REVIEW

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The Evolution of Cardiovascular Ultrasound: A Review of Cardiac Point-of-Care Ultrasound (POCUS) Across Specialties

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ABSTRACT

The use of cardiac point-of-care ultrasound (POCUS) is now widespread in clinics, emergency departments, and all areas of the hospital. Users include medical trainees, advanced practice practitioners, and attending physicians in many specialties and sub-specialties. Opportunities to learn cardiac POCUS and requirements for training vary across specialties, as does the scope of the cardiac POCUS examination. In this review, we describe both a brief history of how cardiac POCUS emerged from echocardiography and the state of the art across a variety of medical fields.

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INTRODUCTION

In 1963, a cardiologist borrowed a neurologist's ultrasound probe and placed it on the chest of a patient to determine if he could detect a pericardial effusion.[1] At this fundamental level, the application of a probe at the *point-of-care* was simply *cardiovascular ultrasound*. The term "echocardiography" developed to encompass various aspects of a burgeoning field including training, protocolization, quality control, and technologic development.[1] As cardiovascular ultrasound became invaluable to the diagnostic process, the North American response to high-volume demand was separation of skills in acquisition and interpretation to create an efficient delivery service: the echocardiography laboratory. To maintain quality, guidelines and standards developed further. These, along with the cost of an ever-sophisticated machine, created barriers to entering the practice of echocardiography. Thus, application of cardiovascular ultrasound ended up in the domain of specialists following a practice competency pathway. However, the practice of cardiovascular ultrasound continues to evolve, and perhaps it may now be seen as a "devolution" from the structured echocardiography lab, back to its origins, and into the hands of nonconventional users. This

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review summarizes the current state of cardiac point-of-care ultrasound (POCUS) incorporated by various specialties.

Choosing the Term "Cardiac POCUS"

In the early 2000s, there was some obfuscation of whether bedside ultrasound scans should be considered echocardiograms. There was an outpouring of terms, including bedside ultrasound, mini-echo, portable echo, handheld ultrasound, pocket echo, and focused ultrasound. In an early report by members of the American Society of Echocardiography, the term POCUS was suggested to distinguish bedside scans from echocardiography to preserve the standards, training, and reporting structure innovated by the formal services of echocardiography labs.[2,3] In this classification, both echocardiogram and cardiac POCUS may be viewed as a subset of the general term *cardiovascular ultrasound.* The term *cardiac POCUS* gained further global acceptance during the COVID-19 pandemic to best describe provider-led, bedside scanning, reducing exposure to contagion for other personnel and facilities, and is now the principal terminology utilized for this connotation.[4]

CLINICAL SIGNIFICANCE

- Cardiac POCUS is in widespread use by many different specialists.
- Cardiac POCUS is used in a range of settings from home-based care, to clinics, to all areas of the hospital.
- Cardiac POCUS training and core applications vary among specialties.

Recognition that POCUS users are not performing a complete echocardiogram reduces barriers to entry to cardiovascular ultrasound, freeing POCUS users to come from differing training backgrounds. Distinguishing "cardiac POCUS" from echocardiography also frees it from the advanced tools recommended to comprise a formal echocardiogram including 3D, contrast, and strain analysis. This term is also consistent with, and useful for, descriptions of other noncardiac types of POCUS, such as chest POCUS or renal POCUS.

The Definition of Cardiac POCUS: Limitations and Freedoms

Cardiac POCUS is the application of cardiovascular ultrasound, to assess the heart and its vessels by the medical provider at the bedside, to answer an immediate question. Cardiac POCUS is limited in scope, defined by the skill set of the operator, and the indication particular to their specialty area. Thus, there are multiple secondary definitions of cardiac POCUS, varying by specialty. However, a common feature of cardiac POCUS across specialties is its distinction from an echocardiogram. Whereas an echocardiogram is a formal, requisition-based referral service that always 1) is acquired by a credentialed sonographer following a defined protocol, 2) is interpreted by a trained physician, 3) provides a structured report, 4) is archived, and 5) is usually conducted through a formal testing facility, cardiac POCUS does not require *any* of these 5 components. POCUS has an inherent freedom from the requirements of a formal echocardiogram, although it remains limited in scope. The degree of freedom varies by resource setting, institutional requirements, and policy, and as scope evolves among specialties.

