the fourth and final stage of residency, and it is during this stage that trainees demonstrate readiness for autonomous practice (Oswald & Abbott, 2016). Through qualitative semi-structured interviews, we aim to characterize and explore this discrepancy within cardiac surgery training to identify challenges, barriers, and areas of improvement. As there is a poor understanding of how decisions surrounding autonomy are made, we also aim to explore staff and trainee perspectives surrounding operating autonomy to identify any potential misalignments in expectations. Better characterizing the gap between competence and autonomy can help develop a standardized approach to gradually increasing trainee autonomy in the operating room, which could lead to more confident and independent surgeons entering the workforce.

Methods:

Setting and Participants

This qualitative research study was carried out through the University of Alberta using virtual interviewing. Ethical approval was granted by the University of Alberta Health Research Ethics Board. Information regarding the study and consent were e-mailed to all participants. Written consent was waived, with verbal consent being given. All program directors and the most senior resident enrolled in the Competence-By-Design program across Canada were recruited. In the setting that the program director or resident did not agree to participate in the study, additional members of the faculty and training programs were recruited to attempt to achieve representation across Canada. For the sake of anonymity, programs that participated will not be disclosed.

Interview

Data for this study was collected through the form of semi structured interviews of both trainees and faculty surgeons. Interviews were conducted over Zoom and recorded for audio and saved to AW's computer. All interviews were conducted by a single individual (AW). There was some overlap between the interview questions for trainees and faculty and both sets of interview questions were organized by demographics, scenario, competence, autonomy, and barriers within surgical training (Appendix A). Certain questions were formatted to be answered with a yes or no or other dichotomous form. Majority of questions were open ended. Each interview was transcribed verbatim by Happy Scribe and reviewed by AW.

Data Analysis

We used both a thematic analysis and a content analysis to analyze interview transcripts. There were four research questions: Question #1: What are the attitudes and perspectives of cardiac surgery staff and trainees on competency and autonomy? Question #2: What is the goal of surgical training? Question #3: What is needed for independent practice? And Question #4: What are the barriers to achieve an autonomous surgeon by graduation? Data analysis was primarily performed by AW and grouped by trainee and faculty. A hybrid approach to coding was used to answer predetermined questions and allow room for new questions that came from the data. Transcripts were reviewed and marked with different colored pens to correspond with the different questions. Representative quotes for each question were then organized into an excel spreadsheet. From there, themes were developed. A second coder went through the transcripts in a similar way. An additional group of expert educators reviewed the results. Primary author and senior faculty met several times to review the results and refine the data presentation.

Results:

Participants

There was a total of 16 participants, 9 faculty surgeons and 7 trainees. There was representation from nine out of the 12 cardiac surgery programs in Canada. Five programs had representation by both trainee and program director (Tables 6.1 and 6.2). Trainee level ranged from first year trainee to PGY-4 (Table 6.1) and six out of nine surgeons were within their first 10 years of practice. Only two out of nine surgeons had any formal teaching in training (Table 6.2).

Participant ID	Gender	Year of Residency	Program Director
P1	Male	PGY-4	P8
P2	Male	PGY-4	P10
P3	Female	PGY-4	P12
P4	Female	PGY-1	N/A
P5	Male	PGY-3	P13, P14
P6	Female	PGY-4	P15
P7	Female	PGY-4	P15

Table 6.1: Trainee participant demographics. (PGY-post graduate year)

Participant ID	Gender	Graduation Year	Trainee	Years as Faculty	Formal Training in Teaching?
P8	Male	2014	P1	6.5	N
P9	Male	2012	N/A	7	N
P10	Male	2019	P2	<1	Y
P11	Male	2015	N/A	5.5	N
P12	Male	2014	P3	7	N
P13	Male	2014	P5	14	N
P14	Male	2006	P5	15	N
P15	Male	2017	P6, P7	5	Y
P16	Male	2007	N/A	15	N

Table 6.2: Faculty surgeon participant demographics

Scenario Based Questions

There was a total of 16 participants, 9 faculty surgeons and 7 trainees. Interviews varied by length, the shortest interview was 31 minutes, and the longest interview was 60 minutes. There was representation from nine out of the 13 cardiac surgery programs in Canada. Five programs had representation by both trainee and program director

(Tables 6.1 and 6.2). Trainee level ranged from first year trainee to PGY-4 (Table 6.1) and six out of nine surgeons were within their first 10 years of practice. Only two out of nine surgeons had any formal training in teaching (Table 6.2).

Scenario Based Questions

Both faculty surgeons and trainees were given three hypothetical coronary artery bypass grafting (CABG) scenarios and asked to indicate whether the primary operator role was performed by the surgeon or the trainee. Scenario #1: Everything technically was done by the trainee in a CABGx3, except the distal anastomoses were completed by the faculty. Scenario #2: The trainee completed all the distal anastomoses in the CABGx3 but didn’t do anything else. Scenario #3: The trainee did the entire procedure technically, but the staff controlled the flow of the case, for example, when to give cardioplegia, when to go on CPB, where to make the arteriotomies. There was an agreement amongst trainee and faculty on who should log the case (Table 6.3). Important elements that contribute to who should log the case will be presented.

Critical Step of the Procedure

Expectation when logging a case as primary operator is the individual who did most of the procedure and the most important parts of the operation. In scenario one the trainee performed majority of the operation but didn’t do the most important part, as illustrated by the following quote: “*Because the distal is the money.”*

Majority of the Procedure

In the second scenario majority agreed that faculty did the procedure, because even though the trainee performed the most important aspect of the case, they did not perform the majority (Table 6.3). A caveat in this scenario is a faculty would tell a trainee they could log the case if they knew the trainee was comfortable with the other parts of the case, *"If I said you do the distals today, in my mind you're comfortable with all the other stuff and I just needed to get going."*

Competent not Autonomous

In the third scenario, almost unanimously everyone agreed that the trainee should log the case as they performed all the technical elements of the procedure (Table 6.3). Faculty and trainees alike recognized that this does not mean they are ready to do the procedure independently, *"but is it, like, ready to go done? You did it all of it yet, no, not quite."*

Scenario	*Trainee Response (n=7)*		*Illustrative quote*	*Faculty Response (n=9)*		*Illustrative quote*
	Trainee	Faculty		Trainee	Faculty	
Q1: Everything technically was done by the trainee in a CABGx3, except the distal anastomoses were completed by the faculty surgeon.	1	6	"I log the cases that I do all of it on, so, like, pretty much 100%."	1	8	"So, for me, primary is doing pretty much the meat of the operation and everything else."
Q2: The trainee completed all the distal anastomoses in the CABGx3 but didn't do anything else.	1	6	"I think it's a personal thing, and we have this debate all the time about how do we label things, and I think you have to account for the transition steps, the fluidity, like putting it all together."	3	5	"If I said you do the distals today, in my mind you're comfortable with all the other stuff and I just needed to get going."
Q3: The trainee did the entire procedure technically, but the staff controlled the flow of the case, for example, when to give cardioplegia, when to go on CPB, where to make the arteriotomies.	6	1	"Technically speaking, the trainee would have done all aspects of the case. But I think there's an understanding that if the staff had not been there, they wouldn't have been able to control the flow or there are many other dimensions to being completely independent that were not addressed in that case. But I think if the trainee did all aspects technically and understood the decision making and flow, then I think it's reasonable to say that that trainee did the case."	9	0	There is a difference when it turns into the CBD now, the transition to practice, where trainees, a couple of years before they're fully independent, will be able to do all the technical aspects, and then that last part where you're actually making all the decisions, that's more a transition to practice kind of time.

Table 6.3: Scenario based question: who did the case, trainee, or faculty surgeon?

Content Analysis

Out of all the participants, 56.3% (9) believed that the transition to practice (TTP) EPAs were unreasonable to achieve, six out of those nine participants were faculty surgeons. There was nearly unanimous agreement amongst all that during the TTP year trainees would not be performing procedures without a faculty member being scrubbed (Table 6.4). As outlined in EPA #4 (Table 1.2) the trainee should function as the primary operator with an "experienced assistant." As mentioned by one participant, the experienced assistant is a faculty surgeon: *"I think a staff surgeon is an experienced assistant. I think that all of us have done cases with the staff surgeon as the assistant and they come for the important parts and then they scrub out."*

Nearly unanimously, participants believed that competency and autonomy are not the same (93.8%). Whereas competency was generally felt to be a steppingstone towards autonomy (Table 6.4), there was also agreement that current surgical training aims to produce a competent surgeon (86.7%), but ideally would be produce an autonomous one. Faculty surgeons mainly use subjective forms of assessment (88.9%) (Table 6.4), with one faculty surgeon identifying EPAs as a form of objective measurement: *"So there are objective measures. So, the EPAs try hard to delineate the objective things that we should be assessing. There is a subjective assessment as well, whether you call that a gestalt or just a subjective assessment, that's through just a general observation."* Another faculty member noted looking for two elements of a trainee's performance*, "me, most of the time, is it functional and is it safe...So there are safety metrics in my mind and there are also functional outcomes of how it looks, how it performs, whatever that procedure is."*

We asked participants about nontechnical skills for surgeons (NOTSS), such as situation awareness, decision making, teamwork and leadership. There was a mixture of responses on whether nontechnical skills contribute more to the development of competency or autonomy. Only 20% felt that NOTSS contributed to competency alone: *“I think that those are more towards autonomy because, again, your competency is just that you can do something...But to be truly autonomous as a surgeon, you need to be able to manage all those outside factors like patient selection.”* Participants were asked whether technical skills of a surgeon or NOTSS were more important for independent practice. For this question there was a disagreement amongst faculty and trainees. Trainees (85.7%), believed that NOTSS were more important for independent practice, whereas there was a varied response from faculty surgeons. A faculty surgeon replied with the following, *“I think having a technical competence is the key. Outcomes matter and outcomes are surgical outcomes...but I think for decision making, there is always a multidisciplinary involvement, but technically, it is always the surgeon who's just operating.”* Despite the perceived importance of NOTSS, 0% of trainees indicated that they were specifically taught nontechnical skills during residency. One trainee indicated that they are taught through observation, *“They're taught in a way maybe not directly, but you also have to be a little bit proactive and see what cases your staff are saying no to or saying yes to and compared to what your decision was or what your judgment was at that time.”* A faculty surgeon noted regarding the EPAs, *“If you look at all the EPA's, the vast majority are technical. So that is certainly something that we focus on... because the EPAs don't, for the most part, don't directly judge that or evaluate that.”*

Question	**Trainee Responses (n=7)**	**Illustrative Quote**	**Faculty Responses (n=9)**	**Illustrative Quote**
Are the transition to practice (TTP) EPAs reasonable to achieve?	Y: 57.1% (4) N: 42.9% (3)	"I think the achievement of these entirely depends on the abilities of the trainee, to be honest with you...They were like, they are achievable, but it will be tough for every single person to achieve these things."	Y: 33.3% (3) N: 66.7% (6)	"No, I think it's appropriate to strive for those goals. Whether it's appropriate to not pass a trainee who doesn't achieve those goals, I think that's a different question. The problem is, if you don't put those goals in there, we're never going to move the needle to try to get to that point."
During the TTP will trainees be allowed to operate only with an assistant?	Y: 0% N: 100% (7)	"No. Absolutely not. Absolutely not."	Y: 22.2% (2) N: 77.8% (7)	"I doubt it. No. What you have to remember is that surgeon's reputation is still on the table."
Are competency and autonomy the same?	Y: 14.3% (1) N: 85.7% (6)	"Well, I think they're different.… But competency is being able to apply your autonomy in a way that is competent."	Y: 0% (0) N: 100% (9)	"I think being competent is one component of being autonomous...but I think in order to be autonomous, you have to be competent."
What is the goal of surgical residency, a competent surgeon, autonomous surgeon, or both?	Competent: 85.7% (6) Autonomous: 0% Both: 14.3% (1)	"To get a competent trainee...Whereas I think that the goal should be to be autonomous."	Competent: 87.5% (7) Autonomous: 0% Both: 12.5% (1) (1 did not answer)	"I think our goal has always been to produce competent surgeons. I think it would be great if we could strive to produce autonomous surgeons...I think that if we can strive

				for competency and people can go out and be well surrounded by other colleagues that can help lead them towards autonomy”
Do NOTSS contribute more to the development of competency or autonomy?	Competent: 28.6% (2) Autonomy: 42.9% (3) Both: 28.6% (2)	“I think that those are more towards autonomy because, again, your competency is just that you can do something...But to be truly autonomous as a surgeon, you need to be able to manage all those outside factors like patient selection”	Competent: 12.5% (1) Autonomy: 37.5% (3) Both: 50% (4) (1 did not answer)	“Both. I see it as a serial thing. So if you're not competent, you're not going to achieve autonomy.
What is more important for independent practice, technical skills, nontechnical skills, or both?	Technical: 0% NOTSS: 85.7 (6) Both: 14.3% (1)	And I think we all know surgeons who have very good technical skills but very bad outcomes. And usually these are driven by either poor patient selection, wrong operation for the wrong patient, bad timing, or it's because the entire team around the operation is not functioning	Technical: 25% (2) NOTSS: 37.5% (3) Both: 37.5% (3) (1 did not answer)	“I think that's mostly the decision making because I think that's one of the harder things to get as well. And it's based mostly on experience and making mistakes and learning from them.” “I think technical elements are so hard in heart surgery, right? And there's just 1000 things that can go wrong technically and it's really hard and not everyone's going to get it

				and not everyone should be a heart surgeon."
Are NOTSS taught in residency?	Yes: 0% No: 100% (7)	"I think they can definitely be taught. I think we do a terrible job at teaching them."	N/A	N/A
Do you use a subjective or an objective assessment when evaluating trainees?	N/A	N/A	Subjective: 88.9% (8) Objective: 11.1% (1)	"I think it's way more subjective...So what we've been doing thus far has worked reasonably well, and it will take time to determine whether objective numbers will really add to our assessment of competence."

Table 6.4: Content analysis with illustrative quotes from both trainees and faculty surgeons.

Thematic Analysis

Table 6.5 highlights the themes, subthemes, and illustrative quotes of this analysis. Following the table, further discussion of those results will take place.

Research Question	**Themes**	**Subthemes**	**Illustrative quotes**
Question #1a): What are the attitudes and perspectives of cardiac surgery staff and trainees on competency?	Expected level of skill, that is reproducible and to a particular standard	Subjective assessment	"So, competence is the ability to achieve a goal or I guess a performance of an aspect to the standard that's acceptable"
		No clear criterion for trainee progression – subjective gestalt	"For me, it's just watching them do things."
	Tension between training level and expectation of competency	"A PGY-x should be able to do x, y, z"	"Some cases I don't really negotiate beforehand if it's like a CABG, it's more like assumed that a senior trainee will be doing most if not all the steps." "So, most of the surgeons are still treating us by year instead of by how much experience we have"
	Graduated responsibility		"We're looking to make sure that they can do a certain task with a fairly high level of consistency without complication and the need for intervention."
	Contentious Royal College expectations	EPAs are not reasonable for every trainee	"I think that they're reasonable for some people to learn...But somebody who's not gifted, if they're successfully completing CABG and AVR in a safe way, then maybe that's okay. And then they need some more time to kind of develop further...So I just don't think that it's reasonable to have a trainee do these things" "Advanced procedures with an assistant. So those ones, again, I think, really depend on the surgeon you're working with. But I don't think that it's necessarily a reasonable idea to say that all trainees in Canada would be competent at an aortic dissection

			or even things like a Bental by the time they finish, depending on who they're trained with and how much they're allowed to do. I think those are procedures that, as a junior staff, you can call upon senior staff to help you with cases like that until you get your comfort level up. But I don't think they're necessarily things that we can say all trainees across Canada are going to be competent at those procedures by graduation.
		Fellowship level of training	"Are they going to be doing this in their practice? is that something that is needed to be done by every trainee versus something that could be done sort of at a fellowship level?"
		Training programs are struggling to keep up with the change in scope of a practicing cardiac surgeon	"And the problem is that the Royal College is trying to push an agenda which is too far, too fast, I think, for cardiac surgery, and it does not reflect a thoughtful engagement with cardiac surgery programs across the country in terms of, is this achievable?"
		EPA scoring system unclear	"There are also many staff that don't understand the scoring system in CBD. So, there'll be things that you do completely autonomously, where you're getting a two or a three, and then things where you're doing in the or that you need a little help and you'll get a five. So, the scoring system isn't good. It's not taught well to the staff what the scoring system is." "I think people will be overstating what they can do, or the programs will realize, oh shit, we're going to have a bunch of people that aren't going to be able to graduate or else people won't be graduating in the last year."
Question #1b): What are the attitudes and perspectives of cardiac surgery staff and trainees on autonomy?	Autonomy is a step beyond competency and involves decision making preoperatively, intraoperatively, and postoperatively.	Independence from faculty supervision	"Having been able to accomplish a given task without external guidance.... And that's how we differentiate it from competency that the guidance part, I think, is not needing outside help necessarily is important for autonomy"

	Requirement for staff-level experience	No feedback is still feedback	"Because I think that when you have staff in front of you, even when they don't say anything, that is still feedback.... So even the fact that they don't say anything, you know that they will never let you do something that would endanger the patient"
		Not autonomous until your name is the only one on the chart	"Yeah, well, it's the big thing, and this will be a hard thing to get even in that transition to practice, is that the stress of it all is way worse than anybody would expect. And it's kind of a cliche that it feels different when your name is on the chart"
Question #2: What is the goal of surgical training?	Ideal goals may not be realistic	In an ideal world an autonomous surgeon, but in reality, a competent surgeon	"I think our goal has always been to produce competent surgeons. I think it would be great if we could strive to produce autonomous surgeons...I think that if we can strive for competency and people can go out and be well surrounded by other colleagues that can help lead them towards autonomy"
	Safe surgeon		"Safe cardiac surgeons, who have a baseline level of function, who have enough insight to go and get further training if they should need it"
	Prepare for fellowship training	Time period for further specialization	"I'm going to say competence, because within the confines of, like, our specialty and the expectations of further training and being brought in and sort of mentored into early staff hood, I think residency, the way it's laid out is residency is for competency."
		Time period for trainees who need more time	"So, competency, I would say, is more important because you can still go to fellowships, or you can still go into program and get mentored into the autonomy" "I almost don't necessarily think it needs to be there at a trainee level. I think seeing the transition of many staff in their early stages of operation, I think we're achieving higher levels of competence at the residency stage. And then a lot of these things are then reinforced at the fellowship level. And I think there's an ongoing learning process in the first year of staff."

