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Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Cardiac Ultrasound

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Cardiac Ultrasound

by

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Abstract

The use of focused cardiac ultrasound (FCU) as a diagnostic and monitoring tool in critical care medicine continues to expand. However, little attention has been placed to date on assessment tools that might critically evaluate the image acquisition skills of echocardiographers employing FCU in their practice. This study developed and evaluated a comprehensive assessment tool for FCU image acquisition in a cohort of intensive care residents learning FCU. Resident participants' FCU image acquisition skills improved quickly and then reached a plateau. The FCU assessment tool developed was able to discern changes in FCU image acquisition performance over time and also distinguish between echocardiographers of different skill levels. The study results provide preliminary validity evidence for the new FCU assessment tool, that with further study, might have practical utility as a tool employed for summative assessment and certification in this growing area of acute care medicine.

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CHAPTER ONE: INTRODUCTION

Critical care medicine residents must acquire a great deal of knowledge and develop complex skills during their training so that they may become competent caring for critically ill patients requiring life support in the intensive care unit (ICU). Diagnosis and management of cardiorespiratory failure and shock states has become the sine qua non of "life support," and therefore, identification and treatment of the causes of shock (i.e., hemodynamic compromise) in critically ill patients is a daily exercise in the ICU. Critical care physicians have long sought diagnostic and monitoring tools to complement their clinical skills and aid this process either by invasively or non-invasively collecting data to help delineate the cause of a patient's hemodynamic compromise and help inform their treatment. Until recently, this was predominantly achieved by placing a pulmonary artery catheter (PAC), which is an invasive way to gather and monitor physiologic hemodynamic data.[1,2] However, reliance on the PAC has steadily declined in recent years in favour of safer, non-invasive methods of hemodynamic assessment.[2] Instead, focused cardiac ultrasound (FCU) has emerged as an alternate assessment and monitoring tool to aid in the diagnosis and management of unstable ICU patients in shock.[3]

Focused cardiac ultrasound (also known as bedside limited echocardiography, limited or focused transthoracic echocardiography or point-of-care cardiac ultrasound) has gained increasing popularity in critical care and other acute care medicine disciplines (emergency medicine, anesthesia, general surgery, and internal medicine) because it is fast, non-invasive and versatile.[4-6] It provides real-time information about the structure and function of the heart unavailable through other bedside assessments to guide physician decision-making.[4-6] Unlike other ways to assess and monitor hemodynamics, FCU also offers the distinct diagnostic

advantage of being able to directly visualize the heart, pericardium and great vessels to identify pathology.[7,8] Given these advantages, FCU has tremendous potential to offer more clinically useful information than many other conventional hemodynamic monitoring strategies.[9]

In contrast to quantitative cardiac ultrasound or comprehensive echocardiography performed by cardiologists, FCU provides qualitative assessments at the point-of-care to answer focused clinical questions about the potential etiologies of hemodynamic compromise.[4,10,11] In this paradigm, FCU is done contemporaneously with patient care and is typically performed within minutes of an identified need.[10] Thus, FCU is particularly valuable for time-sensitive conditions when cardiac ultrasound is required on an urgent or emergent basis to facilitate rapid diagnosis and clinical decision-making. To meet this need, critical care physicians trained in bedside ultrasound are uniquely positioned to utilize FCU to evaluate, diagnose and monitor their patients.[10]

For all of these reasons, there has been a surge of interest in FCU in critical care medicine with an ever-increasing and enthusiastic chorus of calls for incorporation of FCU training programs for critical care medicine trainees.[12-14] Specialist societies have also recognized this need and produced several endorsements and expert consensus statements on FCU.[11,15-19] This has led has led some authors to conclude that all critical care physicians need echocardiography skills in the 21st century.[12,18,20]

Despite these calls to action, the enthusiasm for FCU in ICU must be tempered with the reality that adopting any new diagnostic technology presents significant challenges.

Incorporation of FCU in critical care is presently hindered by a lack of evidence informed training programs as well as a formalized and validated accreditation process that would allow acute care trainees to not only develop, but also to demonstrate their skills. Obtaining the skills of acquisition and interpretation of high quality echocardiographic images typically only occurs within formal echocardiography fellowship training programs for cardiology and cardiovascular anesthesia.[4] These training programs were neither designed for, nor intended to meet the distinct needs of the non-cardiologist, acute care physician who aspires to learn and employ FCU in their practice.[4,9]

Recognizing the need for critical care trainees to develop expertise in FCU and the paucity of formal learning opportunities that existed to do so, the Department of Critical Care Medicine (DCCM) at the University of Calgary developed its own FCU curriculum to address this learning gap and fill this unmet educational need. Implementation of this innovative, multi-modal curriculum to teach acquisition and interpretation of FCU began initially in 2011 as a pilot curriculum. In 2012, the second iteration of the curriculum was implemented. Despite this educational advance, what is not yet fully known is the amount of practice and experience necessary to obtain defined levels of competency in acquiring FCU images.

Statement of the Problem

Based on the preceding discussion, the principle objective of this study was to develop, implement and evaluate a comprehensive assessment tool for critical care trainees learning to acquire FCU images in the ICU.

Chapter 2 reviews the relevant literature that laid the foundation upon which this study subsequently evolved, paying particular attention to the emerging body of literature on FCU curricula and to medical education literature on the development of assessment tools and expertise. A description of the materials and methods employed in this study follows in Chapter 3. The results of this project are outlined in Chapter 4. Finally, Chapter 5 discusses the relevance and impact of the study findings and comments on the study's limitations as well as future directions for research in this exciting area.

CHAPTER TWO: LITERATURE REVIEW

All post-graduate medical training programs share a desire to ensure that their trainees, upon graduation, possess the requisite knowledge and skill to be competent to practice their chosen specialty. Developing and implementing assessments that identify "real" competence in the workplace is intimately tied to and inextricably part of fulfilling this desire. While the desire to ensure that trainees develop into professionals fit for practice has always existed, a paradigm shift in medical education away from opinion or intuition-based assessments coupled with increasing calls for accountability, has firmly placed evidence-informed assessments at the forefront as not only desirable but necessary benchmarks of quality in medical education.[21] Consequently, a more systematic approach to developing and implementing assessment tools for medical education is needed; to drive and stimulate learning, provide feedback on efficacy of educational interventions and, finally, to protect patients and society at large.[22] This is certainly the case for FCU as an emerging hemodynamic monitoring tool in an era of outcomes-based education.

Before embarking on further discussions about the development of assessment tools, it is important to highlight some of the controversies surrounding the adoption of FCU in critical care as well as the emerging body of literature pushing for its incorporation in acute care specialties.

Focused Cardiac Ultrasound vs. Formal Comprehensive Echocardiography

The development of FCU has not been without some degree of misunderstanding and controversy.[11,15] Part of this controversy stems from a great deal of confusion about what FCU entails in comparison to comprehensive cardiac ultrasound performed by cardiologists that

provides quantitative characterization of cardiac abnormalities and hemodynamics as well as greater use of additional ultrasound tools (e.g., Doppler, 3D).[11] As already mentioned, FCU provides qualitative assessments at the point-of-care which seek to answer simple clinical questions about the potential causes of shock in critically ill patients.[4,10,16] The objectives of FCU include assessment of left ventricular (LV) and right ventricular (RV) function, assessment of the pericardial space for effusion or tamponade and assessment of volume status.[4] Focused cardiac ultrasound does not provide quantification or equivalent diagnostic capability compared to comprehensive echocardiography, nor is the user expected to delineate and quantify all findings viewed during the study.[11,16] Rather, FCU is performed concurrently with patient care to help provide early or preliminary diagnostic information to physicians, thereby enhancing their bedside exam and overall diagnostic impression.[11] It may also be particularly useful when patients' hemodynamic instability precludes their transport for other conventional forms of diagnostic imaging.[11] Therefore, FCU is particularly indispensable in time-sensitive conditions when cardiac ultrasound is required on an urgent or emergent basis to facilitate rapid diagnosis and treatment. In these instances, even well-staffed formal echocardiography services may not be able to perform these studies in a clinically useful time frame, particularly during night-time and weekend hours.[10]

In the medical community, valid concerns related to training standards, scope of practice, quality assurance and oversight continue to be raised about non-cardiologists employing FCU as a diagnostic and monitoring tool to aid in caring for critically ill patients. These concerns are not unfounded or insignificant since cavalier application of FCU beyond a defined scope of practice risks adverse consequences for patients. But FCU has never been intended to supplant or achieve

equivalency with formal cardiac ultrasound performed by cardiologists. Rather it is intended to be complementary to it.[4,15] Nonetheless, it is evident that in order to gain more widespread acceptance within the medical community, critical care physicians will have to demonstrate considerable acumen with this technology and prove that FCU can not only be safely employed but also meaningfully influence patient care.

Focused Cardiac Ultrasound by Non-Cardiologists

A growing body of literature in a broad variety of critically ill patients suggests that FCU assessments by non-cardiologist physicians are safe, feasible and accurate.[7,23-29] Limited transthoracic echocardiography (TTE) improves the bedside cardiovascular physical exam and aids in diagnosis.[30-32] FCU has been shown to augment traditional bedside assessments of critically ill patients to aid in the determination of volume status and left ventricular systolic function.[28,33,34] In the ICU, FCU has also been demonstrated to be effective in mechanically ventilated patients and shown to be useful in predicting their fluid responsiveness and in guiding their vasopressor and hemodynamic therapies.[7,27,35-38] Patients who suffer cardiac arrest in the emergency department (ED) or ICU may also benefit when FCU is used to evaluate for pericardial effusion and cardiac tamponade or cardiac standstill during cardiopulmonary resuscitation.[39,40] Moreover, the early post-arrest resuscitation phase may also be guided by FCU to quickly assess for left ventricular function, pericardial tamponade, pulmonary embolism and volume status—findings that can sometimes be hard to determine with physical exam alone.[11,41]

To date, there are no large randomized clinical trials or meta-analyses documenting the impact of focused echocardiography on clinical outcomes of critically ill patients.[8] However, an

expanding number of studies do attest to the utility of FCU in positively influencing their care. Focused cardiac ultrasound has been demonstrated to directly change ICU patient management in 25% to 51.2% of cases.[27,35,42,43] More recently, a single-center Canadian study compared early standardized echocardiography by intensivists versus conventional management of 74 ICU patients with undifferentiated shock and found that early echocardiography improved 28-day survival as well as the number of days alive and free from invasive mechanical ventilation and vasoactive infusions to support blood pressure.[44] Finally, evidence is mounting to suggest that with recent improvements in technology and miniaturization, FCU can be cost effective in reducing the number of formal quantitative echocardiograms performed.[45]

On the strength of this evidence, FCU has been demonstrated to be an indispensable extension of the physical exam that can positively impact patient care and influence the management of critically ill patients. It may even favourably influence their survival. Unfortunately, significant barriers continue to impede widespread adoption of FCU in ICU.

Barriers to Focused Cardiac Ultrasound in the ICU

A recent survey of all critical care residency program directors in the United States confirmed the challenges that lie ahead if FCU is to be incorporated into routine use in ICU.[46] While nearly all program directors (92%) felt ultrasound training was useful, only 55% of programs provided any form of FCU training.[46] Nearly half (48%) believed that cardiac ultrasound required a long training time and 40% of respondents reported that their institution lacked sufficient faculty proficient in ultrasound use.[46] Furthermore, 25% of respondents reported they did not know how to get their residents trained in FCU and 13% reported the lack

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of an ultrasound machine in their training program.[46] Unfortunately, no studies exist within the

Canadian critical care context to verify the findings of our American colleagues. Moreover, few

formalized training programs currently exist within the Canadian context for critical care trainees

to learn FCU (Dr. Jason Lord, University of Calgary Critical Care Medicine Program Director,

personal communication, November 18, 2012). Therefore, it seems reasonable to conclude

Canadian critical care trainees face similar (and potentially more significant) barriers to

developing expertise in FCU. If FCU is to grow and gain prominence, these important barriers

will need to be thoughtfully addressed so FCU can be learned and successfully incorporated by

critical care trainees in the future.

Persistent Issues in Focused Cardiac Ultrasound

Barriers to training aside, a persistent issue in the realm of FCU has been the paucity of

evidence that informs what core competencies and training and certification standards are

necessary for physicians utilizing FCU as a tool to help guide care of critically ill patients.

Learning FCU encompasses two important components: the acquisition of high quality

ultrasound images and subsequently their interpretation. Both of these components initially

represent a high cognitive load for novices.[47,48] Once the fundamental concepts have been

learned, the trainee must participate in deliberate practice in order for their knowledge schemas

and technical acumen to grow and mature toward achievement of expert performance.[49,50]

Historically, training and assessment in FCU have largely been through apprenticeship

and experiential learning, with heavy emphasis placed on hours-in-training and numbers-based

competency thresholds. Today, practical training in FCU continues to be largely informal and informed by having trainees complete a set number of didactic and hands-on training hours accompanied by a portfolio of a set number of echocardiograms that have been expertly proctored and/or reviewed. Few evidence informed training curricula exist for FCU and standards for training and quality control continue to be defined.[11,15-17,19,26,51-54] Recommendations remain nebulous— yet what is universally accepted is that FCU training should include three key components: didactic education, hands-on image acquisition practice and image interpretation experience.[11] The recommended threshold number of FCU studies has varied contentiously from a minimum of 25 up to 100 supervised echocardiograms.[17-19,55] Indeed, expert opinion and consensus statements rather than evidence-informed knowledge and skill assessments have principally determined current training standards.[17]

Therefore, exactly how intensivists will become fully trained and accredited in FCU remains contentious and needs to be more clearly delineated by evidence-informed curricula and assessments.[9] While intensivists are best positioned to know the needs of their specialty as cardiac ultrasound expands beyond the purview of cardiology, this comes with commensurate responsibility to ensure patient safety through high-quality training and certification standards for image acquisition and interpretation of FCU. Inadequate training, misdiagnosis or misinterpretation of findings (i.e., false positive or false negative FCU examination) leading to inappropriate intervention(s) or delayed treatment(s) risks harming patients.[9,11,56] Going forward it is incumbent upon medical educators to not only develop the training standards and curricula that will teach ICU trainees the knowledge and skills to acquire and interpret FCU but also to

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simultaneously develop high quality assessment tools and quality assurance programs if focused echocardiography is to be offered in the intensive care unit.[9]

Development of Assessment Tools in Medical Education

The adage "assessment is the tail that wags the dog" highlights the accepted educational premise that assessment drives learning.[57] In this sense, "to test" is not only to determine the worth of the object (i.e., the trainee) by trial—it is also to improve the quality of the object (i.e., the impact of assessment on the trainee's development).[22,58] Understanding this dual meaning of assessment is critically important because it not only informs the development of assessment tools but also helps us to understand criteria for good assessment instruments.

In designing any assessment tool one must first consider the outcome or outcomes that need to be assessed (and their alignment with the curriculum), the level of assessment required (i.e., formative or summative) and the stage of development of the trainees as well as the available resources.[22,57-59] Bloom's Taxonomy provides a useful framework from which to approach the requisite outcomes in terms of the knowledge, skills and attitudes required of any professional activity.[60] Deciding how to conceptualize an approach to the development of an assessment tool is not the same as selecting the elements that will comprise it, however. Selection of elements is usually informed through a systematic process of task analysis and generation of consensus from a breadth of expert opinions.[58] Throughout this process medical educators must make measured and sometimes difficult choices in designing and implementing a new assessment tool to evaluate physician competence to practice and expertise.

Competence in Medical Education

Competence is a complex construct that is not only difficult to precisely define, but also may mean different things to different medical educators. The Oxford Dictionary defines competence as having the necessary ability, knowledge or skill to do something successfully. Although professional standards of competence delineate key technical, cognitive and emotional aspects of medical practice, an all-encompassing definition of professional competence as it relates to the medical profession is not as widely agreed upon.[61] Medical professional competence has been defined as "the habitual and judicious use of communication, knowledge, technical skills, clinical reasoning, emotions, values, and reflection in daily practice for the benefit of the individual and the community being served."[61] Competence has also been defined as, "possessing the required abilities in all domains in a certain context at a defined stage of medical education or practice."[62] It is developmental, impermanent and multi-dimensional.[61-63] For any statement about competence, descriptors that specify the requisite abilities, context and stage of medical training or practice are necessary.[62]

While performance is directly measurable, competence is an inferred quality or trait.[61] Yet this does not mean that performance and competence are two separate domains—quite the opposite in fact.[64] Rather, for each domain of competence (or competency), there is a corresponding spectrum of ability where competence is a point on a spectrum of improving performance ranging from novice on one end to expert on another (Figure 1).[62,65,66] In this sense, competence is the ability to perform at a certain level within a given context for a certain competency, and therefore, performance must be measured to assess the attribute competence in the performer.[64,67]

Figure 1. The Dreyfus and Dreyfus Model of Skill Acquisition[65]
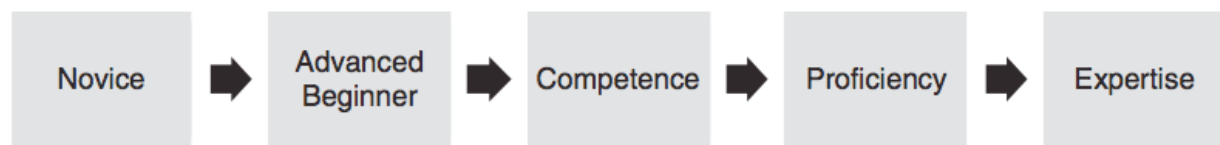
Professional Development: From Novice To Expert

Professional development theories on the transition from novice-to-expert are increasingly relevant in medical education.[68] They attempt to answer questions like: what defines an expert?; how do experts develop?; what allows experts to achieve superior performance? These questions are important, for they allow us to develop an understanding of what needs to be assessed in order for us to determine how to assess practitioners' competency and/or expertise.[68]

Although most agree that expertise develops through learning and lived experience, a universally accepted and precise understanding of how this process occurs does not exist. This is partly because expertise does not have a single unifying theory to describe its development.[68] Instead, theories about expertise draw from a variety of disciplines including: education, cognitive psychology, philosophy, neuroscience and psychometrics, among others.[68] The following discussion highlights some of the important theoretical groundwork regarding development of expertise, paying careful attention to medical education.

As highlighted in the preceding discussion, the Dreyfus model of skill development describes a multistage process marked by transitory phases progressing from novice on one end of a continuum to expert on the other (Figure 1).[65] The Dreyfus brothers were originally

commissioned by the United States Air Force to describe the development of the knowledge and skill of a fighter jet pilot.[69] Subsequently they applied their model more broadly to skills like playing chess and driving a car.[65,70] For simple tasks (e.g., riding a bicycle) expert performance may be achieved relatively quickly, but for other more complex activities (e.g., playing chess), decades may be required.[50] More recently the Dreyfus' model has gained popularity and considerable interest from medical educators.[21]

The Dreyfus model of skill acquisition not only describes the evolution through five stages from novice to expert, but also subsumes ideas about how individuals actually learn.[65,70-72] A novice learner uses analytic reasoning to follow rules that are context-free—he or she does not link cause and effect.[70,72] Because of inexperience and an inability to filter and prioritize, synthesis of information is difficult.[70] Advanced beginners gain experience in real-world situations and start to understand their environment within contextual features. They begin to be able to sort through rules to determine what is important based on their previous experience.[70] However, learning still occurs within a detached, analytical frame of mind.[72] After considerable experience, individuals learn guidelines which dictate their actions in real situations so they may become competent at the skill or problem in question. They begin to apply pattern recognition and now are able to see the bigger picture, however, rare or challenging problems still require reliance on analytic reasoning.[70] The proficient stage of development is characterized by the individual using their intuition to realize what is happening and by the development of increasing comfort with uncertainty. He/she relies on memorized principles or maxims to problem solve and determine appropriate action, even in instances of ambiguity (extrapolating from a known situation to an unknown one).[70] Finally, experts are capable of working intuitively on any

problem, no longer requiring first principles to guide their action.[72] Expert performance is fluid and non-reflective—it happens "unconsciously, automatically and naturally."[71] An expert simply "does" what is required, yet retains a heightened ability to perceive discriminating features that do not match the typically encountered pattern.[70]

For Dreyfus and Dreyfus, the progression from novice to expert is characterized by a transition from rigid adherence to rules and procedures (i.e., rule based) and analytic reasoning (i.e., conscious and controlled) to a more intuitive, non-analytic (i.e., unconscious, automatic) modus operandi that relies heavily (and almost exclusively) on implicit knowledge (i.e., knowledge that is acquired through practical experience and that can't be explicitly stated or formalized).[65,71,72]

Medical educators have adopted the Dreyfus model in an attempt to explain clinical skills, not only for simple tasks but also for clinical problem solving.[21,70] They have recommended the model be used as a rubric to understand medical competencies.[21,69] Our American counterparts at the Accreditation Council for Graduate Medical Education (ACGME) and the International Competency Based Medical Education (ICBME) Collaborators have also adopted this framework to understand medical competencies.[62]

Concerns have been raised that medical experts do not predominantly operate intuitively in their daily routines, however.[72] This is particularly true for more challenging or difficult clinical problems or tasks. Instead, medical educators have proposed that experts rely on a hybrid system which dovetails implicit and explicit knowledge (i.e., knowledge that can be verbalized

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and is under conscious control) and that both knowledge structures may provide real-time feedback to influence the other.[70,72,73] It is the rich interplay between these domains of knowledge that accounts for experts' ability to solve complex problems and perform skilled tasks.[72] To better understand explicit knowledge, one must first understand theories on the cognitive processes of memory systems.

