Crit Ultrasound J (2011) 3:1–12
DOI 10.1007/s13089-011-0052-9

ORIGINAL ARTICLE

An integrated ultrasound curriculum (iUSC) for medical students: 4-year experience

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Received: 1 December 2010 / Accepted: 15 December 2010 / Published online: 1 February 2011

Abstract A review of the development and implementation of a 4-year medical student integrated ultrasound curriculum is presented. Multiple teaching and assessment modalities are discussed as well as results from testing and student surveys. Lessons learned while establishing the curriculum are summarized. It is concluded that ultrasound is a well received, valuable teaching tool across all 4 years of medical school, and students learn ultrasound well, and they feel their ultrasound experience enhances their medical education.

Keywords Ultrasound · Education · Medical students · Integrated curriculum

Introduction

In 2006, the University of South Carolina, School of Medicine introduced an integrated ultrasound curriculum (iUSC) across all 4 years of medical school [1]. The curriculum was based on a point-of-care "focused" ultrasound program that was developed for emergency medicine physicians and trainees [2]. Focused ultrasound examinations are designed to answer specific clinical questions, such as "Is this patient's right upper quadrant pain due to a gallstone?" This approach to patient care has been facilitated by rapid advances in ultrasound technology. These include the development of laptop-sized ultrasound systems capable of producing high-quality digital images that rival the larger, more expensive systems. The newer systems are also very user friendly making them more accessible to the non-traditional user of ultrasound such as primary care physicians. These advances in technology, combined with the clinical value of point-of-care ultrasound and the potential of ultrasound as a teaching tool for courses such as human anatomy and medical physiology, made the introduction of ultrasound into medical student education a logical and timely institutional decision.

Prior to the creation of the iUSC in 2006, ultrasound had been incorporated into medical student curricula to a limited degree [3–13]. Since 2006, a number of additional reports of ultrasound in undergraduate medical education have appeared [14–20]. However, to our knowledge, ultrasound had not been systematically implemented across all 4 years of education as both a teaching tool, and an important bedside clinical tool, to be learned by every student. Much has been learned in the first 4 years of the ultrasound curriculum. The purpose of this review is to share the integrated curriculum, the lessons learned, and to offer some thoughts on what the future may hold for ultrasound as a standard in medical education.

The curriculum

The integrated ultrasound curriculum (iUSC) for medical students that developed from 2006 to 2010 is presented in Table 1.

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Table 1 Integrated ultrasound curriculum (iUSC)

First year (M1)
Orientation week: before classes begin
1. 50-min hands-on introductory ultrasound session: scan the neck
Fall semester: in conjunction with anatomy
1. Introductory lecture and demonstration: history of ultrasound, basic physics, definitions/terms, screen orientation, technique, "knobology"
2. Introduction to cardiac ultrasound (laboratory session)
Left parasternal long axis view (PLAX): B-mode only; identification of heart chambers, valves, review screen orientation, knobology, depth, focus, frequency, gain
3. Neck ultrasound (laboratory session)
Carotid artery: B-mode and color flow mode—trace from common carotid to bifurcation, transverse and longitudinal views, principles of color flow
Internal jugular vein: B-mode and color flow mode; anatomic differences of internal jugular vein and carotid artery, shape, vessel wall, collapsibility, perform valsalva
Thyroid gland: B-mode; thyroid (both lobes and isthmus); texture, cysts, measurements, label structures
4. Pelvic ultrasound (laboratory session)
Urinary bladder: B-mode; identify bladder, measure volume, note artifacts like acoustic enhancement
Ureteric jets: color flow mode; test of obstruction
5. Right and left upper quadrants (laboratory session)
Liver, gall bladder, right/left kidney, Morison's pouch, diaphragm, and spleen: B-mode
6. Ultrasound OSCE: scan and identify right kidney/liver/Morison's pouch, left kidney/spleen, PLAX of the heart, carotid/internal jugular; student is also evaluated on their interaction with the standardized patient
Spring semester: in conjunction with physiology
1. Introduction to vascular ultrasound-vascular hemodynamics (laboratory)
Common carotid artery analysis
B-mode: transverse and longitudinal views
Color flow: direction of flow, high quality images
Spectral Doppler/pulse wave: principles of measuring velocity, arterial and venous pulse wave forms
2. Heart ultrasound: hemodynamics (laboratory)
Apical 4 and 5 chamber views (B-mode and color flow mode): wall motion, valve motion, cardiac cycle with color flow
3. Cardiogenic shock: cardiac views: PLAX, apical four-chamber, subcostal (laboratory session)
Cardiomypoathy: assess wall motion and shape of the left ventricle (LV) during cardiac cycle
Cardiac tamponade: assess for pericardial effusion, the right ventricle (RV) size and compression with cardiac cycle
Pulmonary embolism: assess for RV strain: size and compression with cardiac cycle; assess for RV/RA for thrombosis
Assessment: Questions are added to the physiology written examination to test understanding of physiology/ultrasound concepts in the context of a clinical case
Second year (M2)
Fall semester: in conjunction with Introduction to Clinical Medicine (*ICM*)
1. Ultrasound physics (review lecture): ultrasound wave formation, piezoelectric effect, tissue interfaces, common artifacts, ultrasound safety issues, ALARA (as low as reasonably achievable) principle, etc.
2. Cardiac ultrasound: standard cardiac views (laboratory session)
Parasternal long and short axis, apical 4 and 5 chamber, subcostal; chambers, valves, wall thickness and motion
3. General abdomen (laboratory session)
Liver, gall bladder, kidneys, spleen, urinary bladder, aorta, inferior vena cava (IVC); identify structures and measure organ size
4. Abdominal aorta assessment (laboratory session)
AAA screening; transverse and longitudinal, B-mode, color flow and pulse wave, three measurements, characteristics that differentiate aorta from IVC
5. Lower extremity venous ultrasound (laboratory session)
Rule out deep venous thrombosis (DVT) in femoral, saphenofemoral junction, and popliteal vein: compression test, color flow
6. Ultrasound OSCE: apical four-chamber view and identify all structures, multiple views of the abdominal aorta with measurements