Question #3: What is needed for independent practice?	Initial supportive role of more senior faculty members	Mentorship	"In my view, I feel all who have trained in Canada and graduated, I would say majority, are able to operate very well, routine cases then the support system that I call onboarding is the key. So if any center does not offer that to a new attending, a young attending, the fault is on the center and that's an obstacle actually, I don't see that every center does that."
	Nontechnical skills – decision making	Smart patient selection	"I think that's mostly the decision making because I think that's one of the harder things to get as well. And it's based mostly on experience and making mistakes and learning from them.... And I think that's where people can get into trouble the quickest is by making some bad decisions"
		*Poorly trained in residency	"I think they can definitely be taught. I think we do a terrible job at teaching them." "I think for sure they can be taught. In medicine we don't get a lot of training regarding communication or management or leadership or these kinds of things."
	Lived experiences	You don't know what independence is until you know	"The transition to practice will be good from the technical point of view and I think from a decision making and a judgment, but I don't think it will emulate the coping and dealing with the stress of it all. ...I don't think it's something that people can truly appreciate until they experience it."
Question #4: What are the barriers to achieve an autonomous surgeon by graduation?	Patient factors	Patient safety	"I think patient safety is a key factor." "I think it's fine to let them struggle for a little bit, as long as it's not harming the patient"
		Medical legal issues	"Number one, medical legal risk. Just how our field has very little risk for error and how our outcomes are monitored very closely."
	Surgeon factors	Surgeon comfortability with the	"Surgeons who aren't comfortable enough themselves to give up their case fully to a trainee in training because they're

	procedure themselves	worried about a reflection on themselves, and they're worried about handing over that responsibility.” “At my level, I still consider sort of an early career. Yeah, there are some that if I don't do them enough in my even hands, then my comfort level, even though I'm probably one of the more generous from what the trainees tell me in terms of giving in the OR. But there are some things that let's say I would still need to have my hands on versus someone who's much more senior surgeon and I think they understand that and appreciate that.”
	Number of years surgeon has been in practice	
	Surgeons are not educators	“And not everybody has the same rapport with trainees and has the same interest in educating the surgeons of the future instead of just letting them be exposed to what people are doing.”
Trainee factors	Different pace of learning	“I think in an ideal world, it would be nice to have specific metrics that are reproducible or standardized across training programs. However, I also worry that in doing that, people learn at different rates in different ways, and I worry that in doing that, I think we would overall have a certain standard, but some trainees might not succeed in that kind of program, whereas otherwise they maybe can come out as competent surgeons.”
Time	External factors – OR management issues	“We're time limited in terms of time of certain cases and such, then we'll say, okay, in this case you'll do this, this and this, and you'll keep going until kind of we're getting pushed for time.”

	Lack of exposure to procedure type	“I think a better way of putting it is I think some of the goals, the targets are beyond what a trainee is likely to get exposed to based on particular surgeon and that particular trainee”
Program Setup	Lack of consistency: multiple sites, multiple surgeons	“You may be assigned to virtually any staff any given day so there's not a lot of consistency there and it's a little bit of a challenge.”
	Level of exposure to the growing breadth of cardiac surgery	“But I know that one of them has done it, but the other two have not because they haven't seen it in their training.”

Table 6.5: Thematic analysis with supportive illustrative quotes from both trainees and faculty surgeons.

Question #1a): What are the attitudes and perspectives of cardiac surgery staff and trainees on competency?

There was a consensus that competency was felt to be an expected level of skill, that is reproducible and to a particular standard of that surgical specialty: *"The ability to demonstrate a skill to the level that is expected of a professional in surgery."* Identified in the content analysis, competency is determined by a subjective assessment by faculty members, "*I think that bird's eye view, subjective stuff is still important because especially experienced surgeons, when they're seeing something, they get an idea of whether something is good enough or not."* With subjective assessments, there is no clear criterion for trainee progression, and this contributes to a tension between training level and expectation. This tension results in operative experience being limited for junior trainees compared to senior trainees, *"I think we do a good job giving trainees hands on experience toward the end of training, but I think we need to do a better job towards the beginning of training and middle*."

With the introduction of Competence-By-Design, contention between the Royal College of Physicians and Surgeons of Canada expectations of an autonomous trainee at graduation and the current practice of Canadian cardiac surgery programs has been created. As identified in the content analysis, the specified EPAs for the TTP year were felt to be unreasonable for every trainee to achieve. This is confounded by an expectation that cardiac surgery trainees will go on to fellowship to further develop their skills, placing less pressure on residency programs to prepare trainees for independent practice.

Contributing to the contention is an unclear EPA scoring system for the TTP year, such as what defines an "experienced assistant." A participant responded with, "*Well, let's just put it this way, so if you look at Transition to Practice, EPA number four, it says performing this with an experienced assistant, right? So being able to do a Bentall with an experienced assistant, that's one. Now, being able to go out and do a Bentall completely by yourself with a first-year trainee in your first year of practice, that might be pushing your luck, but that's not what EPA number four says."* The EPA scoring system is also subjective, introducing rater variation depending on which faculty surgeon is assessing the trainee.

Question #1b): What are the attitudes and perspectives of cardiac surgery staff and trainees on autonomy?

Autonomy was felt to be beyond competency and highly revolves around decision making preoperatively, intraoperatively, and postoperatively. There was a general sense that to be autonomous, you as the trainee are capable of functioning independently from the faculty surgeon, *"Autonomy is being able to be able to do tasks that you are competent at independently."* Put in a different way, to be autonomous, a trainee must be competent, but a trainee can be competent and not autonomous. To achieve autonomy in residency is challenging for a multitude of different reasons. Again, like the assessment of competency, it is a challenge to assess a trainee's readiness for independence, *"It's a bit like trial and error...But it's a combination of the trainee telling us what they're comfortable with, hearing from their other supervisor, what they've done and how they've progressed, and then just giving them a chance."*

Many individuals felt that a trainee can never truly possess autonomy during residency because the responsibility of the patient is ultimately always with the faculty. Faculty members acknowledged that during the transition to practice year, while they will not feel comfortable not scrubbing for the procedure, they plan on remaining silent and provide as little guidance as necessary, *"My goals is in TTP, and maybe I'm going off on a tangent here. We will be there, but my goal is to say absolutely nothing. But if I see something that's going to either harm the patient or harm my reputation. Trust me, you'll be a surgeon someday, too, and you'll have a reputation to defend. I'll say something, all right? And I have no issue with that. But my goal is to stand there and say nothing, and if that's the case."* This leads to the issue of being able to determine whether someone is capable of being independent after they graduate and do not have a faculty member present, "*Because I think that when you have staff in front of you, even when they don't say anything, that is still feedback.*"

Question #2: What is the goal of surgical training?

Nearly unanimously, participants believed the goal of surgical training was to produce competent surgeons (86.7%, Table 6.4). Individuals expressed that in an ideal world, it would be autonomous surgeons, but within the restraints of surgical residency, a competent surgeon is enough. A trainee expressed the following, *"And I think if at the end of residency you can very comfortably deal with the common things and you can at least start to initiate management of the complex things, then I would consider that to be a successful residency training...So the reality is probably the bar that we set is a little bit lower than what we would hope for at the end of your training…"* Along the same lines, there was the belief that ultimately a safe surgeon is the goal.

An additional theme that emerged, was that the assumption after residency training is that you're not going into independent practice, you are going to fellowship, *"So competency, I would say, is more important because you can still go to fellowship."* Which wasn't agreed to by all, *"In the past, there's been the philosophy that some of those things' trainees will learn in fellowship. Right. And personally, I don't really agree with that. Certainly, there's lots of things that people will learn in fellowship, and they'll likely get better at a lot of other things as well. But those are EPA's that are highlighted to say they have to be able to do that."* Another faculty reflected on their own experience, *"I felt that I had decent training during residency, but I felt that I became a competent, autonomous surgeon during fellowship rather than during residency. I think I had the tools during residency, but then I solidified that later on. I do hope that we can have trainees feeling what I felt at the end of fellowship, that they feel that at the end of residency, I think it's harder to achieve, but I think it's possible."*

Question #3: What is needed for independent practice?

Identified by trainees and faculty alike, a successful transition to independent practice requires ongoing mentorship from faculty surgeons at your center, *"I think those are procedures that, as a junior staff, you can call upon senior staff to help you with cases like that until you get your comfort level up."* While technical competency is needed for independent practice, it is the nontechnical skills, such as decision making (patient selection) that are crucial, *"But I think to be independent, it is the decision making more than the competence. Because if you can make decisions, you'll know your abilities on competence, and then you won't take on things you shouldn't be. If you have confidence and no decision making, you'll kill more people than the person doing it* *the other way around."* Another participant said, *"And I think we all know surgeons who have very good technical skills but very bad outcomes. And usually these are driven by either poor patient selection, wrong operation for the wrong patient, bad timing, or it's because the entire team around the operation is not functioning,"*

Finally, the notion that residency can only prepare you for independent practice to a certain extent, and that ultimately lived experiences are needed, *"And I guess complementing the answer is, I think we need a period after training where you're allowed to fly on your own kind of thing, to develop your autonomy or confidence or both together, I guess. Right. To polish, I guess, your judgment and decision making. You build the knowledge, you know what to do, but now you need to fly solo a little bit just to build the confidence, or I guess on top of that, the autonomy to make those decisions."*

Question #4: What are the barriers to achieve an autonomous surgeon by graduation?

Lack of consistency amongst who the trainee operates with daily. Out of the nine programs interviewed, only one program incorporated a model where the trainee worked with a single surgeon for an extensive period. Majority of programs are organized with a team-based model, where a trainee will work with 2-3 surgeons at a time. An additional barrier to provide a longitudinal relationship between trainee and faculty surgeons are programs who have multiples sites that the trainee must rotate through. *"I think that the model of working with someone different every time can only work if you over the last five years, everybody has spent a lot of time with that trainee."*

As mentioned previously, the notion that you can't be autonomous until you are autonomous comes down to patient safety, "*Technical demand and importance of* *efficiency while on pump in the OR, I think are important, and that ties into patient safety, of course,"* and the medical legal issues, *"I think that patients would be shocked to learn if the surgeon was not scrubbed in. I don't think our patients are ready for that."* Patient safety and medical legal issues prohibit trainees from functionally independently for critical aspects of the operation.

Volume and exposure to the breadth of cardiac surgery are two important factors that contribute to the trainee's ability to develop competency. As this will be impacted by the surgeon trainees are working with, both from a comfortability level and a surgeon's case load. During a rotation, trainees may only work with surgeons who perform aortic surgery, when what they really need to develop is their coronary skills. *"So, there are some things on that list I think that it's certainly a sort of a minimum that any cardiac surgeon should do and others that are not in our current structure. I would say none of our surgeons would be giving mitral valve repair, I wouldn't because I'm not the mitral guy and if a mitral comes in I see it once in a while so I probably won't versus XX may because he's doing the mitrals."*

Time is another barrier. Trainees have different learning styles and will progress at different rates. Compared to the previous era of trainees without duty hour restrictions, time in the operating room has been reduced, *"But you know, the amount of time I was in the or was like I want to say a good 30% 40% more time in the or than currently I find trainees are spending. And so yeah, when I look at my cohort myself and like two or three other surgeons plus or minus one year or a few years and a lot we're achieving skin to skin stuff. When I surveyed around was by third year my first cases of skin-to-skin cabbage and AVRs and stuff was third year. I think some trainees will reach* *it now who are ahead of the curve but is not the average trainee achievement. It may be at a slightly later stage, but that pushes everything else that's more complex a little further down and then you come to the end."*

Time also relates to logistical issues, as there are many external factors that need to be considered, such as OR management and rarity of case types*, "And if the day is going to take longer, we're going to lose nurses. And if we lose nurses, you cancel cases. And if you cancel cases, you have patients dying on the wait list. Is that safe?"*

Discussion:

This study explored the attitudes and perspectives surrounding competency and autonomy in Canadian cardiac surgery trainees and faculty. It was generally agreed upon that competency is an ability to perform a specific task to an acceptable standard with reproducibility. Competence as is defined by the dictionary is "the quality or state of being functionally adequate or having sufficient knowledge, judgment, skill, or strength (as for a particular duty or in a particular respect" (Merriam-Webster, 2022b). Autonomy was felt by most to be a step beyond competency and is the ability to make decisions, independently. Autonomy as is defined by the dictionary is "the quality or state of being independent, free, and self-directing"(Merriam-Webster, 2022a). Participants believed that the goal of surgical training was to produce competent trainees, which is in discordance with the RCPSC which is meant to prepare graduating trainees for independent practice.

Barriers to producing autonomous surgeons are many but identified themes included lack of clear assessment tools, program set-up including external factors such as OR management, surgeon, and trainee factors. As there is a paucity of validated assessment tools for intraoperative procedures in cardiac surgery, a call to create objective, procedure assessment tools may be required to help facilitate this gap (White et al., 2022). Previous studies on general surgery trainees identifies similar barriers, such as level of surgeon comfort, desirability of the surgeon to teach, relationship with surgeon, time constraints, trainee skill level and preparation of the trainee (Cassidy et al., 2021; Hammond Mobilio et al., 2020; Hashimoto et al., 2016; Teman et al., 2014). Chen et al. (2017) identified five key components from expert surgical teachers' assessments of trainee's readiness for autonomy including: resident characteristics, medical knowledge, and beyond the current case (example: residents' reputation, evaluations) factored in with attending variable and context variable (example: emergency, OR restraints, case complexity) (Chen et al., 2017).

In general, goals of surgical education are outlined as producing trainees with: (1) sufficient knowledge, (2) communication skills, (3) proficient technical skills, and (4) excellent clinical judgement (Thomas, 2006). Communication skills and clinical judgement fall under the umbrella term of nontechnical skills. Identified in this study is the need for nontechnical skills to bridge the gap between competency towards autonomy and the need for nontechnical skills for independent practice. Despite this sentiment, nontechnical skills are poorly implemented into surgical residency programs (Allard et al., 2020; Dedy et al., 2013, 2016; Kim et al., 2022; Vervoort & Hirji, 2020).

Possible solutions to barriers identified are changing models of training from multiple sites, multiple preceptors to a single preceptor or small team to provide consistency to trainee learning. Longitudinal contact has previously been identified to help facilitate entrustability in the operating room, as it allows for trainees to demonstrate competency over time (Sandhu et al., 2017). Progressive entrustment can help foster an environment for autonomy. A common theme that emerges is rapport between trainee and faculty as it contributes to operative autonomy, providing more consistent interaction between trainees and faculty is an important solution (Hammond Mobilio et al., 2020; Salim et al., 2020; Teman et al., 2014). Progressive entrustment parallels with scaffolding and fading as they pertain to the cognitive apprenticeship model (Collins & Kapur, 2014; Lajoie, 2010). An additional consideration is the strategic planning on matching of trainee to preceptor, to identify the EPA needs of the trainee with the faculty that more commonly performs those cases or who are more suitable to teaching a particular level of trainee.

An additional barrier is the contention between the RCPSC EPA requirements for the TTP year and the realistic operative expectation. In chapter five, we demonstrated that graduating trainees were not functioning at a "supervision only" level of autonomy as per the Zwisch scale (Darosa et al., 2013; Meyerson et al., 2017), which is in keeping with the faculty surgeon respondents that the TTP EPAs are not realistic for every trainee. Surprisingly, there is a discrepancy between trainee respondents regarding the TTP EPAs who believe they are realistic to achieve. This discrepancy has been previously noted in the literature on resident expectation and faculty evaluation (Meyerson et al., 2017). As outlined as a possible solution in chapter five was allowing trainees to spend more time in the transitioning phases, "active help" and "passive help", to help prepare them for their final year of practice. This sentiment was expressed by a faculty participant who responded with *"I think we do a good job giving trainees* *hands on experience toward the end of training, but I think we need to do a better job towards the beginning of training and middle*." Changing the mentality that even more complex or advanced procedures can provide a learning opportunity if the learning objective is geared towards the trainee may be a solution. Lillemoi et al. (2019) created an "educational timeout (ETO)" as an intervention to help improve the educational experience of their general surgery residents (Lillemoe et al., 2020). This ETO had three questions to help determine the learning objective for that case, (1) what step of the operation do I want to focus on? (2) what is my current level of competence for this step? And (3) what techniques or strategies can I use to reach my goal competence level for this step? (Lillemoe et al., 2020). They found there was improved resident educational experiences and because there was a specific learning objective, it allowed for better postoperative feedback from their faculty (Lillemoe et al., 2020). An important element is the creation of learning objectives should be a shared responsibility between both faculty surgeon and trainee (Woelfel et al., 2020). The idea of an educational contract can help increase learning opportunities for trainees and can simplify the teaching for faculty surgeons. A similar model, called the BID (briefing, intraoperative teaching, debriefing) model could help reduce time restraints in the operating room by simplifying what the faculty surgeon feels responsible to teach by emphasizing the learning objectives discussed in the briefing (Roberts et al., 2009). A final essential component is the debriefing, which includes four components: (1) reflection of the learner, (2) general principles, (3) reinforcing what was done right, and (4) correct mistakes (Roberts et al., 2009).

Conclusion:

Our approach to cardiac surgery training can be improved, and this study is the first of its kind to use a qualitative analysis on trainee and faculty surgeons' opinion on cardiac surgical training. Previous studies have identified similar barriers to operative autonomy and moving forward we need to focus on the solutions. Creating a more comprehensive approach to cardiac surgery training, focusing on the creation of an educational contract between trainee and faculty and emphasizing both technical and nontechnical skills will be essential for trainees to graduate ready for an independent practice.

Based on the needs assessment and qualitative analysis, we will now move into our discussion on simulation-based training, starting with our novel simulator design for technical skills and concluding with our team-based training model for nontechnical skills.