CARDIAC POCUS ACROSS SPECIALTIES OF CLINICAL PRACTICE

Emergency Medicine

Emergency medicine physicians were among the first specialists to perform limited bedside cardiac ultrasound with the primary goals of identifying life-threatening conditions such as cardiac tamponade or significant reduction in left ventricular function. Cardiac POCUS grew out of a larger effort to facilitate rapid bedside diagnoses of many emergency conditions using ultrasound, such as aortic aneurysm, abdominal bleeding in the setting of trauma, and ectopic pregnancy. Ultrasound education is now widespread in North American emergency medicine training programs, and the scope of bedside cardiac assessment includes visual assessment of ejection fraction and pericardial effusion, but may also extend to basic quantitative left ventricular function, right ventricular strain, and simple measures of diastolic dysfunction. Cardiac POCUS in the emergency setting continues to focus on assessments that reduce the differential diagnosis for a particular patient encounter, guide further care, and facilitate the diagnosis of emergent conditions.

Instruction in cardiac POCUS for emergency medicine trainees has been endorsed by the Royal College of Physicians and Surgeons of Canada and the American Board of Emergency Medicine.[5,6] The Canadian Academy of Emergency Physicians, the American College of Emergency Physicians, and the American Academy of Emergency Medicine all recognize cardiac POCUS as a core competency for emergency medicine.[7-9] Ultrasound training for residents is integrated into the specialty training curriculum, while physicians in practice typically complete a minimum of 16 hours of didactic instruction (including hands-on experience) followed by 150 supervised scans across a variety of core study types.[8,10] In the last 20 years a sub-specialist class of emergency medicine physicians has developed, who—either by virtue of prior practice or additional fellowship training—have achieved additional competencies that include spectral Doppler modalities, regional wall motion assessment, and (in some cases) transesophageal qualifications. There is no recognized certification in ultrasound for emergency physicians beyond completion of residency training or documentation of completion of a practice-based training pathway. US ultrasound fellowship graduates may pursue a Focused Practice Designation in Advanced Emergency Ultrasound from the American Board of Emergency

Table Cardiac POCUS Across Medical Specialties

Specialty	Recommending Agencies	Available Training	Core Cardiac Applications of POCUS
Anesthesiology	ASRA,[21] CAS,[19] SOCCA[22]	Not mandated in most residency programs.[23] External training opportunities available.	Hemodynamic evaluation, volume status, myocardial ischemia, ventricular size and function, valvular abnormalities, hypertrophic cardiomyopathy, evaluation of pericardium (effusion, tamponade, guidance in pericardiocentesis), detection of pacing capture, cardiac arrest [18,19]
Cardiology	ASE[24,25]	Training mandated in majority of internal medicine/cardiology residency programs. Additional fellowship training in formal echocardiography is common.	Ventricular size and function, elevated left heart filling pressures, valvular abnormalities, left ventricular hypertrophy, hypertrophic cardiomyopathy, aortic aneurysm, pericardial effusion, cardiac arrest
Critical care	ACCP,[26] CCCS,[20] SCCM,[16] WINFOCUS[27]	Not mandated in all fellowship programs.[28] External training opportunities available.	Shock, ventricular size and function, wall motion abnormalities, valvular abnormalities, TEE in cardiac arrest, management of mechanical/extracorporeal support
Emergency medicine	ACEP,[29] CAEP[30]	Training mandated in majority of residency and fellowships.[31] External training opportunities available.	Ventricular size and function, identifying pericardial effusion, volume status, guiding pericardiocentesis, confirmation of transvenous pacing wire placement, aortic aneurysm
Family medicine	AAFP[32]	Not mandated in most residency programs. AAFP has published recommended curriculum guidelines.	Ventricular size and function, pericardial effusion, valvular function, volume status
Internal medicine	AAIM,[13] CIMUS,[33] EFIM,[34] SHM[14]	Training mandated in majority of residency programs. External training opportunities available.	Ventricular size and function, pericardial effusion, atrial size, valvular function, volume status, aortic aneurysm
Nephrology	No published POCUS guidelines/ recommendations	Fellowship curriculums have been proposed.[12]	Ventricular size and function, pericardial effusion, volume status, cardiac output
Obstetrics-Gynecology	SOGC[35]	Not mandated in residency or fellowship programs.[36]	Bedside assessment for fetal cardiac activity, Doppler assessment of fetal circulation
Pediatrics/Neonatology	ESPNIC,[17] AAP[37]	Not mandated in most residency programs.[15] Mandated in pediatric emergency medicine fellowships.[37]	Tamponade and pericardial effusion, ventricular size and function, assessment of umbilical venous catheters and central lines, assessment cardiac filling and volume status