When thinking about explicit knowledge, one might logically conclude that what distinguishes experts from novices is superior memory skills. This is not the case, however, as human working memory for novel information only has a limited capacity of seven units (plus or minus two)—and this cannot be improved with learning.[47,48,74] What distinguishes experts from novices is not the number of units they are actually able to store, but the richness and well-organized nature of the information contained within these seven (plus or minus two) units of memory. This ability to store progressively larger and more richly detailed chunks of information into well-organized units of memory for long term retention and rapid recall is known as "chunking."[47,48] Chunks of information are stored in memory in increasingly complex and inter-connected knowledge or semantic networks to form cognitive schemata.[75,76] Thus, expertise develops as learners intentionally combine simple ideas into more inter-related, complex ones. Schemas can then be treated as a single unit of working memory and this dramatically decreases the cognitive load associated with the performance of a given task.[47,48]

For novices it is very difficult to initially organize and meaningfully store new information or isolated facts without a pre-existing information scaffold upon which it can be contextualized and linked to other concepts and ideas. Over time, with individual learning and

lived experience, however, organizing and appending new information to the pre-existing cognitive structure for retention and rapid recall becomes easier. Eventually, the rich details contained in these semantic networks become automated and internalized in the form of illness scripts (i.e., concise prototypical illness presentations) and instance scripts (i.e., illness scripts with contextually relevant features used for recognition).[75,76] The development of these cognitive constructs is domain specific, highly individualized and idiosyncratic.[68] The process or the way two experts may solve the same problem may vary dramatically, yet ultimately they are able to reach the same solution. Understanding chunking, semantic networks, cognitive schemas and illness scripts is of central importance in understanding the development of expertise in medicine. Not only because schemas organize knowledge more thoroughly but also because they diminish the cognitive resources required when working on complex problems.

Insight into the development of expert performance in medicine can also be traced to the theory of deliberate practice (DP).[49,50] Nobody becomes an outstanding professional without accruing significant experience.[49] However, experience alone is an insufficient guarantor for the development of expertise. Ericsson argues almost everyone can achieve an improvement in performance with initial experience, however, the rate of progression is highly variable and many do not continue to augment performance over the ensuing years.[49] The nature of the differences that account for the variability of individual performance is still not fully understood. Traditional theories attribute these differences in performance to innate biologic abilities that are not influenced by experience or training.[49] The theory of DP provides an alternate framework to account for these differences.[49]

The domain-related activities necessary for improving performance can be classified as DP.[50] Ericsson and colleagues identified a set of necessary conditions where practice had uniformly been associated with improved performance.[77] Significant improvements were noted when individuals were: 1) given a defined task; 2) motivated to improve; 3) provided with feedback and; 4) given ample opportunity for repetition and refinement of their performance.[77]

The most easily understood examples of deliberate practice can be found in children picking up a sport or learning to play a musical instrument. When first introduced to a new, unfamiliar task (e.g., playing piano) a novice is usually unable to perform the required steps or functional manoeuvres and failures result.[50] With time, and often help from instructors or more advanced peers, the required functional actions can be delineated through some combined process of trial-and-error, repetitive practice and problem solving.[50] By gaining more experience the performer is not only increasingly able to generate the required functional actions but the demands of doing so require less and less effort.[50] After limited training of up to 50 hours, most individuals' performance becomes adapted to the typical situational requirements and becomes sufficiently automated to the point where they are no longer able to make conscious and intentional changes to their behaviour.[50] When this level of automaticity has been achieved, additional experience often does not refine the accuracy of behaviour or the structure of the mediating mechanisms—a performance plateau is reached.[50]

In stark contrast, budding experts continue to improve their performance as a function of experience because they pair it with DP.[50] They counteract their tendencies toward automaticity by striving toward a higher, more reliable performance standard achieved through refinements of

their technique and control of their actions. To do so, they deliberately seek out and construct

new training scenarios (applying the pre-conditions above) to ascend beyond the arrested

progress characteristic of the so-called performance plateau.[50] Research in a wide range of

domains of expertise has demonstrated that approximately 10,000 hours of activities meeting the

criteria for DP are required to win in international competitions.[78,79] Ericsson has also

challenged the Dreyfus model's assertion that experts operate intuitively by showing that experts

can actually recall and report on their thought processes and other critical aspects of encountered

situations.[78,79]

As highlighted above, feedback plays a well-recognized part in DP efforts to refine

technique and control actions.[77] At various stages of expertise development the learner may be

unaware of the processes mediating their action(s), therefore, the critical eye of a more advanced

observer who provides feedback to the performer can be crucial for improvement. Feedback in

this sense can be thought of as information provided regarding aspects of one's performance or

understanding.[80] Ideally, this information is specifically targeted to the task at hand in order to

fill an understanding or performance gap. This gap may be reduced in any number of ways

relating to the performer's affective (e.g., increased effort or engagement) or cognitive processes

(e.g., restructuring understanding, indicating alternate directions or more effective strategies to

be pursued).[80] Importantly, the performer can then confirm, add to, overwrite and fine tune

feedback to assimilate it and make it part of their own repertoire.[80] They can also choose to reject

it.[80]

It is not surprising then, that the quality of the feedback provided can be a powerful determinant of future success or performance gain. Research has shown that feedback is most effective when it is specific and goal-focused and provides information on correct rather than incorrect responses.[80-82] It is also most effective when it is based on direct observation and provided in a timely and regular manner within a respectful environment that poses little perceived threat to self-esteem.[80-82]

 The common thread of all of these well-established theories on expertise is that its development is time-consuming, deliberate, multi-stage, domain-specific and highly idiosyncratic. The important influence of effective feedback can also not be understated in the development of expertise. Furthermore, experts, both consciously and unconsciously, demonstrate greater mastery of requisite knowledge; ability to perform a skill; or to problem solve— and, for each of these, they do so more efficiently than their novice counterparts.

The Assessment of Competence and Expertise

Indeed it can be difficult to adequately objectify or quantify in measurable ways all of the elements that make up a construct like competence or expertise. For these reasons, it is widely accepted that no single assessment tool might fully capture all of the requisite data to evaluate something as complex as physician competence and expertise in any given area. However, one often cited schema for conceptualizing the level of competence assessed is demonstrated by Miller's Pyramid of Competence.[57]

Miller's Pyramid depicts the hierarchical facets of clinical competence ranging from "knows" at the bottom of the pyramid to "does" at its apex (Figure 2). Historically, most assessment efforts have focused on evaluating the facets at the bottom of the pyramid at the "knows" (basic facts) and "knows how" (applied knowledge) level, to the detriment of focusing on the ultimate goals of "shows how" and "does," in order to capture how the individual performs habitually. The latter can only be assessed by assessing the physician or trainee based on what he or she does in their clinical work with real patients on a day-to-day basis in the workplace. This has proven challenging for numerous reasons, and only a few validated assessment tools exist at the "does" level of Miller's pyramid.[61,63] Yet assessments at this level remain the ultimate objective for medical educators to strive toward, especially in an era of competency based medical education.

Figure 2. Miller's Pyramid of Professional Competence[57,58]
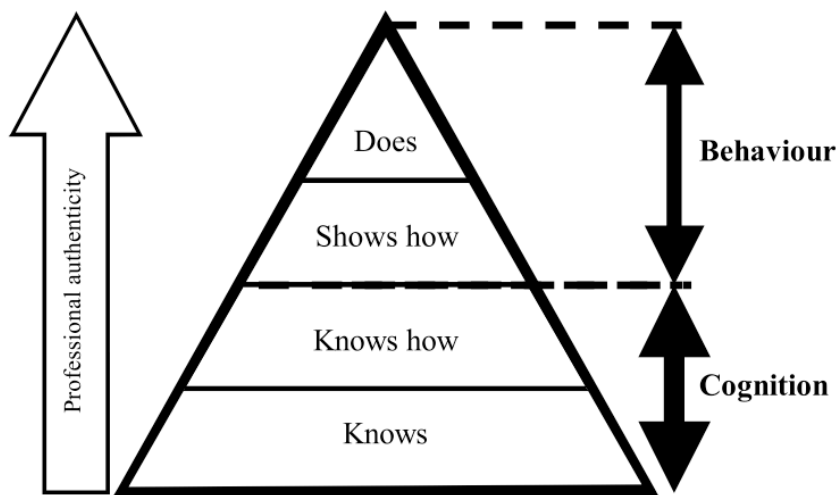
Criteria for Good Assessment

Good assessment is a form of learning that should provide guidance and support to address learning needs and foster professional competence.[63] van der Vleuten described five criteria to assess the utility of an assessment: reliability (the degree to which the assessment is accurate and reproducible), validity (whether the assessment measures what is purports to measure), impact on future learning and practice, acceptability to faculty and learners and cost.[83] Conceptually, van der Vleuten also described the multiplicative nature of the criteria to help make decisions about assessment practice—if the utility of one of the elements was zero, the utility of the assessment could only be zero. For example, if an assessment tool is reliable and valid, but acceptable to no one it has no utility. This led him to conclude that a perfect assessment instrument was an illusion and that trade-offs between what was desirable and what was attainable were innevitable.[83] The reality that assessment design is often a compromise between rigor and practicality is now well recognized.[58]

More recently, the 2010 Ottawa Consensus Conference outlined seven criteria for good assessment.[22] These were: validity or coherence (there is a body of evidence to support the use of the results of an assessment for a particular purpose); reproducibility or consistency (results of the assessment would be similar if repeated under similar circumstances); equivalence (the same assessment yields similar scores across different institutions or cycles of testing); feasibility (the assessment is practical, realistic and sensible for the circumstances and context); educational effect (the assessment motivates those who take it to prepare in a fashion with educational benefit); catalytic effect (the assessment provides results and feedback in a fashion that enhances education and drives learning forward); and acceptability (stakeholders find the assessment

credible).[22] Although no single set of criteria apply equally well to all situations, multiple criteria

for good assessment currently exist to inform the development of any new assessment tool. The

relative importance of each of the criteria will in turn be determined by the context and purpose

of the assessment (e.g., formative or summative) as well as the stakeholders (learners, faculty,

institutions, regulatory bodies, patients and the public at large) which the assessment serves.[22,63]

As highlighted above, validity evidence forms an indispensible part of the development

of all assessment tools. Validity refers to the underlying evidence that supports or refutes the

meaning or interpretations that are assigned to assessment tool results.[84,85] Without evidence for

the validity of the interpretations and uses of assessment tool scores, assessments themselves can

have little intrinsic meaning.[85] Moreover, more ambitious uses of assessment tool results (e.g.,

summative assessment or high-stakes certification or credentialing) necessarily require more

robust validity evidence from multiple sources in order to confidently support the proposed

interpretations and decisions derived from assessment scores.[22,84,86]

Focused Cardiac Ultrasound Assessment Tools

Informed by the preceding discussion, a comprehensive literature search was performed

in an attempt to identify specific studies that would help guide the development of a FCU

assessment tool. This involved screening articles published between 2000 and 2013 on four

research databases: PubMed, Medline, EMBASE, and ERIC (Educational Resources Information

Center). Since FCU is a relatively new innovation in acute care medicine, the search was

restricted to articles published in the literature since the year 2000. The MeSH headings:

"echocardiography;" "focused echocardiography;" "assessment tool;" "evaluation tool;"

"curriculum;" "residency;" "critical care;" "emergency medicine;" "general surgery;" "internal medicine," and "anesthesia" were each used independently and in combination with each other. Hand-searches of bibliographies from relevant articles were also undertaken to further identify pertinent studies that could guide the development of an assessment tool for FCU.

The results of this literature search revealed no publications clearly describing the development, implementation and evaluation of an assessment tool for FCU. Unfortunately, as of June 2013, no objective metrics or validated tools to determine competency in FCU exist.[11] In order for high quality FCU in ICU to continue to evolve it is evident that such a tool is greatly needed. There are, however, a handful of studies that have significant relevance to the current project which warrant further discussion. These studies describe the FCU curricula that have been developed to date and also report on the number of FCU training studies that might be required to develop competence in FCU.

Focused Cardiac Ultrasound Curricula

Only a few articles in the literature describe the development of FCU training curricula and for acute care residents. Jones et al., implemented a novel focused transthoracic echocardiography (TTE) curriculum (i.e., FCU) for first through third year emergency medicine residents (n=21) with varying levels of exposure to non-cardiac ultrasound (between 10-20 hours of didactics and between 20-150 proctored non-cardiac ultrasound exams).[54] Using a blended teaching design of didactics and hands-on training, a 6-hour curriculum for FCU was developed. Residents were later assessed using a knowledge test and a practical examination on healthy volunteers that required them to obtain adequate echocardiography images/windows and

correctly identify basic cardiac anatomical structures. Study findings demonstrated statistically significant improvements in knowledge on written examinations and practical examinations testing essential components of correct FCU performance and interpretation.[54] The major limitation of this study was that normal subjects without any obvious pathology were utilized in this study and that the practical examination consisted of only correct identification of normal cardiac anatomy. Nonetheless, it served to demonstrate that emergency medicine residents with minimal training could quickly acquire knowledge and basic skills in FCU.

Vignon et al., implemented a pilot FCU curriculum (consisting of 3 hours of didactic lectures and 5 hours of hands-on training) for 4 non-cardiologist residents with no previous FCU experience.[26] After completion of the focused training and during the subsequent 2 months of their ICU rotations, all patients ($n= 61$) who required a transthoracic echocardiogram were subsequently examined by the trainee and by a trained American Society of Echocardiography (ASE) level-III intensivist echocardiographer. For each patient, operators attempted to answer rule-in, rule-out clinical questions about cardiac performance or pleural effusion. Experienced intensivists performed shorter examinations with better imaging quality and had fewer unanswered questions. Yet, clinical questions were adequately appraised by residents as reflected by reasonable agreement between experts and novices for left ventricular (LV) dysfunction, LV dilatation, right ventricular (RV) dilatation, pericardial effusion and pleural effusion.[26]

In 2011, Vignon et al., implemented and assessed a new curriculum for training non-cardiologist residents in ICU FCU.[51] This curriculum blended a 12-hour learning program consisting of didactics, interactive clinical cases and tutored hands-on sessions for 6 non-

cardiologist residents without previous experience in FCU. Findings again demonstrated that

expert intensivists required less time to perform studies and had fewer unanswered questions

than novice residents. Nonetheless, residents were still able to adequately assess LV function and

identify LV dilation, RV dilation and a dilated inferior vena cava.[51]

How Much Focused Cardiac Ultrasound Image Acquisition Training is Enough?

A few recent studies have contributed badly needed evidence to inform FCU training

efforts by beginning to provide some data to help answer the question: how much training is

sufficient to begin to develop competence in FCU image acquisition?

Hellman et al., studied the performance of novice internal medicine residents ($n = 30$)

learning hand-carried cardiac ultrasound on stable medical in-patients.[87] After a brief, targeted

training curriculum, residents performed an average of 7.7 FCU (maximum of 22) during the

study. Using a technique of linear regression analysis and extrapolating the regression lines

beyond the range of their defining data, they concluded that an "acceptable" level of skill might

be reached after 20-40 ultrasounds.[87]

More recently, Chisholm and colleagues studied the trajectory of FCU image acquisition

expertise in attending emergency physicians (n = 14).[88] On average, participants completed 28

echocardiograms on patients (with an average of 8 of these 28 done under direct supervision with

feedback) and then underwent an image acquisition test that required them to capture 5

compulsory FCU views on a normal male volunteer whose echocardiographic windows were

deemed suitably easy. Time to acquire an "acceptable" view was the key assessment variable.[88]

During the testing, 85% of the participants were able to obtain the requisite parasternal long axis and parasternal short axis views in < 120 seconds. However, the apical four chamber views and subcostal four chamber views presented more challenge with only 57% and 70% respectively being successful in acquiring these views in the pre-defined time limit.[88]

Vignon and colleagues' two studies of novice operators learning FCU in the ICU also provide evidence to suggest that residents' skills in FCU image acquisition mature at a reasonably fast rate, but might require more experience to attain a "good" level of global imaging quality (defined as identification of 50% of left ventricular endocardial borders; equivalent to a score = 2).[26,51] After an average of 15 focused echocardiograms (range 11-20), the mean image quality grade of 4 non-cardiology resident participants in the first study was 1.75 ± 0.66.[26] As previously mentioned, however, experienced echocardiographers (with level III American Society of Echocardiography certification) performed their echocardiograms in shorter time, obtained more acoustic windows and their image quality was statistically superior to novices for all echocardiographic views (i.e., parasternal long axis, parasternal short axis, etc).[26] In the second study, six non-cardiologist residents performed a mean of 33 (range 29-38) focused echocardiograms on ICU patients.[51] Although residents' echocardiograms continued to require more time to complete having attained this amount of FCU imaging experience, their imaging quality was statistically inferior to experienced intensivist echocardiographers for only the parasternal short-axis view after 33 studies.[51] The proportion of good-to-excellent vs. poor imaging quality acoustic windows for the other required views (i.e., parasternal long axis, apical 4 chamber, subcostal) was statistically similar between both groups.[51]

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Sadly, the heterogeneity of clinical contexts, learners, training curricula, imaging protocols and methods of assessment in these studies impedes a precise understanding of how much training and oversight is actually sufficient to achieve defined levels of competency in FCU. However, the results suggest that with limited, tailored FCU training between 20-40 studies, non-cardiologist echocardiographers with little or no previous experience in echocardiography can feasibly develop minimal competency and reliably perform FCU to address simple clinical questions.

Unfortunately, all of these studies failed to developed formal assessment tools as a means to guide assessment of trainee performance or to document change in their image acquisition skills over time when exposed to real patients with a breadth of pathologies. No practical assessment tool currently exists in the literature to assess intensivists' skill in acquiring FCU images in real-time under bedside ICU conditions.[11]

Statement of Purpose

An assessment tool that could evaluate the critical aspects of FCU image acquisition and image quality and report on the learning curve for FCU in the ICU would be useful to guide the development of future training curricula and inform evidence-based ICU FCU training standards. It could also have practical utility as a tool employed in summative certification and for assessing competence and the maintenance of skills of independent practitioners of focused echocardiography. At this time, little is also known about the workload novices experience when trying to learn FCU or the pace at which they acquire FCU image acquisition skills.

Guided by the preceding discussion, the following research objectives and research questions were identified:

Research Objectives

This study formed part of a larger project to develop and implement a novel, multi-modal focused TTE curriculum for critical care trainees in the DCCM at the University of Calgary. The aim of this study was to develop and evaluate a comprehensive and useable assessment tool for assessment of ICU trainees acquiring FCU images. A secondary aim was to attempt to characterize the workload ICU trainees experience while trying to learn FCU. This included:

1. Development of an assessment tool to evaluate trainees' skills in FCU image acquisition at the bedside.

2. Implementation and prospective examination for evidence of validity of the aforementioned assessment tool in a cohort of ICU residents.

3. Implementation of a workload inventory tool to examine the experiences of ICU residents learning FCU.

Research Questions

This project aimed to achieve these objectives in order to answer the following research questions:

1. Can a comprehensive FCU assessment tool be developed that is sensitive to incremental changes in performance over time?

2. Can a comprehensive FCU assessment tool be developed that differentiates between different levels of expertise in FCU?

3. What evidence exists to demonstrate that the FCU assessment tool is reliable and that the inferences drawn from FCU assessment tool scores are valid?

4. What is the initial workload of ICU residents learning to acquire FCU images in the ICU and does this change over time?

CHAPTER THREE: METHOD

This chapter contains background information on the educational environment within the intensive care units (ICUs) in Calgary, including the new cardiac ultrasound curriculum for the Critical Care Residency Program. It then outlines the method used to develop, implement and subsequently evaluate the FCU assessment tool for critical care trainees.

General Study Overview

This was a prospective study involving a cohort of ICU residents learning FCU as part of a new curriculum introduced in the Critical Care Medicine Residency Training Program at the University of Calgary. This study involved the development, implementation and subsequent evaluation of a new assessment tool to evaluate image acquisition skills in FCU by comparing novice echocardiographers (i.e., the critical care medicine residents learning focused cardiac ultrasound) to experienced echocardiographers (i.e., the staff physicians with formal training in echocardiography).

