National Ultrasound Curriculum for Medical Students

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Abstract: Ultrasound (US) is an extremely useful diagnostic imaging modality because of its real-time capability, noninvasiveness, portability, and relatively low cost. It carries none of the potential risks of ionizing radiation exposure or intravenous contrast administration. For these reasons, numerous medical specialties now rely on US not only for diagnosis and guidance for procedures, but also as an extension of the physical examination. In addition, many medical school educators recognize the usefulness of this technique as an aid to teaching anatomy, physiology, pathology, and physical diagnosis. Radiologists are especially interested in teaching medical students the appropriate use of US in clinical practice. Educators who recognize the power of this tool have sought to incorporate it into the medical school curriculum. The basic question that educators should ask themselves is: "What should a student graduating from medical school know about US?" To aid them in answering this question, US specialists from the Society of Radiologists in Ultrasound and the Alliance of Medical School Educators in Radiology have collaborated in the design of a US curriculum for medical students. The implementation of such a curriculum will vary from institution to institution, depending on the resources of the medical school and space in the overall curriculum. Two different examples of how US can be incorporated vertically or horizontally into a curriculum are described, along with an explanation as to how this curriculum satisfies the Accreditation Council for Graduate Medical Education competencies, modified for the education of our future physicians.

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Ultrasound (US) has long been recognized as an extremely useful diagnostic imaging modality because of its real-time capability, noninvasiveness, portability, and relatively low cost. In addition, imaging with US does not carry the risks associated with the administration of intravenous contrast material or the potential hazards of ionizing radiation. Hence, many medical and surgical subspecialties are increasingly embracing the use of US, finding it to be an adjunct to or extension of the physical examination. Some have referred to it as the "sonoscope."[1] Others have described US as "the visual stethoscope of the 21st century."[2] The use of US beyond its traditional role within the department of radiology has been termed "point of care" US. Furthermore, some medical schools, taking advantage of recent technical advances in portable US technology, have begun to incorporate education in US within the medical school curriculum.[3–7]

While welcoming the increasing general awareness of the utility of US, both the Society of Radiologists in Ultrasound and the Alliance of Medical School Educators in Radiology (AMSER) believe that radiologists should play an important role in the creation of a US curriculum. As imaging experts, radiologists are best able to instruct medical students how to utilize the diagnostic capability of US most effectively and in addition are best able to direct the clinician to other more appropriate imaging tests when US is not likely to be clinically useful (ACR Appropriateness Criteria®).[8] Accordingly, this document highlights what aspects of US should be taught to medical students, as well as when and how US can be most effectively introduced into medical school preclinical and clinical curricula.

The broad goals of this curriculum are 2-fold:

(1) Preclinical: utilization of US to enhance student understanding of anatomy, physiology, and pathology.
(2) Clinical: teach students how to use US effectively as a problem-solving tool in the diagnosis of disease. As a corollary, students also need to learn the limitations of US and when other imaging modalities may be more appropriate.

Achieving these goals can be greatly facilitated through direct "hands-on" experience. Through an appreciation of how US is performed, students will learn its strengths and weaknesses far better than by passive examination of US images. However, such hands-on experience should not be expected to guarantee that students will become adept at rendering diagnoses from images or become competent at performing complete diagnostic US examinations, because the acquisition of such interpretive and scanning skills requires prolonged exposure and dedicated practice. Such skills are typically acquired during a formal residency or fellowship.[9]

The intended audience for this curriculum includes US practitioners, departments of radiology, and deans of medical schools. We recognize that the proposed curriculum is a comprehensive one, and teaching all elements may not be feasible at any given institution. In particular, the inclusion of the "hands-on" portion is labor intensive. Introducing this curriculum onto preexisting courses may increase the likelihood of successful implementation. Although it is not our intention to dictate how medical schools may apply the curriculum, by providing 2 different models (Appendices 1 and 2), we hope to stimulate medical school educators to consider its implementation.

The proposed curriculum has been organized as follows: part 1 deals with content, part 2 with a mechanism for potential deployment over a 4-year period, whereas part 3 addresses how the curriculum meets the Accreditation Council for Graduate Medical Education (ACGME) competencies, as modified for medical students.