Table 1 continued

Second year (M2)
Spring semester: in conjunction with ICM
1. Female pelvic ultrasound: transabdominal (laboratory session)
Uterus, ovaries, pouch of Douglas
2. Doppler (lecture): color Doppler, spectral Doppler, power Doppler
3. Vascular ultrasound (laboratory session)
Inferior vena cava assessment and volume status/central venous pressure estimation
4. Ultrasound-guided procedures (laboratory session with ultrasound phantoms)
Central venous access (internal jugular vein)
Pleural effusion detection and pleurocentesis
Ascitic fluid/free fluid in peritoneal cavity: detection and paracentesis
5. Assessment of patient with undifferentiated shock (laboratory session)
RUSH protocol: rapid ultrasound for shock/hypotension—assess LV function, rule out pericardial effusion/tamponade, assess for RV strain from pulmonary embolus (PE), volume status from IVC size and dynamics, scan abdomen and pelvis for free fluid, assess lungs for pneumothorax and pulmonary edema, assess aorta for rupture, assess femoral vein for DVT
Open ultrasound labs
During the first 2 years (M1 and M2) open laboratory sessions are held weekly during a time when no other classes are scheduled. Students are encouraged to come in pairs or small groups and practice their ultrasound skills on each other. At least one ultrasound faculty member is available to help with scanning and answer questions.
Pathology and problem-based learning
Ultrasound images are used in pathology lectures and in small group sessions in both pathology and problem-based learning to enhance clinical case presentations. These are opportunities to correlate clinical findings, pathological findings, and ultrasound images as they relate to clinical practice.
Third year (M3)
Hands-on training and objective structured clinical examinations (OSCE) at the end of each clerkship
1. Internal medicine
Thyroid ultrasound: patient with a history of thyroid symptoms, after the focused history and physical exam, each student must properly scan the thyroid, identify, and measure a cyst
Septic patient who needs central-line placement for intravenous access
2. Family and preventive medicine
Abdominal aortic aneurysm (AAA) screen—elderly patient with risk factors for AAA, student must discuss the procedure with the patient, perform the ultrasound examination, discuss results, and educate the patient about AAA
3. OB/GYN
OB ultrasound exam: patient is 27 weeks pregnant with a history of vaginal bleeding, student must perform an obstetrical ultrasound and determine fetal number, heart rate, placental location, and fetal position
4. Pediatrics
Assess volume status/dehydration: 9-year old with history of nausea/vomiting and poor oral intake, student must assess volume status using the aorta/inferior vena cava ratio
5. Surgery
Assess a trauma patient using the FAST exam (focused abdominal sonography for trauma): each student must scan a patient for trauma and assess for fluid in the chest (pleural, pericardial), abdomen, and pelvis
6. Critical care medicine
Two-week rotation in the critical care unit: three formal teaching sessions plus daily opportunities to scan for pathology. Pathology and scanning (heart, lung, abdomen) to assess volume status with static and dynamic scans of IVC, heart function, pericardial effusion, evidence of pulmonary embolus (parasternal long and short axis, apical four-chamber view, subcostal view), pneumothorax and pulmonary edema (lung sliding, multiple B lines)
Fourth year (M4)
Four-week emergency medicine ultrasound elective: students spend most of their time scanning patients in the emergency room. Attending physicians ultrasound fellows work with students and review images
"Hands-on" ultrasound sessions have been added to the traditional fourth-year radiology elective