Setting

This study was conducted in the multisystem ICU and the cardiovascular surgery ICU (CVICU) at the Foothills Medical Centre (FMC). The FMC is a large Alberta Health Services (AHS) tertiary care hospital in Calgary, Alberta that is affiliated with the University of Calgary. The multisystem ICU is a closed ICU that contains 28 beds and cares for a breadth of medical and surgical as well as trauma and neurocritical care patients. The cardiovascular surgery ICU (CVICU) contains 12 beds and cares predominantly for post-operative cardiac surgery patients. The combined annual census for both intensive care units was approximately 2400 patients

annually for 2010 and 2011 (Dr. David Zygun, FMC ICU Unit Director, personal

communication, June 15, 2012).

Approximately 25 board certified critical care attending physicians staffed the two units

and supervised critical care residents completing rotations in ICU during the study period. Five

of the 25 critical care attending physicians had formal expertise in transthoracic

echocardiography. Along with the Residency Training Program Director, they were responsible

for delivery of the new FCU curriculum to trainees. They also shared their time and expertise to

aid in the development, implementation and evaluation of the assessment tool described in this

study.

Focused Cardiac Ultrasound Curriculum

In response to growing calls for incorporation of FCU in ICU, the DCCM at the

University of Calgary developed a multimodal curriculum to train critical care resident

physicians in FCU. The curriculum consisted of an initial 8-hour didactic lecture series on FCU

(Appendix A), followed by approximately 8 hours of interactive hands-on training sessions in

image acquisition on normal volunteers. Subsequently, critical care resident physicians began to

independently acquire their own FCU images on real patients in each of Calgary's critical care

units. This study took take place concurrently during the deliberate practice phase of the

educational curriculum when resident physicians started to practice FCU on real patients in the

intensive care unit.

Study Participants

The Critical Care Residency Program at the University of Calgary is two-year training

program for physicians who have completed background training in various medical disciplines

including: internal medicine, general surgery, emergency medicine, neurosurgery and anesthesia.

The Program is fully accredited by the Royal College of Physicians and Surgeons of Canada.

Resident physicians typically begin their extra training in critical care in either their 4th, 5th or 6th

post-graduate year following their base specialty. All residents enrolled in the Critical Care

Medicine Residency Training Program (n=6) at the time of the study were invited to participate.

Inclusion criteria were: first or second year critical care medicine resident; participation

in the didactic FCU lecture series; and participation in the hands-on mentored training sessions

for image acquisition on normal volunteers as part of the new curriculum to teach FCU.

Exclusion criteria were: not having participated in the didactic lecture series or hands-on training

portion of the new curriculum. We collected identifying data about the participants including:

background medical specialty training, year of critical care fellowship training, and previous

echocardiography training (if any).

Participant Recruitment and Informed Consent

A hand-delivered invitation letter was used as a means of participant recruitment

(Appendix B). Critical Care Medicine residents were notified of their voluntary choice to take

part, requirements for their participation and the potential risks and benefits associated with their

participation in the study. All participants were required to provide written approval indicating

their informed consent prior to commencing the study (Appendix C). Resident participants were free to withdraw from the study at any time.

Development of the Focused Cardiac Ultrasound Assessment Tool

A preliminary FCU assessment tool to evaluate echocardiographers was developed by Dr. Jonathan Gaudet and Dr. Jason Waechter. The assessment tool is a scorecard to assess the requisite elements and diagnostic quality of focused transthoracic cardiac ultrasound images. Preliminary development of the assessment tool was informed by the developmental framework outlined by Bloom's Taxonomy and by George Miller's Assessment Pyramid, as well as a thorough review of the ICU echocardiography literature and medical education literature on the development of assessment tools.[11,15-17,22,57,60,89]

An expert working group comprised of local experts in echocardiography (DCCM echocardiographers; n=5) and medical education (members of the thesis supervisory committee; n=3) was formed to continue to develop and improve the design of the assessment tool. Using the preliminary tool as a starting point for deliberation, feedback on the key domains and specific content of the assessment tool was solicited from the expert working group to ensure face and content validity for each of the subsections of the assessment tool. This iterative process began with individual emails, followed later by a series of face-to-face expert working group meetings until consensus was achieved on the final assessment tool to be used in the study (Appendix D).

Setting the Assessment Tool Minimum Performance Standard

Using a modified Angoff method, a criterion-referenced absolute minimum performance standard (MPS) for competency as measured by the FCU assessment tool was defined *a priori* by the DCCM panel of echocardiography experts.[90,91] The DCCM panel of echocardiography experts consisted of 6 DCCM members with extra training and ASE certification in cardiac ultrasound (4 with ASE Level III transthoracic certification and 2 with ASE perioperative certification). Two iterations of the cut-score-setting process were used as part of the judges' deliberations to determine the minimum performance level for the assessment tool. This was done in an attempt to decrease the variability between judges' item estimates and to improve agreement between judges.[92] At the conclusion of the standard setting process, the MPS for the assessment tool was determined to be 53.8 points out of a possible grand total of 68.

Implementation of the Focused Cardiac Ultrasound Assessment Tool

After completion of the initial didactic lecture series and initial hands-on training sessions at the beginning of the FCU curriculum, trainees then progressed to the deliberate practice phase of the curriculum by independently acquiring their own focused transthoracic echocardiogram images on real ICU patients. It was at this point in the FCU curriculum that the FCU assessment tool was implemented and data collection began as part of this study.

Assessment Intervals

All resident participants were required to complete and track a total of 20 FCU exams on ICU patients as part of this study. However, formal assessments using the FCU assessment tool only occurred at three pre-defined assessment intervals. Assessment intervals for resident

participants corresponded to the 1st and 2nd (assessment interval 1), the 10th and 11th (assessment interval 2), and the 19th and 20th (assessment interval 3) focused cardiac ultrasounds performed. Thus, 6 of the first 20 FCU studies for each trainee were formally evaluated at defined points using the FCU assessment tool.

The number of FCU exams completed by each resident was prospectively tracked using an individually completed FCU tracking journal (Appendix E). Trainees were required to obtain the signature of their supervising attending physician to certify that they had actually completed each echocardiogram. Assessment intervals took place only after trainees had completed the requisite number of practice FCU studies.

When the resident participant had completed the required number of studies for each assessment interval to take place, an evaluation session with one of the experienced attending physician echocardiographers was scheduled. Further FCU practice studies were not completed until the pre-specified assessment interval had taken place.

Practice cardiac ultrasounds between assessment intervals were not formally archived and could be completed in any of the Calgary ICUs that the critical care residents completed mandatory ICU rotations as part of their fellowship training (i.e., the Foothills Medical Centre ICU and CVICU; the Peter Lougheed Centre ICU; and the Rockyview General Hospital ICU). Between assessment intervals, resident participants received weekly emails reminding them of the need to complete the requisite number of practice cardiac ultrasounds and to adhere to the outlined patient data collection requirements.

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Training of Resident and Experienced Attending Physician Echocardiographers

Before starting the first assessment interval, resident physicians (n=6) and experienced attending physician echocardiographers (n=3) received brief, targeted training about correct implementation of the FCU assessment tool and the research protocol for each assessment interval. This training included instruction on all of the requisite elements of the FCU assessment tool and the appropriate sequence to acquire and save FCU images as part of the study. Instruction was also provided on the appropriate method for exporting and archiving images as part of the study.

Study Patients and Informed Consent

Patients receiving invasive mechanical ventilation in the two intensive care units at the Foothills Medical Centre (or their surrogate decision-makers) were approached and asked to voluntarily participate in the study by allowing the resident and experienced attending physician echocardiographer to perform a transthoracic FCU examination on them. Surrogate decision makers were required to provide consent in instances where the patient was unable to personally consent (i.e., patients in a coma or with an altered mental status or patients receiving sedation or pain medications impairing their capacity to consent).

The potential risks and benefits of study participation (including the information collected and how it would be used and safeguarded) were explained to the patient or appropriate surrogate decision-maker. Written informed consent was required from the patient or the appropriate surrogate decision maker before study enrolment (Appendices F and G). The decision to participate (or not participate) in the study did not influence the quality of or

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subsequent course of any patient's medical care. Following provision of consent, the responsible ICU medical team continued to make all necessary investigation and treatment decisions for the patient.

Patient Selection Criteria, Clinical Characteristics and Safety Provisions

The main inclusion criterion for study was a patient receiving invasive mechanical ventilation via an endotracheal tube or a tracheostomy. Preference was given for patients who were in shock requiring vasoactive infusions for hemodynamic support, however this was not mandatory for study participation. Patient exclusion criteria were: patients who could not safely be rolled onto their side or moved into a position with their head down or bed flat (e.g., spinal precautions, significantly elevated intracranial pressure) or patients, for any reason, whose responsible attending physician did not feel it was appropriate for them to participate.

Resident participants collected several important clinical characteristics of the study patients at the time their FCU was performed. These included: age; gender; reason for ICU admission; height; weight; pre-existing pulmonary or cardiovascular disease; vital signs; and whether or not the patient required hemodynamic support with infusions of vasoactive medications.

In order to pose no threat to patient safety, vital signs on bedside monitors and IV infusion pumps were visible to resident physicians, experienced attending physician echocardiographers and bedside nursing staff while FCU studies were performed. In the event that emergent diagnostic or therapeutic interventions for patient care were required while the

echocardiograms were being completed, the cardiac ultrasound was immediately stopped and the health care team caring for the patient intervened as necessary to address the patient's clinical condition.

If the experienced attending physician echocardiographer observed a significant abnormality while performing the patient's FCU as part of the study, they shared their findings with the responsible medical team. When this occurred, they also recommended to the responsible medical providers that a formal quantitative echocardiogram be obtained and interpreted by a cardiologist.

Assessment Interval Protocol

At each assessment interval, the resident participant and the experienced attending physician echocardiographer each performed two focused transthoracic echocardiograms on two separate, intubated ICU patients. All experienced attending physician echocardiographers who performed focused cardiac ultrasounds as part of this study had obtained at least ASE level III transthoracic echocardiography certification. The assessment interval protocol for one patient is outlined below.

During a patient encounter, the experienced attending physician echocardiographer and the resident echocardiographer each independently performed a complete bedside transthoracic FCU as defined by the FCU assessment tool. The attending physician's FCU always preceded the resident participant's echocardiogram. The experienced attending physician echocardiographer was permitted to position the patient as they saw fit for their FCU. Patients

were positioned as necessary using standard pillows or a Prevalon Turn Assist and Positioning Device (SAGE Products Incorporated, Cary, IL, USA) according to the echocardiographer's preference. Sterile, water soluble, Aquasonic 100 ultrasound transmission gel (Parker Laboratories Incorporated, Fairfield, NJ, USA) was used for all studies. The required sequence of image acquisition was as follows: parasternal long axis; parasternal short axis (aortic level, mitral valve level, mid-papillary muscle level, left ventricular apex); apical four-chamber; subcostal long axis and; subcostal inferior vena cava (IVC) and subcostal IVC M mode. Echocardiographers were permitted to save up to, but not more than, two images from each of the standard positions outlined above. Following completion of the echocardiogram, patients were returned to a neutral position in their bed.

Resident participants were not allowed to watch any aspect of the preparation, patient positioning or image acquisition steps during the experienced attending physician's echocardiogram. Immediately following completion of experienced attending physician's echocardiogram, the resident participant conducted their FCU in a similar manner on the same patient. Resident participants were observed by the experienced attending physician echocardiographers during their performance of the FCU, however, no guidance regarding patient positioning or FCU image acquisition was provided to them at any point during the exam.

The time required for resident participants and attending physician echocardiographers to perform their complete FCU was prospectively collected and recorded. A standard Timex Ironman stopwatch (Timex Corporation, Middlebury, CT, USA) was used for all timing measurements. The bedside nurse performed timing for the experienced attending physician

echocardiographer. In turn, the bedside nurse or the experienced attending physician performed

the timing for the resident participant. Timing began when the ultrasound probe was placed on

the patient's chest and timing ended when the echocardiographer performing the study had

indicated they had completed the required acquisition of images outlined in then FCU

assessment tool. A hard copy of the FCU assessment tool was available as a reference at the

bedside for both echocardiographers to refer to (if needed) during their cardiac ultrasounds

(Appendix D).

Echocardiography Platforms

Focused cardiac ultrasound images at each assessment interval for this study were

acquired with a Philips iE33 xMATRIX ultrasound platform (Philips Electronics, Andover, MA,

USA) using a X5-1 cardiac ultrasound transducer (Philips Electronics, Andover, MA, USA). The

standard 2D adult echocardiography presets were used to acquire two dimensional cardiac

ultrasound images recorded as loops consisting of two beats. Study echocardiographers were

responsible to manually adjust the depth and the gain as appropriate while acquiring all of the

images.

Cardiac ultrasounds performed by resident participants between assessment intervals (i.e.,

echocardiograms 3 through 9 and 12 through 18) were performed with either a SonoSite

Micromaxx ultrasound platform using a P17 ultrasound transducer (SonoSite Incorporated,

Bothell, WA, USA) or an M Turbo ultrasound platform using a P21X ultrasound transducer

(SonoSite Incorporated, Bothell, WA, USA). Echocardiograms acquired using these ultrasound

platforms were not saved or archived as part of this study.

Coding and Archiving of Focused Cardiac Ultrasounds at Assessment Intervals

In addition to its cardiac ultrasound capabilities, the Philips iE33 xMATRIX ultrasound platform also has the capability to archive cardiac ultrasound studies and export them for later review and analysis. Resident and experienced attending physician echocardiograhers were assigned unique study identification numbers for the purpose of coding and archiving their FCU studies at each assessment interval (see Data Handling). Each echocardiogram was coded and archived using one of these unique study identifiers. No patient identifying information was recorded in any of the echocardiograms as part of the study. Archived studies were exported to a USB key and stored on a secure, password-protected AHS Network drive for later review. Exported studies were subsequently permanently deleted from the echocardiography platform and the USB key.

Review of Archived Focused Cardiac Ultrasound Studies

Archived FCU studies performed as part of the study were independently reviewed and scored by two blinded evaluators according to the FCU assessment tool criteria for image acquisition and overall diagnostic quality. Evaluators did not have knowledge of the echocardiographer who performed the study (i.e., the resident participant or experienced attending physician echocardiographer), the assessment interval, or the echocardiogram number. Only the unique study identifier number for coding was visible to them during their review of the echocardiograms.

Two critical care attending physicians with ASE perioperative echocardiography certification served as the blinded reviewers. Both reviewers participated in a two-hour training

session for correct implementation of the new assessment tool before using it to evaluate FCU images acquired in this study. As part of the training, two sample FCU exams of varying quality (from ICU patients not enrolled in the study) were systematically reviewed and evaluated according the FCU assessment tool criteria. During the training session, the two reviewers were permitted to discuss their scoring of the echocardiograms and develop consensus regarding how the echocardiographic images would be scored using the weighted grading scale outlined for each item in the FCU the assessment tool (Appendix D).

The same two reviewers were then responsible for the blinded review of all of the studies performed by resident participants and experienced attending physician echocardiographers alike during the course of the study. Both evaluators reviewed all of the echocardiograms independently and scored them according to the FCU assessment tool.

Evaluating the Workload of Focused Cardiac Ultrasound Using the Modified NASA-TLX Workload Assessment Tool

Developing the skills to acquire FCU images is challenging and represents a high cognitive workload for novices.[47,48] The learning curve is steep initially and deliberate practice is required in order for skills to grow and mature toward achievement of expert performance.[49,50] The NASA-TLX is a multidimensional workload assessment scale that has been employed in over 500 published studies to help characterize the subjective workload operators experience in performing a task.[93,94] Although initially developed for application in aviation, the NASA-TLX assessment tool has since been applied to numerous domains, including medicine.[93-97] It elicits

trainees' subjective ratings in order to capture the essence of the workload associated with the acquisition of a particular skill and provides valuable practical information about perceived performance during early phases of learning a new skill.[93,94]

A modified version of the NASA-TLX was developed for FCU and implemented in this study in order to capture resident physician participants' perceptions and opinions about their performance of echocardiography (Appendix H).[93,94] The modified NASA-TLX tool had six rating items: mental demand; physical demand; time demand; effort; performance; and frustration and anxiety. Descriptors from the original tool were modified in order to make the modified NASA-TLX tool more relevant to the task of FCU. Resident physician participants and experienced attending physician echocardiographers were asked to complete the modified NASA-TLX tool following every focused echocardiogram at each assessment interval throughout the study. This information was recorded and stored in each participant's FCU journal and collected at the end of the study. For the purpose of data analysis, subscale ratings were analyzed instead of generating a single overall workload score.

Global Rating Scale of Focused Cardiac Ultrasound Image Acquisition Proficiency

At each assessment interval resident participants were directly observed while performing their FCU studies by an attending physician with experience in echocardiography. After the resident had completed their echocardiogram, the experienced attending physician echocardiographer was required to complete a global rating scale of the trainees' proficiency in FCU image acquisition (Appendix I). Trainees did not see the results of the global rating scale. As an educational intervention, the experienced attending physician was required to provide the

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resident participant with individualized, formative feedback after they had completed each echocardiogram at each assessment interval of this study.

Data Handling

Study Identifiers

Resident physicians were assigned 6 unique study identification numbers for research purposes. Study identification numbers were generated using a random number generator (accessible at: http://www.random.org) that produced random, four-digit integers between 1000 and 1999. Prior to starting data collection an e-mail was sent to each participant that contained their assigned study numbers. All FCU exams performed by the resident physician were archived with one of these unique study numbers. Experienced attending physician echocardiographers were also assigned unique four-digit study numbers for research purposes and all of their FCU studies were archived with one of these unique study numbers.

The master list linking resident physician or attending physician names to unique study numbers was kept in a file on a password-protected computer in a locked office in the Office of the Senior Associate Dean, Education, at the University of Calgary. The coding associations between name and unique study numbers were solely known by Dr. Jocelyn Lockyer. Reviewers responsible for blinded review of archived echocardiograms were not aware of these associations. Dr. Lockyer did not have any direct role in the evaluation of trainees.

In order to be able to link participants' completed echocardiograms with unique study identifiers, both the resident and the experienced attending physician echocardiographers sent an

e-mail to Dr. Lockyer containing the unique study ID number they used at each assessment interval for each echocardiogram, as well as the time required to complete their echocardiogram. To ensure the ability to link the data was not lost, this information was also recorded in the resident participant's assessment interval echocardiography journal (Appendix J).

Resident Participant Data

De-identified resident physician data from the study was entered into a Microsoft Excel database (Microsoft Corporation, Redmond, WA, USA) and stored on a password-protected computer in a locked office within the DCCM at the University of Calgary. Resident physician performance during the study was not available to the Critical Care Residency Program Director or to attending physicians evaluating them on their rotations and was not used as a means to determine resident participants' progress in their residency.

Patient Data

Resident physicians collected information regarding the clinical characteristics of study patients using an assessment interval echocardiography journal (Appendix J). Resident journals were stored in the locked ICU fellows' office at the Foothills Medical Center when not in use. Clinical characteristics collected included: age; gender; reason for ICU admission; height; weight; pre-existing pulmonary or cardiovascular disease; vital signs; and whether or not the patient required hemodynamic support with infusions of vasoactive medications. This information was entered into a Microsoft Excel database (Microsoft Corporation, Redmond, WA, USA) and stored on a password-protected computer in a locked office in the DCCM at the

University of Calgary. After the data was entered into the database, confidential shredding was used to destroy the resident participants' assessment interval echocardiography journals.

Review of Archived Focused Cardiac Ultrasounds

Patients' FCU studies were anonymously archived on an Alberta Health Services, password-protected Network drive using only the unique study identifiers assigned to the resident physician participants and attending physician echocardiographers. Archived FCU studies were reviewed directly from this Network drive using Xcelera cardiology image management software (Philips Electronics, Andover, MA, USA). At the conclusion of the study all archived FCU studies were deleted from the Network drive. Results from blinded review and scoring of study FCU studies according to the assessment tool were entered into a Microsoft Excel database (Microsoft Corporation, Redmond, WA, USA) and stored a password-protected computer in a locked office in the DCCM at the University of Calgary.

Outcome Measures

The primary outcome measure for this study was the overall grand total score evaluated by the FCU assessment tool over time. The secondary outcome measure was resident participant performance compared in relation to the performance of experienced attending physician echocardiographers. Additional outcome measures were: trainee efficiency (i.e., overall FCU assessment tool score/time required to acquire FCU images) over time and in comparison to the efficiency of experienced attending physician echocardiographers; global rating scale of resident proficiency in FCU over time; and resident scores obtained from the NASA-TLX workload

inventory compared to scores obtained from experienced attending physician echocardiographers.