PART 1: THE NATIONAL ULTRASOUND CURRICULUM FOR MEDICAL STUDENTS

The curriculum is based on the AMSER National Medical Student Curriculum in Radiology.[10] The following sections outline goals for both preclinical and clinical years.

Preclinical

Familiarity With the Basic Principles of the Physics of Ultrasound

Analogy to SONAR
Image acquisition: sound transmission and reflection, scatter, acoustic window
Image optimization: depth, focal zone, time-gain compensation, gain, field of view
Posterior acoustic properties: posterior enhancement (increased sound transmission), sound attenuation, acoustical shadowing
Artifacts: near field, reverberation, edge refraction, mirror image
Terminology: echogenic, hyperechoic, hypoechoic, anechoic, isoechoic
Characteristics of simple fluid, complex fluid, soft tissue/solid, air/gas, bone/calcium
Imaging modes: B-mode (gray scale), Doppler (spectral, color, and power), M-mode

Knowledge of Instrumentation

Basic probe and image orientation: sagittal, transverse, coronal
Transducers: frequencies, types (linear, curvilinear, sector, transvaginal), near field, far field
Machine settings: transducer frequency, depth, focus, gain, time-gain compensation
Control buttons: freeze, save images, cine loop, measure with calipers

Describe Advantages of Ultrasound

Real-time dynamic imaging (importance of real-time multiplanar scanning; advantage of cine clips over static images)
Multiplanar imaging (nonstandard imaging planes)
Portable
Lack of ionizing radiation
Lower cost
Improved soft tissue resolution compared with noncontrast computed tomography (CT)
Safe, noninvasive

Describe Limitations of Ultrasound

Obese patients (attenuation, scatter, image degradation)
Impedance to transmission of sound waves: air (lung, bowel gas), bone, metal
Smaller field of view
Operator dependence
Less interexamination reproducibility relative to CT

Correlate Patient Safety and Ultrasound

Obstetrics: no ionizing radiation; however, US is not entertainment and thus should not be used to create a "prenatal family photo album"
Pediatrics: no sedation, no ionizing radiation
Gynecology: pelvic imaging in women of reproductive age
US and magnetic resonance imaging are methods to reduce ionizing radiation exposure
Heat deposition, cavitation: Doppler, gray-scale imaging
ALARA (as low as reasonably achievable) principle

Identify Classic Appearances of Normal Structures on Ultrasound

Liver, gallbladder, pancreas, spleen, kidneys, aorta, inferior vena cava (IVC)
Urinary bladder, uterus, ovaries, prostate
Obstetrical scan: basic fetal anatomy (head, abdomen, heartbeat, limbs, umbilical cord, placenta, cervix)
Subxiphoid view of heart for pericardial effusion
Femoropopliteal venous system (with and without compression)
Internal jugular vein, subclavian vein (for venous access)
Carotid artery (relation to internal jugular vein, carotid bifurcation)
Diaphragm (hyperechogenicity and movement)
Normal lung (pleural line, sliding lung sign)
Thyroid
Musculoskeletal: tendon (principle of anisotrophy), muscle, surface of bone, joint fluid
Note: Hands-on scanning is ideal and should be organized, if at all possible. Students can scan each other under supervision, which can be arranged with attending physicians, staff sonographers, local school of sonography, and so on.

Clinical

List Appropriate Indications for Common Ultrasound Examinations

(Students should be familiar with the ACR Appropriateness Criteria® Web site as a general guide for all imaging studies)

Characterization of masses (cystic, solid, complex)
Clinically suspected fluid accumulations (ascites, pleural effusion, pericardial effusion, abscess, hematoma)
Evaluation of right-upper-quadrant (RUQ) pain
Obstructive jaundice
Clinically suspected appendicitis in children, young patients, or pregnant women
Suspected splenomegaly
Renal failure, hematuria, flank pain
Screening (and following) abdominal aortic aneurysms
Pelvic mass, pain, abnormal vaginal bleeding
Obstetrics: abnormal bleeding, dating, heartbeat, fetal anatomy, decreased fetal activity, suspected ruptured membranes, premature labor
Evaluation of palpable neck/thyroid mass
Evaluation of scrotal pain, mass
Pediatrics: recurrent urinary tract infections, suspected neonatal brain hemorrhage, abdominal or pelvic mass, abnormal neonatal hip examination, tethered cord
Echocardiography: pericardial effusion with or without tamponade, right-sided heart strain, valvular dysfunction, cardiac/chamber enlargement, calculate ejection fraction
Carotid bruit; evaluation of transient ischemic attack
Lower- or upper-extremity swelling or pain (suspected deep vein thrombosis)
Evaluation of musculoskeletal pain (muscle, tendon, or other superficial soft tissue origin), effusions, collections
Guidance for interventional procedures (see separate listing)