Table 1 continued

Fourth year (M4)
Ultrasound independent study: students can spend 4 weeks with the ultrasound faculty developing their knowledge and skill in ultrasound, assist with M1 and M2 ultrasound labs, perform literature searches, and participate in original research
Two-day Capstone ultrasound course offered at the end of the 4th year: this course stresses ultrasound skills most important for students as they prepare for internship (ultrasound-guided procedures, FAST exam, RUSH exam)
Web-based learning modules
Throughout all 4 years students have access to a series of ultrasound learning modules (topics include: history of ultrasound, physics, instrumentation, liver, cardiac, AAA, etc.)

During the first (M1) and second (M2) years of medical school, multiple teaching modalities and testing are used in the ultrasound curriculum. These modalities include classroom lectures/demonstrations, a series of web-based learning modules, required laboratory sessions, voluntary open laboratory sessions, written and web-based ultrasound questions, and objective structured clinical examinations (OSCE) using standardized patients (paid models taught to simulate patients and evaluate students).

Curricular content

M1 year

In the first semester of the first year, ultrasound is incorporated into the gross anatomy course. Ultrasound laboratory sessions and web-based learning modules are coordinated with the anatomical regions being taught in the classroom and the dissection laboratory. Students learn to scan and identify a number of structures in the neck, the abdomen, the pelvis, and the chest.

In the second semester of the M1 year, ultrasound is part of the medical physiology course. The emphasis during this segment of the curriculum is on cardiovascular hemodynamics. Both the concepts and the applications of color flow and spectral Doppler are introduced. Students are taught to measure the velocity of blood flow, to distinguish between arterial and venous wave forms, and to differentiate laminar flow from turbulent flow. Students learn to perform apical four- and five-chamber cardiac views using B-mode and color flow. Heart wall motion, valve motion, and blood flow throughout the cardiac cycle are evaluated using a four-chamber cardiac view. The final physiology ultrasound laboratory of the course is considered an "integrative" exercise in which the students use much of what they have learned in the course to assess a patient in cardiogenic shock. Each student is required to obtain multiple cardiac views (parasternal long axis, apical four-chamber, subcostal), to rule out pericardial effusion with cardiac tamponade, to note heart size and global contractibility, and to evaluate for right ventricular strain as evidence of pulmonary embolism.

M2 year

Throughout the second year of medical school, ultrasound is incorporated into the year-long Introduction to Clinical Medicine course which includes physical diagnosis, problem-based learning, and pathophysiology. Ultrasound material has also been introduced in the two-semester Pathology Course. In the M2 year, there are two review lectures/demonstrations, eight laboratory sessions, and an OSCE. Web-based learning modules continue to be an important component of the curriculum. Ultrasound knowledge and skills are taught to complement course material in physical diagnosis and pathophysiology, and common clinical scenarios are presented in preparation for the M3 clinical clerkships. For example, a web-based learning module and an ultrasound laboratory session have been developed that cover the prevalence, risk factors, and scanning protocol for screening elderly patients for abdominal aortic aneurysms (AAAs). In addition, students learn how to measure liver, kidney, and spleen size. Other important skills learned during the M2 year include screening for deep venous thrombosis (DVT); assessment of intravascular volume status by scanning the inferior vena cava; detection of abdominal and pleural fluid; identification of pneumothorax and pulmonary edema; and ultrasound-guided procedures such as central-line placement. The last laboratory session of the second year requires the student to demonstrate many of these ultrasound skills by performing the RUSH protocol (rapid ultrasound for shock/hypotension) on a standardized patient with a clinical scenario written to indicate that the patient presents with hypotension [21].

It is important to note that the iUSC is not intended to replace developing good physical examination skills. Bedside ultrasound is a complement to the patient history and physical examination. In fact, there is some evidence to suggest that ultrasound can be used to enhance the development of physical examination skills [5, 6, 22].

In the pathology course, ultrasound images and pictures of gross and microscopic pathology are used to broaden the students' knowledge of pathological entities encountered in different organ systems. Ultrasound images have been incorporated into the course lectures in subjects such as cardiovascular, pediatric, gastrointestinal, hepatic, and genitourinary pathology. Ultrasound images are also part of small group teaching whereby students can review the history, physical exam findings, laboratory data, and ultrasound images for individual cases. As an example, in small group a case is presented of a middle-aged woman with chronic right upper quadrant pain. The ultrasound reveals a thickened wall of the gallbladder, gallstones, and acoustic shadowing. A picture of the gross pathological specimen shows thickened wall, edematous mucosa, and gallstones. The microscopic pictures show a thickened mucosal wall and a submucosal inflammatory infiltrate with lymphocytes. This leads to a discussion of chronic cholecystitis with cholelithiasis with the corresponding clinical, pathological, and ultrasound findings [23].