Data Analysis

The scores from each subsection of the assessment tool were summed and an average was taken from the scoring reported by each blinded reviewer to provide an overall mean grand total score on the FCU assessment tool. Overall scores were expressed as means with standard deviations, or percentages as appropriate. Resident participant FCU assessment tool performance and efficiency at each assessment interval were compared using paired samples *t*-tests. Additionally, trainee performance was also compared to the expert echocardiographer reference standard and expert echocardiographer efficiency measure at each evaluation interval using independent samples *t*-tests. Effect size was determined using Cohen's *d*. Inter-observer agreement was calculated using intraclass-correlation. Reliability of the assessment tool was assessed using Cronbach's α coefficient.

Mean scores and standard deviations were calculated for the results of the modified NASA-TLX score for each item of the tool and for data obtained from the global rating scale. Resident participant modified NASA-TLX scores at each assessment interval were compared using paired samples *t*-tests. Independent samples *t*-tests were used to compare modified NASA-TLX item scores for focused echocardiograms performed by residents to echocardiograms performed by experienced attending physicians. Pearson's *r* was used to explore whether or not the results of the global rating scale correlated with resident participants' overall grand total scores on the FCU assessment tool. It was also used to explore whether or not any correlation

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existed between participants' modified NASA-TLX performance scores and overall grand total scores on the FCU assessment tool.

All data were double checked for accuracy when being entered into the Microsoft Excel database. All statistical calculations for data analysis were performed using the Statistical Package for Social Sciences (SPSS) version 20 for Macintosh (IBM corporation, Armonk, NY, USA). Two-sided p-values < 0.05 were considered statistically significant. Table 1 summarizes the data sources and data analysis performed to evaluate the main research questions of this study.

Ethics Approval

Approval for the study and research protocol was granted by the Conjoint Health Research Ethics Board (CHREB) at the University of Calgary (Ethics ID: E-24826).

Table 1. Data Sources and Statistical Analyses to Evaluate Each Research Question

Research Question	Data Source (s)	Data Analysis
1. Is the FCU assessment tool sensitive to resident performance change over time?	FCU Assessment Tool Grand Total Scores	• Descriptive analyses • Paired samples *t*-tests • Effect size (Cohen's *d)*
	Efficiency Scores	• Descriptive analyses • Paired samples *t*-tests • Effect size (Cohen's *d)*
2. Can the FCU assessment tool differentiate between different levels of expertise in FCU?	FCU Assessment Tool Grand Total Scores	• Descriptive analyses • Independent samples *t*-tests
	Efficiency Scores	• Descriptive analyses • Independent samples *t*-tests
3. What reliability and validity evidence exists for the FCU assessment tool?	Reliability • Internal consistency • Inter-rater reliability • Inter-observer agreement	• Cronbach's alpha • Pearson correlation coefficient • Intra-class correlation coefficient (ICC)
	Validity • FCU assessment tool development • Minimum performance standard • FCU assessment tool results • Global rating scale of resident proficiency	• Qualitative description • Pearson correlation coefficient
4. What is the workload of learning FCU?	Modified NASA-TLX Results	• Descriptive analyses • Paired samples and independent samples *t*-tests • Pearson correlation coefficient

CHAPTER FOUR: RESULTS

This study took place from late July 2012 until April 2013. The curriculum intervention was introduced to resident participants in late July 2012 and continued until October 2012. Data collection followed in November 2012 when resident physician participants began to independently acquire their own FCU images on real ICU patients and continued until April 2013. During the entire study period, no new FCU educational initiatives other than those described in this thesis were introduced in as part of the critical care medicine residency training program.

Characteristics of Study Participants

Six critical care resident physicians provided written informed consent and agreed to participate in the study. Each of the residents participated in the didactic FCU lecture series and hands-on mentored training sessions for image acquisition at the start of the FCU curriculum. All (100%) residents were male and most (66.7%) residents were in their first year of critical care specialty training (Table 2). The majority of residents (66.7%) were from a medical training background versus a surgical training background (33.3%) (Table 2). Two of the residents (33.3%) reported limited exposure to FCU image acquisition and training during their previous residency training preceding the FCU curriculum's introduction. One second year critical care resident was excluded from participation due to having previously completed a significant amount of echocardiography training in the first year of his critical care training program.

Table 2. Characteristics of Critical Care Resident Participants

Characteristic (N= 6)	
Gender: - Male – no. (%)	6 (100)
Postgraduate Year of Residency Training: - 4 – no. (%) - 5 – no. (%) - 6 – no. (%) - 7 – no. (%)	1 (16.7) 2 (33.3) 1 (16.7) 2 (16.7)
Year of Critical Care Training: - 1 – no. (%) - 2 – no. (%)	4 (66.7) 2 (33.3)
Previous Residency Training Background: - General Internal Medicine – no. (%) - Infectious Disease – no. (%) - General Surgery – no. (%) - Neurosurgery – no. (%)	3 (50) 1 (16.7) 1 (16.7) 1 (16.7)

Characteristics of Study Patients

Written informed consent (from the patient or their surrogate decision maker) was

obtained from 36 mechanically ventilated ICU patients who agreed to participate in the study.

Their clinical characteristics are presented in Table 3. The mean patient age was 55 years (±18)

and most patients were male (63.9%). A third of the patients (33.3%) required infusions of

vasoactive medications to maintain their blood pressure at the time their echocardiograms were

performed. Patients were more likely to have a primary medical diagnosis on admission (55.6%)

and tended to be overweight (mean body mass index = 28). Sepsis or septic shock was the most

frequently encountered diagnosis (30.6%). Pre-existing coronary artery disease (25%) and lung

disease (19.4%) were not uncommon in this cohort of patients. The mean positive end-expiratory

pressure (PEEP) delivered to patients during mechanical ventilation was 8 cm H_2O (±3).

Table 3. Clinical Characteristics of Study Patients

Characteristic (N= 36)	
Age (years) – Mean (±SD)	55 (18)
Male Gender – no. (%)	23 (63.9)
BMI – Mean (±SD)	28 (6)
Type of Patient: - Medical – no. (%) - Surgical – no. (%) - Cardiovascular surgery – no. (%) - Trauma – no. (%)	 20 (55.6) 7 (19.4) 2 (5.6) 7 (19.4)
Sepsis – no. (%)	11 (30.6)
Pre-existing Co-morbid Conditions: - Coronary Artery Disease – no. (%) - Lung Disease – no. (%)	 9 (25) 7 (19.4)
Vital Signs: - Heart Rate – Mean (±SD) - MAP – Mean (±SD) - Respiratory Rate – Mean (±SD)	 90 (17.4) 87 (14.8) 20 (5.3)
Vasopressor Use – no. (%)	12 (33.3)
PEEP (cm H_2O) – Mean (±SD)	8 (3.1)

SD: standard deviation; BMI: Body Mass Index; MAP: Mean Arterial Pressure; PEEP: Positive End-Expiratory Pressure.

Focused Cardiac Ultrasound Assessment Tool Results

Resident Participant FCU Assessment Tool Scores

The first objective outcome measure was the mean grand total FCU assessment tool score. This was determined by taking the average of the two independent reviewers' grand total scores on the assessment tool. Resident participants' mean grand total FCU assessment tool score and standard deviation for assessment interval 1 was 35.10 (±13.29) points in comparison to 40.83 (±10.68) points for assessment interval 2 and 39.88 (± 15.35) points for assessment interval 3 (Table 4). Paired samples *t*-testing did not reveal any statistically significant performance differences between assessment intervals, however, residents' absolute FCU assessment tool scores tended to improve between intervals 1 and 2 and then plateaued between

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the second and third assessment intervals (Figure 3). Effect size analysis comparing resident

participants' mean grand total FCU assessment tool scores between assessment intervals 1 and 2

demonstrated a Cohen's *d* of 0.50.[98] This is regarded as a moderate effect size. However, effect

size analysis between intervals 2 and 3 demonstrated a Cohen's *d* of 0.08 indicating little or no

effect.[98] Overall, the distribution of residents' mean grand total scores was quite high and this

significant performance variability was consistent for all three assessment intervals (Figure 3).

Table 4. Resident Participants' Performance Over All Assessment Intervals

Resident Participants' Performance	Assessment Interval 1	Assessment Interval 2	Assessment Interval 3
Time (minutes) to Echocardiogram Completion – Mean (±SD)	25.90 (8.20)	17.60 (3.51)	16.71 (3.73)
FCU Assessment Tool Section A Total – Mean (±SD)	6.10 (3.93)	7.10 (2.90)	8.35 (3.53)
FCU Assessment Tool Section B Total – Mean (±SD)	7.29 (5.22)	11.02 (3.75)	11.00 (4.09)
FCU Assessment Tool Section C Total – Mean (±SD)	4.83 (2.64)	4.70 (2.62)	5.06 (2.75)
FCU Assessment Tool Section D Total – Mean (±SD)	4.50 (2.69)	4.29 (2.18)	3.27 (2.43)
FCU Assessment Tool Section E Total – Mean (±SD)	6.17 (1.90)	6.63 (1.70)	5.22 (2.54)
FCU Assessment Tool Section DQ Total – Mean (±SD)	6.21 (3.45)	7.08 (2.43)	6.95 (3.70)
FCU Assessment Tool Grand Total – Mean (±SD)	35.10 (13.29)	40.83 (10.68)	39.88 (15.35)
Efficiency (Grand Total/Time) – Mean (±SD)	1.55 (0.95)	2.48 (0.97)	2.61 (1.37)

SD: standard deviation.

Figure 3. Resident Participants' Mean Grand Total Focused Cardiac Ultrasound Assessment Tool Scores
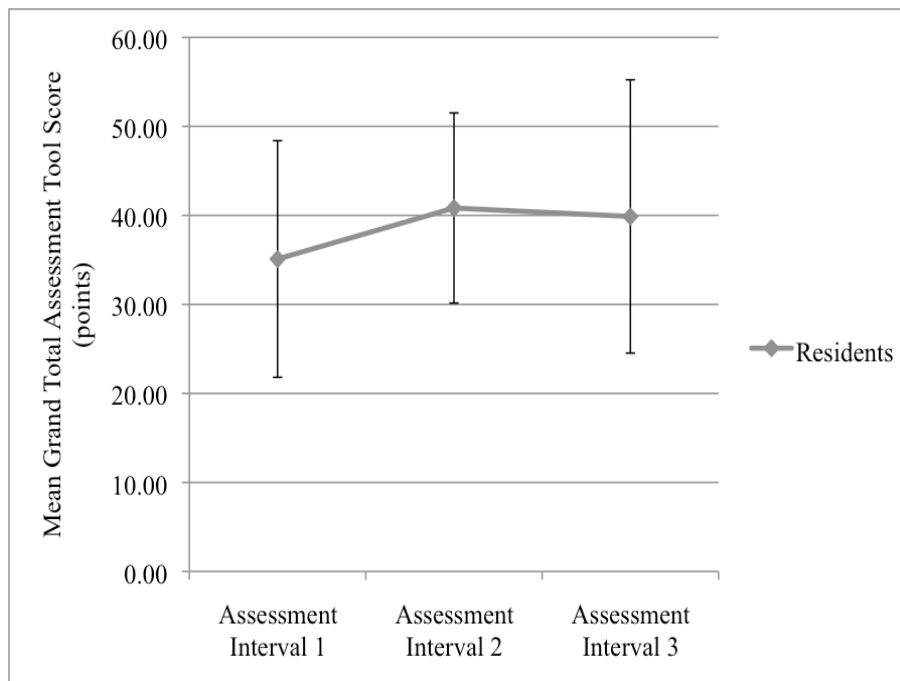
Resident Participant Versus Experienced Attending Physician FCU Assessment Tool Scores

Experienced attending physician echocardiographers' mean grand total scores and standard deviations on the FCU assessment tool were 43.04 points (± 14.63) for assessment interval 1, 52.44 points (± 7.03) for assessment interval 2 and 47.83 points (± 11.08) for assessment interval 3 (Table 5). Experienced attending physicians' FCU assessment tool scores were consistently greater than resident participants' scores (Figure 4). Yet, surprisingly, the only statistically significant difference in performance between resident participants and experienced attending physician echocardiographers was at assessment interval 2 ($t = 3.14$; df = 22, $p = $ <0.01, two-tailed). The lack of statistical significance is likely due to the large distribution of performance scores for both groups of participants at each assessment interval (Table 6).

Table 5. Experienced Attending Physicians' Performance Over All Assessment Intervals

Experienced Attending Physicians' Performance	Assessment Interval 1	Assessment Interval 2	Assessment Interval 3
Time (minutes) to Echocardiogram Completion – Mean (±SD)	16.92 (3.67)	12.25 (3.07)	12.76 (3.32)
FCU Assessment Tool Section A Total – Mean (±SD)	7.25 (3.01)	8.02 (2.97)	9.00 (3.57)
FCU Assessment Tool Section B Total – Mean (±SD)	10.58 (4.55)	14.20 (3.13)	13.21 (3.84)
FCU Assessment Tool Section C Total – Mean (±SD)	5.85 (2.77)	7.10 (1.57)	7.12 (1.62)
FCU Assessment Tool Section D Total – Mean (±SD)	4.79 (2.34)	6.00 (1.62)	4.47 (2.60)
FCU Assessment Tool Section E Total – Mean (±SD)	6.60 (1.07)	7.27 (0.63)	5.73 (2.78)
FCU Assessment Tool Section DQ Total – Mean (±SD)	7.96 (3.35)	9.83 (1.21)	8.50 (2.32)
FCU Assessment Tool Grand Total – Mean (±SD)	43.04 (14.63)	52.44 (7.03)	47.83 (11.08)
Efficiency (Grand Total/Time) – Mean (±SD)	2.77 (1.39)	4.55 (1.32)	4.17 (2.12)

SD: standard deviation.

Figure 4. Resident Participants' and Experienced Attending Physicians' Mean Grand Total Focused Cardiac Ultrasound Assessment Tool Scores
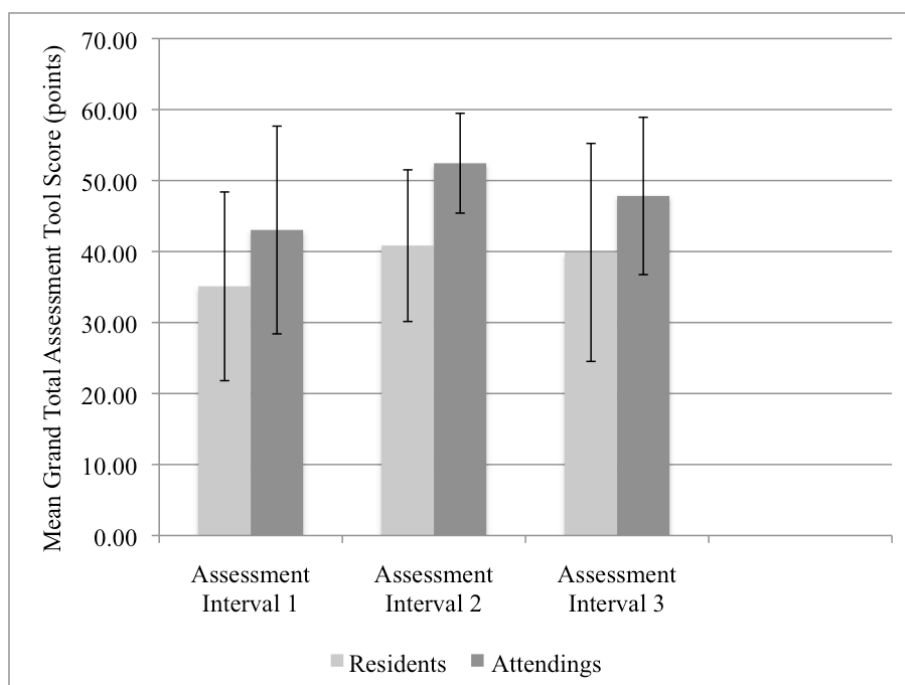
Table 6. Resident Participants' and Experienced Attending Physicians' Performance

Performance	Assessment Interval 1			Assessment Interval 2			Assessment Interval 3		
	R	**A**	*p*	**R**	**A**	*p*	**R**	**A**	*p*
Time (minutes) to Echocardiogram Completion – Mean (±SD)	25.90 (8.2)	16.92 (3.7)	<.01	17.60 (3.5)	12.25 (3.1)	<.01	16.71 (3.7)	12.76 (3.3)	0.01
FCU Assessment Tool Section A Total – Mean (±SD)	6.10 (3.9)	7.25 (3.0)	NS	7.10 (2.9)	8.02 (3.0)	NS	8.35 (3.5)	9.00 (3.6)	NS
FCU Assessment Tool Section B Total – Mean (±SD)	7.29 (5.2)	10.58 (4.6)	NS	11.02 (3.8)	14.21 (3.1)	0.03	11.00 (4.1)	13.21 (3.8)	NS
FCU Assessment Tool Section C Total – Mean (±SD)	4.83 (2.6)	5.85 (2.8)	NS	4.71 (2.6)	7.10 (1.6)	0.01	5.06 (2.7)	7.12 (1.6)	0.04
FCU Assessment Tool Section D Total – Mean (±SD)	4.50 (2.7)	4.79 (2.3)	NS	4.29 (2.2)	6.00 (1.6)	0.04	3.27 (2.4)	4.47 (2.6)	NS
FCU Assessment Tool Section E Total – Mean (±SD)	6.17 (1.9)	6.60 (1.1)	NS	6.63 (1.7)	7.27 (0.6)	NS	5.22 (2.5)	5.72 (2.8)	NS
FCU Assessment Tool Section DQ Total – Mean (±SD)	6.20 (3.5)	7.95 (3.4)	NS	7.08 (2.4)	9.83 (1.2)	<.01	6.95 (3.7)	8.5 (2.3)	NS
FCU Assessment Tool Grand Total – Mean (±SD)	35.10 (13.3)	43.04 (14.6)	NS	40.83 (10.7)	52.44 (7.0)	<.01	39.88 (15.4)	47.83 (11.1)	NS
Efficiency (Grand Total/Time) – Mean (±SD)	1.55 (1.0)	2.78 (1.4)	0.02	2.48 (.98)	4.55 (1.3)	<.01	2.61 (1.4)	4.17 (2.1)	0.04

R: Resident Participants; A: Experienced Attending Physicians; *p*: p value; SD: Standard Deviation; NS: non-significant.

Time Required To Acquire FCU Images

The time required to complete each FCU as outlined in the FCU assessment tool was prospectively measured for all study participants. Resident participants demonstrated steady improvement in the speed with which they were able to complete their FCU image acquisition over successive assessment intervals (Figure 5). Mean time to echocardiogram completion for assessment interval 1 and standard deviation for resident participants was 25.90 minutes (±8.20) in comparison to 17.60 minutes (±3.51) for assessment interval 2 and 16.72 minutes (±3.73) for assessment interval 3 (Table 4).

Moreover, the variability between performers decreased when comparing the first assessment interval to the second and third assessment intervals with a tighter distribution of resident participants' echocardiogram times. Paired samples *t*-testing showed that statistically significant differences existed in time to completion of echocardiograms by resident participants between assessment intervals 1 and 2 ($t = 3.54$; df $= 11$, $p = <0.01$, two-tailed) and assessment intervals 1 and 3 ($t = 4.29$; df $= 11$, $p = <0.01$; two-tailed). However, resident speed in acquiring their echocardiograms did not improve in a statistically significant way between assessment intervals 2 and 3 ($t = 0.73$; df $= 11$, $p = 0.48$; two-tailed).

Figure 5. Resident Participants' Mean Echocardiogram Times
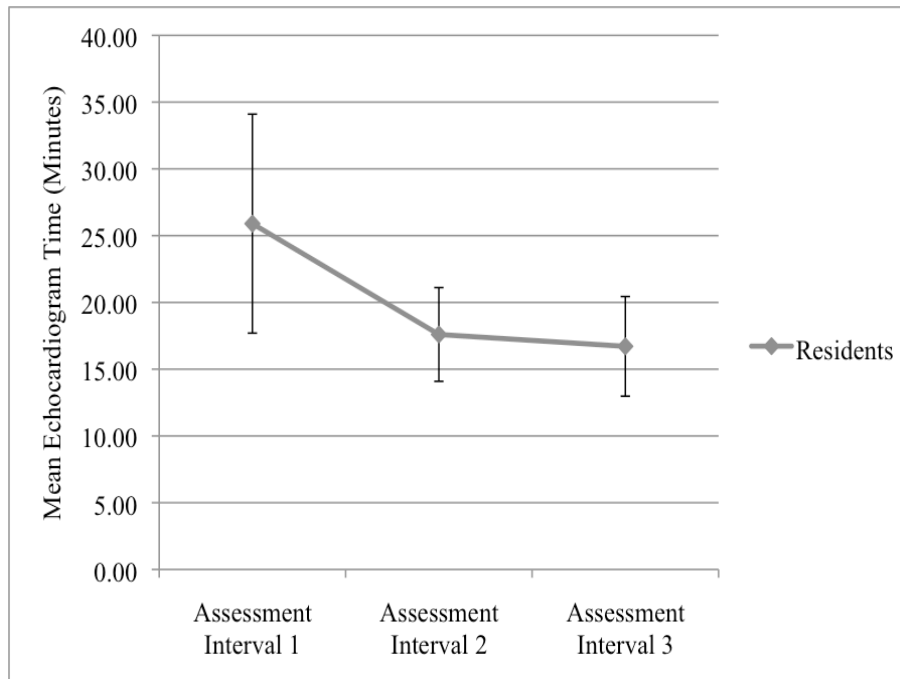
In comparison, experienced attending physicians performed their echocardiograms in less time and with less variability than resident study participants (Figure 6). Mean time to echocardiogram completion for assessment interval 1 and standard deviation for experienced attending physicians was 16.92 minutes (±3.67) in comparison to 12.25 minutes (±3.07) for assessment interval 2 and 12.76 minutes (±3.32) for assessment interval 3 (Figure 6). Independent samples t-testing confirmed that experienced attending physicians' required less time than resident participants to perform their echocardiograms—this was consistent throughout assessment intervals 1 ($t = 3.460$; df $= 22$, $p = \leq 0.01$; two-tailed), 2 ($t = 3.978$; df $= 22$, $p = \leq$ 0.01; two-tailed) and 3 ($t = 2.747$; df $= 22$, $p = 0.01$; two-tailed) (Table 6). Echocardiogram time differences between resident participants and experienced attending physicians did, however, begin to narrow by the third assessment interval (Figure 6).