Observe the Following Ultrasound Studies

RUQ US (liver, gallbladder, bile ducts, right kidney, head of pancreas)
Upper abdominal US (RUQ plus spleen, left kidney)
Aorta, IVC
Pelvic ultrasound (transabdominal and transvaginal scans): urinary bladder, uterus, ovaries, cul de sac, prostate
First-trimester US (gestational sac, yolk sac, embryo, M-mode heartbeat)
Second/third-trimester fetal US (fetal heart beat, placenta, amniotic fluid, cervix)
Breast US (cyst vs solid, US-guided cyst aspiration or biopsy of mass, if possible)
Thyroid US
Venous US
- Upper- or lower-extremity deep vein thrombosis study
- Internal jugular vein and subclavian vein (versus companion arteries; important distinction)

Echocardiogram (basic views)
Neonatal brain US (if possible)
Carotid US (if possible)
Biopsy guidance/fluid aspiration or drainage (if possible)
Note: These studies may be observed on live patients, models, students scanning each other under supervision, recorded examples, videos, and so on.

Recognize or at Least See Classic Examples of Common Pathological Conditions on Ultrasound

Cyst versus complex cyst versus solid mass (could be within liver, spleen, kidney, ovary, breast, testis, thyroid)
Fluid accumulations (pleural, ascites, hemoperitoneum, hematoma, abscess)
Gallstones, acute cholecystitis, biliary obstruction, hydronephrosis, abdominal aortic aneurysm, renal calculi, splenomegaly
Overdistended urinary bladder, Foley catheter in urinary bladder, enlarged prostate
Gynecology: uterine fibroid, thickened endometrium; hemorrhagic ovarian cyst, corpus luteum, ovarian cancer
Obstetrics: first-trimester pregnancy complications (subchorionic hemorrhage, embryonic demise), ectopic pregnancy, placenta previa, incompetent cervix, polyhydramnios, oligohydramnios
Acute deep vein thrombosis in femoropopliteal system, internal jugular vein
Testicular mass, hydrocele, torsion, epididymitis, varicocele
Thoracic conditions: large pericardial effusion (pericardial tamponade), paralyzed hemidiaphragm, pneumothorax
Pediatrics: intussusception, hypertrophic pyloric stenosis, intracranial hemorrhage
Note: These pathological conditions should be recognized in still images (lecture format); however, real-time images (including cine loops) are encouraged.

Describe Clinical Situations Where Ultrasound Is Used to Guide Interventional Procedures

Paracentesis, thoracentesis
Vascular access: peripherally inserted central catheter line, venous or arterial access
Biopsies: liver, renal, transplant, breast, prostate, thyroid, lymph nodes, masses
Localization for aspiration and drainage: abscess, hydronephrosis, cysts
Musculoskeletal procedures: injections, aspirations, foreign body localization, biopsies
Amniocentesis, fetal therapeutic procedures
Sonohysterography, also known as SIS (saline infusion sonography)
Pericardiocentesis (tamponade)

PART 2: IMPLEMENTATION

Incorporating the above curricular content into a 4-year medical school curriculum has many challenges, including (but certainly not limited to) competing content from multiple fields of medicine, variability in the medical school curriculum structure, and limitations in time and resources for teaching hands-on skills such as US imaging.

The following examples for implementation of a US curriculum (offered as Appendices 1 and 2) provide a few options that have been developed at specific institutions and need not be used in their entirety, but serve as models that can be adapted and applied as deemed appropriate for each institution.