Ultrasound images are likewise used as part of the teaching cases in problem-based learning (PBL). PBL is a small group case-based learning format with faculty facilitators. Students are given information about an unknown clinical case including the medical history, physical examination findings, laboratory results, and radiology images to interpret. Ultrasound images pertinent to the case are given to the students for interpretation and are reviewed with the faculty facilitators. For example, students may be given a clinical case of a patient with fever and a new heart murmur and they must make the decision to order an echocardiogram. They then interpret the video loop of an echocardiogram that reveals a mass on the mitral valve consistent with infectious endocarditis. This leads to a set of learning issues to review and discuss including risk factors, clinical presentation, evaluation, physical findings, laboratory and radiology findings, common infectious agents, treatment and prevention of infectious endocarditis.

Teaching modalities

Lectures/demonstrations

Basic ultrasound material such as sound wave physics and ultrasound instrumentation can be more efficiently presented to the entire class at one time in a lecture/demonstration format. Reviewing material from previous semesters and demonstrating scanning techniques are also more efficiently presented to the larger group. These lecture/demonstration sessions are limited to one to two per semester to preserve more time in the curriculum for the hands-on ultrasound experience which is essential for the students to progress in their scanning skills.

Required laboratory sessions

There are generally three to five required laboratory sessions per semester. The class is divided into groups of approximately twenty students each, and groups are scheduled in 1-h blocks. Sessions begin with a brief overview of the objectives of the laboratory session and a demonstration of the relevant scanning technique on a standardized patient. Laboratory sessions are held in a large multidisciplinary room with eight ultrasound stations. Four standardized patients are scheduled for each laboratory. Four ultrasound instructors work with groups of five students at four of the stations. The other four stations are available for students to scan each other once they have completed the laboratory assignment under the guidance of the instructor. A handout describing the laboratory assignment, including specifics on patient positioning, scanning technique, and anatomy has been developed for each session.

Open laboratory sessions

In addition to the required laboratory sessions, voluntary open laboratory sessions are available for students one to two afternoons per week to practice scanning each other. An ultrasound faculty member is available during the open laboratory to answer questions and assist with scanning.

Web-based learning modules

Twenty-two web-based learning modules have been created as listed in Table 2 (http://www.susme.org/learning-modules/) and cover the basics of ultrasound physics, "knobology" (location and use of instrument, knobs, controls, and software), technique, and anatomy. These modules are based on well-established standards and protocols such as those recommended by the American Institute of Ultrasound in Medicine. Interactive self-assessment components are available at the end of some the modules. The modules are available for review by the students at any time throughout the course, thus adding flexibility to the curriculum.

Assessment of students years M1 and M2

All M1 and M2 students undergo an OSCE each year, either at the end of the first or second semester. The content of the OSCEs is based on the ultrasound instruction during the semester. During the semesters when OSCEs are not administered, ultrasound questions are incorporated into the written course examinations or are included in an

Table 2 Learning modules

Physics
Topics
History of ultrasound
Introduction to ultrasound
Introduction to ultrasound transducers
Modes of diagnostic ultrasound
Image orientation and resolution
Introduction to ultrasound artifacts
Bio-effects of ultrasound
Instrumentation
Topic
Instrumentation (LOGIQe)
Abdomen
Topics
Liver ultrasound
Gall bladder and biliary tree ultrasound
Spleen ultrasound
Renal ultrasound
Ureter and urinary bladder ultrasound
Abdominal aorta ultrasound: assessment for AAA
Inferior vena cava and volume assessment
Pelvic
Topics
Female pelvic ultrasound (transabdominal)
Urinary bladder ultrasound
Cardiac
Topics
Left ventricular hypertrophy (LVH) screening in patients with systemic hypertension
Introduction to echocardiography and parasternal long axis view of the heart
Parasternal short axis views of the heart
Subcostal view of the heart
Apical views of the heart

on-line learning module with self-assessment. Test questions assess the student's knowledge of ultrasound and its clinical application.

OSCE format

Each student has 15 min to perform a series of ultrasound scans on a standardized patient under observation by a faculty member. The faculty observer completes an evaluation form on each student similar to the one in Table 3. The student is graded on their interaction with the standardized patient (introduces self, explains the procedure and demonstrates attention to the comfort and modesty of the patient), and their abilities to appropriately use the ultrasound system, to capture pre-determined anatomical structures, and to correctly identify those structures.