Figure 6. Resident Participants' and Experienced Attending Physicians' Mean Echocardiogram Times
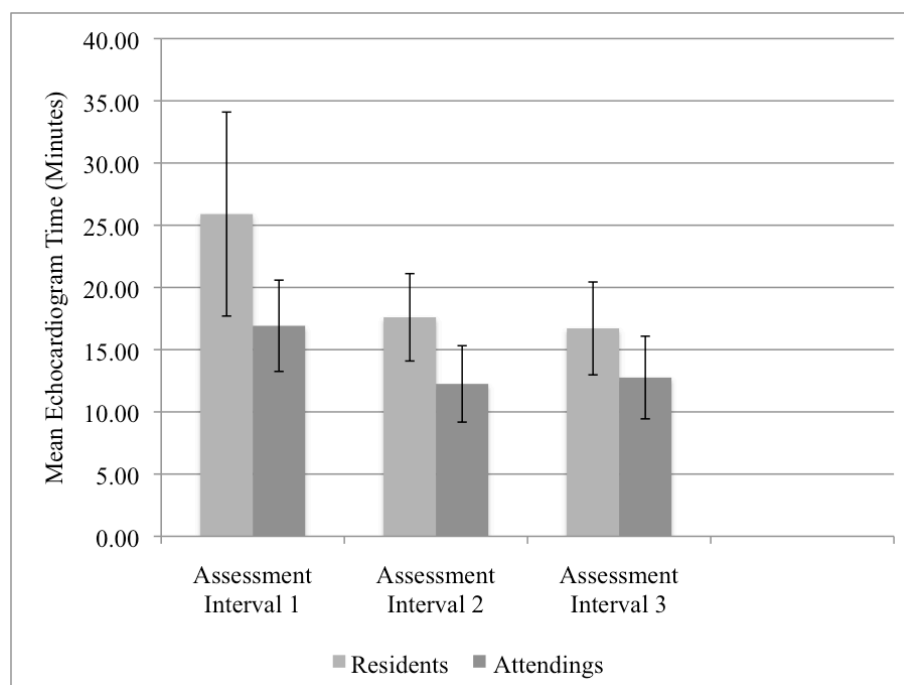
Focused Cardiac Ultrasound Efficiency

The second objective outcome measure, an efficiency score, was calculated by taking the mean grand total score on the FCU assessment tool and dividing it by the time required to acquire all requisite FCU images outlined in the assessment tool. Resident participant efficiency improved at each successive assessment interval (Figure 7). The mean efficiency scores and standard deviations for assessment intervals 1, 2 and 3 were 1.55 (±0.95), 2.48 (±0.97), and 2.61 (±1.37) respectively (Table 4). The biggest absolute gains in efficiency existed between assessment intervals 1 and 2. Statistically significant gains in resident participant efficiency were found between assessment interval 1 compared to 2 ($t = 2.45$; df $= 11$, $p = 0.03$; two-tailed) and assessment interval 1 compared to 3 ($t = 3.07$; df $= 11$, $p = 0.01$; two-tailed) but not for comparison of assessment interval 2 to 3 ($t = 0.28$; df $= 11$, $p = 0.79$; two-tailed), due to the

plateau in both the mean grand total assessment tool scores and only small decrement change in the times required to complete the focused echocardiograms. Effect size analysis comparing resident participants' mean efficiency scores between assessment intervals 1 and 2 demonstrated a Cohen's *d* of 1.01.[98] This is regarded as a large effect size. However, effect size analysis between intervals 2 and 3 demonstrated a Cohen's *d* of 0.11 indicating little or no effect.[98]

Figure 7. Resident Participants' Mean Focused Cardiac Ultrasound Efficiency Scores
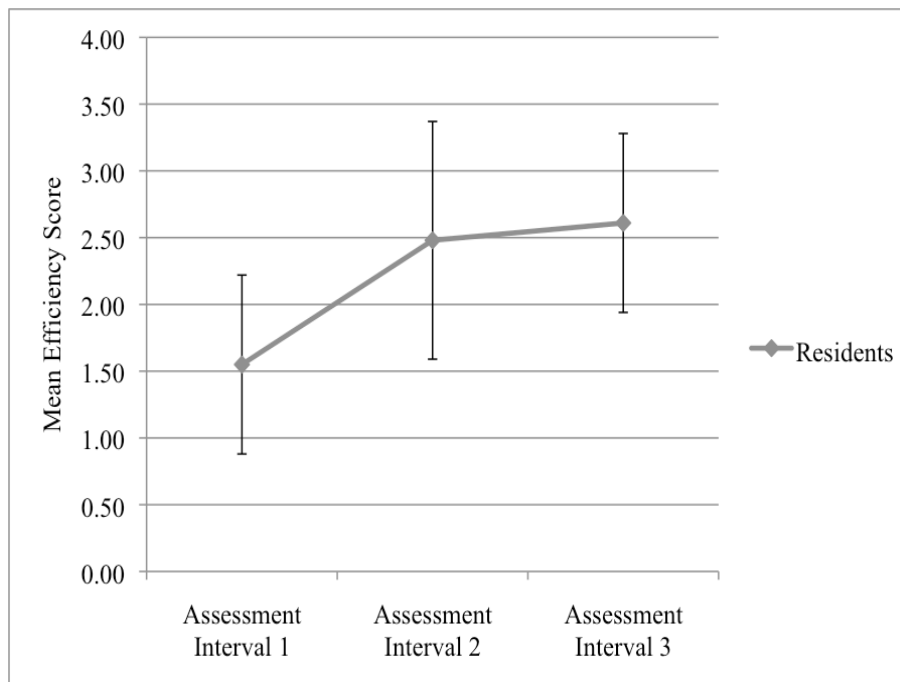
For their part, experienced attending physicians performed with consistently greater efficiency than resident participants (Figure 8). Their mean efficiency scores (± standard deviation) were 2.78 (1.38) for assessment interval 1, 4.55 (1.32) for assessment interval 2 and 4.17 (2.12) for assessment interval 3 (Figure 8). Independent *t*-testing between intervals confirmed these differences were statistically significant throughout assessment intervals 1 (*t* =

2.525; df = 22, p = 0.02; two-tailed), 2 (t = 4.376 ; df = 22 , p = < 0.001; two-tailed) and 3 (t = 2.137; df = 22, p = <0.05; two-tailed) (Table 6).

Figure 8. Resident Participants' and Experienced Attending Physicians' Mean Focused Cardiac Ultrasound Efficiency Scores
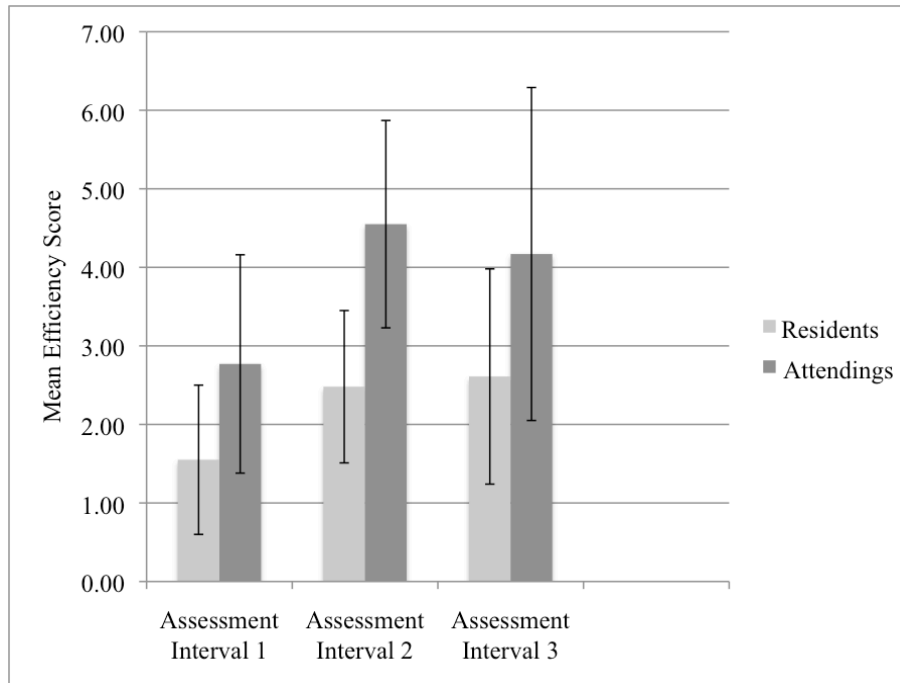
Reliability Analysis

The grand total scores evaluated by the two independent echocardiography reviewers (i.e., raters) were compared to each other to assess the reliability of the FCU assessment tool results. Reviewers' FCU grand total scores were tightly distributed along the regression line in a linear relationship with few outliers and there was a significant, strong positive correlation between reviewers' scores (r = 0.92, N=72, p < .01, two-tailed) yielding an R^2 value of 0.84 (Figure 9). Cronbach's α, a measure of internal consistency, was 0.95. The intra-class

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correlation (ICC) coefficient, a measure of agreement between raters was also excellent at 0.91. Overall, there was excellent agreement between the independent reviewers' FCU assessment tool grand total scores.

Figure 9. Comparison of Reviewers' Focused Cardiac Ultrasound Assessment Tool Grand Total Scores ($R^2= 0.84$)
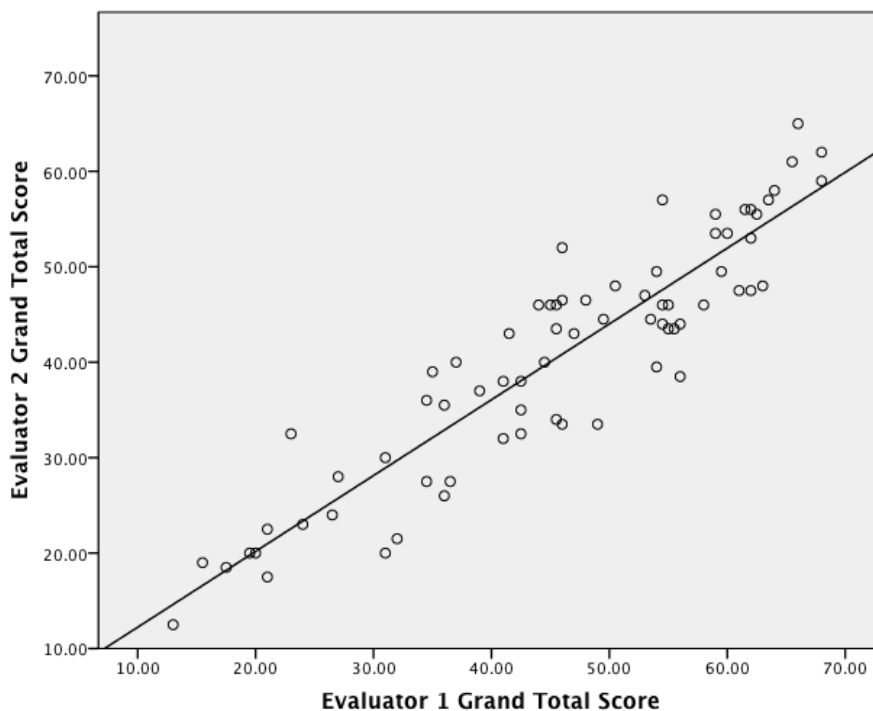
Global Rating Scale of Focused Cardiac Ultrasound Image Acquisition Proficiency

After observing each resident participant perform their echocardiogram, experienced attending physician echocardiographers were asked to rate the resident's ability to independently acquire FCU images (Appendix I). A score of ≥ 3 on the Likert scale indicated competence to acquire focused TTE images independently. Few resident echocardiograms in the first two assessment intervals were rated to have proficiency scores ≥ 3 (Table 7). By the third

assessment interval, 75% of echocardiograms performed were evaluated to have a global rating scale of proficiency in FCU ≥ 3 (Table 7). And, there were statistically significant improvements in global rating scores between intervals 1 and 3 ($t = 4.69$; df = 11, $p = < 0.01$; two-tailed). Yet, the mean global rating scores and standard deviations for assessment intervals 1, 2 and 3 were only 1.92 (± 0.67), 2.33 (± 0.89), and 2.92 (± 0.67) respectively (Figure 10). Thus, experienced attending physician evaluators felt that, on average, resident participants had not yet attained sufficient competence to acquire FCU images independently, even after their 20th echocardiogram (Figure 10). In fact, only one of the six resident participants involved in the study attained a mean global rating scale score ≥ 3 over all three assessment intervals. Finally, there was only a moderate positive correlation (Pearson $r = 0.523$) between FCU assessment tool grand total scores and global rating of proficiency in FCU scores awarded by experienced attending physician observers.

Table 7. Global Rating Scale of Proficiency in Focused Cardiac Ultrasound and Minimum Performance Standard Results

	Assessment Interval 1	Assessment Interval 2	Assessment Interval 3
Global Rating – Mean (± SD)	1.92 (0.65)	2.33 (0.87)	2.92 (0.65)
Number of Resident Echocardiograms with Global Rating ≥ 3 – no. (%)	2 (16.7)	3 (25.0)	9 (75.0)
Number of Resident Echocardiograms where Global Rating Agreed with passing MPS	0	1	3
Number of Resident Echocardiograms Exceeding MPS – no. (%)	1 (8.3)	1 (8.3)	3 (25)
Number of Experienced Attending Physician Echocardiograms Exceeding MPS – no. (%)	3 (25)	6 (50)	3 (25)

MPS: Minimum Performance Standard; SD: Standard Deviation.

Figure 10. Resident Participants' Mean Global Rating Scale Scores
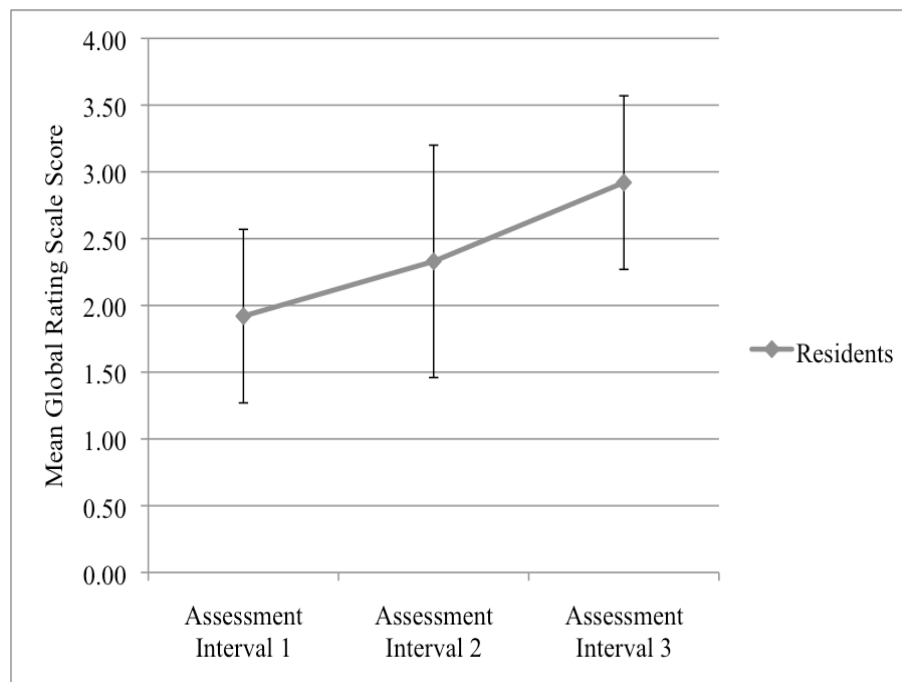
Focused Cardiac Ultrasound Assessment Tool Minimum Performance Standard

Using a modified Angoff method, a criterion-referenced absolute minimum performance standard (MPS) for competency as measured by the FCU assessment tool was established *a priori* to be a cut-score of 53.8 out of a possible 68 points. Very few resident focused echocardiograms by resident participants exceeded the minimum performance standard for assessment intervals 1 and 2 (Table 7). In comparison, experienced attending physicians' scores exceeded the minimum performance standard 25% of the time for assessment interval 1 and 50% of the time for assessment interval 2 (Table 7). By assessment interval 3, 25% of the studies performed by both resident participants and experienced attending physicians exceeded the MPS cut score of 53.8 (Table 7). This provides some evidence to suggest that resident participants began to approach the performance of experienced attending physicians by the time they

completed their 19th and 20 echocardiograms. Overall, however, the number of echocardiograms performed by any participant (i.e., resident or experienced attending physician) that exceeded the MPS at any assessment interval was low.

There was also poor agreement between the number of resident participant echocardiograms exceeding the MPS at each assessment interval and the experienced attending physician's global rating of resident proficiency ≥ 3 (Table 7). In some instances, residents were deemed competent even though their FCU grand total scores did not exceed the MPS and vice versa (Table 7).

Evaluating the Workload of Focused Cardiac Ultrasound Using the Modified NASA-TLX Workload Assessment Tool

A modified version of the NASA-TLX workload assessment tool was developed and implemented to elicit participants' opinions and perceptions of their performance of echocardiography during the study (Appendix H). Immediately after each echocardiogram performed during the study, participant responses were collected on six rating items: mental demand; physical demand; time demand; effort; performance; and frustration and anxiety.

The rating items with the highest mean scores for the first assessment interval were effort (7.00 ± 1.5), frustration and anxiety (6.67 ± 2.1). and mental demand (6.25 ± 2.1). Resident participants reported scores for mental demand, physical demand, time, effort and frustration and anxiety that tended to consistently decline across all assessment intervals (Figure 9). The most

striking change in reported scores were for the effort resident participants exerted to complete

their echocardiograms at successive assessment intervals (Figure 11). Furthermore, their reported

scores about their perceived performance increased with successive intervals from an initial

mean performance score of 4.08 (±2.15) at assessment interval 1 up to a mean of 7.08 (±1.51) at

assessment interval 3 (Figure 11). Paired samples *t*-testing revealed statistically significant

decreases in mental demand, effort required and resident participant frustration and anxiety

between assessment intervals 1 and 2 and 1 and 3. However, there were no statistically

significant differences between intervals 2 and 3 for these parameters (Table 8).   Most striking,

were the statistically significant increases in resident participants' perceived performance over

all of the assessment intervals (Table 8). Resident participants' perceptions about their

performance were only moderately correlated (Pearson *r* = 0.643) with their actual FCU

assessment tool scores, however.