The majority of medical schools begin with a 2-year didactic preclinical curriculum followed by 2 years of clinical experience, as proposed by Flexner[11] over 100 years ago. Acknowledging this, the authors have divided the curricular content into “preclinical” and “clinical” sections, which assists in differentiating essential “preclinical” material best suited for didactic presentations and the occasional workshop/laboratory versus the "clinical" material with "hands-on" skills best suited for clinical clerkships.[12]

Preclinical

In the preclinical years, the US curriculum can be integrated into the overall curriculum to supplement general understanding of anatomy, physiology, and pathology.[13,14] This horizontal incorporation of a US curriculum is likely best organized and implemented by a multidisciplinary group including radiologists and other US specialists with the course directors of the anatomy, physiology, and pathophysiology preclinical courses. Hands-on sessions can also be incorporated into a physical diagnosis course. Appendix 1 describes such a course taken from a 4-year curriculum being piloted at Harvard Medical School, Boston, Mass.

Ideally, the curricular content would be taught in didactic lectures and small-group sessions, enriched by the experience and contribution of US imaging experts. This would include 1 or 2 introductory lectures in US physics, image acquisition, indications, and limitations. Alternatively, some medical schools may choose a more vertical approach, assigning specific hours to ultrasound imaging for didactics and workshops to cover the complete preclinical curriculum. By applying the constructivist theory of learning,[15] the content can be separated into several sessions over the 2 preclinical years to allow building on prior content to improve understanding and retention.

Clinical

Two models are outlined in Appendix 2. The first one offers graduated levels of exposure and imaging experience for medical students during third-year clerkships (Harvard Medical School, Boston, Mass).[16] A second model is more compact, organized as a dedicated 3-day program (Thomas Jefferson University Hospital, Philadelphia, Pa). We offer both examples but realize that ongoing graduate medical education in US imaging will be necessary before competency is reached.[17] With the current wide variability in clinical clerkship requirements, it is conceivable that a student could complete a medical school curriculum without ever directly scanning a patient with US. Although not optimal, the authors recognize that US imaging is largely skill based and requires significant experience to achieve competency.

PART 3: ULTRASOUND AND MEDICAL STUDENT COMPETENCIES (ACGME SPECIFIC, MODIFIED, FOR MEDICAL STUDENTS)

The curriculum must follow the ACGME-mandated competency-based model of learning. The residency competencies have been modified for medical students.[18] These have served as a template, which we have subsequently applied to US knowledge and practice.

1. Medical knowledge: "The medical student should demonstrate basic knowledge of normal anatomy, disease processes, and US"
   a. General medical knowledge
      – normal anatomy
      – disease processes
   b. Ultrasound specific knowledge
      – outlined in the Ultrasound Curriculum
      – pros and cons of US imaging to assess clinical problems
      – accuracy of US for diagnosis of common diseases

2. Patient care: "Medical students should provide care that is safe, compassionate, and effective in diagnosis and management of common health problems."
   a. Diagnostic management skills
      – how to choose the appropriate imaging examination (ACR Appropriateness Criteria®).
      – importance of proper clinical information to interpret US findings
      – influence of patient variables on the US image: body habitus, sex, age
      – difference between preliminary and final report
   b. Visual interpretation skills
      – basic US anatomy: neck/abdomen/pelvis/vessels
      – recognize poor US technique
      – importance of prior images/correlative examinations
      – recognize classic critical findings
   c. Image acquisition skills
      – demonstrates the ability to image select normal anatomy in standard views, as outlined in the curriculum
   d. Knowledge of US interventional procedures
      – biopsies; fluid drainages
   e. Patient safety and US exposure
      – Doppler and potential for cavitation
      – appropriate use: US is not entertainment
   f. Knowledge of new developments in US
      – contrast enhanced US: potential uses
   g. Interacting compassionately with a patient
      – answering questions, explaining the examination
      – how to give bad results

3. Practice-based learning and improvement: "Medical student should continually seek to improve their knowledge and skills by multiple means, be able to self-evaluate, and apply new knowledge to his/her practice."
   a. Use evidence-based methods for selecting when to use US and what US criteria to apply to clinical problems.
      – ACR Appropriateness Criteria®
      – Society of Radiologists in Ultrasound consensus panels on ovarian cysts, endometrial assessment, thyroid nodule biopsy, carotid, shoulder, and first trimester
   b. Research presentation topics appropriately using peer-reviewed literature
      – prepare a PowerPoint presentation on a US topic
   c. Self-assessment modules