AAFP = American Association of Family Physicians; AAIM = Alliance for Academic Internal Medicine; AAP = American Academy of Pediatrics; ACCP = American College of Chest Physicians; ACEP = American College of Emergency Physicians; ASE = American Society of Echocardiography; ASRA = American Society of Regional Anesthesia; CAEP = Canadian Association of Emergency Physicians; CAS = Canadian Anesthesiologists' Society; CCCS = Canadian Critical Care Society; CIMUS = Canadian Internal Medicine Ultrasound group; eFAST = extended focused assessment with sonography for trauma; EFIM = European Federation of Internal Medicine; ESPNIC = European Society of Paediatric and Neonatal Intensive Care; FAST = focused assessment with sonography for trauma; POCUS = point-of-care ultrasound; SCCM = Society of Critical Care Medicine; SHM = Society of Hospital Medicine; SOCCA = Society of Critical Care Anesthesiologists; SOGC = Society of Obstetrician and Gynaecologists of Canada; SOHM = Society of Hospital Medicine; TEE = transesophageal echocardiogram; WINFOCUS = World Interactive Network Focused on Critical Ultrasound.

Medicine by completing a written examination.[11] Canadian physicians can optionally complete certifications through the Canadian POCUS Society. To conduct cardiac POCUS examinations, a minimal degree of training has been defined, although there is no recognized certification beyond residency that is required to practice (Table[12-37]).

Family Medicine

Cardiac POCUS is used in all settings where family medicine clinicians practice, both outpatient and inpatient settings: urgent care, home-based care, and hospital wards. For most family medicine physicians, POCUS has been adopted as an extension of the cardiovascular physical examination and clinical assessment.[38] The American Academy of Family Physicians published the Recommended Curriculum Guidelines for family medicine residents in 2018,[39] and cardiac POCUS was recommended as one of the basic core applications of POCUS. Basic skills in cardiac POCUS are used for detection of pericardial effusion, assessment of global left ventricular contractility, assessment of right ventricular size, and measurement

of inferior vena cava as part of the volume status examination.[39]

Advanced Primary Care Ultrasound Fellowship programs provide training for basic skills as well as advanced skills like calculation of ejection fraction, regional wall motion abnormalities, diastolic dysfunction, left ventricular hypertrophy, and valvular abnormalities including mitral/aortic regurgitation and stenosis. The use of cardiac POCUS is widely recommended by the American Academy of Family Physicians, American College of Physicians, and Society of Hospital Medicine[40] (Table).

An important application of cardiac POCUS for family medicine physicians is in remote or resource-limited settings. Cardiac POCUS may be the only option for underserved settings where a high-end echocardiography machine may be cost-prohibitive and where POCUS availability may help reduce health care disparities.[41]

Internal Medicine

Cardiac POCUS use within internal medicine is now both prevalent and rapidly increasing. Subspecialists of internal medicine in critical care medicine were among the earliest adopters of cardiac POCUS, following the lead of their emergency medicine colleagues for urgent evaluation of acutely decompensating patients.[42,43] Yet over the last decade, POCUS has spread broadly throughout internal medicine, being used by hospitalists, primary care providers, and many subspecialists.[12,44,45]

POCUS, including cardiac applications, is now endorsed by some of the largest internal medicine professional organizations, including the Academic Alliance for Internal Medicine, the American College of Physicians, the Society of Hospital Medicine, and the Society of Critical Care Medicine.[13,14,42,43,46] Additionally, many of those societies who haven't issued a formal statement have shown support through building educational tools and courses.[47] Nearly all endorsements and available trainings include cardiac POCUS as a core component (Table).