Figure 11. Resident Participants' Mean Modified NASA-TLX Scores
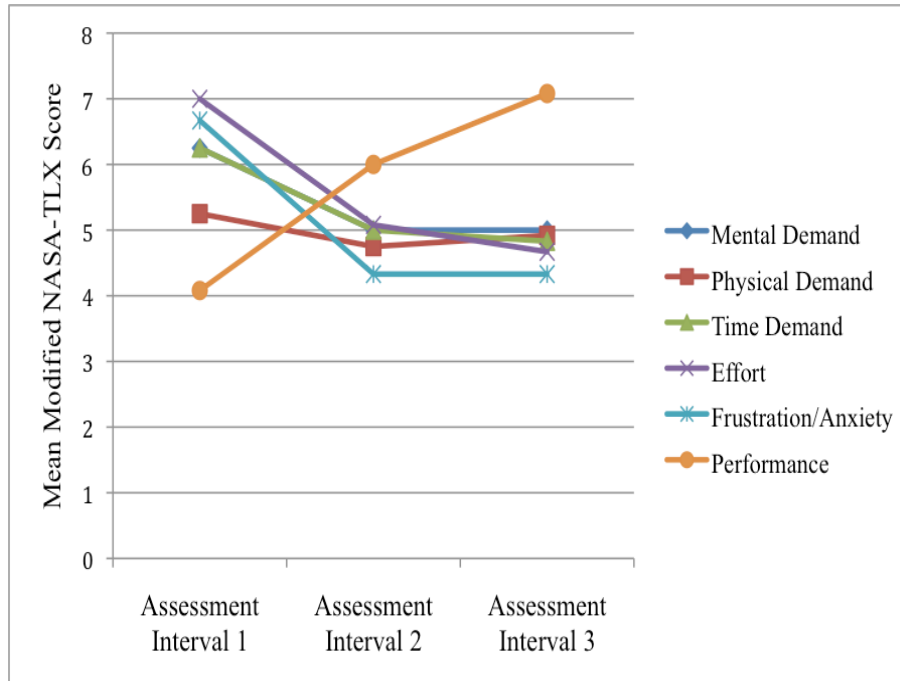
Table 8. Resident Participants' Modified NASA-TLX Paired *t*-Testing Results

	Assessment Interval 1 Vs. 2	Assessment Interval 1 Vs. 3	Assessment Interval 2 Vs. 3
Reported NASA TLX Inventory Scores	*p* value	*p* value	*p* value
Mental Demand	0.03	< 0.05	NS
Physical Demand	NS	NS	NS
Time Demand	NS	0.05	NS
Effort	< 0.01	< 0.01	NS
Frustration/Anxiety	< 0.01	< 0.01	NS
Performance	< 0.01	< 0.01	< 0.05

NS: non-significant.

The experienced attending physicians, for their part, consistently reported they experienced less mental, physical and time demands than residents and required less effort and felt less frustration or anxiety to perform their echocardiograms (Table 9). In comparison to resident participants, experienced attending physicians' modified NASA-TLX mean scores

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remained relatively stable over all three assessment intervals, yet there were few statistically significant differences in mean response scores between the two groups when compared with independent samples t-testing (Table 9; Figure 12). Experienced attending physicians reported that they experienced statistically less frustration or anxiety than resident participants at assessment interval 1 (Table 9).

One interesting observation suggested by the reported modified NASA-TLX scores of experienced attending physicians' was that the group of patients during the second assessment interval was technically less challenging to acquire FCU images on (Figure 12). Reported scores for mental, physical and time demands as well as effort required and performance all suggested the patients enrolled had FCU images that were easier to acquire. Paired samples t-testing of reported modified NASA-TLX scores and experienced attending physician FCU assessment tool scores was performed to explore this further, however there were no statistically significant differences between assessment intervals.

Finally, attending physicians' perceptions about their performance of echocardiograms were more strongly correlated (Pearson $r = 0.788$) with their actual FCU assessment tool scores than resident participants' perceptions of their performance (Pearson $r = 0.643$). This suggests experienced attending physicians possessed greater ability than resident participants learning FCU to interpret and self-evaluate their performance acquiring high quality FCU images.

Table 9. Resident Participants' and Experienced Attending Physicians' Modified NASA-TLX Scores

Reported NASA TLX Inventory Scores	Assessment Interval 1			Assessment Interval 2			Assessment Interval 3		
	R	**A**	**p**	**R**	**A**	**p**	**R**	**A**	**p**
Mental Demand – Mean (±SD)	6.25 (2.1)	5.67 (3.5)	NS	5.00 (1.5)	4.75 (3.0)	NS	5.00 (2.1)	5.42 (2.7)	NS
Physical Demand – Mean (±SD)	5.25 (2.1)	4.83 (3.2)	NS	4.75 (1.4)	3.75 (1.8)	NS	4.92 (1.9)	5.08 (2.8)	NS
Time Demand – Mean (±SD)	6.25 (1.9)	5.33 (2.5)	NS	5.00 (1.2)	4.17 (2.0)	NS	4.83 (1.6)	4.75 (2.4)	NS
Effort – Mean (±SD)	7.00 (1.5)	5.58 (2.7)	NS	5.08 (1.5)	4.58 (2.2)	NS	4.67 (1.7)	5.25 (2.8)	NS
Frustration / Anxiety – Mean (±SD)	6.67 (2.1)	3.75 (2.4)	<.05	4.33 (1.7)	2.92 (2.2)	NS	4.33 (1.6)	4.17 (2.2)	NS
Performance – Mean (±SD)	4.08 (2.2)	5.17 (2.6)	NS	6.00 (1.5)	7.00 (2.4)	NS	7.08 (1.5)	6.58 (2.1)	NS

R: Resident Participants; A: Attending Physicians; SD: Standard Deviation; p = p value; NS: non-significant.

Figure 12. Experienced Attending Physicians' Mean Modified NASA-TLX Scores
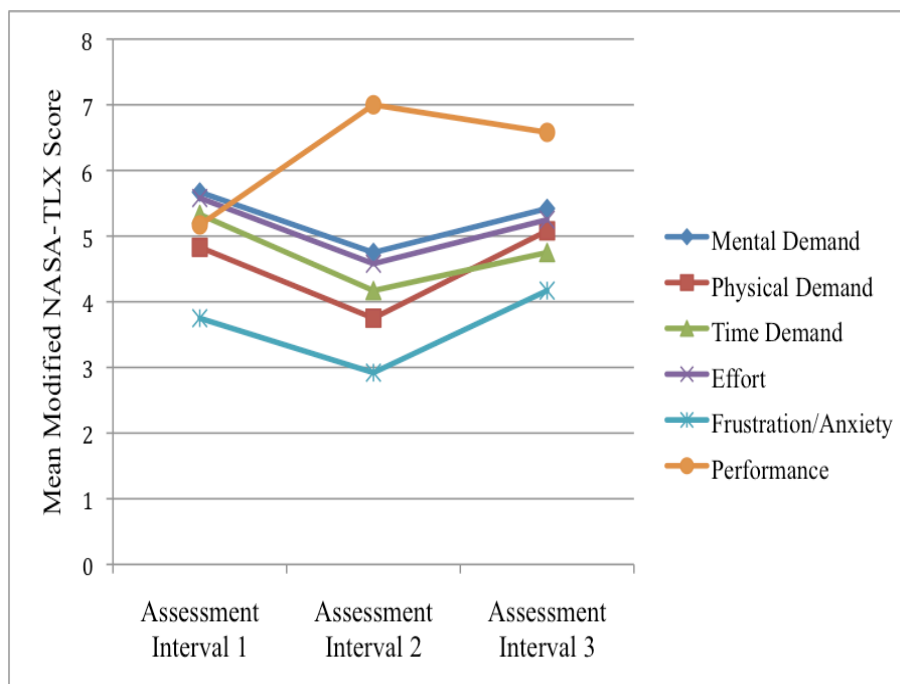
CHAPTER FIVE: DISCUSSION

This prospective study set out to develop and implement a comprehensive assessment tool to evaluate FCU image acquisition and to explore the workload ICU trainees experience while trying to learn FCU. Given the increasing utilization and reliance upon FCU as a diagnostic and monitoring tool in acute care settings, the need for a FCU assessment tool is obvious, particularly when education, training standards and credentialing for FCU continue to be debated and defined. To our knowledge, this is the first attempt to develop a comprehensive assessment tool to evaluate the performance of echocardiographers acquiring FCU images on mechanically ventilated patients in the ICU or in other clinical environments for that matter. It is also the first attempt to characterize the workload associated with learning FCU. The process of developing and implementing the FCU assessment tool sought to answer several important research questions to inform better understanding of the development of expertise in this rapidly expanding area of clinical practice.

1. **Can a comprehensive FCU assessment tool be developed that is sensitive to incremental changes in performance over time?**

This research question sought to determine whether or not the FCU assessment tool could discern changes in resident participants' FCU image acquisition performance over the successive assessment intervals in this study. The first outcome measure, resident participants' mean grand total FCU assessment tool scores, was not found to be statistically different when comparing assessment intervals. However, the trend of absolute scores improved between intervals 1 and 2 and then reached a plateau between intervals 2 and 3. Based on effect size calculations, a

moderate improvement in assessment tool scores occurred between assessment intervals 1 and 2 (Cohen's d = 0.50), yet there was no improvement between assessment intervals 2 and 3 (Cohen's d = 0.08). The distribution of residents' mean grand total FCU assessment tool scores was very large at each assessment interval and this high degree of performance variability was consistent for all three assessment intervals. This finding serves to partly explain the lack of statistical significance and also attests to the idiosyncratic nature of expertise development.[49,50,68] It also means that only generalizations can be made at this point about the potential slope of the learning curve associated with FCU. To comprehensively understand the nature of the development of expertise in this domain will require a larger study with greater participants completing greater numbers of focused cardiac ultrasounds while learning FCU.

The second objective outcome measure was resident participants' efficiency score at each assessment interval. There were absolute increases in resident efficiency with successive assessment intervals. These gains were statistically significant between assessment intervals 1 and 2 and 1 and 3, yet no statistically significant gain existed between assessment intervals 2 and 3. The largest efficiency improvement was between assessment intervals 1 and 2 and this was reflected by a large efficiency effect size (Cohen's d = 1.01). In contrast, no effect size was found for changes in efficiency between intervals 2 and 3 (Cohen's d = 0.11). This is explained by both the plateau in assessment tool scores and only small decremental changes in the time needed to complete the echocardiograms between assessment intervals 2 and 3.

Taken together, the mean grand total assessment tool scores and efficiency scores suggest that the FCU assessment tool is sensitive to changes in resident performance over time. Interestingly, both indices of resident performance in FCU image acquisition (i.e., mean grand total assessment tool score and efficiency score) suggested a plateau or significant flattening in the slope of the trajectory of expertise development between assessment intervals 2 and 3.

Although these findings are preliminary, they are consistent with theories about the development of expertise.[49,50,65,75,76] The trend of steady decline in the time required to complete echocardiograms at each successive assessment interval also bolsters this assertion. With initial training, real-world experience and formative feedback, resident participants (i.e., novices) learning FCU quickly gained increasing fluency with the task and progressed to a new developmental stage. Although the returns in terms of performance were initially rapid, without deliberate practice, incremental gains in the FCU image acquisition performance of resident participants lessened and even ceased—experience alone was an insufficient guarantor of FCU assessment tool success.[50,79]

Research has demonstrated that after approximately 50 hours of training, most individuals' performance attains sufficient automation and adaptation to situational requirements that they are no longer able to consciously mediate changes in their behaviour.[50] Interestingly, the level of FCU imaging experience attained by our resident participants by participating in the FCU curriculum and after having completed their 19th and 20th echocardiograms as part of this study would closely approximate the 50 hour threshold. Finally, mediating influences of

individual patient factors on resident participants' performance aside, the large performance

variability observed in this cohort also suggests that the process of FCU image acquisition

improvement (i.e., the learning curve) is idiosyncratic and highly individualized.[49,50,68] This has

been demonstrated in a number of other areas in medicine for procedures such as colonoscopy,

cesarean section and coronary angiography.[99-101]

2. Can a comprehensive FCU assessment tool be developed that differentiates between different levels of expertise in FCU?

This research question sought to determine whether or not the FCU assessment tool

developed in the study could discern differences in performance between echocardiographers of

differing skill levels—namely resident participants (i.e., novice echocardiographers) from

certified ICU attending physician echocardiographers (i.e., experienced echocardiographers). At

each successive assessment interval, the mean grand total FCU assessment tool scores of

experienced echocardiographers exceeded those of resident participants. It was surprising to find,

however, that the only statistically significant differences in mean grand total scores that existed

between the two groups occurred at assessment interval 2. The lack of statistical significance is

likely accounted for by the large distribution in performance for both groups across all

assessment intervals (performance variability was less for experienced attending physicians,

however).

Using experienced echocardiographers as a "gold standard" reference comparator was intentional in an attempt to try to control for the influence that patient factors had on the acquisition of FCU images. Nonetheless, the performance variability measured still speaks to the tremendous influence that patient technical factors may play in influencing the quality of the acoustic windows that can be acquired when FCU is performed on mechanically ventilated ICU patients. Even in experienced echocardiographers' hands, a proportion of ICU patients in this study simply did not have good quality acoustic windows for all required FCU assessment tool views and, some patients lacked certain acoustic windows altogether. This was reflected in experienced attending physicians' mean grand total FCU assessment tool scores.

Three comparable FCU studies conducted on ICU patients attest to this reality. Marcelino et al., found that experienced attending physician echocardiographers (with 4-11 years of echocardiography experience) were only able to obtain qualitative information from their bedside echocardiograms in 38 of 704 medical-surgical ICU patients (and only half were mechanically ventilated).[102] In a second study of 61 ICU patients, experienced echocardiographers were only able to acquire 91% of the required acoustic windows and their mean grade of image quality was only 1.95 ± 0.76 (where a score = 2 represented good imaging quality).[26] Finally, in a larger study involving 219 ICU patients (66.2% of whom were receiving mechanical ventilation), experienced echocardiographers were only able to attain 88% of the required acoustic windows (888 of 1005 acoustic windows).[51] Given these findings, one can conclude that even experienced echocardiographers may not be able to obtain up to 12% of the possible acoustic windows of ICU patients. Furthermore, even when they are able to obtain

them, the quality of the image may be suboptimal. This percentage may, in fact, actually be higher since the patients enrolled in these studies were not all mechanically ventilated in contrast to this study. This has important implications that must be considered in the development of any FCU assessment tool that outlines "must" obtain acoustic windows with precise anchors to evaluate their image quality (see discussion below on minimum performance standard).

What was most revealing in comparing resident participants to experienced echocardiographers was their difference in efficiency scores. Experienced attending physician echocardiographers' efficiency scores were statistically superior to those of resident participants' across all assessment intervals. Experienced echocardiographers achieved generally higher FCU assessment tool scores while also completing their echocardiograms in a shorter period of time than resident participants, hence their greater efficiency scores. Given the time sensitive demands of FCU, the time required to complete echocardiograms has been emphasized in previous studies as an important determinant of an echocardiographer's skill.[26,51,88] This also makes good intuitive sense because efficiency is a hallmark of expertise. Therefore, the efficiency findings in this study provide strong evidence of the FCU assessment tool's ability to discriminate between echocardiographers of different skill levels.

3. What evidence exists to demonstrate that the FCU assessment tool is reliable and that the inferences drawn from FCU assessment tool scores are valid?

Evidence for the reliability of the FCU assessment tool was examined in several ways. First, FCU assessment tool grand total scores as evaluated by the two independent

echocardiography reviewers were compared with each other. Reviewers' FCU grand total scores were tightly distributed along the regression line in a linear relationship with few outliers. There was a strong positive correlation between reviewers scores which yielded a high R^2 value to indicate that inter-rater correlation was excellent. Internal consistency, as measured by Cronbach's α, was also very high at 0.95. Finally, the intra-class correlation coefficient was 0.91 indicating that there was excellent agreement between the echocardiography reviewers' FCU assessment tool scores. These results all suggest that the FCU assessment tool developed in this study is a reliable assessment tool when independent reviewers are appropriately trained in its use.

Validity is considered of paramount importance in the development of any good assessment tool.[22,83,85] Contemporary validity arguments can be thought of as an evaluation of the plausibility, coherence and completeness of claims made about the interpretations and uses of assessment tool scores.[86] Due to its desired eventual role in summative assessment and certification purposes for FCU, multiple sources of evidence must be gathered in order to construct a meaningful validity argument for the FCU assessment tool.[22,84-86] The Standards for Educational and Psychological Testing note five sources from which to seek evidence for validity, namely: content, response process, internal structure, relationship to other variables and consequences.[84] The desired interpretative meaning associated with FCU assessment tool scores will be discussed with these evidentiary sources in mind. Doing so will hopefully describe how well medical educators can legitimately trust FCU assessment tool results to measure an echocardiographer's image acquisition skill.[103]

The first question to attempt to answer in formulating a validity argument is whether or not the FCU assessment tool captures the requisite elements of FCU?[103] If so, how was the content arrived at?[103] The preliminary FCU assessment tool was informed by current consensus statements regarding the goals and requisite elements of FCU as well as medical education literature on the development of assessment tools.[15-17,22,57,89] A panel of local echocardiography and medical education experts then undertook an iterative process of deliberation until consensus was reached on the final FCU assessment tool implemented in this study. The assessment items that comprise the tool are clearly outlined and fully sample the requisite elements of FCU (Appendix D). The scoring system anchors are precise and clearly defined. They provide meaningful information about different degrees of FCU image acquisition performance. Importantly, they are also not too cumbersome to use because of multiple scoring options.

Response process as a source of validity evidence relates to the integrity of the data and attempts to control sources of error in the experimental design.[85] The experimental design employed relied on FCU studies performed in tandem immediately following each other. Experienced echocardiographers' FCU studies therefore served as a "gold standard" reference in an attempt to control for the influence of patient factors on the quality of FCU images. All study participants who completed FCU studies as part of the study received training on the requisite elements of the FCU assessment tool (i.e., echocardiogram views and their respective point values). A copy of the FCU assessment tool was available for reference at the bedside when completing their echocardiograms as well. All echocardiograms were coded with a unique, random study number to ensure blinding of reviewers. Echocardiography reviewers for the study

were also trained in the implementation of the FCU assessment tool using sample echocardiograms of differing quality. They were permitted to discuss how they would score these echocardiograms in order to develop consensus about the scoring they would award when reviewing the real archived echocardiograms as part of the study. Given that two independent raters reviewed each echocardiogram, a mean of their grand total FCU assessment tool scores was determined to be the most appropriate way of determining the final score assigned to each echocardiogram. For each of these reasons, compelling evidence exists to support the response process validity argument for the FCU assessment tool.

The statistical or psychometric characteristics of the assessment tool are generally considered to form the evidence related to its internal structure.[103] As previously discussed, preliminary reliability evidence for the FCU assessment tool is encouraging. Inter-rater correlation, internal consistency and intra-class correlation measures each provide evidence to suggest the FCU assessment tool is reliable and that the scores are reproducible. More work remains, however, to determine a MPS that is reproducible, especially if the FCU assessment tool is to be used in high-stakes assessment situations.

Relations to other variables constitutes a commonly examined piece of the validity argument. Correlation with scores from another instrument or outcome for which correlation might plausibly be expected is important here.[103] Unfortunately, no other well-established FCU assessment tool currently exists from which to make comparison. Within this study, there was a moderate positive correlation between mean grand total FCU assessment tool scores and global

rating of proficiency in FCU scores. However, some discrepancy between global rating scale scores by experienced attending physicians observing resident participants and FCU assessment tool scores that met or exceeded the MPS was observed. In some instances residents were deemed to be competent to perform FCU even though their FCU assessment tool scores did not exceed the MPS and vice versa.

Interpreting this discrepancy is challenging for multiple reasons. First, experienced attending physicians may have been biased by repeated exposure to resident participants during the study. They may have retained pre-conceived opinions about resident participants' FCU competence based on their previous observations. After having personally completed echocardiograms on the patients themselves, they may also have made a determination about the difficulty to acquire images and this may have also influenced their global assessment of the resident, either positively or negatively. Second, the MPS that was established proved to be overly ambitious, partly because no pre-existing FCU assessment tool performance data was available to inform selection of the MPS. Finally, other work has demonstrated that high checklist scores exceeding a set threshold do not necessarily preclude incompetence on global rating scales.[104] Relations to other variables will need to be carefully studied in future in order to strengthen the validity argument from this evidentiary source for the FCU assessment tool.

Consequential evidence represents the last piece of the puzzle for any validity argument. This aspect of validity refers to the impact or consequences (both intended and unintended) from the assessment scores, decisions and outcomes.[85] Here, the decisions about passing and failing are important, as are the processes used to determine these cut-offs.[85] Using a modified Angoff

method, a panel of 6 local echocardiography experts established the MPS. Surprisingly, the number of echocardiograms performed by any participant (i.e., resident or experienced attending) that exceeded the MPS at any assessment interval was much lower than anticipated, suggesting a pressing need to revisit the MPS cut scores for future iterations of the assessment tool. It also suggests the influence of patient factors on determining the degree of difficulty of FCU image acquisition is difficult to account for— even the experienced attending physicians, quote-on-quote experts, were incapable of consistently acquiring FCU images that met the pre-determined MPS in our study. Previous work has demonstrated that the acquisition of echocardiographic images in critically ill patients is challenging because of multiple factors: inability to position them well, lack of cooperation due to sedation or altered level of consciousness, tachypnea, surgical wounds and chest tubes, among others.[105] As well, patients in this study also had elevated body mass indexes and modest amounts of positive end expiratory pressure applied during mechanical ventilation. Any of these factors could potentially have curtailed the presence of some of the required FCU assessment tool acoustic windows and/or limited their diagnostic quality. What appears clear from the study results is that the MPS that was defined *a priori* failed to sufficiently consider the difficulty of FCU image acquisition in ICU patients.