Results from the M1 examination at the end of gross anatomy in the fall semester of 2008 are typical of those generally obtained: students easily completed the ultrasound exam within 15 min by scanning and identifying the designated structures—kidney, liver and Morison's pouch in the right upper abdominal quadrant, kidney and spleen in the left upper abdominal quadrant, urinary bladder in the pelvis, carotid artery and internal jugular vein in the neck, and parasternal long axis view of the heart. The mean score for the class was 97.4% with a range of scores of 64–100%. A 3-year summary of all OSCEs can be seen in Table 4.

M3 clerkship

Five of the six required core clerkships in the M3 year have additional ultrasound instruction and an OSCE at the end of the rotation (Table 1).

During the Internal Medicine Clerkship, students are exposed to both inpatient and outpatient uses of clinical ultrasound, with two separate OSCE scenarios based on these. Didactic and hands-on instruction add to their first 2 years' experience to provide the knowledge and skills of ultrasound for relevant clinical application while on the clerkship. For example, the students have a didactic and hands-on session with an endocrinologist on the management of thyroid nodules which includes indications, scanning technique, and interpretation of ultrasound thyroid scans. The associated OSCE is a clinical case of a patient complaining of a lump in her neck. The student must obtain a medical history, perform an appropriate physical examination of the neck, and then perform an ultrasound of the neck. The standardized patient for this OSCE has a large thyroid cyst which the student is expected to identify and measure in centimeters. Similarly, the students have a hands-on ultrasound central-line placement session utilizing a head and neck central-line trainer phantom as a part of the clerkship simulation center experience. The associated OSCE involves a sepsis scenario in which the student must obtain informed consent and appropriately image the carotid artery and internal jugular vein of a standardized patient as if preparing for placement of a central-line catheter in the internal jugular vein.

During the Family and Preventive Medicine clerkship, students review with faculty the criteria for AAA screening, review the ultrasound AAA protocol, and practice scanning the aorta. The Family Medicine OSCE consists of adequately discussing the procedure with the patient, performing an ultrasound AAA screen in an elderly patient that fulfills criteria for the screen, and discussing the results with the patient.

After spending time with an obstetrics faculty member as well as a sonographer and practicing scans during the clerkship, students on obstetrics and gynecology are

Table 3 Ultrasound OSCE checklist

UNIVERSITY OF SOUTH CAROLINA SCHOOL OF MEDICINE

Student Name _____ Date _____

Student Number _____ Start time _____

Observer _____ End Time _____

ULTRASOUND OSCE CHECKLIST

Examination Region	Adequate image obtained?		Structure Identified?	
	YES	NO	YES	NO
1. Right Upper Quadrant				
a. Right Kidney-Longitudinal view				
b. Right lobe of Liver-long axis view				
c. Right hemidiaphragm/diaphragm				
d. Morison's Pouch/Hepatorenal fossa				
2. Left Upper Quadrant				
a. Spleen- Long axis view				
3. Pelvic Ultrasound				
a. Urinary bladder-Transverse view				
4. Echocardiography-Parasternal Long axis view				
a. Left atrium				
b. Left Ventricle				
c. Mitral Valve				
d. Interventricular Septum				
e. Right Ventricular outflow tract				
f. Aortic valve				
5. Neck Ultrasound				
a. Right Common Carotid artery				
b. Right Internal Jugular vein				
c. Right lobe of Thyroid gland				
6. Miscellaneous Observations		YES	NO	
a. Did student introduce himself/herself to the patient?				
b. Attentiveness to patient comfort and modesty?				
c. Able to select and change probes for specific exam ?				

Table 4 OSCEs results: percent correct

	2007–2008 (%)	2008–2009 (%)	2009–2010 (%)	$\bar{x}$ (%)
M1				
Mean OSCE score	98.2	97.4	95.6	97.1
Range	78–100	64–100	64–100	68.7–100
M2				
Mean OSCE score	97.2	98.0	91.0	95.4
Range	71–100	83–100	50–100	68.0–100

presented an OSCE scenario of a patient 27 weeks pregnant who reports vaginal bleeding. Using live models, the student must perform an obstetrical ultrasound examination, determine fetal number, heart rate, placental location, and fetal position.

On the surgical clerkship, after reviewing the emergency ultrasound examination for trauma, each student is expected to perform a FAST examination (focused abdominal sonography for trauma) on at least one trauma patient in the emergency room [24]. At the end of the clerkship each student demonstrates the FAST examination on a standardized patient during the surgical OSCE.

While on the pediatrics clerkship, students participate in two ultrasound training sessions in which ultrasound basics are reviewed and students practice scanning. For the ultrasound OSCE, students assess volume status in a child by determining the aorta/inferior vena cava ratio.