CHAPTER SEVEN: SOURCES OF VALIDITY FOR A NOVEL CARDIAC TASK TRAINER FOR TECHNICAL SKILLS

This chapter describes a complete study which looked at the development of a novel cardiac task trainer with functional task alignment to practice cardiac surgical skills.

Introduction:

The traditional apprenticeship model of surgical training is no longer sufficient in the current era of trainee duty hour restrictions, an increased focus on patient safety and an increase in the complexity of cases (Sutherland et al., 2006; Trehan et al., 2014). The operating room is an area of low tolerance for inefficiency and error, and does not allow for deliberate practice, an important building block for expert performance (Ericsson, 2003; Rowse & Dearani, 2019). These limitations may be addressed through simulation. A key element of successful simulation-based training for technical skills is using a model with high functional task alignment, (Hamstra et al., 2014) in which the task aligns with what the trainee will be asked to do in the operating room. Cardiac surgical operations are complicated by minimal space of the mediastinum (the cavity within your chest that contains the heart) and patient anatomic factors, such as varying chest cavity depths. An ideal model for deliberate practice of cardiac surgical technical skills should include a model that incorporates the anatomical constraints of the mediastinum, is patient-specific, easy to access, and allows for deliberate practice (Loor et al., 2016; Russo et al., 2020; Said, 2015). Current limitations of simulators in cardiac surgery are they lack functional task alignment. A needs assessment identified that the two most common simulators used in training are partial task trainers for coronary artery anastomosis and a porcine heart model. The weakness of both is that they are used in isolation without the mediastinal constraints. The major strength of the porcine heart model is the tissue quality and anatomical similarity to human heart. A recent systematic review identified that few assessment tools in cardiothoracic and vascular surgery have validity evidence to support their use (White et al., 2022). Similarly, there are few simulators that have been validated for aortic valve replacement and coronary artery bypass. While studies have shown the effectiveness of using simulation for coronary artery anastomosis, (Fann et al., 2008; Spratt et al., 2019), the literature is scarce on the effectiveness of aortic valve replacement models.

To answer trainees' call for simulation-based training from a recent needs assessment (White et al., 2021), we have developed a portable model to practice coronary artery bypass and aortic valve replacement. Messick's framework focuses on gathering types of evidence including content, response process, internal structure, relationship to other variables and consequences (Calhoun & Scerbo, 2022; Cook & Beckman, 2006). Common sources of evidence of a novel simulator include functional task alignment, content, and relation to other variables as sources of validity evidence, more challenging to obtain for surgical simulators is consequences (Cook & Beckman, 2006; Ghaderi et al., 2015; Kenney et al., 2009; Russo et al., 2020). Functional task alignment assesses the degree of resemblance between the task trainer and the intraoperative task. Content assesses whether the task trainer is a suitable educational tool to teach the constructs of the intraoperative task, and relation to other variables determines whether the task trainer can differentiate between experience levels or skill of the users, or the correlation with other assessment tools (Carter et al., 2005; Ghaderi et al., 2015;

Kenney et al., 2009; Russo et al., 2020; Schout et al., 2010; Soriero et al., 2020). Based on existing limitations of current simulators, the purpose of this study was to design a novel cardiac surgical task trainer for coronary artery anastomosis and aortic valve replacement. The task trainer is meant for use by cardiac surgery trainees or medical students with an interest in cardiac surgery. The task trainer is portable and can be used both for at-home practice or in a controlled environment, such as a simulation lab. Herein, we describe the development of the task trainer and provide a pilot study to gather sources of evidence for validity by using participants of varying experience in cardiac surgery.

Methods:

Ethics Approval

Approval for the study was granted by the Health Research Ethics Board of the University of Alberta. Written consent was obtained from each patient prior to their operation, as patients' geometric data was obtained to develop the simulator. Written consent was additionally obtained from each participant who were involved in testing the simulator.

Task Trainer Development

To create the adjustable and patient-specific task trainer, intraoperative measurements were taken from patients undergoing CABG (N=10) and AVR (N=20). The measurements were taken in three axes using a standard surgical ruler. The measurements were combined to create three levels of difficulty: easy, medium, and hard. The difficulty level is related to skin incision size, mediastinal depth, and the position of the coronary artery/aortic annulus relative to the incision, along with input from the surgeon during data collection regarding case difficulty. The task trainer recreates these variables using a cover with three different aperture sizes to simulate incision size, adjustable depth of the model relative to the incision cover and adjustable craniocaudal location of the model within the task trainer box to simulate anatomical position of the coronary artery/aortic annulus. A hired industrial designer helped create the *beta* version of our task trainer. The *beta* version was developed using a cardboard box. This *beta version* was pilot tested by a senior cardiac surgery trainee and staff cardiac surgeon. Adjustments were made based on initial feedback. The final task trainer was built using plexiglass (Figure 7.1 and 7.2). An engineer at the University took our design and built our final model. The crux of cardiac surgery is being able to operate at depth, requiring adjustments to needle angle. A critical step of an aortic valve replacement is the placement of sutures along the annulus to seat the new aortic valve. The aortic annulus is a fibrous ring that attaches the aortic valve leaflets. The aortic valve is the connection between the left ventricle of the heart and the largest artery in the body, the aorta. A critical step of a coronary artery bypass is the distal anastomosis. The distal anastomosis is when a piece of artery or vein is sewn in a circular fashion to the coronary artery. The distal anastomosis is the location of the distal aspect of the new bypass graft. After discussion with experts (senior trainee, surgeon, and program director), the AVR model and coronary model were designed for trainees to practice those critical steps.

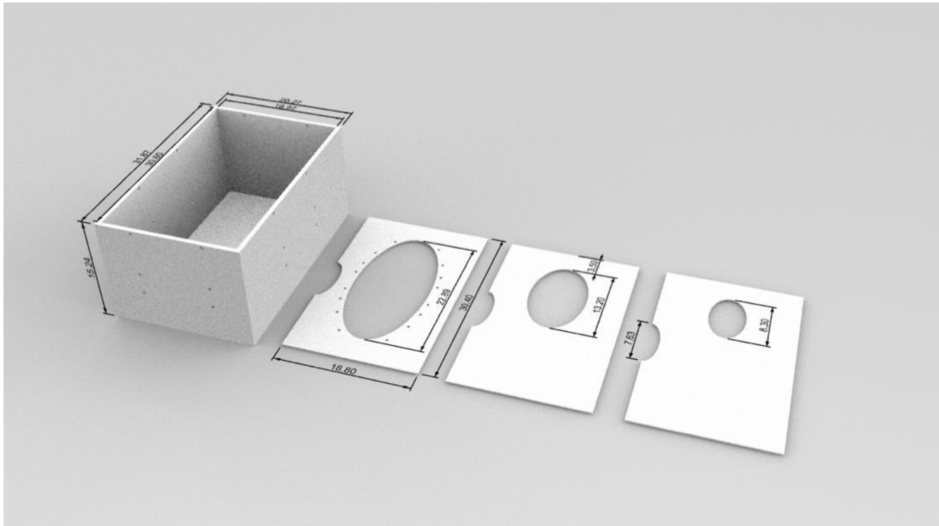


Figure 7.1: Graphical representation of chest cavity with measurements.

Figure 7. 2: Final plexiglass model. Board is positioned at the second level of depth and the largest lid size is shown.

Coronary model

The approach for coronary artery bypass grafting is through a full sternotomy, so the largest incision of the model would be most appropriate for the coronary model. To allow for at-home, individual practice, holes were placed around the edges of the largest incision, to allow for placement of alligator clamps (Figure 7.3). The alligator clamps serve the role of the surgical assistant to hold the conduit for bypass. The CABG model consists of a 3D printed spherical surface made from thermoplastic polyurethane (TPU) with multiple attachment points over its surface to simulate the location and course of various target arteries such as the left anterior descending artery (LAD), obtuse marginal artery (OM) and posterior descending artery (PDA) (Figure 7.3). This allows the trainee to practice different distal coronary targets, depending on how they position the silicone tubing on the spherical surface. The coronary artery was simulated using silicone tubing.

Figure 7.3: Example of the coronary model setup.

AVR model

The approach for an aortic valve replacement can be through a full sternotomy or a hemi sternotomy. Intraoperatively, a hemi sternotomy extends from the sternal notch down to the level of the 4^{th} intercostal space, rather than at the xiphoid process (full sternotomy). This creates a much smaller incision. All three incision sizes would be appropriate for the AVR model, as the model is designed to simulate both a full sternotomy approach and a hemi sternotomy approach to an AVR. The AVR model consists of an aortic root that was cast in silicone using 3D printed molds of a patient's computed tomography (CT) angiogram (Figure 7.4) (Russo et al., 2020). A scan with excellent contrast opacification in the arterial phase and no calcium at the level of the aortic valve was chosen so that the valve could be visualized to create the model. A non-aneurysmal ascending aorta and root was chosen, as that is a more commonly encountered model for a patient undergoing an aortic valve replacement.

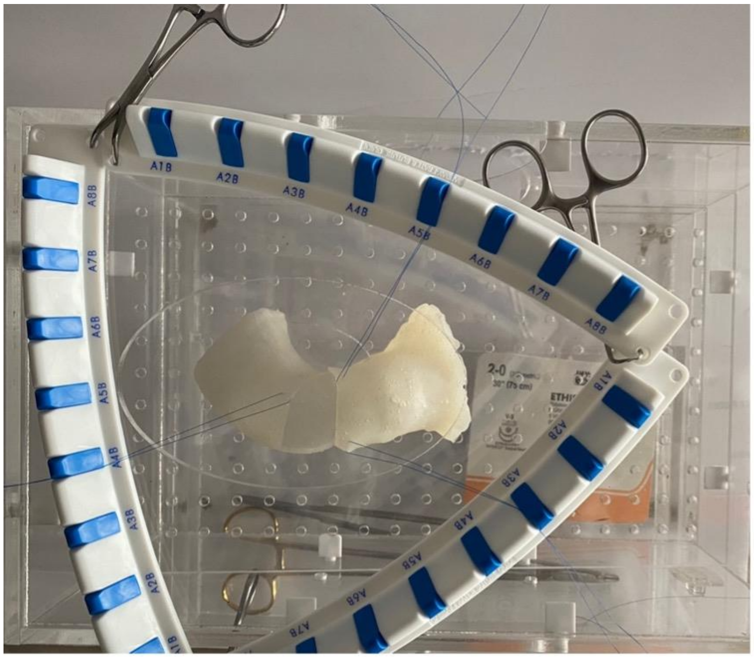


Figure 7. 4: Example of the AVR model setup with the silicone aortic root.

Validity Assessment

Participants

To assess validity, members of the cardiac surgery community from the University of Alberta were recruited. The participants were divided into three groups: novices, intermediates, and experts. Novices were classified as 4th year medical students with an interest in cardiac surgery along with 1st and 2nd year cardiac surgery trainees. Intermediates were classified as 3rd to 6th year trainees. Experts were classified as cardiac surgery fellows and surgeons. Basic demographic data including intraoperative experience were collected from each participant.

Task

Key elements of a coronary anastomosis are suture management, needle angles, bite spacing, and tying a knot using a 6-0 or smaller polypropylene suture. For assessment of the task trainer, participants were asked to sew a 3 mm conduit to a 3 mm coronary artery oriented in the position of the LAD. To maintain consistency, the conduit was beveled by the assessor and the arteriotomy was made in the coronary. The participants were all given the same instructions at the start regardless of their experience level. They were encouraged to take 10-12 bites on the coronary artery to complete the anastomosis.

Key elements of an aortic valve replacement are adequate exposure, excising the valve, annular needle angles, suture management, and implanting the valve in the correct orientation. Normally 12-15 sutures are required to complete an aortic valve replacement. That would equate to 3 commissure sutures and then 3-4 bites per sinus. For assessment of the task trainer, participants were asked to place 6 annular sutures, 3 commissure sutures and then 1 suture at the nadir. To maintain consistency, the aortotomy was created and valve excised to allow for good exposure. Following placement of valve sutures, the participants were asked to place them through the sewing ring of a 21 mm bioprosthetic valve and tied them down.

The participants performed the task in the Surgical Simulation research lab at the University of Alberta using an adjustable table to allow for variation in participants heights.

Validity Evidence

We applied Messick's framework of construct validity, which involves five sources of evidence (Calhoun & Scerbo, 2022; Cook & Beckman, 2006; Ghaderi et al., 2015). Content evidence supports the notion that elements of the task trainer are related to the construct being assessed. Response process refers to the accuracy of the results obtained from the instrument. Internal structure is often thought of as "reliability," how reproducible and generalizable are the results. Relationship to other variables demonstrates that scores can be correlated with other measures, such as experience level or previously used instrument scores. Finally, consequence is the application of the results to the "real world" setting. In this current study we sought to gather evidence of content, process response, internal structure, and relation to other variables (Cook & Beckman, 2006; Ghaderi et al., 2015).

Content

Functional task alignment and content were assessed by having the participants perform a distal coronary anastomosis and an aortic valve replacement using the model. Participants completed a 7-item questionnaire, using a 5-point Likert scale. The coronary model was designed to assess the following procedural steps: anastomotic sewing, anastomotic parachuting, and knot tying. The AVR model was designed to assess annular suturing, valve positioning, and knot tying. These steps were identified by discussion with practicing cardiac surgeons and previously used OSATS tool for AVR and CABG (Feins et al., 2017).

Response process

All tasks performed were recorded. Using video analysis software called BORIS (Behavioral Observation Interactive Software), objective performance data were collected. The following performance metrics were analyzed for the coronary anastomosis task: anastomotic time (minutes), number of bites, number of re-attempts, knot tying (minutes), duration of arterial bites (seconds), duration of venous bites (seconds). Clear definitions were outlined in the video software prior to initiation of video analysis. Anastomotic time started when the needle was loaded on the driver and the final suture after being tied was cut. Re-attempts were defined by 1. reloading the needle and 2. anything other than single entry into the coronary artery. Duration of venous bites and arterial bites were both defined by the moment the needle was loaded to start and the needle was re-loaded to start the next bite to finish.

Performance metrics for the aortic valve replacement model included: total replacement time (minutes), annular suturing time (minutes), knot tying (minutes), annular bite time (seconds) and number of re-attempts. Total replacement time was defined as the initial needle load to when the final suture was cut. Annular suturing time started at the initial needle load to the final annular suture was placed. Annular bite time was defined at needle load to when the needle was removed from the annulus. Re-attempts with the AVR model were defined similarly as 1. needle re-loads and 2. anything other than a single entry into the annulus.

Performance was additionally measured with a Likert scale OSATS tool for AVR and CABG (Feins et al., 2017). Two raters watched the videos and rated the performance of the participants. The Likert scale came with definitions on a scale of 1-5.

Additional parameters by the OSATS tool not captured with our objective performance metrics included hand mechanics, use of needle driver and use of forceps. Raters watched a video of an expert using both models to provide a standard of performance. This served as a question & answer period to clarify any uncertainties in the assessment tool and to discuss any disagreements.

Internal structure

Interrater reliability calculated as percentage of agreement of all observations was calculated for two raters. This was done using the previously published OSATS tool on coronary artery anastomosis and aortic valve replacement. For the coronary model this involved a 10-item Likert questionnaire on a scale of 1-5. For the AVR model this involved an 8-item Likert questionnaire on a scale of 1-5.

Relation to other variables

Using the previously discussed objective performance measures, we looked to provide evidence that the there was a correlation between level of training and scores. All tasks performed were recorded. Using video analysis software called BORIS (Behavioral Observation Interactive Software), objective performance data were collected. The following performance metrics were analyzed for the coronary anastomosis task: anastomotic time (minutes), number of bites, number of re-attempts, knot tying (minutes), duration of arterial bites (seconds), duration of venous bites (seconds). Performance metrics for the aortic valve replacement model included: total replacement time (minutes), annular suturing time (minutes), knot tying (minutes), annular bite time (seconds) and number of re-attempts.

Statistical analysis

Kruskal-Wallis testing was used to compute differences between novices, intermediates, and experts. Mann-Whitney U test was used to compute differences between intermediates and experts. A p-value < 0.05 was considered statistically significant. All statistical analysis was performed using GraphPad Prism version 9.0.0 for Macintosh (Graph Pad Software, San Diego, California).

Results:

Participant demographics

A total of 13 participants were included in the study, including five novices, four intermediates and four experts. All participants were male except for two, one in the novice group and one in the intermediate group. When considering experience, no participant in the beginner group had performed a distal coronary anastomosis or placement of annular sutures. In the intermediate group, all participants had performed a proximal anastomosis and 2/3 had performed at least one distal anastomosis. Similarly, all intermediate participants had at minimum placed annular sutures intraoperatively, while 1/3 had performed an AVR. Baseline opinion on simulation use was assessed. Participants rated the question “how useful is simulation for training purposes” at 4.78/5 and rated “how satisfied are you with previous training models” at 2/5.

Content

Participants were asked to rate the realism of the four procedural steps for the coronary model. The average score was 12.8/15 for intermediates and experts, with no statistically significant difference in the ratings ($p = >0.999$).

Participant were asked to rate the realism of the three procedural steps for the AVR model. The average score was 13.1/15 for all three groups, with no statistically significant difference between groups (p = >0.999).

Participants liked the “angles and orientation and ease of use” of the coronary model. Criticisms of the model were “tissue characteristics.” For the AVR model participants liked "angles and orientation, ease of use, and tissue characteristics”. A criticism of the AVR model was that the clear color of the aortic root made the commissures difficult to see without prompting.

Participants were asked to rank the utility of the two models by answering the following two questions for both the AVR model and coronary model: 1) would you recommend this model as an educational tool and 2) how satisfied are you with this simulation model. All participants would recommend the coronary and AVR model as an educational tool (Table 6.1). Overall, there was high satisfaction with both the coronary model and AVR model of all participants (CABG: p = 0.5 and AVR: p = >0.999).