4. Interpersonal and communication skills: "Medical student can communicate and interact effectively with patients and health care providers."
   a. calms anxious patients, obtains adequate history before doing a US examination, answers questions, explains findings, gives results to patients (or, observes a US specialist's interactions with a patient in similar circumstances)
   b. presents US findings using PACS (picture archiving and communications system) in the context of a clinical conference with peers

c. communicates report findings appropriately to a clinician
d. interacts appropriately with other US radiologists and technicians
e. if possible, presents US-related research at a conference (ie, AMSER)

5. Professionalism: "Medical student should demonstrate a commitment to carrying out professional responsibilities and an adherence to ethical principles"
   a. accepts the limits of their training for utilization of US and the need for and utilization of specialized US training
   b. demonstrates appropriate physician/patient interaction during US examinations
   c. demonstrates appropriate sensitivity to the invasiveness of some US procedures
   d. recognizes the importance of image archiving and documentation to ensure appropriate standards of care
   e. timely communication of results, especially critical findings
   f. recognizes the importance of continuing medical education and of the maintenance of an accurate up-to-date CME log
   g. demonstrates awareness of AMSER Web site

6. Systems-based practice: "Medical student demonstrates awareness of the complexities, interactions, and considerations involved in working in the modern health care environment" (ie, the "culture" of the workplace)
   a. observes radiology-clinician interaction in US or emergency department (verbal, written)
   b. awareness of goal of cost-effective imaging
      – knowledge of basic examination cost of US relative to other imaging modalities
      – how proper utilization of US can decrease cost of imaging
      – awareness of potential impact of contrast-enhanced US on future workflow patterns and the political impediments to its implementation in the United States
   c. awareness of the impact of radiation on the potential cancer risk for the population as a whole

CONCLUSIONS

Given the rapid proliferation of medical imaging and the premium placed on techniques that do not utilize ionizing radiation, it is imperative that medical student education include basic US concepts and principles. All medical students, regardless of future specialties, will benefit from a longitudinal exposure to radiology in general and US in particular. From the beginning of medical school as they learn gross anatomy to much more advanced rotations such as a US clerkship, hands-on experience with medical imaging is a valuable part of any student's medical education. This medical student US curriculum can be directly tailored to the level of experience, specific clinical rotations, and medical school resources. Although current medical school curricula have little room for additional content, didactics, and teaching, we believe that it is essential to include the basics of US in the greater framework of general medical education.

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APPENDIX 1: PRECLINICAL CURRICULUM MODEL

Ultrasound and Physical Diagnosis Course

"Ultrasound in physical diagnosis" course (introducing ultrasound [US] into a physical diagnosis course, allowing for small-group hands-on sessions). Students scan each other, models, or patients under direct supervision of fellows/attending physicians/US specialists from pertinent clinical specialties. These are five 2-hour sessions organized as follows:

Session I. Physical Principles of Ultrasound/Intro to Scanning
- a. Short plenary lecture covering basic physics concepts (as per curriculum)
- b. Scanning time: students get introduced to the transducer and basic machine controls by scanning the neck and identifying structures outlined in the curriculum

Session II. Abdomen US
- a. Short plenary introduction to main abdominal organs
- b. Scanning time: students scan models and identify many of the structures outlined in the curriculum. Physical findings (liver or spleen tip, aortic pulsation) are correlated with US findings

Session III. Thyroid US
- a. Short plenary introduction by thyroid endocrinologist, followed by US specialist
- b. Scanning time: students scan patients, if possible

Session IV. Musculoskeletal US
- a. Short plenary introduction by musculoskeletal specialist
- b. Scanning time: students scan each other, or patients from rheumatology, physical medicine and rehabilitation, or sports medicine clinic

Session V: Cardiac US
- a. Short plenary introduction by cardiologist, followed by demonstration, emphasizing chamber and valve recognition, aorta/pulmonary relationships, pericardial space, limited Doppler, and M-mode introduced.
- b. Scanning time: identify 4-chamber view, A-V valves

APPENDIX 2: CLINICAL CURRICULUM MODELS

Model for Third-Year Clerkships

At the start of the third year, a preparatory fundamentals of imaging course, based on clinical clerkships: internal medicine, surgery, obstetrics-gynecology/pediatrics, neurology, psychiatry, are taught. It consists of four 3-hour modules that include a short plenary introductory lecture and small-group discussions, organized by clinical symptoms with discussions of differential diagnosis and appropriate imaging modalities.