Medical intensive care unit experience

Approximately 30% of students on the internal medicine clerkship elect to spend 2 weeks in the medical intensive

care unit. While there, the students review the ultrasound examinations for volume status, global heart function, pericardial effusion, pulmonary embolus, pneumothorax, and pulmonary edema. A basic knowledge and skill assessment is made for each student rotating through the Critical Care Unit at the start of the rotation, and a similar post-rotation evaluation is given at the end of the 2-week block.

Opportunities for ultrasound education in the fourth year (M4)

In the fourth year of medical school, there are several elective opportunities for additional ultrasound experience.

A 4-week emergency medicine ultrasound elective is available that includes didactic sessions, web-based learning modules, and an abundance of opportunities to scan patients in the emergency room. Scans are then reviewed with an attending physician or an emergency medicine ultrasound fellow. Students are expected to complete at least 150 studies with at least 25 in each of the following areas: FAST exam, aorta, gallbladder, kidney, cardiac, and obstetrics and gynecology. Completion of these studies is consistent with the recommendations of the American College of Emergency Physicians 2001 ultrasound guidelines for credentialing in emergency ultrasound [25]. Students also review an article on ultrasound from a recent journal and present the article and lead the discussion at Emergency Medicine journal club.

"Hands-on" ultrasound and additional instruction have been included in a traditional fourth-year radiology 4-week elective. These include reviewing ultrasound images, shadowing hospital-based sonographers, scanning volunteer patients, and practicing ultrasound-guided aspiration on gelatin phantoms with fluid filled targets.

A 2-day ultrasound "Capstone" course is offered to students at the end of the M4 year to help them prepare for internship. The curriculum is designed to be broadly applicable to students entering a wide range of medical residency specialties. The course covers the FAST exam, the RUSH exam, and ultrasound-guided procedures such as central-line placement, thoracentesis, and paracentesis.

Students can also elect to participate in an ultrasound independent study month. During the month, students can work with faculty on original ultrasound research, further develop their ultrasound skills, and assist with the M1 and M2 ultrasound laboratories.

Course evaluations

M1 and M2 students complete an anonymous on-line course evaluation at the end of each semester. The response rates have been above 90%. Table 5 is a summary of course evaluations over the 4-year period. As can be seen, the curriculum has been very well received. Over 90% of the students feel the ultrasound curriculum has enhanced their medical education, has allowed for increased clinical correlation with basic science instruction, and has enhanced understanding and skills of the physical examination. Nearly 75% of M1 and M2 students would like to see more ultrasound in the overall curriculum.

Student comments on the course evaluations have been overwhelmingly positive and have provided constructive feedback that has resulted in numerous improvements in the curriculum.

M3 students complete an ultrasound curriculum evaluation at the end of the academic year and M4 students at the completion of electives and special programs such as Capstone. These evaluations have likewise been very positive.

Lessons learned: 4-year experience

As with most innovations in medical education, practical knowledge has been gained as the ultrasound program has developed. We have learned a number of important lessons in the first 4 years of our iUSC (Table 6).

Start small

Scheduling time in medical student curricula is a challenge at most, if not all, medical schools. Thus, a plan to gradually introduce ultrasound into the curriculum is more likely to be approved and succeed than trying to introduce a comprehensive ultrasound curriculum and requesting large blocks of curricular time at the inception of a new program. Determining a modest number of well defined basic ultrasound objectives for a few courses and clerkships and incorporating these across all 4 years in the form of an integrated or vertical curriculum is recommended. This should be done in close collaboration with course and clerkship directors if the best fit for ultrasound into their portion of the curriculum is to be achieved.

Timing

When the ultrasound curriculum initially began, the students first encountered ultrasound in week three of the first semester in the anatomy course. At that time, many students were still adjusting to the pace and volume of the material to be learned in medical school and learning ultrasound had to compete with many other course priorities. The next year ultrasound was introduced to the new students in small group sessions during orientation week before classes officially began. The students learned basic ultrasound principles, started to feel somewhat comfortable

Table 5 Summary of student curriculum evaluations

Questions	Mean Likert Score[a]	Mean% responding agree or strongly agree (%)
M1 class		
1. The use of ultrasound in gross anatomy has enhanced my ability to learn basic anatomy	4.07	81.2
2. The use of ultrasound in physiology has[b] enhanced my ability to learn basic physiology	3.79	69.8
3. I found the scheduled hands-on laboratory sessions with standardized patients helpful in learning ultrasonography	4.53	94.0
4. I found the open laboratory sessions used to practice scanning each other helpful in learning ultrasonography	4.23	79.4
6. I found the overall educational experience in ultrasound enhanced my medical education	4.48	94.6
7. I would like to see more ultrasound in the curriculum	4.14	77.5
M2 class		
8. The use of ultrasound in the Introduction to Clinical Medicine (M2) has allowed for increased clinical correlation with basic science instruction	4.30	90.7
9. Ultrasound has enhanced my understanding and skills of the physical exam	4.31	92.0
3. I found the scheduled hands-on laboratory sessions with standardized patients helpful in learning ultrasonography	4.58	93.5
4. I found the open laboratory sessions used to practice scanning each other helpful in learning ultrasonography	4.11	73.2
6. I found the overall educational experience in ultrasound enhanced my medical education	4.48	93.6
7. I would like to see more ultrasound in the curriculum	4.08	73.3