	Coronary Model				AVR model			
Question	N	I	E	P-value	N	I	E	P-value
Would you recommend this model as an educational tool? (/5)	4.8	5	4.7	>0.999	5	5	5	-
How satisfied are you with this simulation model? (/5)	5	5	4.7	0.5	4.8	4.7	4.7	>0.999

Table 7.1: Evidence of content for the coronary and AVR model. (N= novice, I= intermediate, E=expert)

Internal Structure

Each participant's performance was scored out of 40 for the AVR model and out of 50 for the coronary model. IRR between the two raters was 83.3% and 82.2% for the AVR and coronary models, respectively.

Relation to Other Variables

There was a statistically significant difference between groups in multiple performance metrics in both the coronary and AVR model. Regarding the coronary model (Table 7.2), anastomotic time (min) was longest for novices, with experts having the fastest time ($p = 0.032$). The number of times a beginner and intermediate had to re-attempt an anastomotic bite was greater, while the expert groups had no re-attempts ($p = 0.04$). The time it took to take a bite on the coronary artery and on the venous conduit was longer for novices and intermediates, compared to experts (arterial: $p = 0.01$, venous: $p = 0.023$).

The total time it took to conduct an AVR using the model was statistically significantly different, favoring the experts with the fastest time ($p = 0.004$) (Table 7.3). As stated earlier, placing sutures around the annulus is the critical step of an AVR, as expected it differed significantly amongst the groups favoring the experts ($p = 0.025$). Placing sutures along the rim of the new valve did not differ between the groups ($p = 0.05$), with a trend towards faster times as experience level increased. The number of re-attempts differed significantly between the groups ($p = 0.043$), with the novices and intermediates having to re-attempt annular bites more frequently than experts. Knot tying also significantly differed between the three groups, with novices taking a longer time to tie down the valve than experts ($p = 0.004$).

Behaviors	Novice(n=4)	Intermediate (n=3)	Expert (n=3)	p-value
Anastomotic time (min)	15.30 ± 4.95	13.82 ± 1.83	8.26 ± 0.58	0.032
Number of bites	11.25 ± 0.96	16 ± 3.61	14 ± 3	0.086
Number of re-attempts	11.5 ± 6.45	16 ± 12	0 ± 0	0.040
Knot tying (min)	1.44 ± 0.4	0.88 ± 0.35	0.53 ± 0.15	0.062
Duration arterial bites (mean, s)	20.37 ± 6.35	14.21 ± 2.13	7.52 ± 0.77	0.01
Duration venous bites (mean, s)	21.39 ± 5.40	15.98 ± 1.54	10.72 ± 1.90	0.023

*numbers are presented in mean ± SD

Table 7.2: Evidence of relation to other variables for the coronary model using video analysis.

Behaviors	Novice (n=3)	Intermediate (n=3)	Expert (n=3)	P-value
Replacement time (min)	28.50 ± 0.68	21.90 ± 3.95	15.40 ± 1.50	0.004
Annular suturing time (min)	10.17 ± 1.23	8.78 ± 1.90	6.29 ± 0.446	0.025
Ring suturing time (min)	5.30 ± 0.22	4.90 ± 1.30	3.50 ± 0.34	0.05
Knot tying (min)	7.36 ± 0.58	5.17 ± 1.34	3.49 ± 0.3765	0.004
Annular bite time (mean, s)	21.99 ± 2.57	19.14 ± 6.29	10.25 ± 1.71	0.05
Number of re-attempts	7.67 ± 2.31	6.00 ± 3.46	0.67 ± 0.58	0.043

*numbers are presented in mean ± SD

Table 7.3: Evidence of relation to other variables for the AVR model using video analysis.

Discussion:

The goal of this study was to develop and provide initial sources of evidence using Messick's framework for a cardiac task trainer for core cardiac surgical skills (Cook & Beckman, 2006; Ghaderi et al., 2015). CABG and AVR was chosen as simulation tasks based on a recent needs assessment of Canadian cardiac surgery trainees (White et al., 2021). We were able to produce a cardiac task trainer that is portable and adjustable, based on real patient measurements. This study provides initial assessment of the task trainer regarding functional task alignment and utility. We believe our task trainer to be suitable for at-home practice of coronary artery anastomosis and aortic valve replacement.

All participants agreed that there was a high level of realism of the procedural tasks. While the opinion of the experts is the most important for content, all participants were asked about the usefulness of the model as an educational tool. Almost unanimously was the model given a 5/5 on the value of use. Consistent with the concept of "desirable difficulty" (Bjork et al., 2011, Bjork & Bjork, 2020), a trainer should be adjustable and provide a challenge appropriate to a trainee's experience level. If the model is adjusted so that the trainee cannot overcome the challenge, then the difficulty is "undesirable". At-home practice allows the trainee to adjust the difficulty level themselves. Increasing difficulty is thought to prevent a “plateau effect" of skill, meaning if a high performing trainee on initial assessment continues to practice the same task, they will unlikely score better on the post assessment (Fann et al., 2008; Rowse & Dearani, 2019). Adjustability also aids in preventing a "ceiling effect" with a simulator, allowing more experienced users to use the same task trainer as less experienced users, but modified to match their capabilities.(Fann et al., 2008; Rowse & Dearani, 2019).

We believe at-home practice with this model will allow the trainee to be more prepared for opportunities given in the operating room There are two different thoughts towards training schedules, “massed practice” versus “distributed practice”. Massed practice refers to practice that is delivered in continuous blocks of time with minimal or no break in between (Moulton et al., 2006). For example, a surgical bootcamp would be classified as massed practice. Distributed practice refers to practice that is spread over periods of time with breaks in between. Within fields of psychology and athletics there is evidence that distributed practice is favored over massed practice in terms of motor skill acquisition and retention (Lee & Genovese, 1989). Moulton et al., (2006) compared distributed practice to massed practice on the ability of junior trainees to perform a microvascular anastomosis. Although both groups demonstrated improvement in microvascular anastomotic skill from pre-test to post-test, the individuals in the distributed practice group performed significantly better on retention testing and outcomes measures such as number of hand movements, time, and global ratings (Moulton et al., 2006). At-home practice will help enable distributed practice as it will be more readily available.

An additional strength of this simulator is functional task alignment. Functional task alignment ensures that the task being performed resembles how the task will be performed in vivo (Hamstra et al., 2014). In cardiac surgery, the limited space of the mediastinum and various depths at which surgical tasks are performed contribute to the challenges of surgery. The incision(s) of our model and layers of depth are based off the real mediastinal constraints of patients. The platform within the task trainer allows the user to adjust the position of the distal coronary or aortic annulus craniocaudally or laterally. The narrowed aortic root is taken from a real patient's CT scan. These elements enhance the functional fidelity of the model. There are three potential strategies of using this task trainer; 1) identifying preoperatively a patient who's anatomy may present a technical challenge, for example a patient with a long-standing history of COPD likely to have a deep chest; 2) following an operation where the trainee struggled for a particular reason, they can recreate elements that may have contributed to their difficulties, and 3) regular deliberate practice not based off any particular patient. Other steps trainees can take to easily increase functional task alignment include wearing surgical loupes and surgical gloves while using a simulator. 3D printing and patient specific surgical rehearsal preoperatively is a growing field. Such technology is already present for use in specific procedures of general surgery, urology, and plastics (Andolfi et al., 2017; Bati et al., 2020; Melnyk et al., 2022). The main users of this technology in cardiac surgery are congenital cardiac surgeons given the complexity of the anatomy; rarely is it used in adult cardiac surgery (Hermsen et al., 2017; Hussein et al., 2021). Only more recently has the technology shifted to provide hands-on surgical training with such models to trainees. Limitations of this technology as a training tool are in the cost and access to the printers. A benefit of the task trainer in our study is that not only is the aortic root patient specific, but the entire chest cavity is patient specific.

The predominant limitation of this task trainer is the tissue quality is not as realistic as a traditional porcine model or human tissue as it is synthetic. Procedurally, the specific step that is most difficult to simulate for the coronary model is the arteriotomy. The vessels used are synthetic without pathology compared to intraoperative where the coronary arteries are full of calcium. With the AVR model, the coronary ostia are not present within the aortic root. The AVR model also does not simulate debridement of the aortic annulus of calcium. From a validation studies perspective, there is further work to be done. We have attempted to provide initial evidence for content, response process, internal structure, and relation to other variables, but ongoing study is needed to continue to add sources of evidence, including consequence (Cook & Beckman, 2006; Ghaderi et al., 2015). Reliability was not assessed because of the small sample size and the difficulty in getting participants in the first place.

Conclusion:

Simulation-based training should be used as an educational adjunct to teach the necessary skills of surgical trainees to ensure the safety of our patients. As previously stated in the introduction, a task trainer for technical skills should have high functional task alignment, be readily available, and allow for adjustability. A task trainer that is portable and adjustable allows for at-home practice and the prevention of a plateau effect on skill. Our initial sources of evidence for validity may be sufficient for the task trainer's current use in at-home practice. A higher level of evidence would be required should the task trainer be used to grade a trainee's performance or in any other high-stakes assessment. In the next chapter, we will present the findings from our learning curve study using our model.

CHAPTER EIGHT: HOME PRACTICE FOR CORONARY ANASTOMOSIS AND AORTIC VALVE REPLACEMENT USING A NOVEL CARDIAC TASK TRAINER

In chapter seven we provided initial sources of evidence for our novel cardiac task trainer. In this chapter we conduct a learning curve study using the novel cardiac task trainer to further evaluate the educational value of our novel cardiac task trainer.

Methods:

Participants

Junior trainees (PGY1-2) from the University of Alberta and University of Calgary were recruited for their participation (N = 4). Approval for the study was granted by the Health Research Ethics Board of the University of Alberta. Written consent was obtained from each participant.

Task

The participants were asked to practice at home using our novel cardiac task trainer. Details pertaining to the design of the task trainer can be found in chapter seven. The study period was over the course of five weeks. During the first week all participants underwent an initial assessment with AW, this included instruction on how to use the task trainer and feedback on their performance. Participants were then provided with a task trainer, as well as materials (surgical instruments, sutures etc.) required to allow for practice over the course of three weeks. During the 5th week, the participants underwent a final assessment with AW. The minimal requirement for participation in the study was submission of one video per week of the training period. In total each participant should have five videos for analysis.

Participants were required to do two tasks: 1) distal anastomosis and 2) aortic valve replacement (AVR). The distal anastomosis was performed with a 7-0 polypropylene and oriented in the position of the left anterior descending artery, participants were encouraged to take 10-12 bites for their anastomosis. For the aortic valve replacement, the participants were provided with silicone aortic roots and asked to place a total of six valve sutures (three sutures for the commissures and three sutures at the nadir of each cusp). For the training period, participants were not required to do the full valve replacement if no surgical assistant was available. Annular suturing was the main objective.

Subjective Assessment

The subjective assessment included a modified OSATS for AVR and anastomosis on a Likert scale of 1-5, 1= poor, unable to accomplish goal, marked hesitation and 5= excellent, able to accomplish goal without hesitation, showing excellent progress and flow. The modified tools can be found in Appendix D.

Objective assessment

Using BORIS (Behavioral Observation Research Interactive Software), pre-determined behaviors were analyzed. The following performance metrics were analyzed for the anastomotic task: anastomotic time (minutes), the duration of arterial bites (seconds), the duration of venous bites (s), knot tying (s), parachuting, number of re-attempts, and number of times suture was corrected. Re-attempting a bite was defined as anything other than single entry into the coronary artery and needle reloads. Total number of errors was a combination of bite re-attempts, needle reloads and suture correction.

For the AVR model the following performance metrics were analyzed: annular suturing time (minutes), annular bite time (seconds) defined by needle load to when the needle was removed from the annulus, and number of re-attempts. Like the coronary model, re-attempts were defined as 1. needle re-loads and 2. anything other than a single entry into the annulus.

Data Analysis

Data was analyzed using Prism 9.4.0 for macOS. ANOVA was used to compare performance over study period. A p-value < 0.05 was considered statistically significant. In the cases of a significant p-value, multiple comparisons were used between session 1 and each subsequent session.

Results:

Participant and Compliance

A total of four participants were included in the study, two second year trainees and two first year trainees. Prior to the start of the study, only one participant had had operative experience performing a distal anastomosis. Over the course of the study period, the same participant had performed additional distal anastomosis in the operating room and placed < 10 annular sutures, but never an entire valve replacement. The remaining three participants did not have any operative experience performing a distal anastomosis or placing annular sutures.

Only one participant had 100% compliance to the study protocol, with five out five videos to analyze. The remaining three participants had at minimum three videos for analysis. For the AVR model, 3/4 participants had a final assessment with AW. For the coronary model, 2/4 participants had a final assessment with AW. No participant practiced outside of the minimum requirement for the study.

Subjective Assessment

There was a statistically significant difference in the modified OSATS score for both the coronary and AVR model (p = 0.003 and p = 0.021, respectively, Figure 8.1 and Table 8.1). After week #1 the scores of the coronary model statistically improved (Table 8.2), for the AVR model, the difference was only apparent at the time of final assessment (Table 8.1).

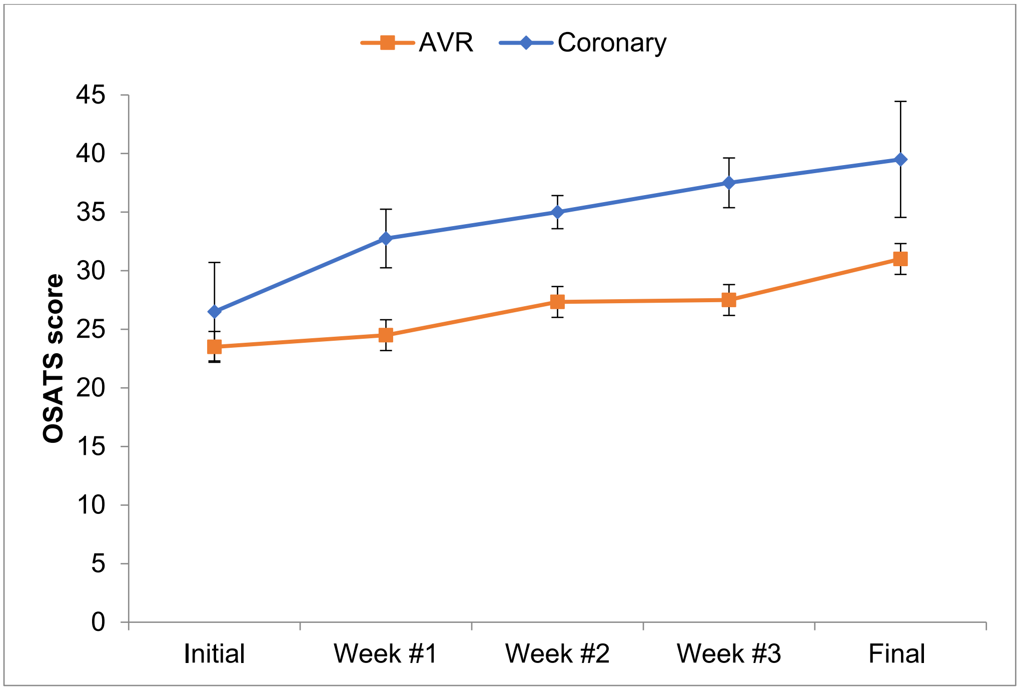


Figure 8. 1: Subjective assessment over time for the coronary and AVR model.

Model	Initial	Week #1	Week #2	Week #3	Final	p-value
Coronary	26.5 ± 4.2	32.8 ± 2.5	35 ± 1.4	37.5 ± 2.1	39.5 ± 4.9	0.003
AVR	24 ± 3.4	25 ± 2.6	27 ± 1.5	28 ± 2.1	31 ± 1.7	0.021

Table 8.1: Comparison of subjective mean performance over time for both the coronary and AVR model.

	Initial	Week #1	Week #2	Week #3	Final
Coronary model score	26.5 ± 4.2	32.8 ± 2.5	35 ± 1.4	37.5 ± 2.1	39.5 ± 4.9
vs. Initial	-	p = 0.063	p = 0.011	p = 0.007	p = 0.002
AVR model score	24 ± 3.4	25 ± 2.6	27 ± 1.5	28 ± 2.1	31 ± 1.7
vs. Initial	-	p = 0.972	p = 0.265	p = 0.334	p = 0.011

Table 8.2: Multiple comparison of initial assessment to week of study for both coronary and AVR model. Expressed as mean ± SD.

Objective Assessment

There was no statistically significant difference in objective metrics of performance for either the coronary model or the AVR model (Table 8.3 and 8.4). Although not statistically significantly different, if we look at the trends for the coronary model in Figure 8.2, it will appear that there was improvement over time. The pattern of improvement is not as obvious with the AVR model (Figure 8.3). There is an improvement in annular suturing time, annular bite time, average annular bite time but not number of re-attempts.

Behavior	Initial	Week #1	Week #2	Week #3	Final	p-value
Anastomotic time (s)	1062.66 ± 131.45	924 ± 154.88	995.39 ± 363.28	1012.12 ± 414.83	712.13 ± 67.87	0.555
Total arterial bite time (s)	342.69 ± 37.56	247.11 ± 44.32	282.13 ± 115.67	249.11 ± 68.4	181.08 ± 12.78	0.118
Average arterial bite (s)	26.01 ± 3.69	18.61 ± 2.59	20.43 ± 7.79	18.35 ± 4.11	14.54 ± 1.84	0.096
Total venous bite time (s)	341.06 ± 39.55	268.81 ± 110.32	269.87 ± 80.52	324.20 ± 142.40	210.40 ± 43.25	0.485
Average venous bite (s)	25.71 ± 1.76	20.4 ± 8.2	19.7 ± 5.48	23.77 ± 9.3	16.96 ± 4.42	0.496
Re-attempts	20.75 ± 2.36	19 ± 4.76	22.67 ± 12.1	14.5 ± 12.02	10.5 ± 3.54	0.412
Error	24.75 ± 4.92	22.25 ± 4.99	26 ± 11.36	17 ± 11.31	10.5 ± 3.54	0.210

Table 8.3: Comparison of objective metrics over time for the coronary model, expressed as mean ± SD.