In summary, some encouraging empirical validity evidence exists to support FCU assessment tool scores with regard to content, response process and internal structure. On the other hand, evidence for validity in terms of relations to other variables and consequences is minimal. It must also be emphasized that these results are preliminary. Because validity is an on-going process of collecting data about the assessment instrument and then critically evaluating it

for the specific purpose and context in which the tool is used, more evidence is needed to bolster the validity argument for the FCU assessment tool.[85,86] This is particularly true with regard to establishing a more meaningful MPS that might begin to inform a data-driven definition for competence in FCU image acquisition. At this early stage, FCU assessment tool results can provide useful formative feedback to trainees learning FCU. It will be essential to build up more validity evidence before implementing it as a summative assessment tool in high-stakes assessments for credentialing purposes (see directions for future research).

4. What is the initial workload of ICU residents learning to acquire FCU images in the ICU and does this change over time?

A modified NASA-TLX workload assessment tool was developed and implemented in this study in order to begin to characterize resident physician participants' perceptions and opinions about the workload associated with learning FCU. Scores reported by resident participants suggested that their initial investment in terms of effort and mental demand were high. They also initially experienced a high degree of frustration and anxiety in performing their focused cardiac ultrasounds and were discouraged by their perceived performance. Resident physicians' reported ratings of their perceived performance then dramatically increased in a statistically significant way at each assessment interval over the first 20 FCU studies. The greatest change in perceived performance occurred between assessment intervals 1 and 2, however. Conversely, reported scores for mental demand, physical demand, time, effort and frustration and anxiety declined over time. Yet the only statistically significant differences that

existed were for decreases in mean ratings for mental demand, effort and frustration and anxiety between the first and second assessment intervals.

These results provide early evidence to suggest resident participants' comfort with, confidence in, and perceived performance of FCU steadily increases with time but that the most substantial rate of gain occurs in the first 10-11 FCU studies. The findings are consistent with theories about cognitive load and the acquisition of expertise in medicine.[47-50,75,76] By gaining experience, resident participants were not only increasingly able to generate the performance steps needed to acquire FCU images, but they also felt more confident doing so because the task became less demanding and required fewer cognitive resources to complete.[47-50] One potential explanation for the initial phase of rapid gains in comfort and confidence and performance reported by trainees in the first 10-11 studies is that it may correspond to a period where trainees are acquiring the basics of FCU.[49,50] Following this, they may begin to appreciate more subtle and challenging aspects of FCU that will require more fine tuning of skills and greater procedural dexterity on their behalf in order to become adept at FCU.[49,50] This in turn may have influenced their reported modified NASA-TLX scores and might begin to explain the reported results.

Finally, attending physicians' perceptions about their performance of echocardiograms were more strongly correlated (Pearson $r = 0.788$) with their actual FCU assessment tool scores than resident participants' perceptions of their performance (Pearson $r = 0.643$). This suggests experienced attending physicians may possess greater ability than resident participants learning

FCU to interpret and self-evaluate their performance acquiring high-quality FCU images. It also raises the possibility that trainees starting to learn FCU may be overconfident in their initial assessment of their image acquisition abilities. This has important diagnostic and clinical decision-making implications at the point of care. Being over confident in the quality of FCU images could lead to misinterpretation of echocardiographic findings and incorrectly influence patient management, risking harm for patients. This also speaks to the very important need for close supervision of trainees learning FCU and for timely review of their FCU studies by trained, experienced echocardiographers.

How Much is Enough?

This study's findings give reason to pause in an attempt to begin to answer an as-yet unresolved question in FCU, namely: "how much FCU experience is enough for novice echocardiographers to develop competence to acquire FCU images?" A few small studies have contributed some critically important initial evidence and have found that 20-40 FCU training studies may actually be sufficient to develop reasonable competence in FCU.[51,87,88] Unfortunately, disparate FCU curriculums, groups of learners, clinical contexts, imaging protocols and assessment methods used to evaluate echocardiographer performance limits the generalizability of these results. Furthermore, "acceptable" image quality was either not explicitly or sufficiently rigorously defined in some of these studies to make valuable inferences about the FCU image acquisition results. In contrast, the FCU assessment tool developed in this study makes explicit what "acceptable" or "good" image quality is using clearly defined

descriptors and weighted scoring anchors. This could prove useful in trying to define and standardize what is meant by "good" or "acceptable" imaging quality going forward.

It also appears that a signal exists to indicate that certain FCU views or acoustic windows are more challenging than others to obtain.[51,88,102] In research done to date, exactly which FCU views present more difficulty than others has not been consistently identified.[51,87,88,102] Unfortunately, this study failed to clearly demonstrate any statistically significant trends that speak to the difficulty of obtaining different FCU acoustic windows when comparing novices and experienced echocardiographers (Table 5).

Considering the results of this study along with the totality of what is already known about FCU in the ICU, a clearer picture emerges that begins to answer the question of "how much FCU image acquisition training is enough?" With a small amount of experience (approximately 10 focused cardiac ultrasounds), novices learning FCU can quickly develop their skills to become advanced beginners.[65,66] The rate of acquisition of expertise from this point forward requires more clarification because the task of performing FCU is challenging and obtaining FCU images on intubated patients in the ICU even more so.[105] Even after modest experience (approximately 20-35 studies), trainees learning FCU in ICU do not consistently approach the skill level of experienced echocardiographers in terms of the time required to acquire the images or the quality of the acoustic windows obtained.[26,51,88] In fact, this study suggests there may even be a performance plateau reached after this level of experience that requires more targeted training and deliberate practice to ascend toward competence, proficiency

and expertise.[49,50,65,66] Some FCU acoustic windows may also be more challenging than others to obtain and this too may require deliberate practice in order to improve FCU image acquisition skills.

Limitations of the Present Study

There are a number of limitations associated with this study that merit further discussion. The first, and perhaps largest, limitation is that this study was conducted in a single center with only a small cohort of ICU resident participants. The variability in resident participant performance was also very high. These factors limit the generalizability of the study findings.

The FCU image acquisition protocol for this study, which included timing each of the focused cardiac ultrasounds and direct observation and a global evaluation of the resident participant's FCU proficiency by an attending physician, may have induced stress and pushed resident participants to complete their echocardiograms faster than they normally might have. It may also have altered their usual behaviour in performing FCU and this might have influenced their image acquisition. Although it was explicitly forbidden in the study protocol, subtle unintentional coaching by the experienced echocardiographers observing resident participants during their echocardiograms may also have occurred and biased results. The feedback provided to resident participants after their echocardiograms may have also have been of variable quality and influenced the rate of skill acquisition.[80] While experienced attending physicians were formally required to provide individualized, formative feedback after observing each resident

perform their echocardiogram, this was not standardized and was not possible to control for in the study.

Data collection (i.e., completion of echocardiograms) for the study required more time than initially anticipated because resident participants completed the echocardiograms in their free time while completing their usual clinical rotations and duties. Consequently, some residents gathered experience in FCU more slowly and sporadically than others. Although resident participants seemed motivated to participate, time constraints due to other clinical commitments clearly dictated the schedule and rate at which their studies were performed. Thus, scattered or haphazard accrual of experience may have influenced the rate of FCU skill acquisition or may even have potentially contributed to decay of skills previously gained. Evidence from other medical domains shows that without on-going task performance, skills decline and complications can ensue.[106-110]

Experienced attending physicians observed resident participants performing their echocardiograms at each assessment interval and then were required to provide an overall global rating of the resident's proficiency in FCU. Due to the small number of resident participants in our study, experienced attending physician evaluators may have been influenced by their previously observed performance of each resident and this may have biased their assessment of the resident's abilities in FCU. They may also have held preconceived ideas about the amount of training required to attain competence in FCU that influenced their performance assessments.

This study also does not yet comprehensively answer the question regarding the amount

of training necessary for individuals to achieve competency in FCU in ICU. This is partly due to

the fact that no quantitative, data-driven definition for competency presently exists in this field.[11]

Unfortunately, the MPS selected and used in this study proved to be too ambitious, as even

expert echocardiographers were incapable of achieving success on a significant proportion of the

patients they performed focused cardiac ultrasounds on.

The FCU assessment tool developed in this study is ideally used when FCU studies can

be completed in tandem with an experienced echocardiographer serving as a "gold standard"

reference. This is also an important limitation of the FCU assessment tool—it requires a

tremendous investment of time and effort on the part of experienced echocardiographers in an

effort to control for the influence of individual patient factors on FCU image acquisition and

diagnostic quality.

Directions for Future Research

Recognizing these limitations, this study should be replicated in a larger cohort of acute

care trainees learning FCU. Preliminary results suggest that the FCU assessment tool developed

in this study is reliable and that valid inferences can be drawn from its results. Therefore, it

deserves to be studied in a larger cohort of acute care specialty residents employing a similar

curricular intervention and a fresh set of echocardiography reviewers. Doing so will not just

provide more valuable information about the performance of the FCU assessment tool. It will

also help to determine the criteria that ultimately might permit a more objective definition of

competence in FCU and help address the issue of the training needed to achieve it. With this in

mind, it is suggested that future research endeavours go well beyond the first 20 FCU studies

trainees complete, perhaps even out to the first 40-50 studies in order to better understand how

the assessment tool performs and also to further characterize the learning curve associated with

this complex task. Unfortunately, time and resource constraints in this study (related to

availability of ultrasound platforms and human resources) did not make it practical or realistic to

permit this to occur. Instead, three discrete assessment intervals spaced throughout the first 20

echocardiograms were determined to be most feasible and were therefore selected. In future,

collecting more data using the FCU assessment tool may also permit a better understanding of

which FCU views present the greatest challenge to learn. Going forward, it will also be

important to continue to elicit the workload trainees experience beyond the first 20 FCU studies

using the modified NASA-TLX assessment tool and for medical educators to attempt to tailor

their educational interventions in ways that thoughtfully address those needs (e.g., curriculum

design, instructional methods, type and amount of guidance provided during hands-on FCU

studies, etc).

Given the study findings, the MPS established for the FCU assessment tool in this study

needs to be revisited in future. It will either need to be lowered or a new MPS will need to be

determined. In hindsight, it was perhaps too ambitious to have selected such a high cut-score

(approximately 80% of the total FCU assessment tool total score) given the difficulty of

obtaining images on mechanically ventilated ICU patients. In the future, it may be more

appropriate to select an MPS cut score of $\geq 80\%$ of the experienced echocardiographer's FCU

assessment tool score as an appropriate data-driven measure of FCU image acquisition

competence. This will require further deliberation from the panel of expert echocardiographers

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and medical educators. Measured decisions will need to be taken by the panel to balance competing interests of rigor and practicality of the FCU assessment tool.[22,58,83]

The difficulty in determining a meaningful MPS in this study highlights the persistent challenge in FCU to try to establish a data-driven definition of competence. This process of standard setting will necessitate more data collection and on-going input from a group of experts in FCU and medical education. This task will be demanding given the mediating influence of individual patients on the difficulty of FCU image acquisition. Unfortunately, obtaining FCU images on real patients is not a static task! For this reason, an echocardiographer's image acquisition skill ideally needs to be examined over a sample range of patients of varying difficulty. Perhaps an average of their performance scores could then be determined in order to assess their competence to acquire FCU images in ICU patients. This will be especially important in instances where an experienced "gold standard" comparator (i.e., experienced attending physician echocardiographer) is not available. It will also be vitally important if the FCU assessment tool reaches a point where strong enough validity evidence exists to support its use for summative evaluation and certification purposes.

The study results speak to the sizeable investment in training that may be required in order for novices to begin to achieve a level of expertise in FCU image acquisition. They do not, however, address the level of on-going training or experience needed to maintain these skills once they have been developed. Nor do they answer more important clinical questions regarding the extent to which FCU might impact care decisions to meaningfully influence ICU patients' outcomes. Furthermore, this study did not focus any attention on the rate at which novices

acquire FCU image interpretation skills, the second essential component of overall FCU expertise. Answers to these important questions ultimately need to be sought if FCU in ICU is to continue to mature and prove its worth.

Summary

The enthusiasm for and adoption of FCU as a diagnostic and monitoring tool in intensive care and other acute care specialties continues to expand. With growing evidence to support FCU implementation in acute care medicine it seems increasingly clear that FCU may well be the way of the future for rapid hemodynamic assessment of critically ill patients. The way forward for incorporating FCU in acute care specialties from an education, training and credentialing standpoint remains less clear, however.

Literature continues to emerge advocating how FCU should be taught, along with prescriptive expert consensus statements on the threshold number of FCU studies required for trainees to become competent in this new field. However, many of these decisions are arbitrary and need to be critically examined. With the paradigm shift toward competency based medical education and evidence-informed assessments, the traditional apprenticeship model comprised of a threshold number of mentored procedures and a subjective gestalt about a trainee's competence is no longer a sufficient determinant of competence to practice. Moreover, the development of expertise is highly idiosyncratic and a well-developed, evidence-informed understanding of the workload and learning curve for FCU does not yet exist. Much remains to be elucidated about the development of expertise in this new area and further study is greatly needed.

Conclusion

Focused cardiac ultrasound in intensive care medicine has entered an exciting stage of development. Unfortunately, like in many other areas of medical education, we've put the "cart" in front of the proverbial "horse," however. While adoption of FCU has surged forward enthusiastically, development of assessment tools to critically evaluate trainees' FCU image acquisition skills and make valid inferences about their performance has not. A pressing need for FCU assessment tools that provide meaningful results to evaluate trainees' expertise and define and delineate competency standards remains.

This study represents a first attempt to fulfill this unmet need by developing a comprehensive assessment tool for FCU in ICU. The results suggest that the FCU assessment tool developed can both discern changes FCU image acquisition performance over time and between echocardiographers of differing skill levels. Preliminary evidence to support the reliability and validity of the inferences that can be made using the FCU assessment tool have been described herein. This study also adds to the current knowledge about the development of expertise in FCU in several important ways. The study results provide a first glimpse into the initial workload trainees experience while learning FCU. Second, the results add to a growing body of literature on the trajectory of the development of image acquisition expertise that can inform future FCU training efforts. While ICU residents can definitely learn FCU image acquisition, the development of sufficient competence will require considerable investment in education and training that, arguably, may be more substantial and require more FCU studies than initially envisioned or anticipated. Finally, with further study, the FCU assessment tool may

prove useful for competency assessment and could be used for promotion and certification

purposes in this burgeoning area of intensive and acute care medicine.

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APPENDIX A: Cardiac Ultrasound Curriculum Lecture Series

Lecture/Session
1. Focused cardiac ultrasound introduction and ultrasound physics
2. Cardiac anatomy and ultrasound artifacts
3. Image acquisition: standard focused echocardiography views
4. Image acquisition: optimizing echocardiography views
5. Echocardiography interpretation I
6. Echocardiography interpretation II
7. Clinical incorporation I
8. Clinical incorporation II

APPENDIX B: Resident Participant Study Invitation Letter

Subject: Research Study: Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography

Investigators: Dr. Jonathan Gaudet, Dr. Jason Waechter, Dr. Kevin McLaughlin, Dr. Jocelyn Lockyer

Dear Colleagues:

On behalf of myself and our study principal investigator (Dr. Jocelyn Lockyer) I would like to invite you to participate in a medical education research study we are currently conducting entitled: "Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography." This is a small, prospective study that will attempt to objectively assess your focused echocardiography image acquisition skills using a novel assessment tool we have developed. This is being done as part of my MSc program in Medical Education.

Please read the attached information sheets carefully and complete the consent form should you agree to participate. You will be provided with a copy of the information sheets and the consent form for your records as well as a copy of the novel assessment tool. If you have any questions please do not hesitate to contact me (jonathan.gaudet@albertaheathservices.ca) or my supervisor Dr. Jocelyn Lockyer (lockyer@ucalgary.ca).

Thank you for considering participating in our study. We greatly appreciate your contribution to furthering the development of critical care cardiac ultrasound. Sincerely,

Jonathan Gaudet MD, FRCPC
Clinical Scholar
Department of Critical Care Medicine
University of Calgary

Jocelyn Lockyer PhD
Senior Associate Dean – Education
University of Calgary

APPENDIX C: Resident Information Sheet and Informed Consent Form

Study Title: Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography

Principal Investigator: Dr. Jocelyn Lockyer   **Phone:** (403) 220-4248

Co-Investigators: Dr. Jonathan Gaudet, Dr. Jason Waechter, Dr. Kevin McLaughlin

INTRODUCTION
You are being invited to voluntarily take part in a research study. Before you agree to participate, please read the following information carefully. This information sheet and consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. You will receive a copy of this form.

BACKGROUND
Focused cardiac ultrasound is becoming an important diagnostic tool for physicians caring for patients with shock in the intensive care unit. This study is part of a larger curriculum to teach focused cardiac ultrasound to critical care resident physicians in the Department of Critical Care Medicine at the University of Calgary. As part of this project, we have developed a new assessment tool to evaluate resident physician performance in acquiring focused cardiac ultrasound images.

WHAT IS THE PURPOSE OF THE STUDY?
The purpose of this study is to examine your performance as a critical care resident physician learning cardiac ultrasound and to determine whether the novel assessment tool can distinguish between ultrasonographers of different skill levels or whether or not the instrument is sensitive to change over time.

WHAT WOULD I HAVE TO DO?
If you agree to participate in this study, you will receive an 8 session didactic lecture series on the principles and application of focused transthoracic echocardiography for hemodynamic assessment, along with 8 hours of mentored bedside practice performing cardiac ultrasounds on normal volunteers. Following this, you will begin performing focused cardiac ultrasounds on real ICU patients. As part of the study, you will be required to independently complete a total of 20 transthoracic focused echocardiograms. You will have protected time during your rotations in the ICU in order to complete the required studies. Selection of patients will be left to your discretion and to the discretion of the attending ICU physician. The only inclusion criteria for patient selection will be an intubated ICU patient. Although you will complete a total of 20 echocardiograms, for the purposes of this research study, there are three assessment intervals corresponding to your 1st and 2nd echocardiograms (Assessment Interval # 1), your 10th and 11th echocardiograms (Assessment Interval #2) and your 19th and 20th echocardiograms (Assessment Interval #3).

Each assessment interval will involve you independently performing two cardiac ultrasounds on two separate, intubated ICU patients. You will not be provided any assistance in acquiring the images. An experienced attending physician echocardiographer will also perform an echocardiogram on the same patients to serve as a gold standard comparator. The images acquired from both studies will be archived on the Philips Sonos 4500 cardiac ultrasound platform for later review by a blinded interpreter (one of the attending physicians in our Department with expertise in echocardiography). Your echocardiogram images and the images of the experienced echocardiographer will be evaluated using the novel assessment tool and the results will be compared. After each echocardiogram you will also be asked to share your opinions about the workload of performing each focused cardiac ultrasound and the experienced attending physician will also complete a global evaluation of your performance.

It is anticipated that each assessment interval will require approximately two hours of your time. This will be protected time during your rotation that will be scheduled in advance in order to coordinate with an attending physician. It will be your responsibility to have completed the exact required number of studies (and not more) preceding each assessment interval.

During each assessment interval, for each patient you complete an echocardiogram on, you will be asked to collect information regarding their clinical characteristics (i.e., age, gender, reason for ICU admission, APACHE II, BMI, vital signs, PEEP and whether or not the patient required vasopressor support at the time the studies were performed). This will be stored in a journal that you will be provided. The journal is to be treated in a confidential manner and must be left in the locked residents' office when not in use. Journals will be collected at the end of the study period and the data will be inputted into a database. It is crucial that you make every effort possible to diligently and accurately collect the clinical characteristics of the patients you perform echocardiograms on as part of the study. Periodically throughout the study, you will receive email reminders about meeting the requirements for the study.

WHAT ARE THE POTENTIAL RISKS?
There are no potential risks to disclose. Your performance as part of the study will not be used to determine your progress in the echocardiography training curriculum or in your residency program and your results will not be shared with the residency program director or attending physicians responsible for completing your rotation evaluations.

WILL I BENEFIT IF I TAKE PART?
Knowledge gained from this study will help develop a new assessment tool to evaluate physicians' image acquisition skills in focused cardiac ultrasound and serve to better define the learning curve associated with developing expertise in cardiac ultrasound. This will help shape the evolution of performance standards for critical care cardiac ultrasound. Your contribution will have a direct impact in this evolution and may positively influence the future care of critically ill patients.

As part of the educational curriculum associated with this project, you will be provided with didactic teaching and hands-on training at the start of the curriculum as well as teaching and

formative feedback by the experienced attending physician echocardiographers after each cardiac ultrasound performed as part of the assessment intervals.

DO I HAVE TO PARTICIPATE?
Participation in this research study is voluntary. This study is not part of the required training program for critical care medicine. You are free to withdraw from the study at any time (by verbally indicating to the investigators you would like to withdraw) and your professional evaluation will not be affected in any way.

WILL I BE PAID FOR PARTICIPATING, OR DO I HAVE TO PAY FOR ANYTHING?
There are no costs or reimbursement associated with participating in this study.