Despite the increase in use and organizational support, at present there are no formal internal medicine residency training requirements set by the American Board of Internal Medicine. Yet the landscape of POCUS training is changing rapidly; with 25% of internal medicine residency programs reported formal training in POCUS in 2012, increasing to 61% in 2020.[15,48,49] Additionally, there are now several internal medicine POCUS fellowships available for advanced POCUS training after residency, although these remain uncertified by the Accreditation Council for Graduate Medical Education at this time.[16,50]

The scope of cardiac POCUS use in internal medicine depends on both the environment where it is practiced and the skill of the practitioner who uses it. Yet, generally recognized core examinations largely mirror those of emergency medicine, including qualitative assessment of left ventricular systolic function, identification of pericardial effusions, relative chamber size, and estimation of central venous pressure through measurement of the inferior vena cava. More advanced techniques such as right ventricular function, diastology, and valvular assessments are sometimes employed by those with further training, especially in more remote or higher-acuity clinical environments.

Pediatric and Neonatal Medicine

While there is overlap between POCUS applications in pediatric and adult patients, cardiac POCUS in children must consider the unique physiologic changes that occur during development, especially in the immediate postnatal period. During this period, systemic vascular resistance increases drastically as the placenta is taken out of the circuit, while pulmonary resistance falls as the infant takes their first breaths. At the same time, shunts that served important purposes in utero, such as the foramen ovale and the ductus arteriosus, must close.[51] This makes cardiac POCUS in the neonatal intensive care unit a dynamic challenge. Furthermore, standardized curricula and training pathways in cardiac POCUS do not exist for general pediatricians, pediatric hospitalists, or neonatal and pediatric intensive care providers. As a result, multiple international societies have collaborated to provide expert guidelines.[17,51] These societies agree that structural, congenital defects suspected on POCUS should be referred to pediatric cardiologists (Table).[17,51]

Assuming that the typical postnatal transition occurs without complication and congenital defects are not present, pediatric cardiac POCUS has many similarities with adult cardiac POCUS in its utility in cases of hemodynamic compromise. The same basic views are used to assess ventricular function, pericardial pathology, and central venous pressure. A qualitative "eyeball" assessment may be used to assess ventricular function. More advanced users may employ semi-quantitative measures such as fractional shortening, ejection fraction, stroke volume, mitral annular plane systolic excursion, and end-point septal separation, although it is important to note that several of these measures must be compared with age-appropriate Z-scores and that end-point septal separation is only validated in adults.[17] As in adults, the presence of pericardial effusion should be evaluated with multiple cardiac views and pericardiocentesis should be guided by ultrasound. Measurement of right atrial pressure using the inferior vena cava is slightly different in the pediatric population, as the short-axis view is the view most studied in the pediatric population because it allows side-by-side comparison with aortic dimensions.[52-55] The same caveats apply in both populations, and a meta-analysis showed that inferior vena cava collapsibility has only moderate ability to predict fluid responsiveness in children.[55] In addition, the inferior vena cava becomes an unreliable measure of right atrial pressure when an umbilical central venous catheter is present, as is the case in many infants in the neonatal intensive care unit.[17] There are no minimal training pathway requirements for the

application of cardiac POCUS by pediatricians, although advanced guidelines do exist (Table).

Anesthesiology

Anesthesiologists use POCUS, including cardiac POCUS, to complement the physical examination by obtaining information in real time to guide hemodynamic management and make more accurate differential diagnoses to rule out life-threatening conditions. The American Society of Anesthesia and the Society of Cardiovascular Anesthesiologists described ultrasound examinations' current and potential targets, as well as its use for estimation, evaluation, and potential procedural guidance for many applications, including cardiac (Table).[18]

Cardiac POCUS is not intended to be a comprehensive examination; in addition, most of the POCUS studies in the operating room are performed with small devices that do not have complete packages or capability for advanced analysis. On the other hand, using small devices adds the benefit of portability, more now that handheld devices are widely available and accessible.[56] Many anesthesiology training programs incorporate a POCUS rotation for their residents.[57,58] The Accreditation Council for Graduate Medical Education, American Board of Anesthesiology, and the Canadian Anesthesia Society encourage the integration of POCUS in the field of anesthesia as a core competency.[19,59-61]