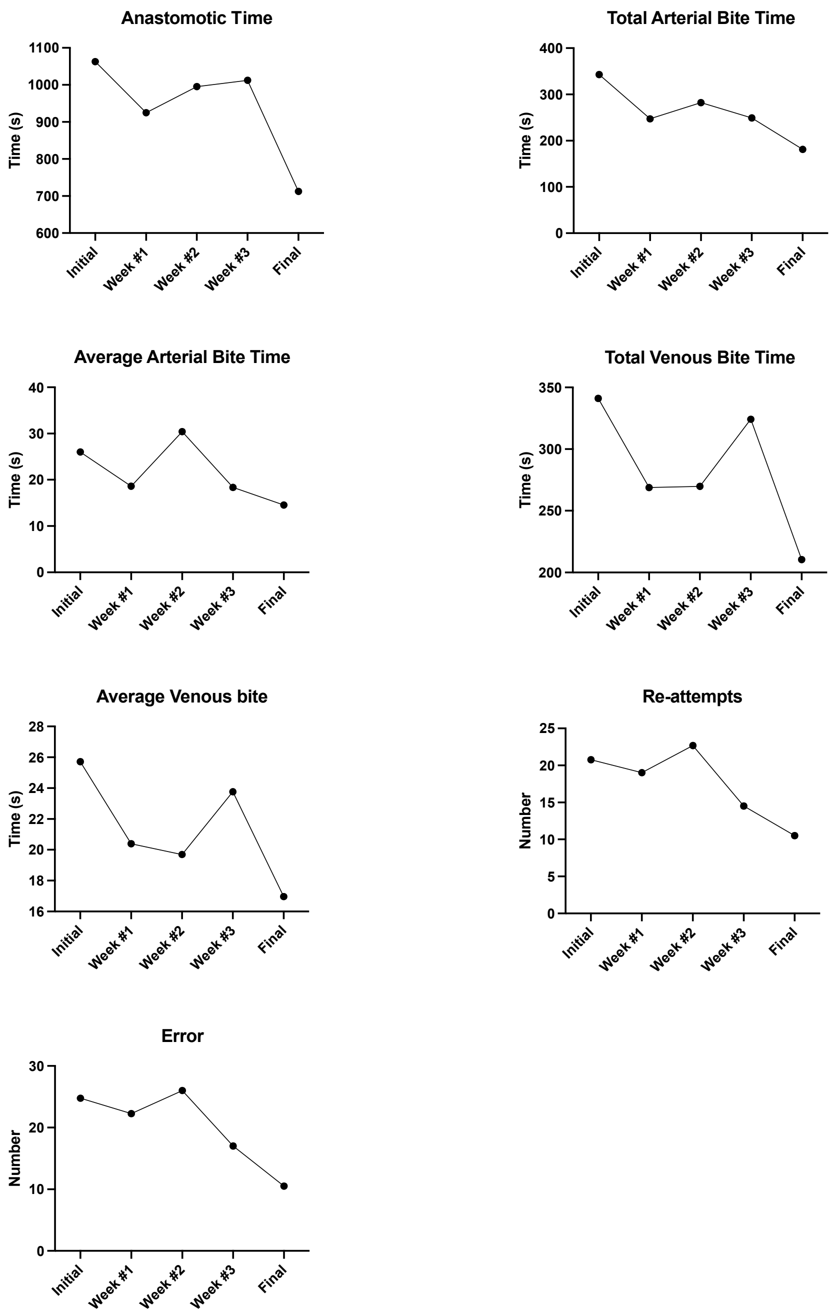


Figure 8.2: Pattern of objective metrics over time for the coronary model.

Behavior	Initial	Week #1	Week #2	Week #3	Final	p-value
Annular suturing time (s)	777.44 ± 409.1	615.11 ± 252.63	571.29 ± 224.76	471.45 ± 287.63	586.22 ± 150.38	0.765
Annular bite time (s)	444.05 ± 222.13	338.5 ± 98.03	320.24 ± 124.05	245.82 ± 117.77	289.77 ± 37.31	0.520
Average annular bite (s)	25.67 ± 8.04	21.2 ± 8.44	22.08 ± 7.83	20.48 ± 9.81	16.37 ± 3.95	0.648
Re-attempts	9.5 ± 5.92	11.25 ± 8.77	4.67 ± 3.51	5.5 ± 0.71	9.33 ± 3.51	0.607

Table 8.4: Comparison of objective metrics over time for the AVR model, expressed as mean ± SD.

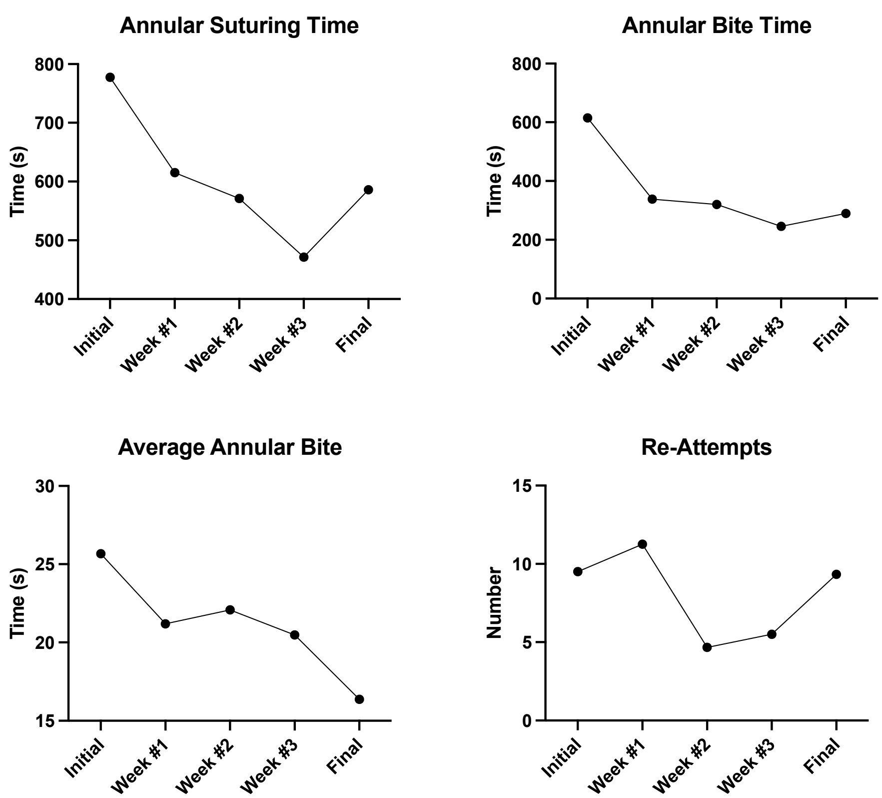


Figure 8.3: Pattern of objective metrics for the AVR model.

Discussion:

Participants performance subjectively improved over the course of the training period for both the coronary and AVR model using the novel cardiac task trainer. Objective metrics of performance did not reach statistical significance for improvement, although there was a visible trend in many of the objective metrics for improvement.

Subjective assessment of surgical performance remains a hallmark within surgical education, with the Objective Structured Assessment Tool Skills being the most used tool, with the most validity evidence (Niitsu et al., 2013; Martin et al., 1997; Vaidya et al., 2020). With the transition to CBD, more robust ways of assessing a trainees performance to determine their progression is needed, certainly more objective metrics are needed (McQueen et al., 2019). Pitfalls to trainee assessment intraoperatively include single rater limitations, rater burnout, and time (McQueen et al., 2019). Video-based assessment is growing in surgical education to provide objective metrics while dealing with the challenges of intraoperative assessment (McQueen et al., 2019). While we noted a subjective improvement in performance, there are likely several reasons why we did not see the same benefit in objective metrics. Poor compliance with the training protocol and small sample size were two major ones. There is certainly a trend towards improvement in time and number of errors, but because data set is incomplete, it is difficult to draw strong conclusions. A benefit of video-based assessment is allowing for anonymity of the participants and to have theoretically unbiased evaluations. A drawback of close-up video is assessment may be affected by the quality of the video (McQueen et al., 2019). In chapter seven, the task trainer used had high interrater reliability >0.8, but the validity may be reduced because full movements of the participants may not have been appreciated with close-up video. As the participants were not functioning in a controlled environment during the training period (Week #1-#3), there were interruptions during the video. While researchers attempted to adjust for interruptions unrelated to the surgical task, this may have affected their performance by drawing their attention elsewhere.

Distributed practice compared to massed practice is felt to be superior for performance improvement and learning (Donovan & Radosevich, 1999; Moulton et al., 2006). Distributed practice is when the learner is given periods of rest between practice and massed practice involves repetitive practice with no rest. In surgical training, massed practice often takes the form as surgical bootcamps. Home practice would be one way to facilitate distributed practice in surgical training. Our results are like previous studies in cardiac surgery that demonstrated no correlation between home practice and performance (Fann et al., 2008; Spratt et al., 2019). This can be explained by poor compliance with training protocol, but an additional consideration is at home when not under direct observation trainees may accept a lower standard of performance than in the initial and final assessment where trainees were under direct observation (McQueen et al., 2019). While participants were provided with feedback, feedback provided later rather than immediately during performance may be less suitable for deliberate practice, which is essential for expert performance (Rowse & Dearani, 2019).

There are several limitations to the study, some of which have already been described. The poor compliance with the protocol is not surprising. A survey conducted of trainees in the United States found that while majority of respondents believed practice to be important for growth and helps with intraoperative performance, very few respondents practiced for greater than 2 hours/week (Kelly et al., 2021). Lack of time being the biggest barrier to practice and lack of instruction being second (Kelly et al., 2021). While home practice is not harmful if done correctly, a hybrid model to training may be superior where there are dedicated times in the week for practice and instruction, and then practice outside of a controlled environment can be used to solidify skills. Previous study recommends mandatory simulation sessions implemented within the curriculum as a key to success (Bath & Lawrence, 2012). An additional limitation is the small sample size, which was an unavoidable limitation given the small number of eligible participants. In Canada, only 1 student is accepted into a residency program every year and we wanted to conduct the study using junior trainees. An additional limitation is the possibility of rater bias, as the author is a surgical colleague to the participants.

Conclusion:

There are a multitude of simulators that exist within cardiac surgery that have been designed for deliberate practice in coronary anastomosis and aortic valve replacement, but few if any have been formally assessed for validity and educational value (Trehan et al., 2014). A benefit of this study is the continuation of a previous study on sources of evidence for validity of the task trainer used. Improvement in subjective performance did improve and future work should try and develop an optimal training protocol for surgical residents incorporating home practice and direct observation and feedback. No study to date within cardiac surgery has been designed to demonstrate transferability of skill to the operating room, which is likely a contributing factor to the lack of uptake of simulation-based training amongst Canadian cardiac surgery programs (Fann et al., 2010; Feins et al., 2017; Mokadam et al., 2017; Ribeiro et al., 2018).

CHAPTER NINE: TEAM-BASED TRAINING FOR NONTECHNICAL SKILLS IN CARDIAC SURGERY

Up to this point, focus has been on individual performance, this next chapter focuses on our team-based training model to train nontechnical skills in cardiac surgery.

Introduction:

As outlined previously in chapter six, surgical residency emphasizes technical skill development despite the growing evidence to support the importance of nontechnical skills, with communication failures in the operating room found to occur 30% of the time (Lingard et al., 2004). This is likely contributed by the unclear link between communication error and patient harm, as there is often not an immediate effect (Agha et al., 2015; Lingard et al., 2004). In other words, a false sense of safety is produced when the communication failure does not result in an immediate visible effect, but the additive effects of multiple communication errors start to the weaken the framework, making the surgical team at risk for causing patient harm (Lingard et al., 2004).

The Nontechnical Skills for Surgeons (NOTSS) rating scale has been studied for reliability and validity and is the most used to tool to assess nontechnical skills of an individual (Kim et al., 2022; Wood et al., 2017). There are four different categories and each category has three elements: situation awareness (gathering information, understanding information, projecting and anticipating future state), decision-making (considering options, selecting and communicating option, implementing and reviewing decisions), communication and teamwork (exchanging information, establishing a shared understanding, coordinating team activities), and leadership (setting and maintaining standards, supporting others, coping with pressure) (Flin et al., 2012).

Examples of good and poor behaviors for each of these elements can be found in the *The NOTSS SYSTEM Handbook V1.2* (Flin et al., 2012).

All surgery requires a high functioning team, but in cardiac surgery that is complicated by the introduction of a perfusionist, who runs the heart lung machine. There is currently no standardization for communication during cardiopulmonary bypass, this was explored by de Lind van Wigngaarden et al. (2019) and their framework for communication was adapted from previous work by Hazlehurst et al. (2007). The modified framework for looking at communication pattern was used in this study. There are many studies that have look at cardiopulmonary bypass simulation, but few studies have looked at team-based training for nontechnical skills (Feins et al., 2017; Hermsen et al., 2021; Hicks et al., 2011; Ramphal et al., 2005). Kim et al. (2022) conducted a study on team-based training for cardiac surgery residents using the NOTSS scoring system but not for cardiopulmonary bypass emergencies. The purpose of this study was twofold: (1) to evaluate communication patterns amongst team members during cardiopulmonary bypass emergencies in a simulated environment and (2) to evaluate nontechnical skills of cardiac surgery trainees over the course of the curriculum.

Methods:

Participants

Members of the cardiac surgery community from the University of Alberta were recruited. This included trainees from cardiac surgery, trainees and faculty from cardiac anesthesia, and faculty perfusion and nursing. A total of 10 individuals participated in the simulation sessions, with five participants being surgical trainees. Approval for the study was granted by the Health Research Ethics Board of the University of Alberta. Written consent was obtained from each participant, prior to the first session.

Simulation Sessions

The simulation sessions took place in the Surgical Medical Research Institute (SMRI). A fully immersive simulated operating room with a porcine heart for cannulation, surgical equipment, multiparameter patient monitors, cardiopulmonary bypass pump, and a transesophageal echocardiogram (Heartworks Dual Simulator, Intelligent Ultrasound North America Inc, Alpharetta, GA, USA) was created (Figure 9.1). The simulation sessions were multidisciplinary and involved cardiac surgery (primary operator and surgical assistant), cardiac anesthesia, cardiac perfusion, and cardiac nursing. Each participant constituted their own sub team.

Scenarios included initiation of cardiopulmonary bypass, weaning from cardiopulmonary bypass and then three emergency scenarios: massive air embolism, iatrogenic aortic dissection, and failure to wean from cardiopulmonary bypass. Before the first simulation session, all participants received a didactic session (2 hours) on NOTSS, examples of good and bad behaviors. While participants were not told which scenario they would be playing an active role in, they were provided with relevant prereading on the scenarios, and management strategies for each scenario was discussed at the beginning. Only confederates (faculty) were informed on which scenario they were participating in on that day. Participants were also “walked through” the simulation set up to familiarize themselves with the equipment and what aspects of the simulation were realistic and what aspects required suspension of disbelief. Scenarios ran to completion and ranged from 15-30 minutes. Each session had a minimum of 2 scenarios and there were 4 sessions in total used for analysis, over the course of 12 months. Each scenario included a “trigger”, or a point in the scenario where an emergency or higher task complexity (weaning from CPB) occurred. Each scenario ended with a debrief, led by AW, and two faculty moderators assigned to that day.

Figure 9. 1: Example of the immersive simulation environment.

Communication Analysis

All sessions were audio and video recorded; these were then transcribed verbatim. Atlas.ti7 (ATLAS.ti GmbH, Berlin, Germany) software for qualitative data analysis was used to analyze transcripts. Verbal sequences were defined as a verbal interaction from one sub team to another (de Lind van Wijngaarden et al., 2019). Verbal exchanges were defined as groups of verbal sequences related to the same topic (de Lind van Wijngaarden et al., 2019).

Communication content

Verbal exchanges and remaining verbal sequences were categorized into six forms of communication: direction, status, goal-sharing, alert, explanation/problem-solving, and permission (Table 9.1) (de Lind van Wijngaarden et al., 2019; Hazlehurst et al., 2007). Examples of communication content can be found in Table 9.2.

Content Type	**Definition**
Direction	"Command an action that seeks to transition the activity system to a new state"
Status	"Create shared understandings about the current state"
Goal sharing	"Create expectation of a desired future state"
Alert	"Convey abnormal or surprising information about the current state"
Explanation/problem-solving	"Create a rationale for the current state
Permission	"Request approval to further transition the activity system to a new state"

Table 9.1: Communication content definitions used in video analysis based on the adapted classification by de Lind van Wijngaarden et al. from Hazlehurst et al.

Content Type	**Example Excerpt**
Direction	Surgeon: Check your pressure, check your swing
Status	Anesthesia: You're in the IVC, cannula is in a good position
Goal sharing	Anesthesia: We are probably going to need some volume Surgeon: Why don't we give another 100
Alert	Anesthesia: Okay X, I see an aortic dissection here Surgeon: Okay perfusion, everyone in the room, this is an emergency
Explanation/problem-solving	Perfusion: Arterial line pressure seems really high Anesthesia: I'm going to see if I can see your cannula again Surgeon: Okay please do, I'm just going to stop there for a second, let me know, what do you see X? Anesthesia: Just trying to see, there's a lot of artifact Surgeon: Okay, I'm going to pull back the aortic cannula
Permission	Surgeon: X, are you okay if we take out the venous cannula? Anesthesia: Yes, everything looks stable up here, I've even come down on my norepi

Table 9.2: Example excerpts of the six content types used in the analysis. X = name of participant

Communication quality

Quality of communication was analyzed to determine resilience to breakdown. We adopted the methodology from *de Lind van Wijngaarden et al.* on verbal communication in the operating room (de Lind van Wijngaarden et al., 2019). Communication was categorized by loop type, open-loop, call back, closed-loop or series. Open-loop communication involves only 1 sub team, call-backs are an exchange between more than 1 sub team, and series involves exchanges between 2 or 3 sub teams. Closed-loop communication being the most resilience towards breakdown involves more than 1 sub team where the initiator of the verbal exchanges responds to the receiver, thereby closing the loop.