CONFIDENTIALITY
Any research data collected about you during this study will not identify you by name, only by a coded study number. The list linking your name and demographic information to your study number will be stored on a password-protected computer in the locked Office of the Senior Associate Dean, Education, to which only Dr. Lockyer will have access. No personal identifiers will be presented in any publications or presentations resulting from this research and data collected will only be presented in aggregate form.

IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?
In the event that you suffer injury as a result of participating in this research, the University of Calgary, the Calgary Health Region or the Researchers will provide no compensation to you. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

Study Title: Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography

Investigators: Dr. Jocelyn Lockyer, Dr. Jonathan Gaudet, Dr. Jason Waechter, Dr. Kevin McLaughlin

Please complete the following:	Yes	No
Have you received and read the information sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss the study?	☐	☐
Do you understand that you are free to withdraw from the study at any time?	☐	☐
Has the issue of confidentiality been explained to you, and do you understand how the information collected in this study will be handled and safeguarded?	☐	☐

SIGNATURES

Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time. If you have further questions concerning matters related to this research, please contact:

Dr. Jonathan Gaudet (403) 991-4281 or jonathan.gaudet@albertahealthservices.ca. If you have any questions concerning your rights as a possible participant in this research, please contact The Chair, Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

Participant's Name	Signature and Date

Investigator/Delegate's Name	Signature and Date

Witness' Name	Signature and Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

A signed copy of this consent form has been given to you to keep for your records and reference.

APPENDIX D: Focused Cardiac Ultrasound Assessment Tool

Study ID #: _____

SCORING:

- **Inadequate (0 pts):** image of structures of interest are not obtained or images obtained are inadequate for assessment.
- **Adequate: (1 pt):** images obtained are adequate for assessment of structures of interest.
- **Optimal (2 pt):** images obtained are optimized for assessment of structures of interest.

SECTION 1: REQUIRED VIEWS

A. Parasternal Long Axis View

Structure(s) To Be Imaged/Image Acquisition	Score
A1. Aortic Valve, LV outflow tract, aortic root?	
A2. Left atrium, mitral valve and leaflets?	
A3. RV and interventricular septum?	
A4. LV endocardial borders and papillary muscles?	
A5. Posterior LV wall and pericardium?	
A6. Structures centered in view? (Yes= 1pt; No= 0 pts)	
A7. Appropriate depth? (Yes= 0.5pt; No= 0 pts)	
A8. Appropriate gain? (Yes= 0.5 pt; No= 0 pts)	
A9. Section Total (/ 12 pts)	

B. Parasternal Short Axis Views

Level	Structure (s) To Be Imaged/Image Acquisition	Score
Aortic Valve	B1. Aortic valve and leaflets?	
	B2. Structures centered in view? (Yes= 1pt; No= 0 pts)	
	B3. Appropriate depth? (Yes= 0.5 pt; No= 0 pts)	
	B4. Appropriate gain? (Yes= 0.5 pt; No= 0 pts)	
Mitral Valve	B5. Mitral valve, leaflets and LV cavity?	
	B6. Interventricular septum?	
	B7. Axis (On axis= 1 pt; Off axis= 0 pts)	
	B8. Structures centered in view? (Yes= 1pt; No= 0 pts)	
	B9. Appropriate depth? (Yes= 0.5 pt; No= 0 pts)	
	B10. Appropriate gain? (Yes= 0.5 pt; No= 0 pts)	

B. Parasternal Short Axis Views (Continued)

Level	Structure (s) To Be Imaged/Image Acquisition	Score
Mid Papillary	B11. Papillary muscles	
	B12. Axis (On axis= 1 pt; Off axis = 0 pts)	
	B13. Structures centered in view? (Yes= 1pt; No= 0 pts)	
	B14. Appropriate depth? (Yes= 0.5 pt; No= 0 pts)	
	B15. Appropriate gain? (Yes= 0.5 pt; No= 0 pts)	
LV Apex	B16. Ventricular apex? (Yes= 1pt; No= 0 pts)	
	B17. Appropriate depth and gain? (Yes= ½ pt for depth and ½ pt for gain; No = 0 pts)	
	B18. Section Total (/ 18 pts)	

C. Apical Four Chamber View

Structure(s) To Be Imaged/Image Acquisition	Score
C1. Both ventricles in view?	
C2. Both atria in view?	
C3. Both MV and TV in view?	
C4. Both MV and TV optimized?	
C5. Structures centered in view? (Yes= 1 pt; No= 0 pts)	
C6. Appropriate depth? (Yes= 0.5 pt; No= 0 pts)	
C7. Appropriate gain? (Yes= 0.5 pt; No= 0 pts)	
C8. Section Total (/ 10 pts)	

D. Subcostal Long Axis View

Structure(s) To Be Imaged/Image Acquisition	Score
D1. Left ventricle with mitral valve?	
D2. Right ventricle with tricuspid valve?	
D3. Contours of the pericardium?	
D4. Structures centered in view? (Yes= 1pt; No= 0 pts)	
D5. Appropriate depth? (Yes= 0.5 pt; No= 0 pts)	
D6. Appropriate gain? (Yes= 0.5 pt; No= 0 pts)	
D7. Section Total (/ 8 pts)	

E. Subcostal IVC View

Structure(s) To Be Imaged/Image Acquisition	Score
E1. IVC and right atrial junction?	
E2. IVC true long axis?	
E3. M mode performed? (Yes = 1 pt; No = 0 pts)	
E4. IVC diameter measured? (Yes= 1pt; No= 0 pts)	
E5. IVC respiratory variation measured? (Yes= 1pt; No= 0 pts)	
E6. Appropriate depth and gain? (Yes= ½ pt for depth and ½ pt for gain; No = 0 pts)	
E7. Section Total (/ 8 pts)	

SECTION 2: OVERALL IMAGE DIAGNOSTIC QUALITY

- **Non-diagnostic (0 pts):** images of interest are inadequate to permit diagnostic assessment.
- **Borderline (1 pt):** images of interest are of borderline adequacy to permit diagnostic assessment.
- **Diagnostic (2 pts):** images of interest are adequate to permit diagnostic assessment.

Were the images of diagnostic quality for the following clinical questions? (Yes= 2 pts; Borderline = 1 pt; No= 0 pts)	Score
DQ1. LV systolic function	
DQ2. LV size	
DQ3. RV systolic function	
DQ4. RV size	
DQ5. Volume status (as reflected by IVC measurement)	
DQ6. Presence of significant pericardial effusion	
DQ7. Section Total (/ 12 pts)	

SECTION 3: FCU IMAGE ACQUISITION TOOL TOTAL SCORE

Section 1	
A9. Parasternal Long Axis (/12 pts)	
B18. Parasternal Short Axis (/18 pts)	
C8. Apical Four Chamber (/10 pts)	
D7. Subcostal Long Axis (/8 pts)	
E7. Subcostal IVC (/8 pts)	
Section 2	
DQ7. Overall Diagnostic Quality (/12 pts)	
Grand Total (Section 1 + Section 2)	
(/68 pts)	

SECTION 4: FCU IMAGE ACQUISITION EFFICIENCY SCORE

Time To Complete Echocardiogram (minutes: seconds): _____

Efficiency Score (Grand Total Pts/Time): _____

APENDIX E: Focused Cardiac Ultrasound Tracking Journal

Name: _____

Focused Echocardiogram #	ICU Site (RGH/PLC/FMC/ CVICU)	Study Date (mm-dd-yy)	Preceptor Name and Signature
3			
4			
5			
6			
7			
8			
9			
12			
13			
14			
15			
16			
17			
18			

APENDIX F: Patient Information Sheet and Informed Consent Form

Study Title: Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography

Principal Investigator: Dr. Jocelyn Lockyer   **Phone:** (403) 220-4248

Co-Investigators: Dr. Jonathan Gaudet, Dr. Jason Waechter, Dr. Kevin McLaughlin

INTRODUCTION
You are being asked to voluntarily take part in a research study. Before you agree to participate, please read the following information carefully. This information sheet and consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. You will receive a copy of this form.

BACKGROUND
Focused cardiac ultrasound is becoming an important diagnostic tool for physicians caring for patients with shock in the intensive care unit. This study is part of a larger project to teach focused cardiac ultrasound to critical care medicine resident physicians in the Department of Critical Care Medicine at the University of Calgary. Part of the curriculum involves resident physicians performing cardiac ultrasounds on real patients in order to help build their skills and expertise. As part of this project, we have developed a new assessment tool to evaluate their performance in acquiring focused cardiac ultrasound images.

WHAT IS THE PURPOSE OF THE STUDY?
The purpose of this study is to examine the performance of critical care trainees learning cardiac ultrasound and to examine the performance of the assessment tool.

WHAT WOULD I HAVE TO DO?
If you agree to participate in this study, after having reviewed and signed the consent form, you will have two separate cardiac ultrasounds performed on you at the bedside. This will involve the resident physician independently performing a cardiac ultrasound, followed immediately after by an experienced attending physician performing a second cardiac ultrasound to serve as a gold standard comparator. This will require approximately one hour of your time and you can rest comfortably in the bed while the studies are being performed. No follow up is required as part of the study.

WHAT ARE THE POTENTIAL RISKS?
Cardiac ultrasound is safe and non-invasive and poses virtually no risk to your wellbeing. You may feel some slight pressure or discomfort from the ultrasound probe on your skin (a small amount of pressure is required to press the ultrasound probe against the skin or between the ribs in order to obtain cardiac ultrasound images). You can request a break if you're feeling too much discomfort.

In the event that emergent treatment interventions for your care are required while the cardiac ultrasounds are being performed, the study will be stopped and the health care team caring for you will intervene as needed.

WILL I BENEFIT IF I TAKE PART?
The information gained by performing your cardiac ultrasound may have clinical utility to positively influence your care. If abnormalities are seen during the course of your cardiac ultrasound as part of this study, the experienced echocardiographer will share this with your responsible medical team and recommend a formal quantitative echocardiogram be obtained. Knowledge gained from this study will also help develop a new assessment tool to evaluate physicians' skills in cardiac ultrasound and serve to better define the learning curve associated with developing expertise in acquiring cardiac ultrasound images. This will help shape the evolution of performance standards for critical care cardiac ultrasound. Your contribution will have a direct impact in this evolution and may positively influence the future care of critically ill patients.

DO I HAVE TO PARTICIPATE?
Participation in this research study is voluntary. You are free to withdraw from the study at any time (by verbally indicating to the research team you are no longer willing to participate) and your continuing medical care will not be affected in any way. If the study is not undertaken, the quality of your medical care will also not be affected.

WILL I BE PAID FOR PARTICIPATING, OR DO I HAVE TO PAY FOR ANYTHING?
There are no costs or reimbursement associated with participating in this study.

WILL MY RECORDS BE KEPT PRIVATE?
Any research data or health information collected about you during this study will not identify you by name, only by a coded study number. Your cardiac ultrasounds will be archived with this study number as well. Your personal health records will remain confidential and all study data will be stored and handled in a confidential manner in accordance with Alberta Health Services (AHS) policy. No personal identifiers will be presented in any publications or presentations resulting from this research and data collected will only be presented in aggregate form.

IF I SUFFER A RESEARCH-RELATED INJURY, WILL I BE COMPENSATED?
In the event that you suffer injury as a result of participating in this research, no compensation will be provided to you by the University of Calgary, the Calgary Health Region or the Researchers. You still have all your legal rights. Nothing said in this consent form alters your right to seek damages.

Study Title: Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography

Investigators: Dr. Jocelyn Lockyer, Dr. Jonathan Gaudet, Dr. Jason Waechter, Dr. Kevin McLaughlin

Please complete the following:	**Yes**	**No**
Do you understand that you have been asked to participate in a research study?	☐	☐
Have you received and read the information sheet?	☐	☐
Do you understand the benefits and risks involved in taking part in this research study?	☐	☐
Have you had an opportunity to ask questions and discuss the study?	☐	☐
Do you understand that you are free to withdraw from the study, without having to give a reason and without affecting your future medical care?	☐	☐
Has the issue of confidentiality been explained to you, and do you understand who will have access to your medical records and how the information will be handled and safeguarded.	☐	☐

SIGNATURES
Your signature on this form indicates that you have understood to your satisfaction the information regarding your participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time without jeopardizing your health care. If you have further questions concerning matters related to this research, please contact: Dr. Jonathan Gaudet (403) 991-4281 or jonathan.gaudet@albertahealthservices.ca.

If you have any questions concerning your rights as a possible participant in this research, please contact The Chair, Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

Participant's Name

Signature and Date

Investigator/Delegate's Name

Signature and Date

Witness' Name

Signature and Date

The University of Calgary Conjoint Health Research Ethics Board has approved this research study.

A signed copy of this consent form has been given to you to keep for your records and reference.

APPENDIX G: Surrogate Information Sheet and Informed Consent Form

Study Title: Development and Implementation of an Assessment Tool for Critical Care Trainees in Focused Transthoracic Echocardiography

Principal Investigator: Dr. Jocelyn Lockyer **Phone:** (403) 220-4248

Co-Investigators: Dr. Jonathan Gaudet, Dr. Jason Waechter, Dr. Kevin McLaughlin

INTRODUCTION
You are being asked to provide surrogate consent for your family member to take part in a research study. You are being asked this because your family member (hereafter referred to as the "subject," or the "participant") is either unable or incapable to provide their own consent due to their illness. Before you agree to provide consent on their behalf, please read the following information carefully. This information sheet and consent form is only part of the process of informed consent. It should give you the basic idea of what the research is about and what participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Take the time to read this carefully and to understand any accompanying information. You will receive a copy of this form.

BACKGROUND
Focused cardiac ultrasound is becoming an important diagnostic tool for physicians caring for patients with shock in the intensive care unit. This study is part of a larger project to teach focused cardiac ultrasound to critical care medicine resident physicians in the Department of Critical Care Medicine at the University of Calgary. Part of the curriculum involves resident physicians performing cardiac ultrasounds on real patients in order to help build their skills and expertise. As part of this project, we have developed a new assessment tool to evaluate their performance in acquiring focused cardiac ultrasound images.

WHAT IS THE PURPOSE OF THE STUDY?
The purpose of this study is to examine the performance of critical care trainees learning cardiac ultrasound and to examine the performance of the assessment tool.

WHAT WOULD THE SUBJECT HAVE TO DO?
If you agree for the subject to participate in this study, after having reviewed and signed the consent form, they will have two separate cardiac ultrasounds performed on them at the bedside. This will involve the resident physician independently performing a cardiac ultrasound, followed immediately after by an experienced attending physician performing a second cardiac ultrasound to serve as a gold standard comparator. This will require approximately one hour of the subject's time and they can rest comfortably in the bed while the studies are being performed. No follow-up is required as part of the study.

WHAT ARE THE POTENTIAL RISKS?
Cardiac ultrasound is safe and non-invasive and poses virtually no risk to the participant's wellbeing. They may feel some slight pressure or mild discomfort from the ultrasound probe on their skin (a small amount of pressure is required to press the ultrasound probe against the skin or between the ribs in order to obtain cardiac ultrasound images). Every effort will be made to minimize any discomfort they may experience associated with the procedure. You are welcome to stay and observe the procedure and indicate to the team you wish for them to stop the study if you feel the participant is experiencing any discomfort.

In the event that emergent treatment interventions for the participant's care are required while the cardiac ultrasounds are being performed, the ultrasound will be stopped and the health care team caring for the participant will intervene as needed.

WILL THE SUBJECT BENEFIT IF THEY TAKE PART?
The information gained by performing a cardiac ultrasound on the participant may have clinical utility to positively influence their care. If abnormalities are seen during the course of the subject's cardiac ultrasound as part of this study, the experienced echocardiographer will share this with the subject's responsible medical team and recommend that a formal echocardiogram be obtained.

Knowledge gained from this study will also help develop a new assessment tool to evaluate physicians' skills in cardiac ultrasound and serve to better define the learning curve associated with developing expertise in acquiring cardiac ultrasound images. This will help shape the evolution of performance standards for critical care cardiac ultrasound. The participant's contribution will have a direct impact in this evolution and may positively influence the future care of critically ill patients.

DOES THE SUBJECT HAVE TO PARTICIPATE?
Participation in this research study is voluntary. You are free to withdraw the research participant from the study at any time (by verbally indicating to the research team you are no longer willing for them to participate) and their continuing medical care will not be affected in any way. If the study is not undertaken, the quality of the participant's medical care will also not be affected. If new information becomes available that might affect your willingness to have the subject participate in the study, you will be informed as soon as possible.

WILL WE BE PAID FOR PARTICIPATING, OR DO WE HAVE TO PAY FOR ANYTHING?
There are no costs or reimbursement associated with participation in this study.

WILL THE RECORDS BE KEPT PRIVATE?
Any research data or health information collected about the research participant during this study will not identify them by name, only by a coded study number. The participant's cardiac ultrasound will be archived using this unique study number. All study data will be stored and handled in a confidential manner in accordance with Alberta Health Services (AHS) policy. No

personal identifiers will be presented in any publications or presentations resulting from this research and data collected will only be presented in aggregate form.

IF THE SUBJECT SUFFERS A RESEARCH-RELATED INJURY, WILL WE BE COMPENSATED?
In the event that the research participant suffers injury as a result of participating in this research, the University of Calgary, the Calgary Health Region or the Researchers will provide no compensation. The research participant still has all their legal rights. Nothing said in this consent form alters their right to seek damages.

SIGNATURES
Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to allow the person you represent to participate. In no way does this waive the subject's legal rights nor release the investigators, or involved institutions from their legal and professional responsibilities. You are free to withdraw the subject from the study at any time without jeopardizing their health care. If you have further questions concerning matters related to this research, please contact: Dr. Jonathan Gaudet, at (403) 991-4281 or jonathan.gaudet@albertahealthservices.ca.
If you have any questions concerning your rights as a possible participant in this research, please contact The Chair, Conjoint Health Research Ethics Board, University of Calgary, at 403-220-7990.

_____   _____
Surrogate's Name   Signature and Date

_____   _____
Investigator/Delegate's Name   Signature and Date

_____   _____
Witness' Name   Signature and Date

APPENDIX H: Modified NASA-TLX Workload Assessment Tool for Focused Cardiac

Ultrasound in ICU (Adapted from original NASA-TLX Workload Assessment Tool)[90-91]

Study ID #: _____

Focused cardiac ultrasound is challenging. After completing your focused cardiac ultrasound, please circle one number in response to each of the following questions:

1. Mental Demand:
How much mental and perceptual activity was required to perform the echocardiogram (e.g., thinking, decision-making, looking, remembering, reasoning, etc.)?

0   1   2   3   4   5   6   7   8   9   10
Low   High

2. Physical Demand:
How much physical activity was required to perform the echocardiogram (e.g., turning, moving, positioning the patient or ultrasound probe, adjusting dials on the cardiac ultrasound platform, etc.)?

0   1   2   3   4   5   6   7   8   9   10
Low   High

3. Time Demand:
How much time pressure did you feel due to the rate or pace of the echocardiogram?

0   1   2   3   4   5   6   7   8   9   10
Low   High

4. Effort:
How hard did you have to work mentally and physically to perform and learn during this echocardiogram?

0   1   2   3   4   5   6   7   8   9   10
Low   High

5. Performance:
After completing this echocardiogram, how successful do you think you were in acquiring high quality focused cardiac ultrasound images?

0   1   2   3   4   5   6   7   8   9   10
Not very successful   Very successful

6. Frustration/anxiety:

How discouraged, frustrated, stressed and anxious (versus gratified, content, relaxed and secure) did you feel during the echocardiogram?

0   1   2   3   4   5   6   7   8   9   10
Low   High

APPENDIX I: Global Rating Scale of Proficiency in Focused Cardiac Ultrasound Image

Acquisition

Study ID #: _____

- **After having observed the resident complete their echocardiogram, please rate the trainee's overall ability to independently acquire focused cardiac ultrasound images (check one box):**

1	2	3	4	5
Not yet competent to acquire images ☐	Borderline competence to acquire images ☐	Competent to acquire images ☐	Above average competence to acquire images ☐	Functions at the level of a consultant ICU echocardiographer ☐

Evaluator Name: _____

Signature: _____

APPENDIX J: Resident Participant Assessment Interval Echocardiography Journal

Assessment Interval # _____, Patient # _____, Echocardiogram # _____.

Study ID # used	
Study ID # used by staff physician echocardiographer on the same patient	
Time required for you to complete your study (min:secs)	
Time required for staff person to complete their study (min:secs)	

PATIENT CHARACTERISTICS

Age (yrs)	
Gender (M/F)	
Height (cm)	
Weight (kg)	
Reason for ICU	
Post CV Surgery (y/n)?	
APACHE II score	
Pre-existing Lung Disease (y/n)?	
Pre-existing Heart Disease (y/n)?	
Vasopressor Use (y/n)?	
HR (beats/min)	
BP (mm Hg)	
RR (breaths/min)	
PEEP (cm H_2O)	