Critical Care Medicine

Basic cardiac POCUS is part of the training curriculum for critical care medicine in Australia and Europe,[62,63] with India[64] and Canada[20] having guidelines in place. Australia, France, Europe, the United States, and the UK have advanced accreditations specifically in "critical care echocardiography."[62] Critical care echocardiography differs from cardiac POCUS in that users are trained in techniques such as spectral Doppler to make advanced hemodynamic determinations with advanced cardiac views. More recently, the National Board of Echocardiography, in collaboration with the American College of Chest Physicians, the American Thoracic Society, the Society of Critical Care Medicine, the National Board of Medical Examiners, and other partner societies, developed an Examination of Special Competence in Critical Care Echocardiography (known as CCEeXAM).[65]

Nephrology

Nephrologists practice in a diverse array of settings, including outpatient clinics, hospital wards, intensive care units, outpatient dialysis centers, and home dialysis centers. Accordingly, cardiac POCUS with assessment left ventricular ejection fraction, pericardial effusion, relative right ventricular size, and inferior vena cava size and collapsibility is helpful across multiple practice settings, such as evaluation for cardiorenal syndrome in a patient with new chronic kidney disease in an outpatient nephrology practice, evaluation of hemodialysis patient with intradialytic hypotension, and rapidly differentiating etiologies of shock in critical care nephrology.[66]

For patients with acute kidney injury or end-stage kidney disease on any dialysis modality, nephrologists are assessing volume status sometimes multiple times per day and assessing response to ultrafiltration. The physical examination is remarkably insensitive and unspecific for the detection of volume excess, so POCUS evaluation of volume status, including cardiac POCUS, adds critical and timely information.[67,68]

For these reasons, uptake of POCUS has been increasing in recent years, with 38% of nephrology training programs having implemented a POCUS curriculum and fully 95% of nephrology training programs planning on incorporating POCUS in future years.[69] The main barrier is lack of trained faculty.[69] To fill this demand, major nephrology and kidney care organizations have organized stand-alone POCUS programs for fellows and faculty.[70] Increasingly, early career nephrologists interested in POCUS in nephrology are undertaking 1-year clinical ultrasound fellowships to become thought leaders and site directors (Table).[71]

Remote and Rural Medicine

Ninety-seven percent of the geographic United States is considered nonurban or rural, which accounts for low-population-density regions containing approximately 19% of the population.[72] On average, the rural population is older, with a lower level of education and higher rates of being uninsured. Compared with those living in urban areas, rural residents have higher rates of mortality from heart disease, respiratory disease, cancer, stroke, and unintentional injury, and thus represent a high-risk population with significant illness burden.[73] Transport time, travel distance, transport cost, and risk of transfer increases in these communities. Available tertiary care centers with bed capacity may be limited for these hospitals and rural systems. Availability of echocardiograms and formal cardiology consultation options decrease the further the distance away from urban centers, and providers working in these areas require a broad skill set. In the United States, widespread implementation of cardiac POCUS programs in rural health face many challenges. Barriers include access to training, mentorship, and equipment. In Canada, the Accelerated Remote Consultation Tele-POCUS in Cardiopulmonary Assessment program links tertiary hubs with geographically remote "spoke" regions to provide tele-mentorship of Tele-POCUS skills for physicians that previously did not have access to such imaging training or implementation.[74]

Some of the most isolated, rural, or resource-poor providers would have the greatest benefit from an advanced skill set in advanced cardiac POCUS, given severe resource limitations. In rural areas, there often is a great sense of tension between the acceptance of limited diagnostic evidence and limited interventional options, weighed against the

systemic or patient-borne cost of obtaining timely advanced diagnostic evaluation and advanced management. Greater skill set in advanced cardiac POCUS can help to bridge these competing tensions.

CONCLUSION

Cardiac POCUS is a form of cardiovascular ultrasound that is performed at the bedside by the patient's medical provider, usually to answer an immediate question. Cardiac POCUS has evolved, in part, due to barriers to entry falling due to technologic advances such as miniaturization, and it is anticipated to continue additional advances such as artificial or augmented intelligence and Tele-POCUS. Currently, many medical specialists are performing cardiac POCUS, and its use continues to expand into diverse disciplines such as pediatrics, anesthesiology, and nephrology. Generalist physicians in both internal and family medicine use cardiac POCUS across the inpatient and outpatient settings. Several specialty areas have developed training or credentialing methods for their domains to support this use, yet these continue to remain undefined for a large proportion of current users. There appears to be a trend toward cardiac POCUS training beginning in medical training prior to specialization as an emerging general competency, which should assist in competency building for all, but this, too, currently lacks standards and guidelines.

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