In all forms of communication except for open-loop communication we categorized it as substantive or insubstantive. With substantive call-backs the receiver responds with information pertaining to the original verbal sequence. With insubstantive call-backs, the receiver responds with an affirmation, for example, “yes.” Verbal exchanges were also labelled as direct or indirect. Direct being that the initiator of the verbal exchange specifically used a name. Examples of communication quality can be found in Table 9.3.

Communication Quality	Example Excerpt
Closed loop	Surgeon: Alright X can you bump your pump please Perfusion: Bumping the pump Surgeon: And off Perfusion: Off
Open loop	Anesthesia: I'll turn the lungs on *No response*
Call-back	Perfusion: ACT is 200 and climbing Surgeon: Okay thank you
Series	Anesthesia: How much volume do you have back there? Perfusion: about 200 but I'm keeping up with the root vent Surgeon: O, sorry, root vent is off Perfusion: Okay root vent is off
Directed	Surgeon: Alright just so you know Dr. X, we have our SVC and IVC cannulas in
Undirected	Surgeon: Can you give heparin please? Anesthesia: Yep, heparin is given
Substantive	Anesthesia: Placement looks good Surgeon: Placement looks good, okay thank you very much
Insubstantive	Anesthesia: I'm just running a little bit of dob and a little bit of vaso because of the low EF preop Surgeon: Okay

Table 9.3: Example excerpts of the different communication quality metrics for resilience to breakdown. X = name of participant

Additional Performance Measures

Cardiac surgery trainees were subjectively evaluated for their nontechnical skills using the NOTSS rating scale. Specifically, we looked to see if there was improvement in NOTSS over the course of the curriculum time frame on CPB emergencies. Each category of NOTSS (situation awareness, decision making, communication and teamwork, and leadership) was evaluated, and each category contained three elements. These were evaluated on a 4-point Likert scale or not applicable if it did not apply to the scenario (4 = good, 3 = acceptable, 2 = marginal, and 1 = poor).

Statistical Analysis

Three different factors were analyzed: (1) Communication between team members (surgery, anesthesiologist, perfusion, nursing, and surgical assist). Comparisons were made using a one-way ANOVA. (2) Communication during phase of the procedure, pre- and post-trigger. Comparisons made using a paired T-test, and given that the time periods were different, communication was looked at per minute. (3) Behavior comparison using the NOTSS rating scale across sessions. ANOVA was used and post-hoc analysis was used to compare performance by trainee and by scenario. A p-value <0.05 was considered statistically significant.

Results:

Verbal sequences and exchanges

There was a total of nine sessions included in the analysis, six sessions were cardiopulmonary bypass emergencies (which included three scenarios repeated twice) and three sessions were cardiopulmonary bypass basics (initiation and weaning). These nine sessions resulted in a total of 1083 verbal sequences categorized into 843 verbal exchanges. The surgical sub team was responsible for majority of exchanges at 68.9% of all exchanges, followed by anesthesia (16.5%), perfusion (10.1%), assistant (3.7%), and nursing (0.8%).

Communication between team members

Communication content

The most frequent type of communication overall was status (45.1%), followed by direction (27.6%), and permission (10.8%). All forms of communication were used by team members except alert, explanation, and goal sharing were not used by the nurse or assistant (Figure 9.2). Looking at the core three members, the most common form of communication for the surgeon was status, followed by direction. For the anesthesiologist, perfusionist, and nurse, status was the most common form of communication. For the assistant, direction was the most common form of communication (Figure 9.2).

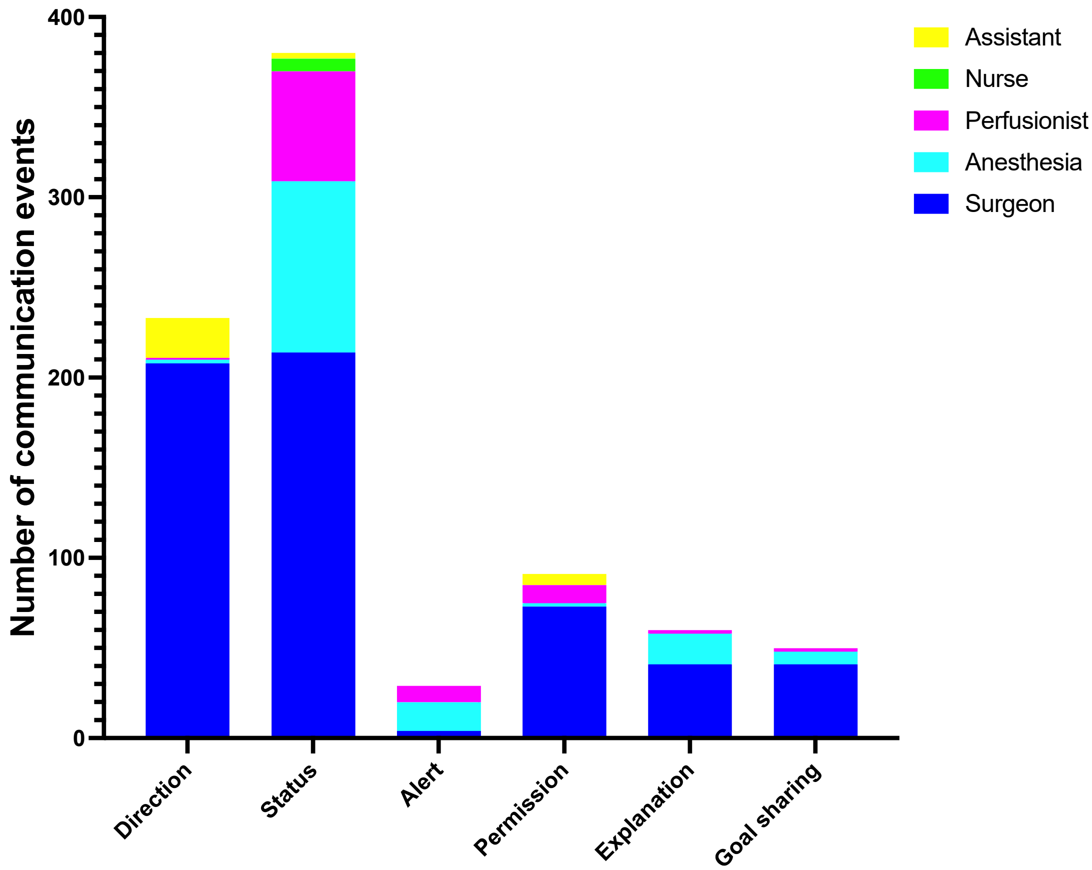


Figure 9.2: Breakdown of communication content type by subteam.

There was a statistically significant difference between communication content type amongst the core three team members for direction (p = <0.001), status (p = 0.004), permission (p < 0.001), and goal sharing (p < 0.001) (Table 9.4).

Content Type	Surgeon	Perfusionist	Anesthesiologist	p-value
Direction	1.19 ± 0.73	0.01 ± 0.02	0.02 ± 0.04	<0.001
Status	1.26 ± 0.85	0.56 ± 0.51	0.26 ± 0.18	0.004
Alert	0.03 ± 0.05	0.09 ± 0.05	0.05 ± 0.05	0.054
Permission	0.42 ± 0.23	0.02 ± 0.03	0.07 ± 0.09	<0.001
Explanation	0.29 ± 0.45	0.10 ± 0.11	0.01 ± 0.02	0.100
Goal sharing	0.24 ± 0.17	0.04 ± 0.06	0.01 ± 0.02	<0.001

Table 9.4: Average communication events per minute by core three team members. Expressed as mean ± SD.

Communication Quality

Call back was the most common form of communication (49.7%), followed by closed loop communication (22.9%), open loop communication (17.6%), and series (9.7%) (Figure 9.3). This trend was consistently seen amongst the core three team members.

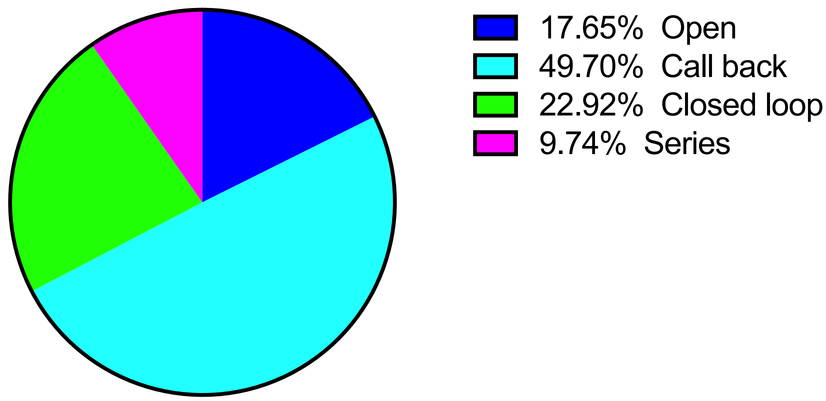


Figure 9. 3: Resilience to breakdown by loop type.

Communication pre- and post-trigger

Communication content

When looking at the behavior of the whole team, content type differed significantly pre- and post-trigger for status ($p = 0.04$), alert ($p = 0.033$), explanation ($p = 0.031$), and goal sharing ($p = 0.011$) (Table 9.5).

Content Type	Pre	Post	p-value
Direction	1.39 ± 0.78	1.22 ± 1.01	0.560
Status	1.66 ± 0.84	3.07 ± 2.25	0.04
Alert	0.08 ± 0.07	0.39 ± 0.35	0.033
Permission	0.48 ± 0.29	0.68 ± 0.65	0.279
Explanation	1.17 ± 0.23	1.90 ± 1.05	0.031
Goal-sharing	0.18 ± 0.12	0.49 ± 0.38	0.011

Table 9.5: Communication content type pre- and post-trigger. Expressed as mean events/min ± SD.

Looking at the core three team members there was no statistically significant difference in content type pre- and post- trigger except status and goal sharing increased post trigger by the surgeon (p = 0.024 and p = 0.042, respectively).

Team Member	Direction	Status	Alert	Permission	Explanation	Goal sharing
Surgeon						
Pre	1.2 ± 0.7	1.02 ± 0.66	0	0.38 ± 0.19	0.11 ± 0.14	0.16 ± 0.09
Post	1.17 ± 1.02	1.76 ± 1.26	0.08 ± 0.14	0.56 ± 0.51	0.65 ± 0.98	0.38 ± 0.34
p-value	0.938	0.024	0.126	0.259	0.096	0.042
Perfusionist						
Pre	0.01 ± 0.04	0.18 ± 0.24	0.03 ± 0.06	0.05 ± 0.07	0 ± 0.01	0
Post	0.03 ± 0.08	0.33 ± 0.35	0.12 ± 0.15	0.11 ± 0.17	0.01 ± 0.03	0.04 ± 0.08
p-value	0.650	0.311	0.205	0.245	0.678	0.227
Anesthesiologist						
Pre	0.02 ± 0.03	0.35 ± 0.20	0.04 ± 0.06	0.02 ± 0.05	0.06 ± 0.1	0.03 ± 0.06
Post	0	0.05 ± 1.03	0.2 ± 0.26	0.01 ± 0.03	0.24 ± 0.26	0.07 ± 0.12
p-value	0.182	0.077	0.152	0.546	0.063	0.269

Table 9.6: Communication content type pre- and post- trigger for the core three team members. Expressed as mean ± SD

Communication quality

Loop type did not change significantly pre- and post-trigger, except a decrease in open loop communication (p = 0.014) (Table 9.7). Specifically looking at call backs, they were substantive (74.6%) but undirected call backs (82.0%). Post-trigger there was a decrease in the amount of insubstantive call backs (p = 0.003). (Table 9.8).

Loop Type	Pre	Post	p-value
Open	9.11 ± 7.39	2.00 ± 1.66	0.014
Closed	8.44 ± 6.46	5.56 ± 4.28	0.309
Call back	19.78 ± 11.36	11.44 ± 8.76	0.120
Series	2.56 ± 1.74	3.78 ± 2.64	0.315

Table 9.7: Resilience to breakdown by loop type pre- and post- trigger. Expressed as mean events/min ± SD.

Callback Type	Pre	Post	p-value
Substantive	19.11 ± 12.31	18.67 ± 13.00	0.943
Insubstantive	11.56 ± 6.73	2.11 ± 1.54	0.003
Directed	7.00 ± 7.86	4.33 ± 4.77	0.365
Undirected	32.67 ± 18.39	18.11 ± 11.83	0.085

Table 9.8: Resilience to breakdown by call back type pre- and post- trigger. Expressed as mean events/min ± SD.

Behavior performance over sessions

CPB emergencies

There was a statically significant difference in total NOTSS score over the course of the six emergency CPB scenarios (p = 0.001) and this was contributed by a significant difference in situation awareness, decision making, and leadership (Figure 9.4, Table 9.9). There was not a statistically significant difference in teamwork (p = 0.508).

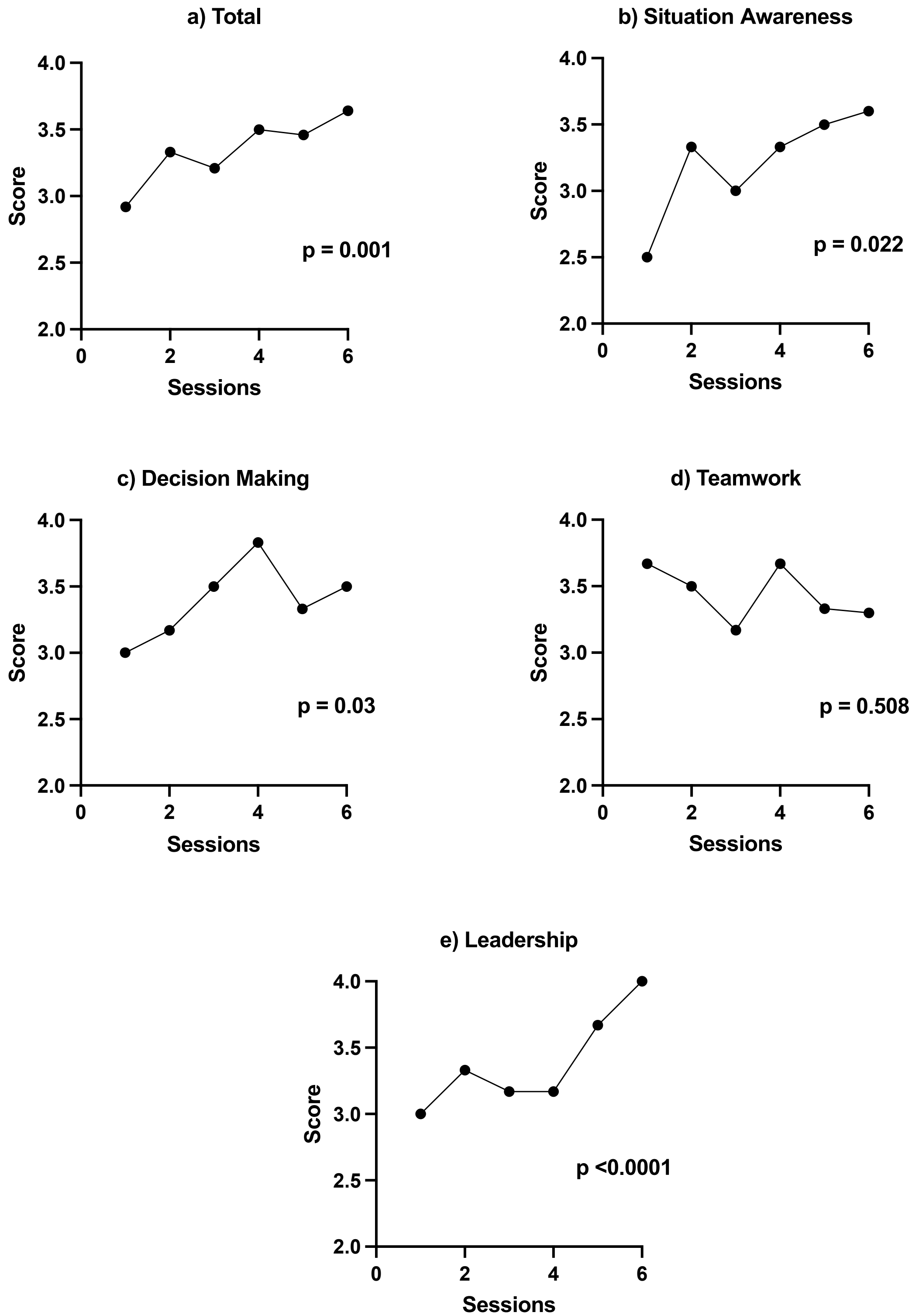


Figure 9. 4: Average NOTSS score over the course of six emergency CPB sessions, a) total b) situation awareness c) decision making, d) teamwork, e) leadership.

NOTSS	1	2	3	4	5	6	p-value
Situation awareness	2.5	3.33	3	3.33	3.5	3.6	0.022
Gathering information	2	3	2.5	3	3	3	
Understanding information	2.5	4	3	3	4	4	
Projecting and anticipating future state	3	3	3.5	4	3.5	4	
Decision making	3	3.17	3.5	3.83	3.33	3.67	0.03
Considering options	3	3	3	4	3	4	
Selecting and communicating option	3	3	3.5	3.5	3	3	
Implementing and reviewing decisions	3	3.5	4	4	4	4	
Teamwork	3.67	3.5	3.17	3.67	3.33	3.3	0.508
Exchanging information	4	3.5	3	4	3	3	
Establishing a shared understanding	3	3	3	3	3	3	
Co-ordinating team activities	4	4	3.5	4	4	4	
Leadership	3	3.33	3.17	3.17	3.67	4	<0.0001
Setting and maintaining standards	3	3.5	3	3	4	4	
Supporting others	3	3	3	3	3.5	4	
Coping with pressure	3	3.5	3.5	3.5	3.5	4	

Table 9.9 Differences in NOTSS scores between cardiopulmonary bypass emergencies.

CPB Basics

There was a statistically significant difference in the NOTSS score over the three scenarios of CPB basics (p = 0.0004), contributed by situation awareness, teamwork, and leadership (Table 9.10). For CPB basics what did not differ significantly was decision making (p = 0.296).