[a] Scale: 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree

[b] Scores not recorded for 2008–2009 academic year

with the ultrasound system, and had a chance to scan each others' neck vessels and thyroid glands. The sessions were very well received, were a great orientation activity, and helped make the transition to the formal ultrasound curriculum much easier once classes began.

Open laboratory sessions

Timing of scheduled ultrasound laboratory sessions and the variable rate at which students acquire scanning skills can be difficult issues to resolve in a busy medical student curriculum. Open laboratory sessions were added the second year of the curriculum at the request of the students to allow for more scanning time during periods when they were less busy with other course work. These open sessions have been a huge success and have gone far in resolving the timing and rate of learning issues.

Faculty

To get an ultrasound curriculum started, a small group of faculty with expertise and experience in ultrasonography such as radiologists, obstetricians, cardiologists, and emergency medicine physicians is sufficient. It may be necessary to look outside the medical school setting if there is not enough internal expertise. Local physicians and sonographers are additional resources. Ultimately, it will be important to identify a core group of faculty champions from various departments committed to integrating ultrasound into their course or clerkship if the curriculum is to be successful.

For most schools, faculty development in ultrasound will be necessary to sustain and expand the program. Options for faculty development that have proven successful for us include in-service workshops by our faculty experts, workshops by invited ultrasound teaching faculty, central support for attendance at continuing medical education programs at other institutions, access to curriculum web-based learning modules, and ready availability of ultrasound systems to develop scanning skills. Ultrasound education can be presented to the faculty as a potential academic niche with special expertise, research opportunities, grant funding, publications, and leadership within their specialty or subspecialty.

Student feedback

In addition to the student on-line evaluation forms, periodic focus groups are held with the students. The feedback has helped direct the development of the program and has fostered a sense of student partnership in the curriculum.

Table 6 Lessons learned/recommendations for starting a medical student ultrasound program

Start small
Work with course and clerkship directors to determine a limited number of ultrasound objectives initially and expand each year
Timing
Introduce the students to ultrasound and the instrumentation during orientation week, if possible—a great orientation activity and facilitates the transition to ultrasound in formal course work
Open laboratory sessions
Offer open ultrasound practice sessions during times when the students are not as rushed with other curricula demands
Faculty
Faculty champions in multiple disciplines will be necessary for a truly integrated curriculum; faculty development will be needed; ultrasound education can be an academic niche
Student feedback
Provide regular opportunities for students to give feedback on the program and share results with the faculty and administration—important for ongoing support of the program
Student–patient interaction
An opportunity for "clinical time" in the first 2 years and faculty role modeling
Content and resources
Need not develop all teaching material in-house; pursue multiple options for acquiring ultrasound systems: buy, lease, grants, partnerships, donors
Student recruiting
Advertise your ultrasound program to medical school applicants; can give you a recruiting edge

Sharing student evaluation results with department chairs, course directors, the curriculum committee, and the administrative leadership is important for continued support and a broad appreciation of the curriculum by the faculty and administration.

Student–patient interaction

The opportunity for students to interact with standardized patients while performing an ultrasound examination has been a very positive aspect of the curriculum for the students. Students have reported how much they have enjoyed the ultrasound laboratory sessions and interacting with the patients. Thus, these laboratories have provided more "clinical" time in the curriculum the first 2 years and have also created teaching opportunities for faculty to role model and discuss the physician–patient relationship and the role technology plays in that relationship.

Content and resources

When introducing an ultrasound curriculum, it is important to note that not all teaching materials need to be developed de novo. There are significant printed and web-based educational materials available, and much of the web material is free. Most ultrasound organizations have educational components to their websites, and web searches will reveal many others. The number of ultrasound systems needed to start a program will be dependent on the number of students in each class, the number of geographically separate teaching sites, and the ability to schedule multiple laboratory sessions to keep the student–faculty and the student–ultrasound system ratios small. Options for acquiring ultrasound systems include purchasing systems, leasing systems, using systems already in the institution (radiology, cardiology, obstetrics, etc.) at times when they are not in use, developing an educational partnership with an ultrasound manufacturer, and obtaining educational grants and donor support to acquire systems. Some combination of these will allow most schools to initiate an ultrasound program for medical students within an acceptable budget range.