Ultrasound is introduced, along with all other imaging modalities, centered on clinical problems specific for each clerkship (several examples given).

1. Imaging for Internal Medicine
   - – chest pain/dyspnea (eg, pulmonary embolus: computed tomography [CT] pulmonary angiogram, lower-extremity Doppler US)
   - – pleuritic chest pain (eg, pleural effusion: chest CT and chest US)
2. Imaging for Surgery
   - – Right-upper-quadrant pain (biliary colic: US, abdomen CT)
   - – Right-lower-quadrant pain (appendicitis: abdomen CT, US)
3. Imaging for Obstetrics-Gynecology/Pediatrics
   - – abnormal uterine bleeding (eg, endometrial hyperplasia: US)
   - – first trimester bleeding (eg, ectopic pregnancy or miscarriage: US)
   - – projectile vomiting (eg, hypertrophic pyloric stenosis: US, upper gastrointestinal imaging)
   - – abnormal neonatal hip examination (eg, neonatal hip US, plain film)
   - – premature neonatal brain hemorrhage (neonatal head US)
4. Imaging for Neurology/Psychiatry
   - – Transient ischemic attack (eg, head CT, carotid US)
   - – Worst headache (eg, subarachnoid hemorrhage: head CT, transcranial Doppler)

Additional opportunities for US teaching in year 3 for schools with radiology clerkship or elective

1. Students scan each other, under supervision of technologist/radiologist, concentrating on recognizing structures as outlined in curriculum. For schools with US simulators, these may be utilized at this time.
2. Students spend time observing in the US department, under guidance of a staff member, and are brought in on all types of scans.
3. Students present cases of US examinations to a different staff member using hospital PACS (picture archiving and communications system) to illustrate the findings.
4. Students are matched with colleagues on a clinical clerkship (this works best with obstetrics-gynecology or pediatric clerkships) and are brought together for a combined clinical-radiology conference. Student from clinical clerkship presents a case; radiology clerkship/elective student then shows images on PACS; discussion of management or

differential follows (eg, neonate with a fetal renal anomaly discovered on prenatal US, followed postnatally with US, voiding cystourethrogram, nuclear scan, etc).

Model for a 3-Day Program (Year 3 or 4)

The following model is designed for a Compact Ultrasound Course implemented in a total of 3 days, not necessarily in succession. It may be incorporated into the radiology elective or a stand-alone course (preferably in the third or fourth year).

Day 1: Didactic lectures
- Ultrasound physics, instrumentation and knobology with demonstration
- Abdominal US (emphasis on where US is most useful)
- Pelvic US (urinary bladder, gynecology, obstetrics)
- Ultrasound of superficial structures (scrotum, breast, thyroid, superficial soft tissues, musculoskeletal, eye, neonatal brain)

Day 2:
- Hands-on workshop: students scan each other and identify liver, gallbladder, bile duct, spleen, kidneys, aorta, inferior vena cava, urinary bladder, thyroid, internal jugular vein, carotid artery, subclavian vein.
- Observation in US clinical reading area

Day 3:
- Cardiac US (lecture on basic echocardiographic views and common abnormalities)
- Cardiac US demonstration (observation of student being scanned)
- Ultrasound guidance for procedures (lecture on principles and examples)
- Workshop, hands-on for venous access, and needle placement into phantoms
- Using appropriate US imaging: case-based discussions

Ultrasound Elective (Year 4)

For students with an interest in pursuing US and for hospitals with sufficiently large US departments, an intensive elective in US imaging may be offered. Under the direct supervision of a physician or sonographer, the student will scan patients and perform focused US examinations. Student will demonstrate knowledge of instrumentation, knobology, transducer selection, presets, machine settings, and so on. The student will begin with scans of the abdomen, followed by pelvis, small parts, vascular, first trimester, and so on, and may participate in simple guidance procedures (paracentesis, thoracentesis).