NOTSS	7	8	9	p-value
Situation awareness	2.5	4	3.75	0.003
Gathering information	3	4	3.5	
Understanding information	2	4	4	
Projecting and anticipating future state	N/A	N/A	N/A	
Decision making	3	3.5	3.5	0.296
Considering options	N/A	N/A	N/A	
Selecting and communicating option	3	3	3	
Implementing and reviewing decisions	3	4	4	
Teamwork	2.33	4	3.67	<0.001
Exchanging information	2	4	4	
Establishing a shared understanding	2	4	3	
Co-ordinating team activities	3	4	4	
Leadership	3	3.83	3.67	0.009
Setting and maintaining standards	3	4	4	
Supporting others	3	3.5	3	
Coping with pressure	3	4	4	

Table 9.10: Differences in NOTSS scores between cardiopulmonary bypass basics.

All Scenarios

Combining all scenarios together, there was a statistically significant difference in the total NOTSS score ($p < 0.0001$), situation awareness ($p < 0.001$), decision making ($p = 0.05$), teamwork ($p < 0.001$), and leadership ($p < 0.0001$).

Out of the three trainees who participated in a scenario twice, there was a significant improvement in two, $p < 0.0001$ (Table 9.11). There was, however, no significant improvement in performance when the scenario was repeated twice (Table 9.11).

	Groups	Mean 1	Mean 2	Mean difference	St. Error	p-value	95% confidence interval	
							Lower bound	Upper bound
Trainee	1 vs. 9	3.042	3.661	-0.618	0.1434	<0.0001	-0.9656 to -0.2719	
	2 vs. 6	3.333	3.209	0.1244	0.1434	0.77	-0.2224 to 0.4712	
	3 vs. 8	2.702	3.458	0.7560	0.1484	<0.0001	0.3970 to 1.115	
Scenario	1 vs. 6	3.042	3.209	-0.1669	0.1434	0.572	-0.5137 to 0.1799	
	2 vs. 9	3.333	3.661	-0.3275	0.1434	0.07	-0.6743 to 0.01931	
	7 vs. 8	3.500	3.458	0.0419	0.1434	0.988	-0.3049 to 0.3887	

Table 9.11: NOTSS score comparison by the trainee participating and the cardiopulmonary bypass scenario.

Discussion:

Communication patterns in the simulated environment were like communication patterns observed intraoperatively (de Lind van Wijngaarden et al., 2019). We found that communication content type and quality of communication differs amongst team members, as well as pre- and post-trigger. We successfully demonstrated that team-based training can improve nontechnical skills of cardiac surgery trainees. We found that during emergency CPB scenarios, all areas of nontechnical skills improved except teamwork. In basic skills of cardiopulmonary bypass, there was an improvement in all areas of nontechnical skills except decision making.

As outlined in chapter six, nontechnical skills of a surgeon are felt to contribute to the development of autonomy and are essential for independent practice, but nontechnical skills are poorly taught (if taught) during surgical residency (Hull & Sevdalis, 2015; Kim et al., 2022; Vervoort & Hirji, 2020). Errors in nontechnical skills has been shown to be the main cause of errors in the operating room rather than errors in technical performance (Kim et al., 2022; Lingard et al., 2004; Ounounou et al., 2019) A previous study identified that lack of competence, communication breakdown, excessive workload, fatigue, and poor judgement were significant contributors to surgical error (Gawande et al., 2003). These factors would be considered nontechnical skills of a surgeon. Current approaches to teaching nontechnical skills includes simulation (fully immersive environment), role playing, didactic teaching, and courses on crisis resource management (Dedy et al., 2013; Hull & Sevdalis, 2015; Ounounou et al., 2019). Simulation-based training, such as a fully immersive environment receives the highest level of recommendation for training nontechnical skills (Ounounou et al., 2019). Previous work has looked at the combination of a workshop and simulation-based training compared to simulation-based training alone and found no difference between the groups in their performance improvement (Pena et al., 2015).

Communication between team members

Errors in communication have been found to contribute to almost 50% of surgical errors (Kim et al., 2022; Lingard et al., 2004). In our study, the pattern of communication was very similar to what has been observed in the cardiac surgery operating room, with majority of the communication being driven by the surgical team member and status and direction being the most frequent types of communication from all team members (de Lind van Wijngaarden et al., 2019; Hazlehurst et al., 2007). Results are not entirely surprising, because surgical team members are often felt to control the pace of an operation (de Lind van Wijngaarden et al., 2019). Practicing communication skills as a surgical team member in straightforward and crisis scenarios is important because previous human factor analysis modelled from aviation has found that surgeon's behavior directly impacts team functioning (ElBardissi et al., 2007).

Communication pre- and post-trigger

Introducing a trigger into the scenarios allowed us to observe whether there would be a communication or behavior change during a period of stress (Hull et al., 2012). Not surprising, post-trigger the frequency of status, alert, explanation, and goal sharing increased. This is explained by the surgical team member giving less direction and creating a shared mental model for the team during an emergency. Explanation and goal-sharing are more complex interactions, generally spanning longer periods of time than providing direction, a status, or an alert (Hazlehurst et al., 2007). Along similar lines, the quality of communication improved post-trigger, with fewer open loop communication and insubstantive call backs. Although not statistically significant, there was a decrease in closed loop communication post-trigger, an area of improvement for the team (Parush et al., 2011). The decrease in open loop communication was likely because of an increase in series communication, where multiple team members are communicating together. This is different, than what is seen intraoperatively, where during critical events communication is often between two sub teams in the form of call backs (de Lind van Wijngaarden et al., 2019). Call backs was still the most common form of communication post-trigger, an additional area for improvement.

Behavior performance over sessions

Interestingly, teamwork and communication on the NOTSS rating scale did not demonstrate improvement over the course of simulation sessions despite the seemingly positively communication analysis. This is likely because other factors contribute to teamwork and effective communication that isn't necessarily communication content or quality. For example, how the information was communicated, which are subtleties related to the individual (i.e.: how loud they speak), or the use of callbacks with no response by team members (Garosi et al., 2020). While we did see an increase in goal-sharing and explanation post trigger, the surgical sub team still was responsible for majority of communication events, which effective teamwork involves other team members to resolve problems (Flin et al., 2012).

We separated performance by CPB basics and emergencies to look at NOTSS rating over the simulation sessions. While three out of four categories on the NOTSS scale improved, they differed by one. During CPB basics, there was no improvement in decision making, likely because of the familiarity of the case, it is not a scenario that really tests the ability of the trainee to consider their decisions. This is contrast to the CPB emergencies where teamwork and communication was the score that did not improve. A possible reason for this has been outlined already, but an additional thought could be related to periods of stress affecting the trainee's ability to function as a teammate (ElBardissi et al., 2007). Given the small sample size, we also looked at overall performance and found that there was a learning benefit to two out of three trainees on their performance, but there was no significant improvement the second time a scenario was experienced. This could be related to the fact that it was a different participant each time, because clearly there was some benefit to observing colleagues with the performance improvement overall.

The study is not without its limitation. The first one is the small sample size; limits the conclusions we can draw from the study. Participant bias, such as the Hawthorne effect, is relevant here as they know they are under evaluation during the simulation sessions and so their performance may be exaggerated (Hull & Sevdalis, 2015). Given that these were simulations, we are not able to extrapolate performance to the clinical setting. An additional limitation is the unavoidable bias of the rater being unblinded to the participants. Finally, the non-surgical team member participants were considered confederates or experts and we only evaluated the NOTSS performance of the surgical trainee. Future work should look to evaluate the entire team using a tool such as NOTECHS (non-technical skills) (Mishra et al., 2009).

Conclusion:

Nontechnical skills are vital to the successful outcome of patients and there is little evidence in the literature on wide-adoption of team-based training in surgical training programs. This study suggests the feasibility of implementing a team-based training curriculum on cardiopulmonary bypass basics and cardiopulmonary bypass emergencies. It is a promising result to see improvement over the course of the sessions and future work should look to increase sample size and determine whether this impact patient care.

CHAPTER TEN: CONCLUSIONS AND FUTURE DIRECTIONS

In summary, the overall goal of this thesis was to take a holistic approach to cardiac surgery training, starting with a needs assessment followed by design and application of simulation-based training for both technical and nontechnical skills. My personal connection to cardiac surgery made the focus of this work obvious, but the principles and skills sets I've developed can be applied to other surgical specialties.

Kern et al. (1998)'s six-step approach to curriculum development for medical education parallels this process: (1) problem identification and general needs assessment, (2) needs assessment of targeted learners, (3) goals and objectives, (4) educational strategies, (5) implementation, and (6) evaluation and feedback (Kern et al., 1998). Anecdotally, as a cardiac surgery trainee, it was clear that while many other surgical specialties were moving away from an apprenticeship model of training, our specialty was not. Our current approach to surgical training seemed outdated, relying solely on patients to serve as wet labs. No data on simulation use or operative experience existed amongst Canadian cardiac surgery programs (Chapter four and five). Conducting a needs assessment of cardiac surgery trainees and cardiac surgery faculty members allowed us to identify that more simulation was desirable at training programs and that, as predicted, operative experience in the final years of graduation is not where the Royal College of Physicians and Surgeons of Canada expect us to be.

In chapter six, we explored the perspectives of surgical training through semi structured interviews, which identified a huge and important discrepancy between what the RCPSC training requirements are for graduating trainees and what programs feel like they can accomplish. Nearly unanimously, participants believed competency and autonomy to be different, whereby autonomy is a step above competency. Surgical residency is meant to prepare trainees for independent practice and if as a surgical community, we believe competency is the realistic goal and autonomy is the idealistic goal, then we as a surgical community have work to do. We identified multiple barriers in our current training structure to producing autonomous graduates, barriers that as a community can be addressed. Recurring themes included patient safety factors, program design, trainee factors, surgeon factors, and importance (yet underemphasized in training) of the nontechnical skills of a surgeon. Altering program set-up and modifying surgeon factors are beyond the scope of this thesis work, but addressing trainee factors, patient safety factors, and nontechnical skills were the next obvious steps.

To address patient safety factors and variable trainee skill level, practice should occur outside of the operating room using simulators with functional task alignment. As previously stated, there are a multitude of task trainers that exist within cardiac surgery, but few have undergone a design process that we employed to develop a readily accessible, adjustable model with functional task alignment. Being a cardiac surgery trainee provided valuable insight when working with our industrial design student to bring our idea to a physical model. One of the most valuable lessons learned is ultimately all task trainers or simulation models have a role to play in learning if they have construct validity, which implies that the elements of the simulator match the assigned objectives. We concluded that the level of validity evidence for the novel cardiac task trainer developed is suitable for a low stakes environment such as home practice or formative assessment. As the model currently stands, it would not be an appropriate model to use for summative assessment. I believe there is educational utility to the task trainer based on participants feedback but also the demonstrated subjective performance benefit (chapter eight). Further study should look to design the optimal training protocol for surgical trainees. Given the poor compliance with the training protocol, a hybrid model incorporating home practice and a controlled educational setting may be optimal.

The final component was the team-based training introduced in chapter nine. This is an additional strategy to improve barriers to autonomy at a patient safety level, trainee factor level and of course the lack of nontechnical skill training provided in surgical residency. Our study design focused on analyzing communication patterns of team members in a simulated setting of emergencies as well as assessment of nontechnical skills of cardiac surgery trainees over the course of the simulation sessions, with notable improvement demonstrated in trainees' performance. An additional novel skill set for me as a cardiac surgery resident was team-based simulation design, which involves the creation of learning objectives, the development of a specific scenario designed to meet those objectives, the simulation environment, the conduct of the simulation sessions with my simulation consultant, and finally assessment and feedback of these sessions. From there, I then learned how to perform behavioral observation analysis using video-based assessment.

Considering Kern's model of curriculum development, step 3-6 is an ongoing process. What are the identified learning objectives, what educational strategy (ie: didactic teaching, simulation) should be used, followed by implementation of the strategy, evaluation, and feedback (Kern et al., 1998). As mentioned previously, there are multiple barriers to team-based simulation-based training, such as resource availability and time constraints of participants, all of which I had to navigate over the course of this thesis work. An additional consideration of mine was finding the balance between educational value for my colleagues and peers and conducting my research study. Ongoing evaluation and feedback, both of participants and of the simulation is required.

Detailed limitations have already been discussed within the individual chapters. Ultimately though, the most challenging aspect of the thesis was the small sample size at a single institution. The logical next step is to introduce this concept nationwide to help increase the sample size. Identifying the perspectives regarding cardiac surgical training in Canada was the first step to addressing barriers to allow us to come up with practical solutions for those barriers. A limitation not discussed within the individual chapters, is that this thesis work was not designed to assess for transferability of skill to the operating room. As mentioned in the introduction of this thesis, skill transferability to the operating room is the ultimate level of educational value when conducting simulation research.

Future Work

Future direction of this work will start by promoting awareness across the cardiac surgical community that training can be better and needs to be better to meet the current demands of a surgical trainee today. As discussed, compliance with the training protocol was low. While we believe that home practice will allow for more distributed practice, future work will look at designing the optimal training protocol for cardiac surgery trainees involving both home practice but also regularly scheduled mandatory simulation under faculty observation. This study will be conducted by recruiting programs across Canada and their trainees to help increase the sample size. The goal will be to have a task trainer available at all programs.

Designing the optimal training protocol also needs to incorporate regularly scheduled team-based training. Expansion of our current study would be to assess team performance, in addition to individual performance using the NOTSS scale. Anecdotally, there has been positive feedback received from participants on their comfortability and confidence in the operating room, but a study needs to be designed to demonstrate transferability of skill.

Final Thoughts

With this thesis work, we have identified that there is a need for change in how we are currently training cardiac surgery trainees, but these principles can be applied to other surgical specialties. This thesis focused on CABG and AVR when designing the task trainer, but the processes learned can be applied to any procedure. When considering designing a new simulator, the follow steps should be taken; Step 1: Design a simulator with functional task alignment as physical resemblance is less important than the functionality between the task performed in the operating room and on the simulator. Step 2: verify the model. Step 3: demonstrate educational value, and Step 4 (not done): assess transferability of skill to the clinical setting.

Focusing on individual performance and technical skills is not enough to become a successful, autonomous surgeon. Team-based training can improve nontechnical skills and provide a safe learning environment for trainees to manage complex tasks.

My future goals as a cardiac surgical trainee with a passion for surgical education is to produce a well-supported and validated training program to implement across Canada. It is our responsibility to ensure we are graduating trainees who are ready for independent practice so that we can ultimately enhance patient safety.

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APPENDIX

Appendix A

Faculty Survey

1. Which academic centre are you currently employed?
   a) University of Alberta
   b) University of Calgary
   c) University of British Columbia
   d) University of Manitoba
   e) University of Toronto
   f) University of Ottawa
   g) Western University
   h) McGill University
   i) Universite de Montreal
   j) Universite de Laval
   k) Dalhousie University
   l) McMaster University
2. How long have you been in practice for?
   a) 5 years
   b) 5-10 years
   c) 10-20 years
   d) >20 years
3. In which academic centre did you complete your residency training?
   a) University of Alberta
   b) University of Calgary
   c) University of British Columbia
   d) University of Manitoba
   e) University of Toronto
   f) University of Ottawa
   g) Western University
   h) McGill University
   i) Universite de Montreal
   j) Universite de Laval
   k) Dalhousie University
   l) McMaster University
   m) Other
4. Does your cardiac surgery residency program use simulation for training crisis management scenarios?
   a) Yes
   b) No
   c) I don't know
5. Does your cardiac surgery residency program use simulation for training surgical techniques?
   d) Yes
   e) No

f) I don't know

6. Does your cardiac surgery residency program have access to a dedicated simulation facility?
   a) Yes
   b) No
   c) I don't know
7. What kind of simulation tools have you been exposed to as a staff proctor? Select all that apply.
   a) Anastomotic task trainers
   b) Valve replacement task trainers
   c) Stand-alone porcine heart models
   d) CPB simulators
   e) Live animal models
   f) Other; please specify __________
8. What kind of simulation tools were you exposed to as a resident?
   a) Anastomotic task trainers
   b) Valve replacement task trainers
   c) Stand-alone porcine heart models
   d) CPB simulators
   e) Live animal models
   f) I had no experience with simulation
   g) Other; please specify __________
9. How often are you involved as a proctor for formal simulation sessions?
   a) Once a month
   b) More than once a month
   c) 3-4x a year
   d) Once a year
   e) Never
10. How often when you were a trainee did you practice at home with a simulator?
    a) Once a week
    b) More than once a week
    c) Never
    d) Other; please specify __________
11. Please rate your agreement with the following statement: *The current era of cardiac surgery trainees could benefit from more simulation of common cardiac surgical procedures (e.g. coronary anastomosis, aortic valve replacement).*
    a) Strongly agree
    b) Agree
    c) Neutral
    d) Disagree
    e) Strongly disagree
12. Please rate your agreement with the following statement: *The current era of cardiac surgery trainees could benefit from more simulation of uncommon cardiac surgery events (e.g. massive air embolism*)
    f) Strongly agree
    g) Agree

h) Neutral
i) Disagree
j) Strongly disagree

13. Please rate your agreement with the following statement: *The current era of cardiac surgery trainees could benefit from more simulation of crisis management scenarios.*
k) Strongly agree
l) Agree
m) Neutral
n) Disagree
o) Strongly disagree

14. Please rate your agreement with the following statement: *Simulation is something I would like to see more of at my own institution.*
a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

15. Do you think you personally could benefit from simulation in your current practice?
a) Yes
b) No

16. Please rate your agreement with the following statement: *I would feel more comfortable allowing a resident to operate in the OR if they had done some simulation-based training prior to OR.*
a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

17. Please rate your agreement with the following statement: *When a resident has done simulation-based training prior to OR I can tell their skills are improved.*
a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

18. Please rate your agreement with the following statement: *When a resident has done simulation-based training prior to OR I can tell their confidence is improved.*
a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

19. Please list the surgical procedures for which you would like your trainees to have simulation-based training. List as many as you like.