Student recruiting

Students interviewing for admission to medical school are often looking for innovative educational programs that will prepare them well for future practice. Thus, having an ultrasound component in the curriculum can help distinguish a school from other medical schools in the region and give that school a recruiting edge. The iUSC is now highlighted on admissions interview day and in the School of Medicine admissions literature.

Planned additions to the iUSC

Hand-held/pocket ultrasound devices

There are several hand-held or pocket-sized ultrasound devices on the market today. We are exploring how best to introduce these devices into the medical student curriculum. In the spring semester of 2010, we invited a group of M2 and M3 students to scan with a pocket-sized device and provide feedback on the most appropriate time and place in the curriculum to introduce these small units. It was the general consensus of these students that they should be introduced only after the students have learned ultrasound on laptop-sized systems that have larger screens and allow for greater adjustment of ultrasound parameters such as level of focus and scanning frequency. The ultrasound teaching faculty concurred. Our plan is to introduce pocket-sized devices into the second semester of the second year during physical diagnosis after the students have established a solid foundation in ultrasound from training on the laptop systems.

Portal, archiving, competency

We have piloted a mini-PACS system that allows students to send uncompressed images to a dedicated server under a unique identification number. Beginning with the 2010–2011 academic year, all M1 students will be required to capture specific ultrasound images over the course of their 4 years of medical school. These images will be sent to the server for review, feedback, and archiving. The number, variety, and quality of the images will be stored as will be the student's interpretation of their images. Students will be able to access the server for critiques of their scans and receive constructive feedback. These data will provide a basis for the establishment of competencies related to ultrasound.

Conclusions and future directions

Based on our 4-year experience with an integrated ultrasound curriculum, it is clear that ultrasound can be successfully introduced across all 4 years of medical school. It has also been shown that students can readily learn focused ultrasound examinations well and that the students enjoy their ultrasound experience. They overwhelmingly report that ultrasound has enhanced their medical education. As ultrasound technology continues to advance and the evidence continues to mount showing value of point-of-care ultrasound for improving the quality of patient care and patient safety, the role of ultrasound in medical education and practice will inevitably expand. It is imperative for those in medical education to ensure that ultrasound education is introduced and conducted appropriately based on the best available evidence. Experiences among institutions engaged in ultrasound education should be shared and guidelines and basic recommendations for ultrasound in medical student curricula should be established based on well designed outcome studies, expert recommendations, and adult learning principles. It is unlikely that one-sized curriculum for ultrasound will fit all medical schools, and modifications in curricula will need to be made based on the overall educational curricular design for each school, the mission of the school, faculty experience and expertise in ultrasound, administrative and clinical specialty support, and available resources.

There are also significant lessons to be learned from the disciplines of emergency medicine and critical care medicine with respect to developing curricula and standards of practice for point-of-care ultrasound [25–28]. These disciplines have broadened the use of ultrasound across the spectrum of patient care and in virtually any provider location where the focused ultrasound examination is critical in managing the patient [29–39]. Two organizations have joined forces to bring together educators from around the globe to develop an educational roadmap to help ensure ultrasound curricula are developed that are based on the best available information. The Society of Ultrasound in Medical Education (http://www.susme.org/) is composed of multiple specialties in medicine, each bringing their particular expertise and perspective of ultrasound in medical education. The other organization is WINFOCUS (http://www.winfocus.org/), which is an international organization devoted to improving access and the quality of healthcare around the globe through the power of ultrasound and the humanitarian spirit. WINFOCUS has extensive experience in training practicing physicians and health care providers in ultrasound throughout the world, especially in developing countries.

Winfocus and the Society of Ultrasound in Medical Education are jointly sponsoring the First World Congress on Ultrasound in Medical Education (http://www.wcume.org/) for the express purpose of advancing the knowledge of ultrasound in education and to lay the foundation for ultrasound as a standard of medical education around the globe. Medical education in the next decade will likely undergo a true paradigm shift based on the application of ultrasound technology. This shift will fundamentally change how medicine is taught and practiced.

Acknowledgments The integrated ultrasound curriculum at the University of South Carolina, School of Medicine has been supported by General Electric Healthcare. Ultrasound systems and technical support for the curriculum have been provided. All educational studies reported in the review manuscript had University of South Carolina Institutional Review Board approval.

Conflict of interest Two authors, Pat Hunt and Thomas Cook, report financial support and equipment support from General Electric Healthcare for an ultrasound educational and consulting company in which they have invested. No other authors report any conflict of interest.

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