20. Do you have any additional comments or feedback on simulation-based training in cardiac surgery?

Trainee Survey

21. What is your current level of clinical training?
    a) PGY-1
    b) PGY-2
    c) PGY-3
    d) PGY-4
    e) PGY-5
    f) PGY-6
    g) Higher
22. What residency program are you from?
    a) University of Alberta
    b) University of Calgary
    c) University of British Columbia
    d) University of Manitoba
    e) University of Toronto
    f) University of Ottawa
    g) Western University
    h) McGill University
    i) Universite de Montreal
    j) Universite de Laval
    k) Dalhousie University
    l) McMaster University
23. Does your program use simulation for surgical procedure training?
    a) Yes
    b) No
    c) I don’t know
24. Does your program use simulation for crisis management scenarios?
    g) Yes
    h) No
    i) I don’t know

25. Does your program have access to a dedicated simulation facility?
    d) Yes
    e) No
    f) I don’t know
26. What kind of simulation tools have you been exposed to? Select all that apply.
    g) Anastomotic task trainers
    h) Porcine heart models
    i) CPB simulators
    j) Live animal models
    k) Other; please specify __________
27. How often does your institute have formal simulation sessions?
    a) Once a month

b) More than once a month
c) 3-4x a year
d) Once a year
e) Never

28. Do your formal simulation sessions begin with a didactic session?
    a) Yes
    b) No
29. Are there specific objectives outlined at the beginning of each simulation session?
    a) Yes
    b) No
30. Are you assessed by a staff cardiac surgeon at the end of the simulation session?
    a) Yes
    b) No
31. How often do you practice on a simulator at home?
    a) Once a week
    b) More than once a week
    c) Never
    d) Other; please specify ___________
32. Would you be more likely to practice on a simulator at home if you had specific "homework" assigned to you?
    a) Yes
    b) No
33. Please rate your agreement with the following statement: *I found the simulation sessions at the cardiac surgery boot camp useful.*
    a) Strongly agree
    b) Agree
    c) Neutral
    d) Disagree
    e) Strongly disagree
34. Please rate your agreement with the following statement: *I could benefit from more simulation of common cardiac surgical procedures (e.g. coronary anastomosis, aortic valve replacement).*
    p) Strongly agree
    q) Agree
    r) Neutral
    s) Disagree
    t) Strongly disagree
35. Please rate your agreement with the following statement: *I could benefit from more simulation of uncommon cardiac surgical events (e.g. massive air embolism*)
    a) Strongly agree
    b) Agree
    c) Neutral
    d) Disagree
    e) Strongly disagree
36. Please rate your agreement with the following statement: *I could benefit from more simulation of crisis management scenarios.*

a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

37. Please rate your agreement with the following statement: *Simulation is something I would like to see more of at my own institution.*
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
38. Please rate your agreement with the following statement: *I believe my confidence in the OR will grow if given the chance to practice the skills before hand.*
    a. Strongly agree
    b. Agree
    c. Neutral
    d. Disagree
    e. Strongly disagree
39. Please list the surgical procedures and/or concepts you have received simulation-based training on?
40. Please list the surgical procedures you would like to see simulated.
41. Please list the surgical procedures you would like to be able to practice at home?
42. Do you have any additional comments or feedback on simulation-based training in cardiac surgery?

***Included for both Faculty and Trainee**

In the next section there will be a series of objectives mandated by the Royal College of Cardiac Surgeons. Our goal is to determine which objectives are the most important to simulate and the most simulatable skills.

A) General cardiac surgery

Indicate your agreement for each of the following statements.

Median sternotomy

This objective is important to master before completion of residency.

a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

This objective would be valuable as a simulation.

a) Strongly agree
b) Agree
c) Neutral
d) Disagree
e) Strongly disagree

Redo sternotomy

Femoral cannulation/decannulation
Axillary cannulation/decannulation
Initiation of CPB (including aortic and venous cannulation
Weaning from CPB

B) Crisis management scenarios

Indicate your agreement for each of the following statements.

Massive air embolism
Low venous drainage
Iatrogenic aortic dissection
Low CO after CPB
Protamine reaction

C) Ischemic Heart Disease

Indicate your agreement for each of the following statements.

Open saphenous vein harvest
Endoscopic saphenous vein harvest
Open radial artery harvest
Endoscopic radial artery harvest
IMA harvest
Coronary artery anastomosis
Beating heart coronary artery anastomosis
Minimally invasive coronary artery bypass
Repair of postoperative MI complications (VSD, ruptured papillary muscle)

D) Valvular Heart Disease

Indicate your agreement for each of the following statements.

Aortic valve replacement
Aortic root enlargement
Ross procedure
Bentall procedure
Valve-sparing root replacement
Mitral valve replacement
Mitral valve repair
Ministernotomy AVR
Right anterior thoracotomy AVR
Minimally invasive mitral valve repair/replacement
Tricupsid valve repair
Tricupsid valve replacement
Pulmonary valve replacement

E) Thoracic Aortic Disease

Indicate your agreement for each of the following statements.

Aortic valve resuspension
Hemiarch replacement
Total arch replacement
Antegrade cerebral perfusion
Open repair of descending thoracic aorta
Endovascular repair of type B dissection
Endovascular repair of descending thoracic aorta

F) Surgery for arrythmias

Indicate your agreement for each of the following statements.

Pacemaker implantation

MAZE procedure

G) Temporary Mechanical Circulatory Support

Indicate your agreement for each of the following statements.

ECMO

LVAD

BiVAD

H) Cardiac Transplant

Indicate your agreement for each of the following statements.

Donor harvest

Recipient implantation

Appendix B

For the following questions please keep in mind the 4-step Zwisch scale for operative autonomy.

1. Show and tell – resident actively assists surgeon
2. Active help – resident performs actual steps of the operation, but surgeon controls flow of the case and guides the resident through the steps
3. Passive help – resident moves from step to step and controls flow of the case, but with significant assistance from surgeon
4. Supervision only – resident performs the case independently with only supervision or minimal assistance from surgeon.

43. What residency program are you from?
    m) University of Alberta
    n) University of Calgary
    o) University of British Columbia
    p) University of Manitoba
    q) University of Toronto
    r) University of Ottawa
    s) Western University
    t) McGill University
    u) Universite de Montreal
    v) Universite de Laval
    w) Dalhousie University
    x) McMaster University
44. What is your current level of training (excluding academic time, ie: PGY-4 on Masters = PGY-3 clinically)
    a) PGY-1
    b) PGY-2
    c) PGY-3

d) PGY-4
e) PGY-5
f) PGY-6
g) Higher than PGY-6

45. Are you in your final year of residency?
    a) Yes
    b) No
46. On average, are you happy with your current operative experience?
    a) Yes
    b) No
47. On average, how many days a week are you in the OR while on service?
    a) Every weekday
    b) 2-4 days/week
    c) 1 day a week or less
48. On average, how many trainees scrub in for one case (including fellows)?
    a) 1
    b) 2
    c) > 2
49. In general, the opportunities I receive in the operating room align with objectives of training appropriate to my level. (For example: as a PGY-1, I would harvest vein and perform a sternotomy).
    a) Yes
    b) No
    c) I don’t know
50. In general, the opportunities in the operating room are above the objectives of training appropriate to my level. (For example: as a PGY-1, I am cannulating every case)
    a) Yes
    b) No
    c) I don’t know
51. In general, at your centre would you say above PGY-5 you are operating with supervision only for most straightforward cases?
    a. Yes
    b. No
    c. I don’t know
52. On average, does your staff allow you sufficient time to struggle before taking over?
    a. Yes
    b. No
53. Do you discuss with the staff you are working with that day what you are going to get to do? As in do you make a game-plan?
    a. Yes
    b. No
54. Currently, where are you on the Zwisch scale for the following procedures? (Z1=show and tell, Z2=active help, Z3=passive help, Z4=active help).
    a. Sternotomy

   b. Vein harvest
   c. Mammary harvest
   d. Cannulation
   e. Sternotomy closure
   f. CABG
   g. AVR
   h. Mitral annuloplasty
   i. MVrepair
   j. MVR
   k. Bentall
   l. Ascending aortic replacement
   m. Aortic dissection
   n. Emergency CABG
   o. TAVI
   p. Redo sternotomy
   q. Sternal re-wiring
   r. Chest re-opening for tamponade
   s. Resection of atrial myxoma
55. At what PGY level did you first get to operate at Zwisch scale 3 passive help or above for the following procedures.
   a. Sternotomy
   b. Vein harvest
   c. Mammary harvest
   d. Cannulation
   e. Sternotomy closure
   f. CABG
   g. AVR
   h. Mitral annuloplasty
   i. MVrepair
   j. MVR
   k. Bentall
   l. Ascending aortic replacement
   m. Aortic dissection
   n. Emergency CABG
   o. TAVI
   p. Redo sternotomy
   q. Sternal re-wiring
   r. Chest re-opening for tamponade
   s. Resection of atrial myxoma
56. At the end of residency do you think you will be comfortable operating independently for the core breadth of cardiac surgery?
   a. Yes
   b. No
57. Please rank the following reasons for doing a fellowship (1 = most important)
   a. To learn advanced skills
   b. Will need more time to feel comfortable operating independently

c. To get a job at a specific centre
d. This is the way of our specialty

Appendix C
Faculty questions

1. Where did you complete your residency?
2. What year did you complete your residency training?
3. How long have you been in practice for?
4. Have you always been at an academic program?
5. Have you had any formal training in teaching?
6. What is the number of residents you've taught in total or a typical number of residents you teach per year/per block?

Who did the case, for example a CABGx3? Normal EF.

7. Everything technically was done by the resident, except the distal anastomosis. Who did the case? Resident or Staff? And why?
8. The resident completed all the distal anastomoses but didn't do anything else. Who did the case? Resident or Staff? And why?
9. The resident did the entire procedure, but the staff controlled the flow of the case, for example, when to give cardioplegia, when to go on, when to come off and where to put the arteriotomies. Who did the case? Resident or Staff? And why?

10. In your own words, define competence.
11. How do you assess a resident's competency?
12. What objective metrics if any do you use to determine whether a resident is competent? Do you think they are adequate?
13. How do you decide what a resident is going to get to do during any given operation? More specifically, a routine case for you? A less routine case? Or an emergency?
14. Do you feel comfortable allowing a resident to struggle during an operation? Why or why not?
15. Looking specifically at the EPAs for the transition to practice year, do you believe they are reasonable to achieve? And do you believe they are necessary to achieve?
16. Would you feel comfortable allowing a resident in the TTP year operate with only an assistant? Why or not? What would prevent you from doing so?
17. In your own words, define autonomy.
18. Do you believe the goal of residency surgical training is to have an autonomous surgeon or a competent surgeon?
19. Are competency and autonomy different things?
20. Do non-technical skills such as decision-making contribute more to the development of competence or autonomy?
21. Do you think that the nontechnical skills, the judgment, patient selection, et cetera, do you think that those are skills that are taught in residency or the things that you just learn from observation?
22. Do you believe a gap exists between the development of competence and the attainment of operating autonomy? If so, how do you think this gap should be addressed?

23. Do you feel constraints of modern-day surgical training adversely impact the development of resident operating autonomy? Ex. Work hour restrictions, increased scrutiny of operative outcomes, and greater focus on operative efficiency and patient safety.
24. Do you ever scrub out of the operating room, while a resident is operating?
25. How do you assess a resident's readiness for independence?
26. Which is more important for independent practice? Technical elements of the procedure or the nontechnical elements such as critical decision making, and why?
27. Reflecting on your own practice, do you believe you are someone who allows residents to operate? Does your center?
28. Do you teach how you would've liked to be taught when you were a resident? Why or why not?
29. What is the biggest obstacle that you feel most residents will face when transitioning to independent practice?
30. We've talked a lot about the gaps in training and things like that, is CBD the answer to this gap? Is it changing how we're training surgical residents?
31. Anything else you would like to add?

Trainee questions

1. What year are you in?
2. What is the number of staff that you would interact with on a regular basis?
3. How does your program structure their residents when they are on service?

Who did the case, for example a CABGx3? Normal EF.

4. Everything technically was done by the resident, except the distal anastomosis. Who did the case? Resident or Staff? And why?
5. The resident completed all the distal anastomoses but didn't do anything else. Who did the case? Resident or Staff? And why?
6. The resident did the entire procedure, but the staff controlled the flow of the case, for example, when to give cardioplegia, when to go on, when to come off and where to put the arteriotomies. Who did the case? Resident or Staff? And why?

7. In your own words, define competence.
8. How do you prepare for cases on a regular basis?
9. How do you and your staff, decide what you're going to get to do during any given operation? Does it change depending on the staff? What about emergencies or non-routine cases?
10. Does your staff allow you to struggle during an operation? At what point are you looking for help or perhaps for someone to take over? Is it beneficial to struggle in residency?
11. Looking specifically at the EPAs for the transition to practice year, do you believe they are reasonable to achieve? And do you believe they are necessary to achieve?
12. Do your staff ever scrub out of the operating room, while you're operating?
13. Do you believe your staff in your TTP year allow you to operate with only an assistant? Why or not?
14. In your own words, define autonomy.

15. Do you think autonomy and competency are different?
16. What is the goal of surgical training, to produce a competent or an autonomous surgeon and why?
17. Do non-technical skills such as decision-making contribute more to the development of competence or autonomy?
18. Do you believe a gap exists between the development of competence and the attainment of operating autonomy? If so, how do you think this gap should be addressed?
19. Do you think that the nontechnical skills, the judgment, patient selection, etc, do you think that those are skills that are taught in residency or the things that you just learn from observation?
20. Do you feel constraints of modern-day surgical training adversely impact the development of resident operating autonomy? Ex. Work hour restrictions, increased scrutiny of operative outcomes, and greater focus on operative efficiency and patient safety.
21. Which is more important for independent practice? Technical elements of the procedure or the nontechnical elements such as critical decision making, and why?
22. Reflecting on your entire center, do you believe it is one that allows residents to operate?
23. Are you taught how you'd like to be taught in residency? In a perfect world, what would you change about your program?
24. How is your program actively helping you to achieve your EPAs, to ensure you are on track?
25. So we've talked a lot about the gaps in training and things like that, is CBD the answer to this gap? Like, is it changing how we're training surgical residents, or is it just formalizing the training we've been doing?
26. Anything else you would like to add?

Appendix D

A) Coronary assessment tool

	1	2	3	4	5
Graft orientation	Unable to orient Does not know start point Does not know end point Marked hesitation		Orient with some hesitation Knows start and end point with some hesitation		Proper heel-toe orientation Consistent start No hesitation
Bite	Irregular entry/exit Hesitant, multiple punctures Inconsistent distance from edge		Mostly regular entry/exit Mostly single puncture Mostly consistent from edge		Consistent regular entry/exit Consistent single puncture Consistent from edge
Needle angles	Not aware of angles Does not compensate for depth Does not consider subsequent angles		Inconsistently understand angles Partial compensation for depth Partial consideration of subsequent angles		Consistently correct angles Compensates for depth Consistent adjustment for subsequent angles
Needle transfer	Marked hesitation in mounting needle		Able to mount needle with hand and partial manipulation		Able to mount needle and manipulate needle easily
Needle holder use	Awkward finger placement Unable to rotate instrument Inconsistent needle placement Not facile		Functional finger placement Hesitant when rotating Generally good needle placement Moderate facility		Comfortable, smooth finger placement Smooth rotation Consistent proper needle placement High facility
Use of forceps	Awkward or no traction Unable to expose Not able to stabilize needle		Moderate proper traction Able to assist in exposure Able to stabilize but rough		Consistent proper traction Consistent proper exposure Knows when to stabilize, gentle

Suture management	1 No use of tension Suture entangled	2	3 Tension use inconsistently Sutures occasionally get in way	4	5 Proper use of tension Suture never in the way
Knot tying	1 Marked hesitancy, slow speed No follow through Not able to tie, breakage Loose or "air" knot	2	3 Moderate facility, moderate speed Able to tie and tension Occasionally loose	4	5 Consistent facility, no hesitancy Consistent tension and tight
Economy of time and motion	1 Marked hesitation Not aware of goal Unable to do task	2	3 Some hesitation Some awareness of goal Able to do task but discontinuous	4	5 No hesitation Fully aware of goal Able to do task smoothly

B) AVR assessment tool

Annular suturing	1 Hesitant, multiple tries	2	3 Mostly regular entry/exit Mostly single tries at correct placement	4	5 Correct placement No hesitation
Suture placement	1 Unacceptably deep or shallow Incorrect spacing	2	3 More than 50% of sutures plaed incorrectly	4	5 Sutures placed correctly into annulus Annulus sutures organized and flows without hesitation
Suture management	1 Sutures unorganized and mixed up	2	3 Less than half of sutures correctly organized and secured	4	5 All sutures organized and secured
Valve seating and tying*	1 Valve incorrectly oriented	2	3 Valve seats but with difficulty	4	5 Valve correctly oriented

	Valve will not slide down sutures Valve does not seat Sutures not pulled up/pledgets loose Sutures not tied efficiently Valve movement not checked		50% of sutures pulled up and tied correctly		Valves slides down sutures, seats easily Valve movement correctly checked
Needle holder use	1 Awkward finger placement Unable to rotate instrument Inconsistent needle placement Not facile	2	3 Functional finger placement Hesitant when rotating Generally good needle placement Moderate facility	4	5 Comfortable, smooth finger placement Smooth rotation Consistent proper needle placement High facility
Use of forceps	1 Awkward or no traction Unable to expose Not able to stabilize needle	2	3 Moderate proper traction Able to assist in exposure Able to stabilize but rough	4	5 Consistent proper traction Consistent proper exposure Knows when to stabilize, gentle
Economy of time and motion	1 Marked hesitation Not aware of goal Unable to do task	2	3 Some hesitation Some awareness of goal Able to do task but discontinuous	4	5 No hesitation Fully aware of goal Able to do task smoothly

Table 1A) & B): Modified OSATS tools for coronary anastomosis and aortic valve replacement. 1=poor, unable to accomplish goal, marked hesitation, 2= below average, able to partially accomplish goal with hesitation, 3= average, able to accomplish goal with hesitation, discontinuous progress and flow, 4= good, able to accomplish goal deliberately, with minimal hesitation, showing good progress and flow, 5= excellent, able to accomplish goal without hesitation, showing excellent progress and flow. *assessed when applicable